Developing a Biomass Industry in North Dakota

A Report Submitted to
The North Dakota Industrial Commission
Biomass Incentives and Research Program
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Primary Investigators:
F. Larry Leistritz
Nancy M. Hodur

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Executive Summary

A consortium led by NDSU is currently engaged in a project to develop and commercialize technologies to produce fuels and materials from biomass feedstock in North Dakota. The first major milestone in the commercialization effort is to address key economic and engineering questions to determine the technical and economic feasibility of a pilot scale production process. This study, supported by the Biomass Research and Incentive Program of the North Dakota Industrial Commission was undertaken to address those questions. This, the *detailed investigation,* has three objectives: 1) complete a front end engineering and design (FEED) study for a pilot scale plant, 2) determine the best extraction methods for refining cellulosic nanofibers and definition of the process, 3) prepare a strategic business plan for the integration of public and private sector resources to provide investment for pilot plant construction.

Objective 1: The FEED study completed during the detailed investigation phase addressed key engineering and economic questions to quantify the technical and economic feasibility of a pilot scale production process for an integrated biorefinery using AFEX pretreatment. A preliminary design for an AFEX and CAFEX (continuous AFEX) pretreatment has been completed (Appendix A). AFEX processing conditions and enzyme hydrolysis conditions were refined, and organisms capable of utilizing both 5 and 6 carbon sugars were screened.

Objective 2: Microfibrillated cellulose (MFC) appears to be more promising than cellulose nanofibers (CNF). MFC have similar properties but can be produced using a simpler process that costs less than producing CNF. Additional research is needed in this area. Good dispersion of the fibers is critical to producing a polymer with desirable mechanical properties. While preliminary studies appeared to have solved the dispersion issue, these results have not been replicated.

Objective 3: Findings from the detailed investigation were used to develop a proposal for the U.S. Department of Energy for the construction of a fully integrated biorefinery pilot plant using AFEX pre-treated biomass. Funding would have moved the project from the *detailed investigation* to the *development phase*; however the project was not funded due to questions regarding ammonia recovery. Ammonia recovery is a key economic parameter that will drive the feasibility of an integrated biorefinery using AFEX pretreated biomass that will have to be demonstrated before moving to the development phase and construction of a pilot scale plant. Because the overall business climate is more risk averse than at the onset of this project, without further de-risking investors are not willing to make the significant investment necessary to build a pilot plant. Work has begun on an alternate means to demonstrate ammonia recovery at a cost far less than that of an integrated pilot plant. The *development phase* will likely take place in two stages. The first will be to demonstrate ammonia recovery using the new approach currently being developed and the second would be to identify and secure a private sector partner(s) for the construction of a pilot scale plant.

Capitalization and financial performance were estimated assuming ammonia recovery. A commercial plant selling ethanol for $2.19 per gallon yields a 21.6 percent return on investment. Total investment costs were estimated to be $379 million. Life cycle analysis for an integrated biorefinery indicates a 65 percent reduction in greenhouse gas emissions and a 73 percent reduction in fossil fuel usage. Bench scale testing has demonstrated 94 percent of theoretical yield of fermentable sugars, 98 percent recovery of ammonia and 5 percent ethanol titer in high-solids enzymatic hydrolysis and fermentation AFEX pre-treated corn stover. This data demonstrates that an AFEX integrated biorefinery has significant commercial potential.

INTRODUCTION

The economic potential of bio-based fuels and materials is substantial. A consortium led by NDSU is currently engaged in a project to develop and commercialize technologies to produce fuels and materials from biomass feedstock in North Dakota. The first major milestone in the commercialization effort is to address key economic and engineering questions to determine the technical and economic feasibility of a pilot scale production process. This study, supported by the Biomass Research and Incentive Program of the North Dakota Industrial Commission was undertaken to address those questions. This, the *detailed investigation,* has three objectives: 1) complete a front end engineering and design (FEED) study for a pilot scale plant to demonstrate the commercial potential of producing fuels and materials from biomass in North Dakota, 2) determine the best extraction methods for refining cellulosic nanofibers and define the process, 3) preparation of a strategic business plan for the integration of public and private sector resources to provide investment for pilot plant construction. The strategic business plan will discuss the potential nature of operations as well as examine potential markets, capitalization requirements and projected financial performance. Findings for Objective 3 are discussed in the following sections. Findings from Objectives 1 and 2 are detailed in Appendix A, "Developing a Biomaterials Industry in North Dakota" and Appendix B, "Cellulose Nanowhisker Technology Development: Investigation into Utilization of Wheat Straw Residue from Ethanol Production (AFEX + SSF).

STRATEGIC BUSINESS PLAN

The FEED study completed during the detailed investigation phase addressed key engineering and economic questions to quantify the technical and economic feasibility of a pilot scale production process for an integrated biorefinery using AFEX pretreatment. A preliminary design for an AFEX and CAFEX (continuous AFEX) has been completed (Appendix A). These activities are essential prerequisites to the construction and operation of a pilot plant to demonstrate the commercial potential of this technology. Findings from the FEED study were used to develop a proposal for the U.S. Department of Energy (DOE) supported by funding from the American Recovery and Construction Act of 2009 for the construction and demonstration of a fully integrated biorefinery pilot plant using AFEX pre-treated biomass. Funding would have moved the project from the *detailed investigation* stage to the *development phase* to further de-risk and scale up the technology. We learned in early December, 2009 that the $23.5 million project was not funded.

From DOE reviewer comments and de-briefing and conversations with major industry players, a critical issue has emerged. Ammonia recovery is a key economic parameter that will drive the economic feasibility of an integrated biorefinery using AFEX pretreated biomass. Because ammonia recovery is a critical component of the process, it became clear that ammonia recovery would have to be demonstrated before moving on to the *development phase* and construction of a pilot scale plant. Potential industry partners such as ICM, The Andersons and Great River Energy have expressed interest in the technology. However under current economic conditions they are not willing to make the significant capital investment necessary to build a

pilot plant without demonstration of ammonia recovery. Because the overall business climate is more risk averse than 2-3 years ago at the onset of this project, without further de-risking by demonstrating ammonia recovery, investors are not willing to make the significant investment necessary to build a pilot scale plant.

To address this "chicken and egg" scenario, that is, a pilot plant is needed to demonstrate ammonia recovery, but commercial investors are not willing to build a pilot plant until ammonia recovery has been demonstrated, work has begun on an alternate means to demonstrate ammonia recovery. Based on preliminary projections, the cost for demonstrating ammonia recovery using this new approach will likely be far less than the $23 million needed to build the fully integrated pilot plant. Work plans and cost estimates for this new approach are being developed and will be available in the coming months. Once work plans have been developed, efforts will begin to secure private, public or some combination of private and public funds for the ammonia recovery demonstration project.

As a result of the need to demonstrate ammonia recovery prior to the construction of a pilot plant, the *development phase* will likely take place in two stages. The first stage will involve demonstrating ammonia recovery using the new approach currently being developed. Once ammonia recovery has been demonstrated the commercialization process will resume and would involve identifying and securing a private sector partner(s) for the construction of a pilot scale plant. At the onset of this project it was thought that efforts to secure a commercial partner could begin at the end of the *detailed investigation*. However, with the additional requirement of demonstrating ammonia recovery, efforts to identify and begin conversations with potential investors would be premature. Accordingly a detailed strategic business plan aimed at identifying and securing a private sector partner(s) is impossible at this time.

LIKELY NATURE OF OPERATIONS

Two options for commercialization can be envisioned 1) a centralized AFEX/biorefinery where the AFEX treatment facility is co-located at the bioconversion facility (saccharification and fermentation) and 2) a decentralized option where biomass processing and AFEX pretreatment are located separate from the bioconversion facility. Research has indicated that large biorefineries capable of handling 5,000 to 10,000 MT of biomass /day are preferable from an economic standpoint (Carolan, Joshi and Dale, 2007). However, large, biorefineries must contend with increased transportation costs and storage of low bulk density biomass.

The second option is a network of Regional Biomass Processing Centers (RBPC) that would form an extended supply chain for the bioconversion facility. Biomass would be collected and processed at these regional centers using the AFEX pretreatment process. The AFEX pretreatment process makes a stable intermediate material that can be stored with no deterioration of available sugars. Because lignin is moved to the particle surface in the AFEX process (Balan et al. 2006), the biomass is easy to densify without the use of steam or binders normally required for agricultural products (unpublished data, Dr. Bruce Dale, Michigan State University). AFEX treated biomass would be densified and stored on site providing a cost

advantage in terms of storage, handling and transportation. The ability to store and handle biomass using conventional delivery and receiving systems would help to alleviate some of the issues associated with storage, transportation and handling of low bulk density biomass.

An intermediate supply chain entity will likely be created to supply biomass to a centralized biorefinery. Because of the quantity of biomass needed to feed a commercial scale biorefinery (5,000 - 10,000 MT per day), the purchase, storage, transportation and delivery of biomass will be a significant undertaking. It is not likely the biorefinery operator will be inclined to nor have the capabilities to negotiate and contract with hundreds of individual producers and manage the logistics of biomass harvest, storage and transportation. An intermediate supply chain entity may not be as critical an element for regional biomass pretreatment centers. Depending on the scale of the pre-treatment centers, the pretreatment center may function as the intermediate supply chain entity contracting with multiple producers and supply biomass to the end user. Great River Energy, a Minnesota based electrical generation coop currently building a generation facility with capabilities of cofiring biomass, has explored issues related to biomass supply including the necessity of a supply chain entity (Great River Energy, 2009). Additional research is needed to address issues related to harvest, transportation, storage, densification, logistics, dedicated feedstock production, feedstock availability, contracts and producer relationships.

A centralized biorefinery will likely need to utilize various types of biomass. Because of the volume of biomass needed to fuel a commercial biorefinery, multiple feedstocks will likely be used. Harvest, transportation and storage of a single feedstock present numerous challenges. For example there is a very narrow window of opportunity to harvest corn stover. In recent years in North Dakota, weather conditions have delayed the corn harvest into November and December. In some cases harvest has been delayed until the next spring. Harvesting enough stover before the onset of winter to feed a commercial biorefinery in such a short period of time likely under less than ideal conditions may not be feasible. It is more likely that multiple feedstocks will be used. A combination of agriculture residue such as wheat straw and corn stover and dedicated energy crops with biomass harvest taking place at various times of the year may be required. Under a scenario where the biorefinery uses multiple feedstocks, AFEX pretreatment provides an advantage over other pre-treatments. AFEX is effective on multiple agricultural non-woody feedstocks and produces a stable intermediate product that can be stored, transported and integrated with subsequent processing.

Finally, first generation biorefineries will likely be co-located with an existing corn-based ethanol facility. This would reduce capital costs by integrating hydrolyzed and fermented biomass into the existing distillate system. Other advantages would include using existing systems for transportation and marketing the final product. Integrating first generation cellulosic ethanol production with an existing corn based facility would improve the overall economics of the faculty.

POTENTIAL MARKETS

Liquid fuels would be the primary product of the biorefinery. A freestanding commercial cellulosic ethanol plant using AFEX pretreatment is envisioned to produce 120 million gallons of ethanol per year. A significant component of the biorefinery would be its power source. Biomass consists of cellulose, hemicellulose and lignin. Lignin which cannot be converted into fermentable sugars will be burned to produce steam to power the biorefinery. Excess electrical power would be sold back to the grid, generating $8.2 million in income per year. Not only does this approach improve the overall economics by using lignin to power to power the plant, electricity is a marketable output of the biorefinery.

Biomaterials are another potential product of a commercial biorefinery. Cellulose fibers have excellent mechanical properties and when combined with bio-based polymer may used to make biocomposites that could substitute for fiberglass and plastic in many applications including automotive, furniture, office/storage, marine, housing and recreation. Cellulose nanofibers for production of biocomposite materials can be a value-added byproduct in a cellulose to ethanol plant improving overall economic viability. Based on work completed by Dr. Larry Drzal, microfibrillated cellulose (MFC) appears to be more promising than cellulose nanowhiskers (CNW). MFC have similar properties but can be produced using a simpler process that costs less than producing CNF. Additional research is needed in this area. Good dispersion of the fibers is critical to producing a polymer with desirable mechanical properties. While preliminary studies appeared to have solved the dispersion issue, these results have not been replicated. Complete details of for findings related to cellulosic nanowhisker technology can be found in Appendix B, Cellulose Nanowhisker Technology Development.

Animal feed may also represent a potential market for Regional Biomass Processing Centers. Bench scale research has shown that AFEX treated materials has digestibility equal to corn grain for ruminant animals (Bals et al. 2009). Feeding trials are needed to assess the ability of various classes of ruminant to convert various types of AFEX treated biomass to energy.

AFEX pre-treated biomass may also potentially be used as fuel. Pelleted switchgrass is already being marketed as fuel for residential pellet stoves and cofired for commercial electricity generation in Missouri. Great River Energy has expressed an interest in potential for firing either AFEX pre-treated biomass or raw biomass in their co-fire generation facility currently under construction in Spiritwood, North Dakota. Characteristics of AFEX pre-treated material may make it a superior feedstock to untreated biomass. Additional research is required to determine if AFEX treated biomass would be preferred to untreated biomass for electricity generation. AFEX treated biomass can be used on multiple feedstocks and sold into several markets making it less vulnerable to the volatility of a single market. Multiple markets reduce risk and could enhance the prospects for rapid and broad commercial deployment.

CAPITALIZATION REQUIREMENTS AND PROJECTED FINANCIAL PERFORMANCE

Capitalization requirements and financial performance are detailed in Appendix A. These estimates and the following discussion should be considered directional and assume ammonia recovery. The commercial biorefinery is projected to produce a return on investment greater than the cost of capital. A commercial plant selling ethanol for $2.19 per gallon yields a 21.6 percent return on investment. The minimum ethanol price to meet a 9.02 percent return on investment would be $1.58 per gallon. Total construction costs were estimated to be $379 million. Life cycle analysis for an integrated biorefinery indicates a 65 percent reduction in greenhouse gas emissions and a 73 percent reduction in fossil fuel usage. Bench scale testing has demonstrated 94 percent of theoretical yield of fermentable sugars, 98 percent recovery of ammonia and 5 percent ethanol titer in high-solids enzymantic hydrolysis and fermentation of AFEX pre-treated corn stover. This data demonstrates that an AFEX integrated biorefinery has significant commercial potential.

SUMMARY ACCOUNTING

Grant Details	
NDSU Agribusiness & Applied Economics	
Personnel (salary, benefits and consulting services)	$287,872
Travel, communications and supplies	
$ 12,128	
MBI International	
Personnel (salary and benefits)	$347,530
Material, supplies and equipment	$ 70,000
Travel	$ 12,470
Michigan State University	$ 70,000
Total	**$800,000**
Matching Funds	
U.S. Department of Energy	$250,000
USDA ARS	$278,000
MBI International	$150,000
Great River Energy (in-kind)	$25,000
Total	**$703,000**
Other Support	
USDA CSREES	$494,638
ND APUC	$86,100
Total	**$580,738**

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Great River Energy. 2009. Study of the Feasibility of a Biomass Supply for the Spiritwood Industrial Park. A Report to the North Dakota Industrial Commission. **http://www.nd.gov/ndic/renew/projects/r-001-003sp.pdf** (viewed January 22, 2010).

Appendix A

"Front End Engineering and Design of an AFEX Integrated Biorefinery"

FRONT END ENGINEERING AND DESIGN OF AN AFEX INTEGRATED BIOREFINERY

Subaward No. FAR0013936

under NDSU Prime BM001-001

MBI Project No. 1622.001

FINAL REPORT

August 1, 2008 – December 31, 2009

Submitted to
North Dakota State University
Dept. of Agribusiness & Applied Economics
217 Morrill Hall
Fargo, ND 58105
ATTN: F. Larry Leistritz, Ph.D.

Submitted by
MBI INTERNATIONAL
3900 Collins Road
Lansing, MI 48910-8596

Contact:
Bernie Steele
517.336.4645
steele@mbi.org

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Objectives

The goal of this project was to complete a front end engineering and design (FEED) study for a pilot scale plant to demonstrate the commercial potential of this technology, a critical step in establishing a biomaterials industry in North Dakota. Initial efforts were focused on technical and economic requirements for commercializing technology to produce bio-based cellulose nanowhiskers. Specific objectives include:

1. Completing the detail investigation necessary to define:
    - Scalable process design
    - Mass and energy balances necessary to determine the cost of the process
    - A procedure for qualitative and quantitative analysis of the structural materials available from wheat straw
    - A system for analyzing the structural enhancements of polymers from the inclusion of wheat straw fibers
2. Refining the initial investment analysis for the business as data is added to key parameters regarding capitol costs and manufacturing yields.
3. Preparing of a strategic business plan for integration of public and private sector resources to provide investment for pilot plant construction and, when appropriate, construction of commercial manufacturing facilities. The strategic business plan will detail the likely nature of operations of a corporate entity as well as examine potential markets, capitalization requirements, and project financial performance.

Summary

MBI's original concept for continuous Ammonia Fiber Expansion (AFEX) treatment (CAFEX-I) of biomass was based on wood delignification processes in the pulp and paper industry, using a Pandia-type reactor with feed and discharge screws. The advantage of the CAFEX-I approach is that it relies on equipment which has been in use for decades, and has been shown to be effective for a variety of biomass feedstock materials. The operating principles of plug screws and Pandia reactors are largely independent of the fluid properties of the feedstock materials, so that the same equipment can be used to process materials with different properties, with only minor modifications. The primary disadvantage of the CAFEX-I approach is the high capital cost of the equipment required. It is unclear whether a CAFEX-I reactor system could be cost competitive with other leading biomass pretreatments.

Due to concerns over the high equipment costs associated with the CAFEX-I approach, MBI investigated methods for accomplishing the same process operations with lower-cost equipment. The result was the CAFEX-II concept, which uses a progressive cavity pump to charge moist biomass into a pressurized device for mixing with ammonia and steam. The use of a progressive cavity pump is central to the CAFEX-II concept. However since wheat straw could not be pumped with any progressive cavity pump at any moisture level or particle size, we are unable to process wheat straw in the CAFEX-II system.

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In May of 2009, the U.S. Department of Energy released a Funding Opportunity Announcement, DE-FOA-0000096, titled "Recovery Act – Demonstration of Integrated Biorefinery Operations." At that time, the CAFEX-II system was incapable of processing high-impact feedstocks such as wheat straw and corn stover, due to the progressive cavity pumping problems. It was therefore decided to apply for funding to build and operate a CAFEX-I pilot plant, under Topic Area 2 of the FOA. The application includes detailed design information, mass and energy balances for both pilot- and commercial-scale operation of CAFEX plants, as well as techno-economic analysis of a commercial ethanol plant using AFEX treatment.

The compositional, morphological, and surface chemical changes introduced into wheat straw as a result of AFEX and Simultaneous Saccharification and Fermentation (SSF) treatments were studied. Cellulose nanowhiskers (CNW) and Microfibrillated cellulose (MFC) were extracted from this ethanol production residue at reasonable yields. In order to produce a totally biobased composite material, several methods to combine the wet wheat straw based MCF and CNW with Poly Lactic Acid (PLA) were investigated at concentrations up to about 5 wt% including an a new emulsification-freeze drying process, filtration and lamination and spray processing.

Mechanical properties of the composites did not show improvement consistent with the values expected for a reinforcement with properties similar to MFC and CNW. The lack of measurable increases in the composite properties has been attributed to poor dispersion within the PLA matrix.

Good dispersion of the cellulose nanofibers is a key to producing a polymer composite with high mechanical properties and to fully realize their potential as a reinforcing material. Although some preliminary studies had appeared to show that the Emulsion-Filtration technique developed had solved the fiber aggregation problem, after switching to a new source of PLA resin, we have not been able to achieve the same degree of dispersion so far. Further research is necessary in order to identify a processing method that provides good dispersion of the MFC in PLA or other water based polymers.

The fermentability of sugars derived from AFEX-treated wheat straw was assessed using *Zymomonas mobilis* 8b. Ethanol yield based on the available glucose and xylose in the wheat straw was about 62%. There was no sugar residue at the end of the fermentation, which indicates that *Z. mobilis* 8b was able to metabolize both glucose and xylose derived from AFEX-treated wheat straw.

Different combinations of cellulase and xylanase were used in hydrolysis of AFEX-treated wheat straw to determine the most effective enzyme mixture. This experiment showed that it is possible to lower the total amount of enzyme without compromising hydrolysis yield and confirmed that having the right enzyme combination is very critical to reduce the cost of biomass conversion.

Approach

Our approach assumes that cellulose nanofibers for production of biocomposite materials can be a value-added byproduct in a cellulose-to-ethanol biorefinery. Production of cellulosic ethanol from

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wheat straw is dependent on the effects of the Ammonia Fiber Expansion (AFEX) pretreatment process for conversion of cellulosic biomass to fermentable sugars. The AFEX process has been licensed to MBI for development and commercialization. The residual materials from ethanol fermentations contain cellulose nanofibers. The technical approach in this project period addressed the following areas:

1. **Detailed investigation of the AFEX process with regard to processing of wheat straw for conversion of cellulose/hemicellulose to ethanol. The program will seek to optimize the AFEX process for efficient conversion of wheat straw cellulose and hemicellulose to fermentable sugars for production of ethanol and define the mass balances.**
   Key processes to be investigated are:

- **Verify the scalability of a continuous AFEX process design**

Continuous AFEX (CAFEX) approaches – CAFEX-I and -II

Any process for continuous AFEX (CAFEX) treatment of wheat straw will necessarily include operations such as continuous charge and discharge of feedstock into and out of a pressurized reactor vessel, and a reactor vessel that provides adequate residence time for contacting the biomass with ammonia. Economic operation of a CAFEX process will also require operations for recovery and re-use of ammonia. Investigations of various CAFEX process designs have led to two distinct process concepts, which for convenience are referred to as CAFEX-I and CAFEX-II.

CAFEX-I

MBI's original concept for continuous AFEX treatment of biomass was based on wood delignification processes in the pulp and paper industry. In pulp processing, wood chips are fed into pressurized delignification reactor vessels using plug screw feeders. Plug screw feeders are manufactured by various vendors, with some variation in design between vendors, but generally use a motor-driven tapered screw to continuously force feedstock material against a tapered orifice or cone, which compresses the material into a plug. As the plug is forced through the orifice it breaks apart into an expanding chamber, which may be held under pressure by the seal formed by the material plug. Once charged into the pressurized reactor, the material can then be discharged by means of a similar plug screw. The residence time of the material within the pressurized reactor can be controlled by various mechanisms. Pandia-type reactors, which use a horizontal or slightly inclined auger to transport material through a pipe, are widely used in pilot-scale pulp processing operations. Figure 1 shows a diagram of a Pandia reactor with feed and discharge plug screws. CAFEX-I refers to the use of a Pandia-type reactor with feed and discharge screws adapted for continuous AFEX treatment of biomass.

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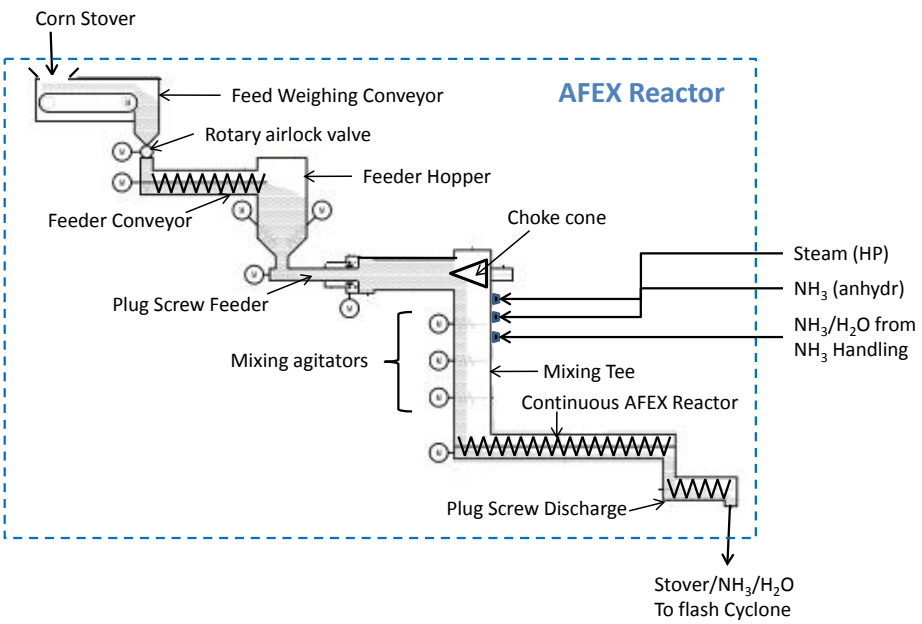

Figure 1. Continuous AFEX reactor system.

The advantage of the CAFEX-I approach is that it relies on equipment which has been in use for decades, and has been shown to be effective for a variety of biomass feedstock materials. The operating principles of plug screws and Pandia reactors are largely independent of the fluid properties of the feedstock materials, so that the same equipment can be used to process materials with different properties, with only minor modifications. Appendix A, attached to this report, includes a letter from Andritz Mechanical Pulping Division, a leading manufacturer of equipment for the pulp and paper industry, stating that their plug screw pressure feeder, horizontal reactor, and discharge device have been shown to meet AFEX processing conditions using various feedstock materials, including wheat straw and corn stover. The primary disadvantage of the CAFEX-I approach is the high capital cost of the equipment required. It is unclear whether a CAFEX-I reactor system could be cost competitive with other leading biomass pretreatments.

CAFEX-II

Due to concerns over the high equipment costs associated with the CAFEX-I approach, MBI investigated methods for accomplishing the same process operations with lower-cost equipment. The result was the CAFEX-II concept, which uses a progressive cavity pump to charge moist biomass into a pressurized device for mixing with ammonia and steam. Residence time of the biomass/ammonia/ steam mixture under AFEX temperature and pressure conditions is then provided using a simple tubular reactor. Discharge from the reactor tube can be controlled using a valve or a positive displacement pump. A CAFEX-II reactor system was designed and constructed in MBI's pilot plant. Figure 2 shows a schematic

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of the CAFEX-II system. Shakedown of this system, including demonstration of adequate temperature and pressure control, has been completed using DDGS feedstock.

The advantage of the CAFEX-II approach is that it uses equipment that is significantly less costly than CAFEX-I. The primary disadvantage of the CAFEX-II approach is that the progressive cavity pump has not been tested for feeding a variety of feedstock materials under pressure.

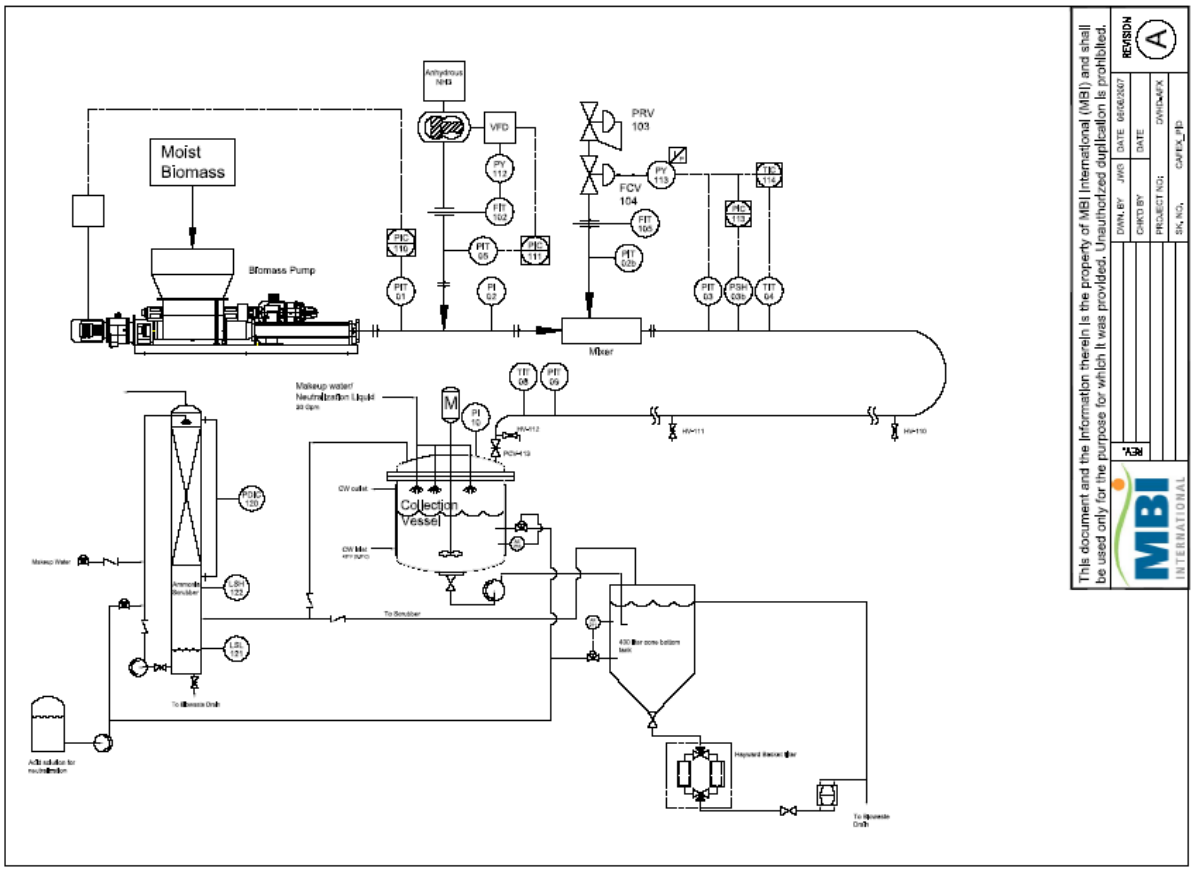

Figure 2. Schematic of CAFEX II Pretreatment System

Wheat straw pumping using progressive cavity pumps

The use of a progressive cavity pump is central to the CAFEX-II concept. Progressive cavity pumps are manufactured by many different vendors, and have been used for decades to pump liquids containing suspended solids, as well as slurries with high solids content. In progressive cavity pumping, as shown in Figure 3, rotation of a helical steel rotor is driven by an electric motor. The rotor turns within an elastomeric stator tube which has a helical internal channel. A series of discrete cavities are formed in the annular gap between the rotor and stator; rotor rotation causes these cavities to progress axially from the inlet to outlet of the pump element, thereby conveying feed material. Volumetric capacity

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depends on the cavity volume and rotor speed, while the maximum differential pressure developed by the pump depends on the number of helical stages within the element.

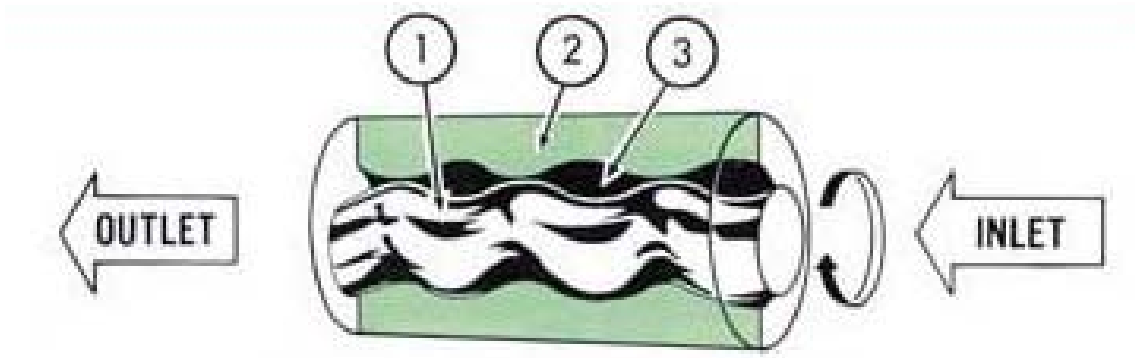

Figure 3 – Diagram of a progressive cavity pump element showing rotor (1), stator (2), and cavities (3). (From www.process-controls.com)

Progressive cavity pumping action requires flow of feedstock material into the cavity as it forms at the inlet end of the pump element. This requirement limits the application of progressive cavity pumping to materials with adequate fluid properties. Many commercial progressive cavity pump models also include an auger that continually conveys feed material from a hopper toward the pump inlet. The feed auger helps to force-feed material into the inlet cavity of the pump element, but materials that resist intrusion into the inlet cavity will not be pumped, despite the auger action.

The fluid properties of moist wheat straw depend primarily on the moisture content and particle size distribution. Table 1 gives water absorption capacities and hydraulic conductivities of wheat straw and other biomass ground to 1 and 2 mm average particle size. It should be noted that AFEX processing of biomass with moisture greater than 80 mass% would be uneconomical due to the high ammonia loading required. However, wheat straw with moisture less than 80 mass% is not saturated, and therefore does not behave as a fluid, but rather as a bed of particles. The hydraulic conductivity of a bed of particles is the proportionality constant in Darcy's Law, and is a measure of the ease with which fluid flows through the bed. The hydraulic conductivities of wheat straw particle beds are quite high, around 0.038 ± 0.001 cm/s, and this high conductivity turns out to have serious implications for progressive cavity pumping.

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Table 1 – Properties of biomass

Biomass	Particle Size (mm)	Water Absorption Saturated Capacity (mass%)	Hydraulic conductivity (k) (cm/s)
Wheat straw	1	87	0.039
Wheat straw	2	86	0.037
Corn stover	1	86	0.0022
Corn stover	2	84	0.0023
Corn fiber	1	65	0.0012
Corn fiber	2	65	0.0074
DDGS	1	61	0.0138

As described above, most progressive cavity pump designs use a feed auger to force feedstock material toward the cavity at the inlet of the pump element. When moist wheat straw is forced by the auger toward the pump element inlet, it becomes compressed into a bed of particles, which releases free water. The high hydraulic conductivity of the particle bed means that the inlet cavity of the pump element can easily draw the free water in, leaving the solid particles behind. This "de-watering" behavior is a common failure mode for progressive cavity pumping of fibrous biomass. Wheat straw pumping tests using various models of Seepex progressive cavity pumps, including BTI 5-24, BTI 17-12, and BTH 17-12 models, all showed de-watering with little or no solids throughput, regardless of moisture content or particle size. For comparison, DDGS do not de-water, due in part to their lower hydraulic conductivity.

MBI has contacted progressive cavity pump manufacturers Seepex Inc. and Moyno Inc. to discuss pumping of high-impact biomass such as wheat straw. The pump manufacturers are aware of the de-watering problem, but to date have no solutions. MBI has also investigated the use of additives, including surfactants, sodium hydroxide and other bases, and heating to modify the properties of wheat straw feeds. While some of these modifications did reduce the extent of de-watering, none provided adequate pumping performance for CAFEX-II processing. Because wheat straw could not be pumped with any progressive cavity pump at any moisture level or particle size, we are unable to process wheat straw in the CAFEX-II system.

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In May of 2009, the U.S. Department of Energy released a Funding Opportunity Announcement, DE-FOA-0000096, titled "Recovery Act – Demonstration of Integrated Biorefinery Operations." At that time, the CAFEX-II system was incapable of processing high-impact feedstocks such as wheat straw and corn stover, due to the progressive cavity pumping problems. It was therefore decided to apply for funding to build and operate a CAFEX-I pilot plant, under Topic Area 2 of the FOA. MBI's application is attached to this report as Appendix B. MBI's application was based on corn stover processing. However, the small differences in the properties of corn stover and wheat straw would have little effect on the operation of a CAFEX-I plant. The application includes detailed design information, mass and energy balances for both pilot- and commercial-scale operation of CAFEX plants, as well as techno-economic analysis of a commercial ethanol plant using AFEX treatment.

- **AFEX processing conditions including temperature, pressure, ammonia loading and retention times**

The most effective AFEX conditions for pretreatment of wheat straw were previously identified using our 1 gallon AFEX reactor. The conditions were chosen based on the highest sugar yields obtained in enzyme hydrolysis of AFEX-treated wheat straw. As part of the presenting work these conditions (temperature:90ºC, ammonia loading: 1 kg ammonia per kg of dry biomass, 60% moisture content and 30 min residence time) were verified in our 5 gallon AFEX reactor. Several AFEX runs with wheat straw were carried out in the 5 gallon reactor under the conditions stated above. The performance of the process was evaluated via enzyme hydrolysis. As it is clear from data presented in Table 2 both reactors demonstrate similar performance. The generated AFEX-treated wheat straw were collected and stored in cold room for further use in hydrolysis and fermentation experiments.

Table 2. Hydrolysis of AFEX-treated wheat straw.

Biomass	ID	Reactor	Temperature, ºC	Ammonia: biomass	Time, min	Moisture content %	Glucose yield%	Xylose yield%
Untreated wheat straw							24±2	6±2
AFEX treaded wheat straw	853-3A, 3B	1 gallon	90	1:1	30	60	60±2	52±2
AFEX treaded wheat straw	961-12A-14B	5 gallon	90	1:1	30	60	61±3	53±2

Hydrolysis were carried out for 72 hr with 15 FPU of cellulase per gram of cellulose. Yields were calculated based on the available sugars in the biomass. Composition is listed in Table 3.

Table 3. Carbohydrate composition of untreated wheat straw based on dry weight

Biomass	% Glucan	% Xylan	% Galactan	% Arabinan	% Mannan
Untreated wheat straw(average of two different batches)	32.43±2	18.46±0	2.24±0.3	2.87±0.5	2.05±1

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- **Enzyme hydrolysis conditions including screening of enzymes for more efficient conversion**

Maximal utilization of all the biomass polymeric sugars is essential to make the economics of biomass processing feasible. Existing cellulase mixtures have been developed to hydrolyze mostly acid/high temperature treated biomass and are not optimal for AFEX-treated material. AFEX-treated biomass, unlike acid treated material, have significant amount of hemicellulose that needs to be hydrolyzed to monomeric sugars. Therefore complete and balanced cellulolytic and xylanolytic systems are required to achieve maximum hydrolysis of plant cell wall polymers at minimal cost. It has been shown that the hydrolysis of glucan and xylan are intimately linked and whatever enhances glucan conversion also tends to increase xylan conversion (and vice versa). It is important to provide not only adequate total hemicellulase activity but also the correct distribution of enzyme activities between cellulase and hemicellulase mixture. In this work AFEX-treated wheat straw was hydrolyzed with different combinations of cellulase and xylanase to maximize both glucose and xylose yield. Recently Novozyme has launched two new enzymes, one cellulase called Ctec and one hemicellulase called Htec. During this reporting period we received samples of these two enzymes and evaluated their performance in hydrolysis of AFEX-treated wheat straw. Table 4 summarizes hydrolysis results of AFEX-treated wheat straw hydrolyzed with different combination of enzymes. Hydrolyses were performed following National Renewable Energy Laboratory (NREL) lap-009 protocol.

The cost of the cellulase enzyme is one of the major contributors to the overall ethanol production cost. It is obvious that any reductions in this cost have a significant effect on the total operating cost. Using the right combinations of enzyme will allow us to reduce the overall enzyme usage. Some of the experiments shown in Table 4 were carried out to identify the lowest enzyme (total amount of protein) loading that can be used in hydrolysis of AFEX-treated wheat straw without significantly compromising the conversion yield.

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Table 4. 72 hr hydrolysis of AFEX-treated wheat straw with different enzymes. Hydrolysis was performed in duplicate and results are presented as the mean value (experiment ID# 948-92)

	FPU of ctec/ g glucan	**mg of Ctec Protein**	**mg of Htec Protein**	**mg of Novo 188 protein**	**Total mg of protein**	**Glucose yield %**	**Xylose yield%**
1	5	4.56	2.736	0	7.296	41.22 ±0.5	49.64 ±2
2	5	4.56	3.42	0	7.98	38.29 ±0.5	46.32 ± 0.5
3	10	9.12	0	0	9.12	24.08 ±1	26.77 ± 2
4	10	9.12	1.368	0	10.488	50.81 ±2	49.71 ±2
5	10	9.12	2.736	0	11.856	51.49 ±1	50.51 ±0.5
6	15	13.68	0	0	13.68	29.48 ±1	30.95 ±1
7	15	13.68	1.368	0	15.048	58.23 ±0.3	53.53 ±1
8	15	13.68	2.736	0	16.416	58.05 ±0	52.81±0.5
9	7.5	7.6	6.08	0	13.68	48.64 ±1	48.98 ±2
	FPU of Spezyme Cp/ g glucan	mg of Spezyme Cp protein	**mg of Htec Protein**	**mg of Novo 188 protein**	**Total mg of protein**	**Glucose yield %**	**Xylose yield%**
10	15	13.9	2.73	10 (~42 CBU/g cellulose)	26.63	72.5 ±0.5	63.99 ±0.5
11	10	9.8	2.73	10 (~42 CBU/g cellulose)	22.53	65.57 ±1	61.39 ± 0.5
12	15	13.9	0	10 (~42 CBU/g cellulose)	23.9	61.2 ±1	53.3 ±2
13	10	9.8	0	10 (~42 CBU/g cellulose)	19.8	52.03 ±1	52.16 ±0.5

Two different cellulases, Spezyme Cp from Genencor and Cellic Ctec from Novozyme, were used in this experiment. Activity of the enzymes was measure following NREL Lap-006 procedure. Protein content of the enzyme products was provided by the manufacturers. Information provided by Novozyme indicates that Ctec enzyme contains enough ß- glucosidase activity; therefore hydrolyses with Cellic Ctec were not supplemented with Novo 188. For further confirmation experiments were set up for hydrolysis of Avicel (pure cellulose) using Ctec with and without Novo 188. As it is clear from the data presented in Table 5, adding Novo 188 not only did not help it actually reduced the glucose yield. On the other hand since Spezyme Cp does not contain enough ß- glucosidase activity, Novo 188 was added to all of the hydrolysis performed with Spezyme Cp.

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Table 5. 72hr hydrolysis of Avicel using Ctec with and without Novo 188. Hydrolysis was performed in duplicate and results are presented as the mean value (experiment ID# 949-83)

Ctec loading	Novo 188	Glucose yield%
15 FPU/ g cellulose	42 CBU/g cellulose	72% ±0
15 FPU/ g cellulose	0	74% ±0

Comparing the performance of Spezyme Cp and Ctec enzyme at the same level of loading (FPU/g cellulose) suggests that Spezyme Cp combined with Novo 188 provides a more effective enzyme combination for hydrolysis of AFEX-treated wheat straw.

Apparent from data presented in Table 4, it is possible to lower the total amount of enzyme in hydrolysis of AFEX-treated wheat straw without compromising hydrolysis yield (comparing experiment # 11 and 12, experiment #4 and 6). These data confirmed that having the right enzyme combination is very critical to reduce the cost of biomass conversion (comparing experiment #6 and 9). These data show that cellulase and xylanase activities can be optimized to reduce the total enzyme loading in enzymatic hydrolysis of AFEX-treated biomass.

- **Screening of organisms capable of utilizing both 5 and 6 carbon sugars**

When choosing a microorganism for fermentation, several important attributes should be considered, including yield, ethanol tolerance, productivity, and growth requirements. Among these traits, ethanol yield has the most impact. If ethanol yield is high, less feedstock would be needed to produce the same amount of ethanol. Based on this requirement, *Zymomonas mobilis,* which has demonstrated highest ethanol yield on sugar complex containing glucose, (Lee, K. J., et al., *Biotechnology letters,* 1980. 2(11): p. 487-492; Rogers, P. L., et al., *Process Biochemistry,* 1980, 15(6): p. 7-11; and Rogers, P. L., et al., *Adv. Biotechnol*., [Proc. Int. Ferment. Symp.] 6th, 1980,) has become one of the most promising microorganisms for ethanol production.

Even though *Z. mobilis has* unique metabolism and ability to rapidly and efficiently produce ethanol from simple sugars, it has not been used commercially for several reasons. One of the major issues is that Z*. mobilis* typically only uses glucose, fructose and sucrose as their substrates. Since pentoses such as xylose is a major component of hemicellulose in most biomass feedstock such as wheat straw, it is usually essential for a fermenting microorganism to use this sugar in ethanol production for a good product yield from biomass. Fortunately metabolic engineering has been successfully applied to develop a *Zymomonas* strain to ferment xylose (Zhang, M., Engineering *Zymomonas mobilis* for efficient ethanol production from lignocellulosic feedstocks. ACS national meeting, 2003 and U.S. Pat. No. 7,223,575), and as well as arabinose (Mohagheghi, A., et al., *Applied biochemistry and biotechnology,* 2002, 98-100: p. 885-898). By genetic engineering technology, engineered *Z. mobilis* could potentially use all sugars present in most biomass feedstock.

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In this study the fermentability of sugars derived from AFEX-treated wheat straw was assessed using *Z. mobilis 8b.* This strain has been developed by NREL and it is capable of using glucose, xylose and arabinose for production of ethanol. The detail of the fermentation is described below.

Two fermentations (experiment ID# 948-90 and 91)at 15% solid loading using AFEX-treated wheat straw and *Z. mobilis 8b* were performed. The fermentations were carried out as Separate Hydrolysis and Co-Fermentation (SHCF) in 7L BiofloIII fermentors. The hydrolysis portion was carried out at 50°C and at pH 4.8 for approximately 72hr. An enzyme cocktail was made for each fermentor in 200 ml of water. Spezyme CP was added in an amount corresponding to 20 FPU/g cellulose, Novo 188 was added in an amount corresponding to 42 CBU/g glucan and plus 10ml of Multifact xylanase (from Genencor). The enzyme cocktail was filter sterilized with a 50mm pre-sterilized 0.2µm filtration unit. The fermentation process began when the fermentor temperature was lowered to 32°C, pH was adjusted to 6.0 using KOH, and the fermentors were inoculated with *Z. mobilis 8b.* The initial OD in each fermentor was about 1.5. Seed and fermentation preparation were carried out according to methods suggested by Mohagheghi et al (Mohagheghi, A., et al., Biotechnology Letters*,* 2004, 26: p. 321-325)

In an effort to minimize the possibility of contamination, it was decided to take only one sample during the hydrolysis period (at 72hr time point). During the fermentation period samples were taken every 24 hr. Samples were analyzed for sugars and ethanol content using HPLC system. Both fermentations were successful and no sign of contamination was observed. The results showed that sugars generated from AFEX-treated wheat straw were fermentable and HPLC results indicated that nearly all of the glucose and xylose were consumed in the first 24 hr of fermentation. Ethanol yield based on the available glucose and xylose in the wheat straw was about 62%. There was no sugar residue at the end of the fermentation, which indicates that *Z. mobilis* 8b was able to metabolize both glucose and xylose derived from AFEX-treated wheat straw. The Table 6 summarizes the hydrolysis and fermentation results obtained from this experiment.

Table 6. Hydrolysis and fermentation results for the fermentation with 15% solid loading AFEX-treated wheat straw.

	Glucose* Yield%	**Xylose* Yield%**	**Ethanol g/l**	**Ethanol* yield%**
After 72hr of hydrolysis	65.95±1	50.5±2	0	0
After 48hr of fermentation			25.2±1	61.6±2

Yields are calculated based on the available glucose and xylose. Presented results are the mean value of the duplicate runs (two fermentations).

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2. Determine the best extraction methods for refining cellulose nanofibers from wheat straw fermentation residues

For production of AFEX-treated wheat straw fermentation residue, two fermentations (experiment ID#881-50(1&2)) were carried out. These fermentations were executed according to NREL Lap 008 protocol with some modifications. The detail procedure is provided below.

Fermentation procedure:

Enzyme preparations:

An enzyme cocktail was made for each fermentor in 150 ml of water. Spezyme CP was added in an amount corresponding to15 FPU/g cellulose, Novo 188 was added in an amount corresponding to 42 CBU/g glucan. The enzyme cocktail was filter sterilized with a 50 mm pre-sterilized 0.2 µm filtration unit (www.nalgenelabware.com).

Medium and inoculum preparations:

Saccharomyces cerevisiae D5A was originally obtained from NREL, and stored frozen in glycerol at -70° C. The medium used in the SSF fermentations contained corn steep liquor (CSL) 5g/L, $MgSO_4.7H_2O$ 0.62 g/l, NH_4SO_4 2 g/l. The inoculum was grown in the same medium as used in the SSF fermentations, but with 2% w/v glucose as substrate. The inoculum was grown in 500 ml baffled Erlenmeyer flasks containing 150 ml of medium each. The flasks were incubated at 30° C and 150 rpm in a Model G25 incubator shaker (NBS, Edison, NJ). The inoculum was prepared in two stages. In the first stage a 150 ml culture was inoculated from a glycerol vial and grown over night. In the second stage 150 ml cultures were inoculated for each fermentor with 0.5ml of the overnight culture. The growth in the inoculum flasks were monitored by measuring the optical density. They were used to inoculate the fermentors when the OD_{600} reached 2.5-3.5, after about 14-15 hours of incubation.

Bioreactor preparations:

The amount of AFEX-treated wheat straw necessary to give 10% solids loading in a 5 liter volume was placed into the 7L BioFloIII fermentor (NBS, Edison, NJ), with the required amount of water containing the CSL and the medium salts. The fermentations were carried out as simultaneous saccharification and fermentation (SSF) in duplicates. As it was instructed by the MSU team (Dr. Drzal's group), who were extracting micro cellulose fiber from the fermentation residue, the AFEX-treated wheat straw was washed prior to the fermentation step. The fermentors were autoclaved for 1 hour. After autoclaving, the fermentors were operated at 30° C, 500 rpm, and pH 5.0. The pH was controlled through the automatic addition of 1M NaOH, and 4N H_2SO_4. The pH of the fermentation was monitored by checking the sample pH using an externally calibrated electrode, and adjusting the BioFloIII automatic pH controller as necessary. The SSF fermentation was started by adding 200 ml of enzyme cocktail and 150

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ml of *S. cerevisiae* D5A inoculum. The initial OD_{600} in each fermentor was about 0.5. Fermentation was carried out for 72 hr and every 24 hr samples were taken for sugar and ethanol analysis. At the end of the fermentation whole broth was collected and weight and volume were measured. Fermentations were carried out in duplicate. Both fermentations were successful and there was no sign of contamination. At the end of the fermentation there was no glucose left, which indicates the sugar generated from AFEX-treated wheat straw were fermentable. Ethanol yield based on the available glucose was about 45%.

Figure 4 is a flow diagram that shows the processes and the steps that have been followed to prepare AFEX-treated wheat straw fermentation residue for extraction of nano cellulosic fiber. The descriptions of the streams shown in Figure 4 are summarized in Table 7. A mass balance was constructed around the processes involved in the production of the fermentation residue. The details of the mass balance are summarized in Table 8. The mass balance was performed by measuring the composition, moisture content and the amount of each stream shown in Figure 4. The compositions and moisture content were measured according to NREL procedures (Laps 002 and 010 respectively). As it is clear from the data presented in Table 8 mass balance closure was achieved for each process.

Figure 4 . Flow diagram for production of AFEX-treated wheat straw fermentation residue

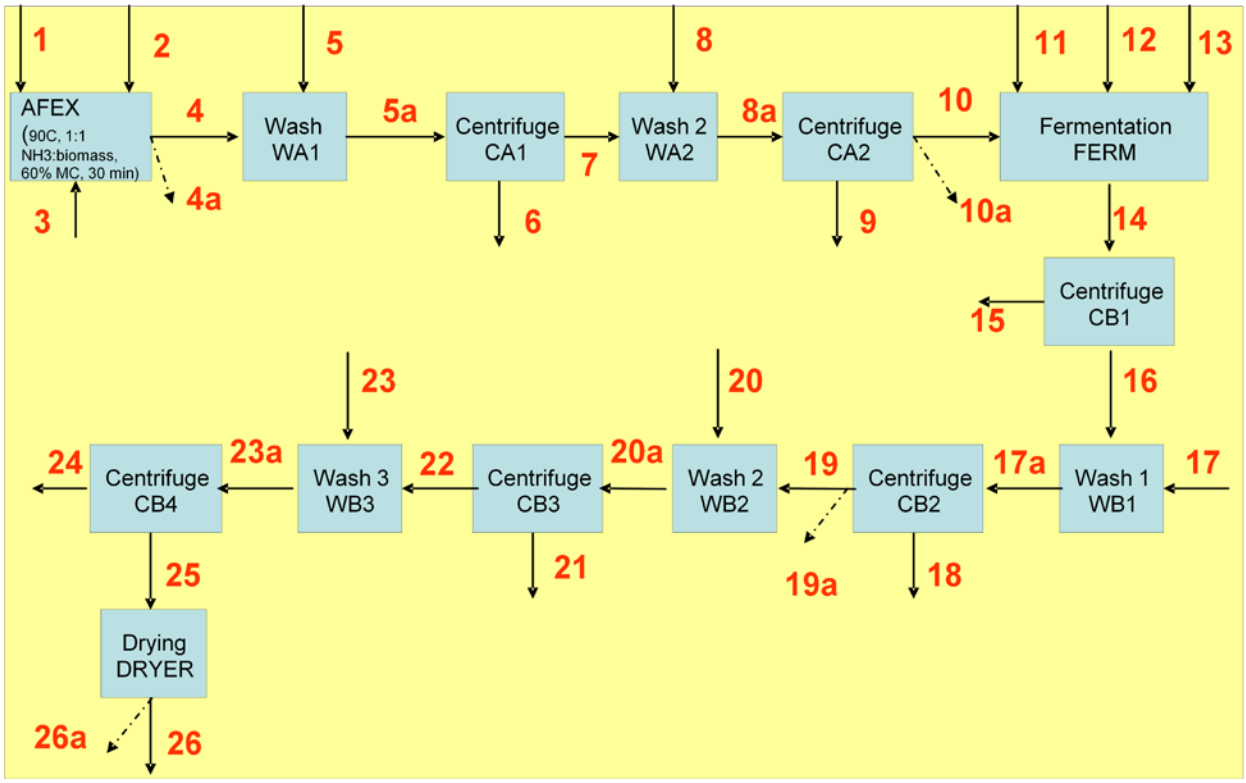

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Table 7. Description of the streams shown in Figure 4

Stream #	Description
1	2500 gram water
2	3750 gram ammonia
3	3750 gram dry wheat straw
4	1500 gram dry AFEX-treated wheat straw
5	15000 gram water, at room temperature, for 30 min.(this was done in 2 batches)
6	For fermentor #1: 5820ml collected wash 1, 0.845% solids
	For fermentor #2: 5700 ml collected wash 1, 0.845% solids
7	For fermentor #1: 2.2K gram collected solid 1, 69.8% moisture
	For fermentor # 2: 2.2KG collected solid 1, 65.8% moisture
8	15000 gram water, at tap DI °C, for how long 30 min.(this was done in 2 batches)
9	For fermentor #1: 6680 ml collected wash 2, 0.216% soild
	For fermentor #2 : 7320 ml collected wash 2, 0.216% solid
10	For fermentor #1: 2616 gram collected solid 2, 70.3% moisture
	For fermentor#2: 2120 gram collected solid 2, 71.9% moisture
11	2669.9 ml media, total liquid in fermentaion 5000ml
12	500 ml Enzyme 57.08 g Spezyme CP, 27.86 g Novo
13	300 ml Yeast inoculum
14	5181.46 gram of whole broth
15	3920 ml liquid broth collected 2.74% solids
16	1241.76 gram fermentation residue collected, 83.5% moisture content
17	731 gram water, at 50°C, for 30 min
18	839.16 gram collected post fermentation wash 1, 1.70% solid
19	680.95 gram collected post fermentation solid 1, 81.85% moisture (#3-#6)
20	245.02 gram water, at 50°C, #1 & #2 added together
21	gram collected post fermentation wash 2, 0.846% solid
22	374.81 gram collected post fermentation solid 2,
23	331.5 gram water, at 50°C
24	774.3 gram collected post fermentation wash 3, 0.382% average solid
25	289.63 gram collected post fermentation solid 3,
26	53.54 gram collected final sample,

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Table 8. Mass balance for the processes shown in Figure 4

Block	stream ID	amount (g)	Feed stream	Process stream	Removed stream	total in (g)	total out (g)	lost/gain	lost/gain (wt%)
AFEX	1	2,500	water			10,000	10,000	-	
	2	3,750	NH3						
	3	3,750	dry wheat straw						
	4	1,500		treated wheat straw					
	4a	8,500			treated wheat straw				
WA1	4	1,500		from AFEX to WA1		16,500	16,500		
	5	15,000	water						
	5a	16,500		from WA1 to CA1					
CA1	5a	16,500		from WA1 to CA1		16,500	15,941	(559)	-3.4%
	6	11,541			liquid after CA1				
	7	4,400		from CA1 to WA2					
WA2	7	4,400		from CA1 to WA2		19,400	18,571	(829)	-4.3%
	8	15,000	water						
	8a	18,571		from WA2 to CA2					
CA2	8a	18,571		from WA2 to CA2		18,571	18,571	-	
	9	13,835			liquid after CA2				
	10	1,730		from CA2 to Ferm					
	10a	3,006			from CA2 to Ferm				
FERM	10	1,730		from CA2 to Ferm		5,500	5,181	(319)	-5.8%
	11	2,970	media						
	12	500	enzyme						
	13	300	yeast						
	14	5,161		from Ferm to CB1					
CB1	14	5,161		from Ferm to CB1		5,161	5,189	28	0.5%
	15	3,948			liquid after CB1				
	16	1,242		from CB1 to WB1					
WB1	16	1,242				1,973	1,973	-	
	17	731	water						
	17a	1,973							
CB2	17a	1,973		from WB1 to CB2		1,973	1,876	(97)	-4.9%
	18	839.16			liquid after CB1				
	19	110.84		from CB2 to WB2					
	19a	925.90			WB1/CB2 to dryer and storage				
WB2	19	110.84				1,449	1,449	-	0.0%
	20	1338.35	water						
	20a	1,449.19		from WB2 to CB3					
CB3	20a	1,449.19				1,449	1,449	-	0.0%
	21	959.17			liquid after WB2/CB3				
	22	490.02							
WB3	22	490.02		from CB3 to WB3		1,170	1,170	-	0.0%
	23	680.17	wash water in						
	23a	1,170.19							
CB4	23a	1,170.19		from WB3 to CB4		1,170	1,159	(11)	-1.0%
	24	774.30			liquid out of CB4				
	25	385		CB4 to dryer					
DRYER	25	384.71		CB4 to dryer		385	385	-	
	26	82.58		**solid for MSU team**					
	26a	302			total liquid removed in drying				

The dried fermentation residue (stream # 26) was further ground, using a regular coffee grinder. The ground sample was sieved and the material that passed through a sieve with 42 mesh screen and retained on a sieve with 60 mesh screen was provided to the MSU team for extraction of micro/nano cellulosic fiber.

The detail of the micro/nano cellulosic fiber work is provided in Appendix C.

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Appendix A

Andritz letter

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3rd August 2009

David Senyk
Vice President Engineering
MBI International
3900 Collins Road
Lansing, MI 48910-8596

Subject: Letter of Confirmation

Dear David:

ANDRITZ is one of the leading suppliers of pulping processes and equipment for all kinds of wood and annual fibers. ANDRITZ is a global company with over 13,000 employees with offices and manufacturing facilities worldwide. ANDRITZ has been active in providing pressurized reactors through our pulp and paper divisions for both wood chips as well as non-woody feedstocks (e.g. bagasse). ANDRITZ has recently intensified their activities in biofuels and biochemicals areas. In the biochemical area this has primarily been with pre-treatment systems (e.g. pre-treatment systems for steam explosion, advanced steam explosion, and dilute acid hydrolysis). In the thermochemical area ANDRITZ provides gasification systems, biomass boilers, etc.

ANDRITZ provides small, medium and very large equipment for traditional pulping applications that is now being utilized for various applications in biofuel / biomass handling. ANDRITZ has also been building smaller pilot and demo systems for the last 25 years (about 100 units and systems in the last 25 years) primarily for the pulp and paper or MDF industries. ANDRITZ also provides equipment for processing feed stocks for food additives, special material recycle systems, and other industries with both wood and non-wood raw materials (forest and agricultural residues, bagasse, leather, plastic residues, fruit baskets, etc)

In the field of biomass processing we supply plant segments and equipment for a wide diversity of raw materials, including:

- Wood
- Straw
- Plastics
- Paper/labels
- Paper pulp
- Sewage sludge
- Industrial waste
- Chemicals
- Municipal waste
- Stabilizers
- Minerals
- Fertilizers

ANDRITZ LTÉE / LTD.

2260, 32e / 32nd Avenue
Lachine, (Québec) H8T 3H4
Tel. (514) 631-7700
Fax (514) 631-3995

In February of 2009 ANDRITZ prepared a technical and commercial budget proposal for a pilot scale biomass AFEX pretreatment system for MBI of Lansing, Michigan. The proposal covered the design and supply of equipment for an approximate 100 kg/hr pretreatment system (pressure feeder, mixing conveyor, horizontal reactor and discharge device) based on corn stover. ANDRITZ is familiar with the AFEX process conditions (temperature, pressure, and residence time) and is confident the equipment specified in our proposal is capable meeting those conditions with either corn stover or wheat straw as the feedstock. ANDRITZ has repeatedly shown this equipment to be capable of meeting similar process conditions with both wheat straw and corn stover in the proposed equipment as well as smaller and larger scale units.

Sincerely yours,

Serge G. Gendreau
Vice President
Mechanical Pulping Division
Andritz Ltd.

ANDRITZ LTÉE / LTD.

2260, 32e / 32nd Avenue
Lachine, (Québec) H8T 3H4
Tel. (514) 631-7700
Fax (514) 631-3995

Appendix B

DOE proposal

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US Department of Energy
Financial Assistance Funding Opportunity Announcement
DE-FOA-0000096

MBI International Proposal Package
"Demonstration of an AFEX Integrated Biorefinery at Pilot Scale"
submitted June 25, 2009

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OMB Number: 4040-0004
Expiration Date: 01/31/2009

Application for Federal Assistance SF-424

Version 02

* 1. Type of Submission:	* 2. Type of Application:	* If Revision, select appropriate letter(s):
☐ Preapplication	☒ New	
☒ Application	☐ Continuation	* Other (Specify)
☐ Changed/Corrected Application	☐ Revision	

* 3. Date Received:	4. Applicant Identifier:
Completed by Grants.gov upon submission.	

5a. Federal Entity Identifier:	* 5b. Federal Award Identifier:

State Use Only:

6. Date Received by State:	7. State Application Identifier:

8. APPLICANT INFORMATION:

* a. Legal Name: Michigan Biotechnology Institute d/b/a MBI International

* b. Employer/Taxpayer Identification Number (EIN/TIN):	* c. Organizational DUNS:
38-2418381	151925179

d. Address:

* Street1:	3900 Collins Road
Street2:	
* City:	Lansing
County:	Ingham
* State:	MI: Michigan
Province:	
* Country:	USA: UNITED STATES
* Zip / Postal Code:	48910-8596

e. Organizational Unit:

Department Name:	Division Name:

f. Name and contact information of person to be contacted on matters involving this application:

Prefix:		* First Name:	Catherine
Middle Name:	M.		
* Last Name:	Johnson		
Suffix:			

Title: Contracts & Grants Administrator

Organizational Affiliation:

* Telephone Number:	517-336-4645	Fax Number:	517-337-2122

* Email: johnson@mbi.org

OMB Number: 4040-0004
Expiration Date: 01/31/2009

Application for Federal Assistance SF-424 Version 02

9. Type of Applicant 1: Select Applicant Type:

M: Nonprofit with 501C3 IRS Status (Other than Institution of Higher Education)

Type of Applicant 2: Select Applicant Type:

Type of Applicant 3: Select Applicant Type:

* Other (specify):

*** 10. Name of Federal Agency:**

Golden Field Office

11. Catalog of Federal Domestic Assistance Number:

81.087

CFDA Title:

Renewable Energy Research and Development

*** 12. Funding Opportunity Number:**

DE-FOA-0000096

* Title:

Recovery Act - Demonstration of Integrated Biorefinery Operations

13. Competition Identification Number:

Title:

14. Areas Affected by Project (Cities, Counties, States, etc.):

Entire United States

*** 15. Descriptive Title of Applicant's Project:**

Demonstration of an AFEX Integrated Biorefinery at Pilot Scale

Attach supporting documents as specified in agency instructions.

Add Attachments | Delete Attachments | View Attachments

OMB Number: 4040-0004
Expiration Date: 01/31/2009

Application for Federal Assistance SF-424 Version 02

16. Congressional Districts Of:

* a. Applicant: MI-008
* b. Program/Project: US-all

Attach an additional list of Program/Project Congressional Districts if needed.

Add Attachment | Delete Attachment | View Attachment

17. Proposed Project:

* a. Start Date: 01/01/2010
* b. End Date: 08/31/2014

18. Estimated Funding ($):

* a. Federal	18,790,237.00
* b. Applicant	4,342,740.00
* c. State	0.00
* d. Local	0.00
* e. Other	354,819.00
* f. Program Income	0.00
* g. TOTAL	23,487,796.00

*** 19. Is Application Subject to Review By State Under Executive Order 12372 Process?**

- [ ] a. This application was made available to the State under the Executive Order 12372 Process for review on .
- [ ] b. Program is subject to E.O. 12372 but has not been selected by the State for review.
- [x] c. Program is not covered by E.O. 12372.

*** 20. Is the Applicant Delinquent On Any Federal Debt? (If "Yes", provide explanation.)**

- [ ] Yes
- [x] No

Explanation

21. *By signing this application, I certify (1) to the statements contained in the list of certifications and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances** and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 218, Section 1001)**

- [x] ** I AGREE

** The list of certifications and assurances, or an internet site where you may obtain this list, is contained in the announcement or agency specific instructions.

Authorized Representative:

Prefix:
* First Name: Venkataraman
Middle Name:
* Last Name: Bringi
Suffix: Ph.D

* Title: President & CEO

* Telephone Number: 517-336-4602
Fax Number: 517-337-2122

* Email: bringi@mbi.org

* Signature of Authorized Representative: Completed by Grants.gov upon submission.
* Date Signed: Completed by Grants.gov upon submission.

Application for Federal Assistance SF-424 Version 02

*** Applicant Federal Debt Delinquency Explanation**

The following field should contain an explanation if the Applicant organization is delinquent on any Federal Debt. Maximum number of characters that can be entered is 4,000. Try and avoid extra spaces and carriage returns to maximize the availability of space.

OMB Number: 4040-0010
Expiration Date: 08/31/2011

Project/Performance Site Location(s)

Project/Performance Site Primary Location ☐ I am submitting an application as an individual, and not on behalf of a company, state, local or tribal government, academia, or other type of organization.

Organization Name: Michigan Biotechnology Institute d/b/a MBI International

DUNS Number: 1519251790000

* Street1: 3900 Collins Road

Street2:

* City: Lansing County: Ingham

* State: MI: Michigan

Province:

* Country: USA: UNITED STATES

* ZIP / Postal Code: 48910-8596 * Project/ Performance Site Congressional District: MI-008

Project/Performance Site Location 1 ☐ I am submitting an application as an individual, and not on behalf of a company, state, local or tribal government, academia, or other type of organization.

Organization Name: National Renewable Energy Laboratory

DUNS Number: 8059480510000

* Street1: 1617 Cole Boulevard

Street2:

* City: Golden County: Jefferson

* State: CO: Colorado

Province:

* Country: USA: UNITED STATES

* ZIP / Postal Code: 80401-3305 * Project/ Performance Site Congressional District: CO-007

Project/Performance Site Location 2 ☐ I am submitting an application as an individual, and not on behalf of a company, state, local or tribal government, academia, or other type of organization.

Organization Name: Novozymes North America Inc.

DUNS Number: 0520909090000

* Street1: 77 Perry Chapel Church Road

Street2:

* City: Franklinton County: Franklin

* State: NC: North Carolina

Province:

* Country: USA: UNITED STATES

* ZIP / Postal Code: 27525-0576 * Project/ Performance Site Congressional District: NC-002

Demonstration of an AFEX Integrated Biorefinery at Pilot Scale: Project Summary

MBI International (MBI) is leading a world-class team of industry, university, and federal laboratory partners to design, construct, and operate an innovative, integrated biorefinery to produce ethanol from corn stover at 1 dry tonne/day (TPD) pilot scale. This team, which includes the National Renewable Energy Laboratory (NREL), Michigan State University (MSU), Novozymes North America, Inc., Vermeer Corporation, ICM Inc., The Andersons, and Airgas, Inc., brings years of experience in design, engineering and construction, feedstocks, biomass processing, enzymatic hydrolysis, microbial strain development, fermentation, and commercialization of biobased products. The MBI team brings a significant portfolio of intellectual property to support the technology, and key technical innovators are integral members of the team. Dr. Bernie Steele, of MBI, will be the Project Director.

This Integrated Biorefinery is underpinned by the Ammonia Fiber Expansion (AFEX) treatment process in which biomass, water and concentrated ammonia are mixed and subjected to elevated temperature and pressure for a brief period. AFEX treatment results in reduced recalcitrance of biomass to subsequent enzymatic hydrolysis, and more effective conversion of resulting sugars to fermentation products. AFEX is a "dry-biomass-in-and-out" process in which the sugars are retained in their polymeric form without any prehydrolysis or partial sugar solubilization. Consequently, AFEX-treated biomass is a *stable intermediate*, one that can be densified, stored, transported and integrated with subsequent bioconversion steps. The unique properties of AFEX-treated biomass give rise to inherent operational flexibility for the AFEX Integrated Biorefinery, addressing supply-chain-logistics challenges, and facilitating broad commercialization and deployment.

The major goals of the pilot-scale AFEX Integrated Biorefinery are to: 1) Operate a continuous AFEX treatment process with ammonia recovery and reuse at 1 TPD; 2) Integrate the AFEX-treated material with high-solids enzyme hydrolysis and mixed sugar co-fermentation steps to demonstrate ethanol production from corn stover at the 1 TPD scale; 3) Evaluate the fermentation residues and determine their value as fuel for steam and electrical generation and 4) Collect performance data and mass and energy balances from these operations and incorporate them into techno-economic models for a commercial AFEX Integrated Biorefinery.

During the proposed project we will 1) procure and pre-process corn stover; 2) treat corn stover with a continuous AFEX process at pilot-scale; 3) recover and reuse the ammonia in the AFEX process; 4) densify the AFEX-treated corn stover to demonstrate storage and transport advantages; 5) perform high-solids enzyme hydrolysis with specifically selected enzymes; 6) ferment both C5 and C6 sugars to ethanol using a recombinant microorganism; and 7) recover the ethanol. The project will include the design and construction of an expansion to MBI's pilot facility in Lansing, Michigan, to house the AFEX process equipment. Bioconversion to ethanol will be conducted at NREL's newly expanded pilot facility in Golden, Colorado. The work plan will be completed in an aggressive but realistic time frame of 44 months with a total budget of $23.5 million. A path to commercialization is outlined in the submission, with the first commercial plant targeted to go online in 2015.

Expected Benefits: The envisioned commercial AFEX Integrated Biorefinery produces ethanol in a cost-effective manner in line with DOE's targets. Life Cycle Analysis shows the potential to reduce greenhouse gas emissions by 65%. Following broad deployment, Petroleum Displacement Analysis shows the potential for AFEX Integrated Biorefineries to displace approximately 120 million barrels of oil/annum by 2030. The project is expected to create or retain more than 100 jobs. There is also a significant opportunity for job creation based on successful commercial deployment of AFEX Integrated Biorefineries, for which the proposed project is a critical enabling step. If cellulosic ethanol produces 16 billion gallons of renewable fuels by 2022 and employment is similar to the current grain ethanol industry, the creation of 535,000 new jobs in cellulosic fuels is possible.

Demonstration of an AFEX Integrated Biorefinery at Pilot Scale
PROJECT NARRATIVE
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1.0 INTRODUCTION

MBI International (MBI) is leading a world-class team of industry, university, and federal laboratory partners to design, construct, and operate an innovative, integrated biorefinery to produce ethanol from corn stover at 1 dry tonne/day (TPD) pilot scale. This team brings together the required knowledge, experience, and facilities to meet the broad range of requirements set forth in DE-FOA-0000096 to successfully demonstrate Integrated Biorefinery Operations at pilot scale. The proposed pilot plant operations and the pathway to commercialization are designed to address three key criteria for sustainable biofuels: (i) cost effectiveness of production (ii) scalability to meet the petroleum displacement objectives in the renewable fuels standards and (iii) reduction in greenhouse gas emissions relative to fossil fuels. Our proposal for an innovative, integrated biorefinery is underpinned by the Ammonia Fiber Expansion (AFEX) treatment process.

AFEX is a biomass treatment process in which biomass, water and concentrated ammonia are mixed in a specified ratio, and maintained at a specified temperature and pressure for a specified time period. AFEX treatment causes significant physical and chemical changes in the biomass, resulting in reduced recalcitrance to enzymatic hydrolysis, and more effective conversion of sugars to fermentation products. The applicability of AFEX to a broad range of agricultural feedstocks has been described in the literature (Alizadeh et al., 2005, Teymouri et al., 2004, Teymouri et al., 2005a, Murnen et al., 2007).

AFEX is fundamentally different from "pretreatment" as defined by the U.S. Department of Energy (DOE). The DOE definition of pretreatment is intimately tied to the concept of "prehydrolysis" of sugars from the biomass, as described in the March 2008 DOE Biomass Multi-year Program Plan document (page 3-31): "*In this [pretreatment/pre-hydrolysis] step, the biomass feedstock undergoes a thermochemical process to break down the hemicellulose fraction of the feedstock into a mixture of soluble five-carbon sugars…and soluble six-carbon sugars. This partial solubilization makes the remaining solid cellulose fraction more accessible for enzyme saccharification later in the process.*"

Unlike most pretreatments, AFEX retains the hemicellulose and cellulose sugars in their polymeric form in the treated biomass. AFEX causes physical and chemical changes in the biomass, but there is no pre-hydrolysis of the hemicellulose fraction nor conversion to monomeric sugars during the

process. No sugar-bearing liquid stream is produced during the AFEX process, as is seen in steam or dilute-acid pretreatment processes. Consequently, unlike pretreated biomass, AFEX-treated biomass may be considered a stable intermediate, one that can be stored, transported and integrated with subsequent processing steps.

The DOE-supported Biomass Refining Consortium for Applied Fundamentals and Innovation (CAFI) studies conclude that AFEX is effective and economical. Following extensive comparative studies at laboratory bench-scale, the CAFI group concluded that: 1) AFEX is an effective biomass treatment method to enhance enzymatic hydrolysis of corn stover to produce clean fermentable sugars, and 2) the estimated cost of commercial production of ethanol using AFEX is competitive with other technologies (Wyman et al., 2005, Eggeman and Elander, 2005).

While AFEX is a promising biomass treatment technology, studies to date have been conducted at laboratory bench-scale in batch-mode reactor systems. The next steps in realizing the commercial potential of AFEX are for MBI and its partners to demonstrate an integrated biorefinery based on the AFEX process. This AFEX Integrated Biorefinery includes the steps of (a) feedstock procurement and processing (b) AFEX treatment operating with continuous processing and ammonia recycle and (c) enzymatic hydrolysis, fermentation and ethanol recovery.

This proposal outlines our plans to demonstrate a scalable AFEX process, integrate AFEX with upstream and downstream processes to demonstrate an integrated biorefinery and define a pathway for rapid commercial deployment of AFEX Integrated Biorefineries.

2.0 PROJECT OVERVIEW

A flow chart of both a conventional and an AFEX Integrated Biorefinery is shown in Figure 1. The first step in both processes is to grow, harvest, and preprocess the biomass into a stable intermediate – harvested biomass – that can be stored and transported as needed for subsequent steps. Next, in a conventional model, the biomass is pretreated, conditioned, enzymatically hydrolyzed, and fermented, after which ethanol is recovered. Note that no stable intermediate is produced between pre-treatment and the subsequent steps. This means that pretreatment must occur at the same location as all subsequent steps, and processing must be followed through to the final product, ethanol.

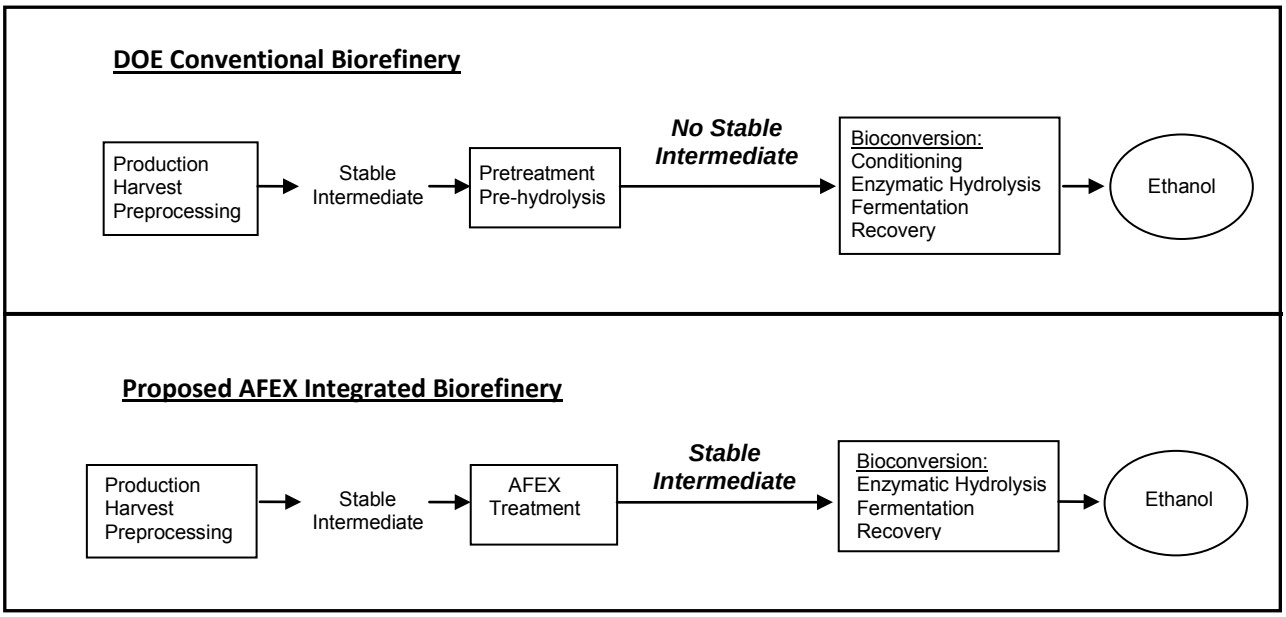

Figure 1. Integrated Biorefinery concepts

For the AFEX Integrated Biorefinery, the preprocessed biomass is subjected to AFEX treatment, which prepares the biomass for bioconversion. Since AFEX is a "dry biomass in - dry biomass out" process, no initial pre-hydrolysis occurs and the resulting AFEX-treated biomass is in a stable intermediate form that can be stored and transported. AFEX-treated biomass does not require subsequent conditioning; therefore, final bioconversion steps are simply enzymatic hydrolysis, fermentation, and recovery.

An AFEX Integrated Biorefinery has inherent flexibility with respect to where the various processes can be located. For example: 1) in a centralized option, AFEX treatment is co-located with the Bioconversion Facility; and 2) in a de-centralized option, AFEX treatment would be located separately from the Bioconversion Facility, with multiple AFEX treatment centers serving a given Bioconversion Facility. We plan to capitalize on this flexibility during the pilot plant and subsequent demonstration and commercial phases. For the proposed pilot plant, we will de-centralize the stages and capitalize on our partners' existing infrastructure.

An AFEX Integrated Biorefinery is integrated in the following ways:

1) It produces ethanol as the primary product from 1 TPD of biomass through the entire process.
2) It links each process stage to the next by the flow of a stable intermediate.
3) It maintains integrity by restricting energy and recycle streams within a given process stage unless two stages are co-located. The only material transferred from one process stage to the next is a stable intermediate.

Advantages of an AFEX Integrated Biorefinery

An AFEX Integrated Biorefinery has compelling advantages over the Conventional Biorefinery shown in Figure 1. These advantages arise from the underlying features of AFEX and the properties of the stable AFEX-treated intermediate. Along with these advantages, AFEX treatment does come with the costs associated with ammonia handling, recovery and reuse. These costs are not borne by steam or acid pretreatment, though these pretreatments do bear other costs such as specialized materials of construction, conditioning of pretreated biomass, and waste handling. In any case, the costs of any treatment technology must be viewed in balance with the benefits conferred by the technology, and such cost/benefit analyses are best done at the integrated systems level. Table 1 below summarizes the underlying features of AFEX, the systems benefits arising from these features, and overall outcomes for the proposed AFEX Integrated Biorefinery.

The benefits summarized above are important from a commercial perspective since they address three key criteria for sustainable biofuels -- cost effectiveness, scalability, and reduction in greenhouse gas emissions. The AFEX stable intermediate can be used as a feedstock for other bio-based products as well as animal feed. A product that can be sold into several markets is less vulnerable to the volatility of a single market. This feature reduces risk and could enhance the prospects for rapid and broad commercial deployment.

Innovations of an AFEX Integrated Biorefinery

In order to realize the significant economic and logistic advantages described above, we propose to demonstrate a scalable AFEX process. Scalability requires the transformation of the batch process into a continuous AFEX process. We propose to then integrate the continuous AFEX process with upstream biomass production/preprocessing steps and downstream bioconversion steps. These combined operations will demonstrate a scalable AFEX Integrated Biorefinery at a 1 TPD pilot scale. Key innovations required to demonstrate a scalable AFEX Integrated Biorefinery include:

1) Design and operation of a continuous AFEX biomass treatment process heretofore practiced only in batch mode
2) Incorporation of ammonia recovery and reuse in the continuous AFEX process
3) Densification of AFEX-treated biomass for storage and transportation efficiency

4) Integration of high-solids enzymatic hydrolysis and mixed-sugar co-fermentation steps with AFEX-treated stover at pilot scale
5) Incorporation of enzymes selected specifically for efficient hydrolysis of AFEX-treated corn stover

The scalable AFEX Integrated Biorefinery featuring these key innovations will represent a breakthrough technology. The features listed in Table 1 are all examples of differentiated, innovative benefits that will arise from commercialization of this breakthrough technology.

Table 1. Advantages of an AFEX Integrated Biorefinery

Feature	Systems Benefit	Overall Outcomes
AFEX can be linked with upstream and downstream steps via stable intermediates	High level of overall process integration from biomass to ethanol	Performs favorably in terms of cost and reduced greenhouse gas emissions
AFEX-treated biomass can be stored and transported	Centralized and decentralized options for integrated biorefinery operation	Flexible deployment of commercial biorefineries in varied geographical areas
Properties of AFEX-treated biomass facilitate densification	Efficient storage and transportation between stages utilizing existing infrastructure	Improves supply-chain logistics
AFEX is effective on multiple agricultural feedstocks	Multiple feedstocks can be processed in a given integrated biorefinery	Mitigates vulnerability to supply chain disruption and facilitates year-round operation
AFEX treatment does not produce high levels of metabolic inhibitors	AFEX treated biomass is compatible with fermentation using diverse organisms	Speeds acceptance of next generation organisms
AFEX treated biomass does not require neutralization, washing or conditioning	AFEX treated biomass can be used as feedstock for a variety of bio-based products	AFEX infrastructure can support both fuels and bio-based chemicals
AFEX-treated biomass can be digested by ruminants	AFEX-treated biomass can be used as animal feed	Addresses food versus fuel tradeoff and land use issues; Reduces market vulnerability

3.0 PROJECT OBJECTIVES

The major goals and aims of the pilot-scale AFEX Integrated Biorefinery are outlined below.

Goals

1) Operate a continuous AFEX treatment process with ammonia recovery and reuse at 1 TPD
2) Integrate the AFEX treated material with high-solids enzyme hydrolysis and mixed sugar co-fermentation steps to demonstrate ethanol production from corn stover at the one TPD scale
3) Evaluate the fermentation residues and determine their value
4) Collect performance data and mass and energy balances from these operations and incorporate them into techno-economic models for a commercial AFEX Integrated Biorefinery

Critical Success Factors (CSFs)

Prior work at MBI and MSU has addressed several technical barriers through bench-scale experiments. As explained in more detail in Section 2 of the Project Execution Plan (PEP), bench-scale batch experiments have demonstrated: 1) 94% of theoretical yield of fermentable sugars from AFEX-

treated corn stover; 2) 98% recovery of ammonia from AFEX-treated corn stover; and 3) 5% ethanol titer in high-solids enzymatic hydrolysis and fermentation from AFEX-treated corn stover. These data demonstrate that our AFEX Integrated Biorefinery has significant commercial potential and is ready for validation at pilot scale.

Barriers that will be addressed in the proposed project include (i) uncertainty in the production cost of ethanol in the AFEX Integrated Biorefinery, (ii) viability of operating a continuous AFEX reactor and ammonia catalyst recovery system, (iii) uncertainty in fermentation and recovery efficiencies and (iv) uncertainty in the heating value of fermentation residues.

The factors critical to successful completion of this project are:

1. Complete techno-economic model of a commercial AFEX Integrated Biorefinery, and determine the minimum selling price and GHG emissions for ethanol produced at a commercial facility, using mass and energy flows determined in pilot-scale performance
2. Demonstrate continuous operation of an AFEX reactor with ammonia recycle at pilot scale
3. Integrate high-solids enzymatic hydrolysis and mixed-sugar co-fermentation steps with AFEX-treated stover at pilot scale
4. Achieve the critical factors above and complete all tasks within the scope, budget, and schedule shown in the WBS

Value Proposition

Our proposal meets Energy Efficiency and Renewable Energy performance objectives as outlined by the DOE Biomass Multi Year Program Plan (2008): 1) to reduce dependence on imported oil; 2) to promote the use of diverse, domestic and sustainable energy resources 3) establish a domestic bioindustry; and 4) reduce carbon emissions from energy production. We have the necessary bench-scale technical and economic performance data that validate readiness for scale up to pilot scale. Our AFEX Integrated Biorefinery will demonstrate the production of ethanol, a primary liquid transportation fuel that supports the advanced biofuels portion of the Energy Independence and Security Act of 2007 and the Renewable Fuel Standards of 2007. Our integrated process employs a unique treatment method, minimizes waste, reduces green house gas emissions by 65%, is highly scalable, utilizes an available feedstock and has the flexibility to operate AFEX treatment at locations other than a centralized biorefinery. To support DOE's goals, our team will proceed rapidly through to demonstration-scale and commercialization. We have a sound business and technology strategy to deploy and/or license and market the technology commercially.

Our team proposes an innovative approach to the integrated biorefinery that is enabled by the AFEX treatment process. This approach addresses several barriers to cost effective production of ethanol from lignocellulosic biomass including: 1) recalcitrance of lignocellulosic biomass to enzymatic hydrolysis; 2) catalyst recovery and recycle; 3) high solids loading of treated materials for enzyme hydrolysis and fermentation; 4) enzyme cost; 5) compatibility of biomass sugar stream with fermentation; and 6) opportunity for improvement in supply chain issues.

MBI is a leader in delivering commercially-viable product and process solutions to address the emerging need for new bio-based products that combine environmentally friendly attributes, sustainable production processes, and renewable raw-material sources. MBI applies multidisciplinary expertise, modern laboratories and a robust, flexible de-risking approach. We utilize pilot-plant facilities to accelerate the development and scale-up of bio-based technologies and we partner with both universities and end-user companies to bridge the gap between early innovations and commercial applications. For this proposal, we have assembled a team of partners that, along with MBI personnel, bring years of experience in design, engineering and construction, biomass processing, enzymatic hydrolysis, strain development and fermentation. This MBI team also brings a significant portfolio of intellectual property to support the technology to be demonstrated and the inventors of the technology

are integral members of the team. We have a unique framework of collaborators that have the experience and full spectrum of capabilities for successful project implementation.

The major team members are:

MBI - MBI International has a successful 27-year history of bringing renewable products from academic research to the commercial market. One example is polylactic acid (PLA). Engineering, scale-up and applications research for production of lactic acid and PLA biodegradable plastics technology were conducted at MBI and MSU with collaboration and support of Cargill Inc., one of the world's largest agribusinesses. Today, this biodegradable polymer is broadly used around the world in both plastics and fibers in clothing and carpets, containers for food and garbage bags, car parts, etc. Another example, Evercorn, Inc., was a successful joint venture between an MBI subsidiary and Japan Corn Starch (one of Japan's leading starch-based industrial products companies) to develop a family of polymer resins that are processed into films and moldable products for disposable use applications. These polymers are strong, water-resistant thermoplastics used in disposable cutlery, plastic containers, and paper coatings. Evercorn's biodegradable products were featured at the Nagano Olympic Games (1998).

Vermeer – Vermeer Corporation manufactures agricultural, construction, environmental, and industrial equipment in Pella, Iowa. From modest beginnings, quality product innovations and demand has allowed the company to expand its offerings to more than 60 countries. Today Vermeer consists of eight manufacturing plants spanning some 110 acres that occupy more than 1.5 million square feet of manufacturing space in Pella, Iowa. Vermeer is recognized as a global leader in forage, tree care, wood-waste processing, composting, compact and underground installation equipment. Vermeer currently employs over 2000 people and is interested in the use and development of its machinery in the cellulosic biofuels industry.

MSU - Michigan State University pioneered the concept of the Land Grant University and has the fundamental infrastructure necessary to establish the foundation for bioeconomy development in Michigan. This includes laboratories and core facilities for instrumentation, computation and modeling; field research facilities across the state; funding for creative new research projects; and pilot and scale-up facilities for unique commercialization expertise through MBI International, a firm with proven success in bringing biotechnology ideas to the market. MSU also has strongly developed links with other research universities and private sector partners, including established relationships with all major agricultural input providers, select biotechnology firms and key manufacturing industries.

NREL - The National Bioenergy Center (NBC) of the National Renewable Energy Laboratory (NREL) has led the nation's efforts in the R&D of bioprocess conversion technology for lignocellulosic ethanol and other fuels and chemicals from biomass for over 30 years. In addition to its world-class bioprocessing laboratories and pilot plant facilities, the NBC is home to over 100 technical and support staff who are focused on R&D of biochemical and thermochemical conversion process for lignocellulosic biomass. Many researchers in the NBC have over 15 years of experience in the development of such processes, including key personnel who will be leading and contributing to the MBI-led project team.
Personnel in the NBC lead and conduct core research tasks for DOE's Office of the Biomass Program (OBP), including several activities with multi-million dollar annual budgets that span the entire range of biochemical conversion technologies, including biomass pretreatment, enzymatic hydrolysis, fermentation, bioprocess integration and scale-up, chemical analysis, and techno-economic analysis. The activities represent the core R&D of DOE's OBP, and NBC researchers are renowned world-wide as experts in all conversion technology aspects, with an extensive patent and publication portfolio.

Additionally, NBC staff members have extensive experience in leading and conducting R&D programs in collaboration with numerous industrial partners to further the deployment of biomass conversion bioprocesses. In recent years, key industrial collaboration projects that the NBC has provided a major technical role included those with DuPont, Abengoa, POET, ADM,

NatureWorks/Cargill-Dow, New Energy Company of Indiana, and Amoco, among others. The NBC staff is proficient in all aspects of managing and conducting such collaborations and has extensively utilized the NBC laboratory and pilot plant facilities in these projects.

Novozymes – Novozymes is a world leader in enzyme development, production and sales and has lead the way in development of next generation enzymes for conversion of cellulosic feedstocks to biofuels and chemicals. Through prior work with DOE they have dramatically increased the efficiency and lowered the cost of these enzymes. Novozymes is currently investing $160-200 million in new facilities in Blair, NE to meet demand for enzymes for the production of first and second generation bioethanol. The new facility will be fully operational in approximately 2010.

Airgas Specialty Products – ASP is a leading distributor of anhydrous ammonia and related services in the United States. The company operates an extensive network of 24 ammonia distribution, field service and office locations. The company is a primary supplier of ammonia to the fast-growing market segment of power plants, oil refineries and other manufacturing facilities nationwide who require ammonia for nitrogen oxide removal. ASP also serves its customers with risk management programs, safety training and equipment and related ammonia quality services.

ICM - ICM is the nation's leading provider of ethanol process design and engineering, with 78 dry-mill fuel ethanol plants operating in the United States and Canada that use ICM ethanol process technology. ICM-designed plants consistently perform 24 hours per day, at least 353 days per year for a 96% runtime – the highest performance measure in the industry. ICM's market success, an approximate 50% market share in current ethanol production, results from the fact that ICM process technology simply runs better, faster, cheaper and with less downtime than competing technologies. ICM employs 30 full-time engineers in its various departments, including process chemical engineers, mechanical engineers, electrical engineers, and civil engineers. ICM also designs, engineers, and installs a proprietary distributive control system (DCS) for ethanol plants that use ICM process technology.

The Andersons - The Andersons is a publicly traded company with 3000 employees and diverse interests that include agribusinesses such as grain and plant nutrients as well as railcar leasing and repair, industrial products formulation, turf products, retailing and most recently, ethanol operations. The Grain Division operates grain terminals in Ohio, Michigan, Indiana, and Illinois with storage capacity of nearly 90 million bushels. The division trades and merchandises more than 250 million bushels of grain in the Eastern Corn Belt and Canada. The Ethanol Division operates three plants; a 55 million gallon/yr plant in Albion, Michigan and two 110 million gallon/yr plants with partner Marathon Petroleum Company.

Readiness to Proceed

MBI has assembled a leading group of partners to work with the innovative AFEX Integrated Biorefinery. The concept for commercialization offers a unique method of improving the supply chain management and economics that have burdened many plans for cellulosic biorefineries. The proposed plan makes use of each partner's unique expertise and facilities. All team members are budget and milestone driven with experienced performance in delivering project results on time and on budget. In addition, significant preliminary work has been done so that the project can move rapidly through the preliminary stage and on to construction.

MBI and its team partners are ready to proceed with the proposed pilot scale AFEX Integrated Biorefinery. Facilities at MBI and NREL are currently permitted for proposed operations and a quantitative process design has been completed. In addition most major equipment vendors for the AFEX treatment plant have been contacted and recent equipment quotations are available.

4.0 PROJECT DESCRIPTION

This section describes the background, tasks, activities, key decisions, the project management processes and the associated budgets that will be undertaken to address the project goals described in Section 3 of this Narrative.

Project Background

The AFEX Integrated Biorefinery is ready to transition to pilot scale. More than 20 years of bench-scale studies on AFEX treatment of biomass have been conducted and may be summarized as follows: (i) AFEX biomass treatment technology has been demonstrated to work on corn stover; (ii) AFEX-treated biomass has been shown to be amenable to densification (iii) AFEX-treated biomass has been shown to be stable upon storage; (iv) AFEX-treated corn stover has been shown to be amenable to saccharification with commercially available hydrolytic enzymes to yield a mix of C5 and C6 sugars; (v) AFEX-treated biomass has been shown to be compatible with saccharification operations at high solids loading; (vi) C5/C6 mixed sugar stream arising from AFEX treated biomass has shown to be fermented to ethanol by a variety of organisms, including *Zymomonas mobilis*; (vii) It has been shown that AFEX-treated biomass does not produce significant levels of microbial growth and fermentation inhibitors; and (viii) The recovery of up to 98% of the ammonia from AFEX-treated biomass has been demonstrated. Detailed background and data related to the above are provided in Section 2 of the PEP.

We have developed a Pro forma projection for an envisioned commercial AFEX Integrated Biorefinery to become operational in 2015 (see Proforma.xls). The assumptions used in this Pro forma are consistent with published technical reports from NREL (Aden, 2008), CAFI (Eggeman and Elander, 2005), MBI (Campbell et al., 2008; Campbell et al., 2009), and MSU (Laureano-Perz et al., 2005; Teymouri et al., 2004; Teymouri et al., 2005a; Teymouri et al., 2005b). The envisioned commercial AFEX Integrated Biorefinery will produce 120 million gallons of ethanol/yr. A significant component of the projection is a residue-combustion plant that produces all heat and power for the facility and sells power to the grid, generating $8.2 million in income.

Using the value of fuel, the financing terms, and the inflation factor provided in the Pro forma forms, the envisioned commercial plant in 2015 produces ethanol for $2.19/ gallon with a 21.6% return on Total Project Investment (TPI). The minimum ethanol selling price (MESP) to meet a 9.02% return on TPI is $1.58/gallon without financing. This MESP is equivalent to the $1.49/gallon projection (for 2012, also without financing) made by NREL at the 2009 Symposium for Biotechnology for Fuels and Chemicals (Humbird et al., 2009) for the dilute acid process when adjusted for inflation at 2.4%/yr to the year 2015. The AFEX Integrated Biorefinery thus provides a cost effective way to produce cellulosic ethanol.

The expected reduction in greenhouse gas emissions for ethanol produced from corn stover in a commercial AFEX Integrated Biorefinery is 65% and the expected reduction of fossil fuel usage is 73%. Further details on these projections are provided in the Life-Cycle GHG Emission Reduction Data (LCA_GHG.xls). The expected petroleum displacement for a commercial AFEX Integrated Biorefinery is 400,000 barrels per year. Further details on this projection are provided in the Petroleum Displacement Analysis (Petro.doc).

Tasks/Activities

This section describes the tasks and activities that will be undertaken to meet the project goals. We are proposing an innovative approach to the pilot-scale AFEX Integrated Biorefinery that capitalizes on the stable intermediates produced in the process, namely harvested corn stover and AFEX-treated corn stover (Figure 1 in Section 2 of this Narrative). These stable intermediates allow the operations to be de-centralized at different partners' locations while maintaining process integration as described in Section 2 of this Narrative. Our approach leverages partners' existing infrastructure, which in turn maximizes the overall cost-effectiveness of the investments, and more importantly, accelerates timelines. The accelerated timelines make this project more amenable with the timelines required by

the American Recovery and Reinvestment Act of 2009 (Recovery Act), while also addressing the national timelines and goals for replacing petroleum and reducing greenhouse gas emissions.

The proposed project calls for: 1) partner Vermeer, to source and prepare the corn stover (Iowa); 2) AFEX treatment in a 1 TPD AFEX processing plant to be constructed and operated at the MBI facility in Lansing, Michigan; 3) high-solids saccharification and mixed sugar co-fermentation at the newly-expanded NREL pilot plant in Golden, Colorado; and 5) MBI and NREL to analyze the composition and determine the value of the fermentation residue. Data collected from the pilot biorefinery will be incorporated into techno-economic models for commercial plants.

The specific roles of the organizations during the proposed pilot-scale project are summarized below.

Location	Iowa	Michigan	Colorado
Primary Role	Vermeer	MBI	NREL
Secondary Role	MSU	MSU/Airgas	MBI/Novozymes/MSU

Figure 2. Locations and roles of organizations during proposed pilot-scale project.

The detailed Work Breakdown Structure (WBS) can be seen in Section 1 of the Project Management Plan (PMP). There are three Budget Periods of activity throughout the Pilot Scale project; Budget Period 1 includes the design, equipment selection, R&D, NEPA determination, Risk Mitigation Plan, final site and construction plan, and construction permits; Budget Period 2 includes the AFEX building construction, equipment installation, shakedown trials, and demonstration (capstone) runs; Budget Period 3 includes on-going pilot-scale operations of the AFEX Integrated Biorefinery, data reporting, and economic modeling.

The R&D effort is aimed at mitigating specific risks as detailed in the Risk Management Plan (Section 4.0 of the PMP), and includes work focused on ammonia recovery and recycle, enzyme selection and loading, and the challenges of pilot scale high solids loading of AFEX-treated corn stover into the hydrolysis and fermentation modules. The information from this work will be integrated into a final design for the integrated biorefinery.

With respect to AFEX equipment design and construction, we are in an advanced state of readiness to proceed because of historical investments made prior to the current FOA. In 2005 MBI commissioned a preliminary design for a 35 TPD AFEX pilot plant from Dick Engineering (Toronto, Ontario). Dick Engineering recently helped MBI revise and update this design, with cost estimates, for 1 TPD scale. Process equipment, piping and electrical costs were included. Budget quotations for major equipment were obtained. We have visited and had numerous discussions with potential vendors of primary equipment related to AFEX processing and ammonia recovery and have preliminary quotations for this equipment. A preliminary environmental assessment has not revealed any impediments to construction and operation of the proposed pilot plant. All facilities are fully permitted for the proposed operations, including storage and handling of anhydrous ammonia. Only conventional building

construction permits will be needed during the course of the project. This should enable our team to progress swiftly through final NEPA approval for the project.

The equipment and facility design phase is expected to take 4-6 months. It is expected that initial procurement of primary equipment for the AFEX reactor can begin within ten months of the project start and will continue through most of the construction phase. It is necessary to begin procurement as early as possible due to the long lead times (estimates supplied by vendors) of the customized equipment required for the pilot plant. The rest of the process design is dependent on the specific equipment selected for the AFEX reactor. The construction and equipment installation phase of the project is expected to take approximately 12 months and will commence when sufficient areas of design are completed for that portion of the project and DOE has approved start on Budget Period 2.

To house the AFEX treatment and ammonia recovery equipment, MBI plans to make an addition to its facility. The addition will be built adjacent to the existing facility in order to use the existing infrastructure. Steam, water, waste disposal, and electrical power distribution capacity already exists that is sufficient to supply the AFEX treatment pilot plant. The addition will match the original construction and appearance of the existing building. Interior architectural details will match MBI's existing building including the masonry walls. One side of the building will have a receiving and storage area for biomass feedstock with direct access to the processing equipment. The building will also feature an electrical/utilities room, control room, and a laboratory area. An employee workstation and meeting area will be located in the building. The building cost estimate was prepared by EPS (South Bend, Indiana), an engineering design firm with 14 years experience in the biotech and energy industries.

Equipment shakedown refers to the process of troubleshooting to achieve functional operation of all process equipment. Due to the uniqueness of the AFEX process, in particular the use of ammonia recovery and recycle, it is expected that the shakedown phase of the project will require approximately 9 months for AFEX and densification operations and 9 months for the hydrolysis and fermentation operations. All reasonable efforts will be made to keep this phase to a minimum while maintaining appropriate quality assurance and safety standards.

Capstone runs refer to a planned campaign of operations of the proposed biorefinery to successfully demonstrate the feasibility of the technology. Approximately twelve months have been allocated for the capstone runs to demonstrate the functionality, reliability and performance of the AFEX Integrated Biorefinery. This is based on the concept of three campaigns similar to industry standards for scale up of commercial fermentations.

Techno-Economic models will include detailed ASPEN PLUS process models with ASPEN ENCARTA costing modules. These models will contain all unit operations, mass and energy balances, and feed, product, co-product and internal streams necessary for proposed commercial operations. These ASPEN models will be combined with Microsoft Excel models for feedstock preparation and logistics, and business and financial plans to create Pro formas for commercial operations. Models will be created for both centralized and decentralized commercial options to update commercialization plans.

Extended operations will be conducted during Budget Period 3 to collect additional data and generate information for input into the techno-economic models, life-cycle analyses and DOE's State of Technology reports.

Schedule, Resource Loaded Plan, and Spend Plan

As noted above, the full WBS and resource loaded plan can be seen in Section 1 of the PMP. Table 2 below shows a summary of the schedule, major tasks/activities, and spend plan for our pilot plant proposal.

The total pilot plant project cost is $23.5 MM over 44 months. The first year will include final R&D work, final design work and initial procurement activities at a cost of $5.4 MM for the year. During

the second year procurement is completed, and construction begins for a cost of $9.7 MM for the year. In year three, construction is completed, as well as facilities shakedown and final demonstration runs required to meet the goals and objectives of the project for a total of $6.7 MM. During the fourth year MBI will continue to operate the pilot plant for approximately 8 months to gather data crucial to design and construction of a demonstration scale plant ($1.7 MM).

Key Decision Points and Project Management

MBI's current project management practice is consistent with DOE O 413.3A and addresses such elements as strategic planning, roles and responsibilities, work planning and control, fact-based decision making, Stage-Gate reviews, financial planning and control, and reporting. As described in the Project Management Plan, MBI uses a Stage-Gate approach to project management, including go/no-go decision points. Our Stage-Gate process is a method for making disciplined decisions about research and development that leads to focused process and/or product development efforts, and is coordinated with our resource loaded plan. Further details on our approach and how we employ this method to measure progress towards achieving our goals is seen in Section 3.2.2 of the PMP and Section 4.3 of the PEP. There are four Stage-Gate Reviews planned for this project. Expected dates for the Stage-Gate reviews and their expected go/no-go decisions are as follows:

Stage-Gate I – September 2010

- NEPA determination must be complete
- Construction plan must be complete
- Building permits must be in hand

Stage-Gate II – November 2011

- Construction and equipment installation are complete and ready for shakedown

Stage-Gate III – January 2013

- Capstone (demonstration) runs are completed
- Techno-economic models are updated using capstone run data

Stage-Gate IV – July 2013

- Techno-economic models justify a demonstration or commercial scale project

In addition to the above, certain critical milestones in Budget Period 2 are go/no-go decisions. If these milestones are not made on time, some recycling would need to be done and delays could be expected until each was completed. These important milestones and their expected dates of completion are:

1. MBI building construction passes inspection for occupancy – 6/2011
2. Independent Engineer approval of AFEX and Densification equipment at MBI – 12/2011
3. Independent Engineer approval of Hydrolysis and Fermentation equipment at NREL – 8/2012

5.0 Path to Commercialization

MBI and its partners have envisioned a clear and aggressive conceptual path to commercialization, with the first commercial plant coming on line in 2015. We believe that this aggressive timeline is achievable because: (i) the primary product is ethanol, which has established market and distribution channels; (ii) we will target existing grain ethanol facilities to which AFEX units will be added; (iii) AFEX equipment can be based on equipment used in alkaline pulping plants; such processes are routinely operated at > 1000 TPD output; and (iv) the financial returns for the envisioned commercial AFEX Integrated Biorefinery are compelling, and should therefore attract capital.

The first step in this path is the proposed pilot scale project. During the first two years on this path (Figure 3), we will build the proposed pilot plant to demonstrate the AFEX Integrated Biorefinery at 1 TPD (Budget Periods 1 and 2). Upon completion of the pilot plant, we will execute the proposed work to collect the mass and energy balances, Life Cycle Analysis (LCA), Techno-Economic data and Capital and Operating cost data necessary to incorporate in a model for a demonstration/commercial plant

(Budget Periods 2 and 3). These data will help us track and understand the supply chain logistics and potential economic and technical utility of both de-centralized and centralized commercial operating strategies (Section 5 of the Business and Commercialization Plan (BCP). In a decentralized option, the size of a demonstration and commercial facility may be similar. In years three and four of this path, in parallel with pilot plant operations, we will partner with key commercial entities to plan a demonstration/commercial facility. During years four to six of this path, we will execute the demonstration/commercial facility plan with our commercial partners. Such a facility will allow us to validate assumptions based on larger-scale operating data, leading to LCA and techno-economic models necessary to determine expanded commercial implementation. We plan to then broadly expand the deployment of AFEX Integrated Biorefineries through licensing arrangements.

Table 2. Spend Plan

Budget Period	Category	2010	2011	2012	2013	Totals
1	R&D	$1.5				$1.5
	Design, Bid, Procure	$0.9				$0.9
	Lab Equipment	$0.2				$0.2
	Model & LCA	$0.1				$0.1
	Proj. Mgmt, Risk Mitigation, NEPA, Reporting	$0.3				$0.3
	Total	**$3.0**				**$3.0**
2	Equipment	$1.6	$3.9			$5.5
	Design, Construction & Installation	$0.6	$5.2			$5.8
	Shakedown Capstone Runs			$5.7		$5.7
	Model & LCA			$0.5		$0.5
	Proj. Mgmt, Risk Mitigation, Reporting	$0.2	$0.6	$0.5		$1.3
	Total	**$2.4**	**$9.7**	**$6.7**		**$18.8**
3	Operation				$1.5	$1.5
	Proj. Mgmt., LCA, Modeling, Reporting				$0.2	$0.2
	Total				**$1.7**	**$1.7**
	Total Budget	**$5.4**	**$9.7**	**$6.7**	**$1.7**	**$23.5**

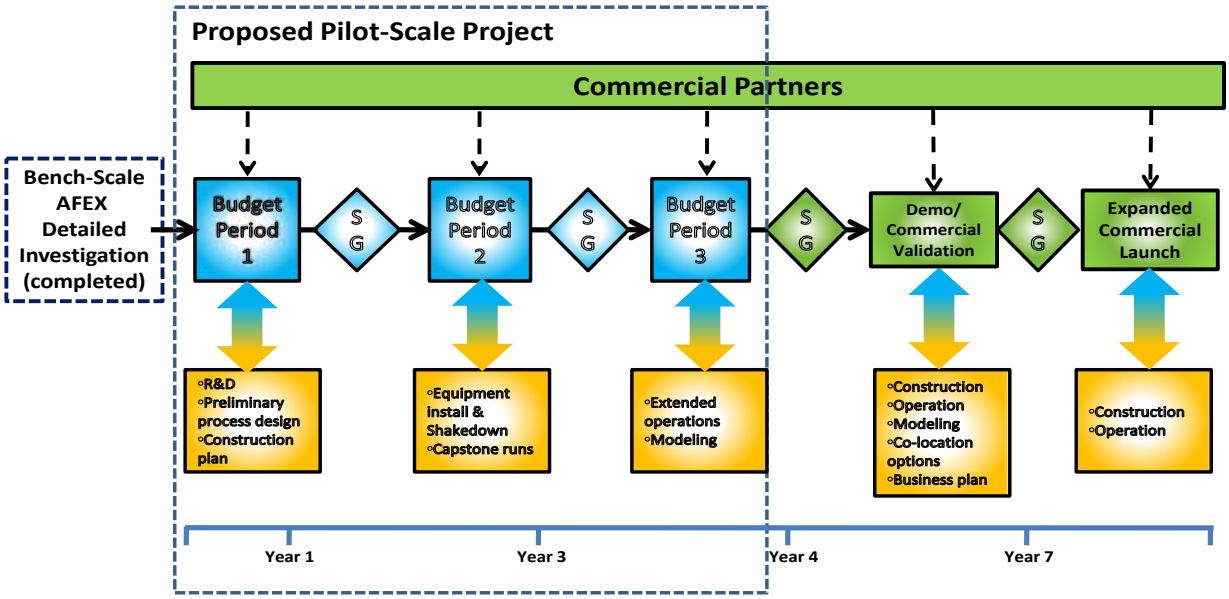

Figure 3. AFEX integrated Biorefinery Path to Commercialization

6.0 Outcomes Related to the Recovery Act

This project promotes and enhances the objectives of the American Recovery and Reinvestment Act of 2009 (Recovery Act). The project is positioned to move expeditiously with construction of new facilities. The project will create and retain jobs in the professional, technical, construction and skilled labor sectors. The project also leverages each partner's existing expertise and facilities, resulting in execution of the work plan in a compressed time frame and thereby accelerating economic recovery.

This project is "shovel ready". A significant level of preliminary design and planning has been completed for the new continuous AFEX treatment facility to be constructed at MBI. NREL is currently in the process of constructing new expanded pilot facilities for high solids processing and fermentation of biomass feedstocks. This advanced level of planning and construction gives us confidence in the proposed timelines for tasks and completion dates. We plan to complete this project in three years and eight months. This aggressive timeline is consistent with the expectations of the Recovery Act.

A significant number of jobs will be created or retained as a result of this project. These jobs may be classified into three categories: (i) Team MBI personnel involved in directly executing the project; (ii) personnel involved in the design and construction of the pilot-scale AFEX processing facility at MBI; and (iii) personnel involved in the design, fabrication, and installation of the specialized equipment used in the project.

In the first category, we estimate that a total of approximately 56.8 Full Time Equivalents (FTE's) will be created or retained over a 44-month period at MBI and partners MSU, NREL, Novozymes and Vermeer. These jobs involve technical experts, technicians or pilot plant operating personnel – all of which are highly relevant for the emerging renewable energy sector ("green jobs").

In the second category, we estimate that the design, equipment installation and construction of the AFEX pilot plant facility in Lansing, Michigan will last 13 months and cost $2.8 million. Assuming an average fully absorbed rate of $130,000 per FTE for these jobs, we estimate that 21 FTE's will be created or retained in this category over the 13-month period.

In the third category, we estimate that the design, fabrication of the AFEX pilot plant equipment will last approximately 10 months and cost $ 5.2 million, of which 50% will be spent on materials and the remaining on labor. Assuming a fully absorbed rate of $100,000 per FTE, we estimate that 26 technical

jobs will be created or retained in this category.

Note that many of these jobs will be located in Michigan, the state that has the highest unemployment rate in the nation, and is greatly in need of economic stimulus. The State of Michigan, the Governor and the Economic Development Group see the advantages of a developing alternative energy industry for economic recovery in Michigan. Commercialization of cellulosic fuels in Michigan can make a significant contribution to this economic development plan. Also note that we are underestimating the total number of jobs in all the categories above since we are not able to accurately estimate the number of jobs created or retained in operations such as raw material production, refining, formulation and transportation.

Finally, there is a significant opportunity for job creation and economic recovery based on successful commercial deployment of AFEX Integrated Biorefineries, for which the proposed project is a critical enabling step. According to the Renewable Fuels Association (www.ethanolrfa.org) the ethanol industry created 154,000 U.S. jobs in 2005 alone, boosting household income by $5.7 billion. It also contributed about $3.5 billion in tax revenues at the local, state, and federal levels. If cellulosic ethanol is to produce 16 billion gallons of renewable fuels by in 2022 and employment is similar to the current grain ethanol industry, we could expect the creation of 535,000 new jobs in cellulosic fuels by 2022.

7.0 CONCLUSION

This proposal warrants the support of the DOE because our scalable AFEX Integrated Biorefinery will address three critical issues that face sustained biomass-to-ethanol production: cost effectiveness, scalability, and greenhouse gas emissions reduction.

The AFEX Integrated Biorefinery is a breakthrough technology comprising multiple innovations for improved biomass processing, supply chain logistics, and bioconversion efficiency. The successful demonstration of these innovations will enable the proposed biorefinery technology to proceed rapidly and cost effectively to commercialization.

MBI International has a successful track record of leading technology development collaborations and accelerating the commercialization of bio-based products. MBI will lead a strong team of collaborators from industry, academia and federal laboratories to design, construct, and operate an innovative, integrated biorefinery at pilot scale. The collective knowhow and experience of the team gives the project a high probability of success.

Successful completion of this project will advance the national goals of (i) reducing dependence on imported oil (ii) spurring the creation of a domestic bio-industry and (iii) creating and retaining jobs and promoting economic recovery.

MICHIGAN STATE
UNIVERSITY

June 16, 2009

Venkataraman (Bobby) Bringi, Ph.D.
President/CEO
MBI International
3900 Collins Road
Lansing, MI 48910

Subject: U.S. Department of Energy Funding Opportunity Announcement DE-FOA-0000096: Demonstration of Integrated Biorefinery Operations

Dear Dr. Bringi,

I am writing to express my unqualified support for MBI's proposal titled "Demonstration of an AFEX Integrated Biorefinery at Pilot Scale". I am fully aware of the scope of the project, the financial investments involved, and the potential risks and upsides associated with the project. Michigan State University is a willing participating partner in this proposal and has prepared a separate letter of commitment as required.

MBI and MSU had in 1998 established a collaboration to develop and de-risk AFEX biomass treatment technology, developed initially by MSU faculty member, Professor Bruce Dale. The current proposal is a logical step to validate the viability of AFEX at pilot scale and to integrate AFEX with the rest of the processing steps to demonstrate an AFEX Integrated Biorefinery at pilot scale. I believe that the proposed AFEX Integrated Biorefinery has the potential to achieve the DOE's goals for the sustainable production of cellulosic biofuels and the reduction of Green House Gas emissions.

MBI and the partners you have assembled are uniquely positioned to meet the challenges represented by the scope of the project, on an aggressive timetable. This team has the substantive experience, intellectual, and financial resources that are required to successfully complete the project within the proposed time and budgets.

The proposed work is complementary to the mission and priorities of Michigan State University. MSU has made a major commitment to the Bioeconomy, as evidenced in part by its participation in the Great Lakes Biotechnology Research Center (GLBRC), funded by the US Department of Energy. I believe that a biomass processing pilot plant, operating at MBI, will greatly enhance current biomass processing programs at the University and within the GLBRC. As a result, MSU and MBI together will be better positioned to accelerate promising biomass-based technologies from early concept to the market.

On behalf of MSU, I am pleased to express my unqualified endorsement of MBI's proposal and would urge DOE's consideration of an award to you and your team.

Best Regards,

J. Ian Gray, Ph.D.
Vice President for Research and Graduate Studies
Ex-Officio Member, MBI Board of Directors

OFFICE OF THE
VICE PRESIDENT FOR RESEARCH AND GRADUATE STUDIES
J. Ian Gray
Vice President
Michigan State University
232 Administration Building
East Lansing, MI
48824-1046
517/355-0306
FAX: 517/432-1171
www.msu.edu/unit/vprgs

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June 23, 2009

D. Bernie Steele, Ph.D.
Director-Operations
MBI International
3900 Collins Road
Lansing, MI 48910-8596

RE: U.S. Department of Energy Funding Opportunity Announcement DE-FOA-0000096: Demonstration of Integrated Biorefinery Operations

Dear Dr. Steele:

This letter is to confirm MBI International's commitment to participate and lead a world class team to demonstrate a pilot-scale AFEX Integrated Biorefinery in response to the DOE solicitation referenced above. A separate letter has been provided as requested to express senior management buy-in to the project, as well as to demonstrate a financial commitment from MBI's parent organization, the MSU Foundation.

As a leader and participant in this project, MBI staff will play key roles in AFEX Treatment; Enzyme Hydrolysis; Fermentation Scale-Up; Plant Design and Engineering; Plant Operations and Maintenance; NEPA and Environmental Permitting; Techno-Economic Analysis; and Commercialization Plan Development. MBI personnel will also participate in quarterly meetings and StageGate reviews.

Using the MBI's normal accounting practices, we have determined the budget for MBI's portion of the project (does not include $3,473,313 for the National Renewable Energy Laboratory in Golden, Colorado) to be $20,014,483, which includes $634,811 in subawards to Michigan State University, Novozymes and Vermeer Corporation. MBI will contribute $4,342,741 (approximately 18.5% of the total project cost of $23,487,796) as cost share in the form of in-kind services.

We look forward to working with the excellent team that MBI has assembled to demonstrate the AFEX Integrated Biorefinery at pilot scale and to ready it for commercialization.

Sincerely,

Venkataraman "Bobby" Bringi, Ph.D.
President and CEO, MBI International

June 19, 2009

D. Bernie Steele, Ph.D.
Director, Operations
MBI International
3900 Collins Road
Lansing, MI 48910

Subject: U.S. Department of Energy Funding Opportunity Announcement DE-FOA-0000096: Demonstration of Integrated Biorefinery Operations

Dear Bernie,

I am writing to express senior management buy-in for MBI's proposal titled "Demonstration of an AFEX Integrated Biorefinery at Pilot Scale" in response to the DOE announcement referenced above. I am fully aware of the scope of the project, the financial investments involved, and the potential risks and upsides associated with the project. I have made key MBI stakeholders and the MBI Board of Directors fully aware of the strategic, financial and operational issues related to MBI's submission.

I have obtained the buy-in and support from the MBI Board of Directors and the MSU Foundation. MBI is a wholly owned subsidiary of the MSU Foundation, and will rely on the Foundation for financial support, which in turn will enable MBI to contribute the cost share required for the proposed project. Further, the MSU Foundation is the owner of the current MBI facility, which will be expanded to house the pilot scale AFEX facility. The attached letter from George Benson and Dr. Ronald Goldsberry outlines the MSU Foundation's and the MBI Board of Directors' support for the financial contribution and the facility expansion.

I have obtained the buy-in and support from the MSU Vice President of Research and Graduate Studies, Dr. J. Ian Gray (see Gray letter). MSU is a key player in the MBI team since AFEX was developed initially by MSU faculty member Dr. Bruce Dale, and MSU is the assignee of the associated intellectual property. MBI has an exclusive license to AFEX technology from MSU. I have also obtained the support of the Great Lakes Bioenergy Research Center (GLBRC), in which MSU is a partner. GLBRC is supportive of MBI's proposal since it would provide an avenue for future research innovations to effectively reach the market place.

MBI's strategy is to bridge the gap between bio-based research and commercial application through collaborative de-risking and external alliances. The proposed project is fully consistent with MBI's strategy, and has the potential to address important national goals of energy security and job creation.

On behalf of MBI, I am pleased to express my unqualified endorsement of and buy-in for MBI's proposal. I commend your efforts to date, and wish you and the team the very best of success.

Sincerely,

Venkataraman "Bobby" Bringi, Ph.D.
President and CEO, MBI international
Member of the MBI Board of Directors

MICHIGAN STATE UNIVERSITY FOUNDATION

2727 Alliance Drive, Ste C, Lansing, Michigan 48910-3338

517.353.9268 FAX 517.353.9215 www.msufoundation.msu.edu

June 16, 2009

Venkataraman (Bobby) Bringi, Ph.D.
President/CEO
MBI International
3900 Collins Road
Lansing, MI 48910

Subject: U.S. Department of Energy Funding Opportunity Announcement DE-FOA-0000096: Demonstration of Integrated Biorefinery Operations

Dear Bobby,

We are writing to express our unqualified support for MBI's proposal titled "Demonstration of an AFEX Integrated Biorefinery at Pilot Scale". In various briefings and presentations over the past six months, you and your management team have made us fully aware of the scope of the project, the financial investments involved, and the potential risks and upsides associated with the project.

The MSU Foundation ("the Foundation"), a Michigan-based not-for-profit organization with over $300 million in assets, has a mission to further the interests of Michigan State University. The Foundation acquired MBI in 2005 and has since developed a strategy for MBI to de-risk, scale up and commercialize MSU innovations, thereby accelerating promising technologies from early state to the market. The proposed DOE submission is a logical step to scale up and integrate AFEX technology, and to commercialize it to enable the pressing national goals of fuel security and sufficiency. The successful execution of this project will create and retain highly skilled jobs in Michigan, and would thus also be consistent with the objectives of the American Recovery and Reinvestment Act of 2009.

On behalf of the Foundation and the MBI Board of Directors, we are writing to specifically express our support for the following items: (i) the Foundation stands behind MBI's commitment to provide a total of $4.4 million in cost share over the period of the proposed project and

(ii) as the owner of the current MBI facility at 3900 Collins Road in Lansing, the Foundation supports the proposed facility expansion described in the submission.

We commend MBI and its partners for the efforts to date and wish you a successful outcome.

Sincerely,

George Benson
Executive Director, MSU Foundation
Member of the Board of Directors, MBI International

Ronald Goldsberry, Ph.D.
Member of the Executive Committee and Board of Directors, MSU Foundation
Chairman of the Board of Directors, MBI International

MICHIGAN STATE
UNIVERSITY

June 24, 2009

D. Bernie Steele, Ph.D.
Director-Operations
MBI International
3900 Collins Road
Lansing, MI 48910-8596

RE: U.S. Department of Energy Funding Opportunity Announcement DE-FOA-0000096: Demonstration of Integrated Biorefinery Operations

Dear Dr. Steele:

This letter is to confirm Michigan State University's commitment to participate in the world class team headed by MBI International to demonstrate a pilot-scale AFEX Integrated Biorefinery in response to the DOE solicitation referenced above.

As a partner in this project, MSU faculty and professional staff will assist with feedstock logistics, facility and process design, life cycle analysis, modeling and updating of the Business and Commercialization Plan. MSU personnel will also participate in quarterly meetings and StageGate reviews.

Using the University's normal accounting practices, we have determined the budget for our portion of the project to be $422,676 which is approximately 1.8% of the total project budget. MSU expects to receive $244,245 in project funding, and will contribute $178,431 (approximately 0.75% of the total project cost) as cost share in the form of in-kind services.

We look forward to working with you and the excellent team that MBI has assembled to demonstrate the AFEX Integrated Biorefinery at pilot scale and to ready it for commercialization.

Sincerely,

Kim Wilcox, Ph.D.
Provost and Vice President for Academic Affairs
Michigan State University

OFFICE OF THE
PROVOST
Michigan State University
Administration Building
East Lansing, Michigan
48824-1046
FAX: 517/355-9601

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Vermeer

Vermeer
1210 Vermeer Road East
Plant 1 P.O. Box 200
Pella, IA 50219
Phone: (641) 628-3141
www.vermeer.com

June 17, 2009

D. Bernie Steele, Ph.D.
Director-Operations
MBI International
3900 Collins Road
Lansing, MI 48910

RE: U.S. Department of Energy Funding Opportunity Announcement DE-FOA-0000096:
Demonstration of Integrated Biorefinery Operations

Dear Dr. Steele,

This letter is to confirm Vermeer's commitment to participate in the world class team headed by MBI International to develop a pilot-scale AFEX Integrated Biorefinery in response to the DOE solicitation referenced above.

As a partner in this project, Vermeer will provide the processed corn stover necessary for this project. We will procure, process to specifications and deliver the corn stover to the processing plant in Lansing, Michigan over the term of the project. We are familiar with your delivery requirements of 3 tons in the first year, 12 tons in the second year, 25 tons in the third year and 20 tons in the fourth year. Vermeer personnel will also participate in quarterly meetings and StageGate reviews during the project.

Using our usual cost structure, we have estimated our total budget at $68,700, of which $35,750 will be requested in project funds and $32,950 will be contributed as cost share in the form of in-kind services. We understand that this cost share contribution is equal to approximately 0.14% of the total project budget of $23,487,796.

We look forward to working with you and the excellent team that MBI has assembled to demonstrate the AFEX Integrated Biorefinery at pilot scale and to ready it for commercialization. We are particularly interested in the concept of Regional Biomass Processing Centers described in the proposal. We understand that such Centers could treat a variety of feedstocks in local communities and deliver densified pretreated feedstocks to a central bioconversion facility. We believe that such a concept would address the supply chain issues inherent in many plans for cellulosic fuel production.

Sincerely,

Sr Proj Engineer
Vermeer Corporation
Pella, Iowa

President's E Star Award

The Andersons

The Andersons, Inc.
P.O. Box 119 • Maumee, Ohio 43537 • 419/893/5050

February 9, 2009

Bobby Bringi, Ph.D.
President and CEO
MBI International
3900 Collins Road
Lansing, MI 48910

Dear Dr. Bringi,

We are providing this letter to you, at your request, in support of US Department of Energy Grant DE-FOA-0000096 entitled Demonstration of Integrated Biorefinery Operations.

The Andersons, Inc. is a publicly traded company with diverse interests that include agribusinesses such as grain and plant nutrients as well as railcar leasing and repair, industrial products formulation, turf products, retailing and most recently, ethanol operations. The Grain Division operates grain terminals in Ohio, Michigan, Indiana, and Illinois with storage capacity of nearly 90 million bushels. The division trades and merchandises more than 250 million bushels of grain in the Eastern Corn Belt and Canada. The Ethanol Division operates three plants; a 55 million gallon plant in Albion, Michigan, a 110 million gallon plant in Clymers, Indiana and a 110 million gallon plant in Greenville, Ohio.

We are interested in improving the economic potential and diversity of our emerging ethanol operations. We continue to monitor progress in the field of cellulosic ethanol, and if the market and technology factors make it economically viable in the future, subject to our management's approval, we would be interested in evaluating investments in cellulosic ethanol technologies, especially to the extent that they synergize with our current assets.

We are familiar with the proposal being prepared by MBI International and its technology partners, Michigan State University (MSU) and the National Renewable Energy Laboratories (NREL) of Golden, Colorado. We have followed the progress at MBI with respect to the AFEX pretreatment technology, which is being developed in collaboration with Dr. Bruce Dale at MSU. We are familiar with the proposed Plan for Commercialization that incorporates the concept of Regional Biomass Processing Centers. We understand that these Centers could pretreat a variety of feedstocks in local communities and deliver densified pretreated feedstocks to a central biorefinery for fermentation and ethanol production as well as offer pretreated feedstock for sale to animal owners for energy feeds.

We believe that the concept of Regional Biomass Processing Centers has merit, and is worthy of the "de-risking" efforts that your team is proposing. We believe that your commercialization plan could (i) address several supply chain challenges inherent in many plans for cellulosic fuel production and (ii) provide rural development benefits for communities growing energy crops or harvesting crop residues.

We concur that a pilot plant, operating in a continuous manner and recycling the ammonia catalyst, is an important element to de-risk the AFEX pretreatment process so that process costs and process efficiencies can be incorporated in a model for an integrated biorefinery.

The Andersons, Inc.
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It is our understanding that this project proposal is designed to accomplish this objective and provide the basis for moving toward a Demonstration Plant.

To the extent that the proposed project develops the information necessary for a commercial opportunity in cellulosic ethanol production, we may be interested in participating in a demonstration plant for cellulosic ethanol production as an addition to one of our existing facilities.

We wish you success on your proposed project, and look forward to being connected and monitoring progress in this area of vital regional, national and global importance.

Sincerely,

The Andersons, Inc.
By: _____
Its: VP GM Ethanol Div

novozymes
Rethink Tomorrow

June 17,2009

D. Bernie Steele, Ph.D.
Director-Operations
MBI International
3900 Collins Road
Lansing, MI 48910-8596

RE: U.S. Department of Energy Funding Opportunity Announcement DE-FOA-0000096: Demonstration of Integrated Biorefinery Operations

Dear Dr. Steele:

This letter is to confirm Novozymes commitment to participate in the world class team headed by MBI International to develop an AFEX Integrated Biorefinery at pilot scale in response to the DOE solicitation referenced above.

As a partner in this project, Novozymes will perform limited research and development to select enzymes that are most efficient in converting AFEX-treated corn stover to monomeric sugars. Novozymes personnel will be involved in techno-economic modeling, life cycle analysis, and shakedown and capstone runs to demonstrate the proposed technology. They will also participate in quarterly meetings and StageGate reviews. Novozymes will also provide all enzymes required for the project.

Using our normal cost structure, we expect our contribution to this project to equal $143,437. The full amount will be contributed as cost share in the form of in-kind services. This contribution will come from employee's time, overhead charges, travel and enzyme costs. We understand this contribution is equal to 0.61% of the total project budget of $23,487,796.

We look forward to working with you and the excellent team that MBI has assembled to demonstrate the AFEX Integrated Biorefinery at pilot scale and to ready it for commercialization.

Sincerely,

By: _____

Title: VP of R&D

Novozymes North America, Inc.
77 Perry Chapel Church Road
P.O. Box 576
Franklinton, North Carolina 27525

Tel: 919-494-3000 Fax: 919-494-3450 Internet: www.novozymes.com

the energy of innovation™

310 N. First St.
Colwich, KS. 67030
Ph: 316.977.6878
Fax: 316.977.6213
icminc.com

June 20, 2009

D. Bernie Steele, Ph.D.
Director-Operations
MBI International
3900 Collins Road
Lansing, MI 48910-8596

Dear Dr. Steele:

ICM is the nation's leading provider of ethanol process design and engineering, with 101 dry-mill fuel ethanol plants operating in the United States and Canada that use ICM ethanol process technology. ICM-designed plants consistently perform 24 hours per day, at least 353 days per year for a 96% runtime – the highest performance measure in the industry. ICM's market success, over 50% of market share in current ethanol production, results from the fact that ICM process technology simply runs better, faster, cheaper and with less downtime than competing technologies. ICM employs 30 full-time engineers in its various departments, including process chemical engineers, mechanical engineers, electrical engineers, and civil engineers. ICM also designs, engineers, and installs a proprietary distributive control system (DCS) for ethanol plants that use ICM process technology. ICM employs another 30 scientists and operators in its two R&D laboratories and pilot plant.

We are aware that MBI and its technical partners Michigan State University, Novozymes Inc, Vermeer Corporation, and The National Renewable Energy Laboratory are preparing a submission for U.S. Department of Energy Funding Opportunity Announcement DE-FOA-0000096. We understand this submission is for a grant to build and operate an AFEX Integrated Biorefinery pilot plant making ethanol from corn stover at 1 ton per day. This biorefinery will utilize the AFEX treatment process, an innovative treatment process that uses ammonia as a catalyst.

Our scientific and engineering experts have reviewed the Process Flow Diagrams and the design engineering work for the proposed AFEX treatment pilot plant that will be a part of the proposal. We believe this plan, in the design engineering phase, is an acceptable plan for a continuous operating system and an ammonia recovery system. We look forward to providing input as these plans move towards construction, and we have an interest in providing engineering services if an award is granted by the DOE.

We also understand that one of your proposed marketing plans could be to partner with other technology providers to market the AFEX integrated process as part of a technology package offered to interested commercial parties. ICM would be most interested in such a marketing venture, as technology integration and successful delivery of technology to market is the main direction for ICM. We have been major technology providers to the dry mill ethanol industry and we plan to have the same impact in the developing the cellulosic ethanol industry. We look forward to working with MBI to this end.

Sincerely,

Douglas B. Rivers, Ph.D.
Director, Research & Development

Airgas

Chris Forney
Airgas Specialty Products
Account Manager
7452 Claremont Street
Canton, MI 48187
CELL (734) 276-7877 eFax (877)349-0207
http://www.airgas.com
chris.forney@airgas.com

June 22, 2009

Bobby Bringi, President & CEO
MBI International
3900 Collins Road
Lansing, MI 48910-8596

Dear Dr. Bringi:

Airgas, Inc. (NYSE: ARG), Radnor, PA, through its subsidiaries, is the largest U.S. distributor of industrial, medical, and specialty gases. Airgas, Inc. is also a leading U.S. distributor of safety products, the largest U.S. producer of nitrous oxide and dry ice, the largest liquid carbon dioxide producer in the Southeast, and a leading distributor of process chemicals, refrigerants and ammonia products.

Ammonia is supplied through Airgas Specialty Products (ASP) of Duluth, GA. ASP, formerly the Atlanta-based Industrial Products Division of LaRoche Industries, is a leading distributor of anhydrous ammonia and related services in the United States. ASP's network of 24 ammonia distribution, field service and office locations, focuses exclusively on industrial applications and serves over 3,000 customers. The company is a primary supplier of ammonia to the fast-growing market segment of power plants, oil refineries and other manufacturing facilities nationwide that require ammonia for nitrogen oxide removal. ASP also serves the metal treating, heat treating, chemical processing, industrial refrigeration, and water treatment industries. Ammonia is one of the most highly used inorganic chemicals in the world today. Worldwide ammonia production in 2004 was 109 million metric tons, according to the United States Geological Survey.

Airgas Specialty Products offers safety training through its Ammonia E-training Program, which is a mixture of on-site, off-site, and Internet-based training customized to your company's training requirements and resources. ASP will develop a program of documented training for each individual who must be trained.

Training is available in the following areas:

- Anhydrous Ammonia Awareness
- Aqua Ammonia Awareness
- Aqua Ammonia and Anhydrous Ammonia Handling-Details
- Ammonia Properties
- Ammonia Safety

These programs will meet OSHA PSM, EPA RMP, and other safety requirements.

RISK MANAGEMENT PLANS

Airgas Specialty Products will develop a PSM/RMP Program uniquely fitted to your company's existing programs and policies. A PSM/RMP program developed for your company will meet all OSHA PSM requirements, EPA RMP requirements, and California CalARP requirements.

Since ammonia is our "core" business, we can often provide on-site ammonia equipment maintenance faster and more cost-effectively than internal staff. You can be assured that our technicians follow all of the latest in PSM/RMP/OSHA safety guidelines.

Services Offered:

- Ammonia Quality Testing
- System Pumpouts
- Storage System Inspections/Repairs
- Tank Refurbishments/Refits
- Complete System Maintenance
- Leak Repair

We are aware that MBI and Michigan State University are preparing a submission for U.S. Department of Energy (DOE) Funding Opportunity Announcement DE-FOA-0000096. We understand this submission is for a $18.8 million grant from the DOE to demonstrate fuel production from corn stover using the AFEX process, a novel pretreatment that uses anhydrous ammonia as a catalyst. We also understand this grant requires a 20% cost share from the participants.

Our engineering group has reviewed the Process Flow Diagram for the proposed AXEX pretreatment pilot plant that will be a part of a proposal. We find this plan, in the design engineering phase and subject to the comments made by our engineers, is an acceptable plan for an ammonia recovery system. We look forward to providing input as these plans move towards construction and will give advice on the safety and regulatory obligations necessary to provide safety to workers and meeting regulatory standards. We also have expertise in recovery of contaminated ammonia and can offer services and advice on how to deal with potential contaminates in the recycled ammonia as it is recovered and reused.

Airgas Specialty Products supports its customers with the above services and advice and we are happy to offer these services to you as you proceed with this project.

Sincerely,
Airgas Specialty Products

Chris Forney
Great Lakes Account Manager
Airgas Specialty Products
Canton, MI 48187
www.airgasspecialtyproducts.com

D. Bernie Steele, PhD **Principal Investigator**
517-336-4645 (office) steele@mbi.org

Education & Training

B.S., Microbiology, Auburn University (1980)
M.S., Microbiology, Auburn University (1984)
Ph.D., Biological Science, Columbia Pacific University (1994)

Professional Experience

1997-Present **MBI International**
Director of Operations: A senior manager with a background in microbial physiology and over 25 years of experience in biotechnology. Currently responsible for all Research & Development operations including Quality Assurance and Laboratory Safety and serves as Biosafety Officer of MBI. Nine years of experience leading development of technologies for the conversion of cellulose to biofuels, platform biochemicals, specialty chemicals and novel nanomaterials.

1996-1997 **Self-Employed, Consulting**
Provided professional consulting services in the area of microbial technologies. This included environmental projects, such as bioremediation, as well as microbial screening and discovery of novel microbial products, strain improvement, and microbial troubleshooting for industrial clients. Projects were conducted throughout North and Central America, Europe, and the former Soviet Union, for the U.S. Army Corps of Engineers and the Defense Special Weapons Agency. OSHA 29CFR 1910.120 40hr certification.

1993- 1996 **Harmon Environmental Services, Inc.**
Vice-President, Scientific Services: Responsible for research and development of biological systems technologies relating to bioremediation and wastewater treatment, and production of all biological products. Designed and implemented successful bioremediation projects for several major industrial clients as well as the U.S. Army Corps of Engineers in the United States and Central America. Coordinated all HES activities with Auburn University, and was responsible for a 190,000 liter capacity fermentation and bioprocessing facility. OSHA 29CFR 1910.120 40hr certification.

1992 **Boeing Defense and Space Group**
Visiting Senior Research Scientist with Analytical Services in Boeing's Missile and Space Division. Responsibilities included methodology development for detection, enumeration and identification of microbes in the Advanced Environmental Control and Life Support System of the International Space Station. This included work on both recycled product water and in control of biofilms and biofouling of the water and air recovery systems. Methodology development included physiological studies, and molecular genetics (PCR) protocols for improved detection limits and rapid identification.

1988-1992 **Auburn University**
Manager of the Fermentation and Bioprocessing Unit in the University's Cell Science Center located in the Auburn University Research Park. Oversaw all fermentation work from 1 L to 250 L scale, including BL-2 fermentations and large scale recombinant fermentations. Research efforts centered on

physiological adaptations to extreme environments and methods development for the screening of microorganisms for industrial use. Research efforts in the area of microbial screening yielded several important discoveries of industrial enzymes and biodegradative organisms. Efforts led to commercialization of products for major chemical companies.

1986-1988 **University of Tennessee/Oak Ridge National Laboratory**
Research efforts focused on microbial screening for industrial products, including industrial enzymes, and ice-biologicals. Additional research included environmental assessment and monitoring of cooling systems in nuclear reactors. This included biocide efficacy testing and evaluation as well as study of physiological mechanisms involved in microbial resistance to biocides. Lead research programs initiated at the Institute with corporate clients such as Eastman Kodak BioProducts and government agencies such as the Tennessee Valley Authority. These collaborations resulted in long term research programs over several years.

1984-1986 **NPI**
Research Scientist: Involved in NPI effort to develop and produce nitrogen-fixing microbial inocula for forestry, horticultural and agricultural applications. This included the discovery and selection of superior symbiotic strains for large scale production of inocula. Projects involving the genetic manipulation of nitrogen fixing bacteria. Served as co-investigator on grants from the National Science Foundation and the US Agency for International Development. Responsible for all fermentation research and for implementation of a reforestation program in Nepal through USAID.

Selected Publications

Steele, D.B. and M.D. Stowers. Techniques for Selection of Industrially Important Microorganisms. Ann. Rev. Microbiol. 45: 89-106. 1991

Ponnampalam, E., D.B. Steele, D. Burgdorf, , and D. McCalla. The Effect of Germ and Fiber Removal on the Production of Ethanol from Corn. Appl. Biochem. Biotechnol. 115: 837-842. 2004

Steele, D.B., S. Raj, J. Nghiem, M. Stowers. Enzyme Recovery and Recycling Following Hydrolysis of Ammonia Fiber Explosion-Treated Corn Stover. Appl. Biochem. Biotechnol. 124: 901-910. 2005

Duncan, M., I. Xiarchos, J. Whims, T. Scott, M. Stowers, B. Steele, and D. Senechal. *U.S. Biobased Products: Market Potential and Projections Through 2025*. U.S. Department of Agriculture OCE-2008-1. 2008. http://www.usda.gov/oce/reports/energy/index.htm

Abstracts and Presentations

Steele, D.B. 2002. Effects of Germ and Fiber Removal on the Production of Ethanol from Corn. International Fuel Ethanol Workshop & Trade Show. Springfield, IL.

Steele, D.B. 2002. Fermentation and Purification Processes for Biomass-Derived Succinic Acid. Annual Meeting of the Society for Industrial Microbiology. Philadelphia, PA.

Hanchar, R., E. Ponnampalam, R. Powell, and B. Steele. 2003. Extraction of Oryzanols and Corn Oil from Distillers Dried Grains and Solubles. 25th Symposium on Biotechnology for Fuels and Chemicals. Breckenridge, CO.

VENKATARAMAN (Bobby) BRINGI Ph.D. **bringi@mbi.org**

Entrepreneurial executive, having created and commercialized a biotechnology breakthrough, brings a rigorous technical background, strong operational experience and proven business development track record to lead MBI International, a Michigan bio-based technology company focused on renewable fuels, chemicals and materials.

Co-founded and built Phyton, Inc., a private biotechnology company with US and German R&D and manufacturing operations. Phyton pioneered and commercialized plant cell fermentation technology to produce the anti-cancer drug, paclitaxel, and executed long-term supply and licensing partnerships with Bristol Myers Squibb. Having achieved sustained profitability, Phyton merged with a private firm, DFB Pharmaceuticals.

PROFESSIONAL EXPERIENCE

President and CEO, MBI International, Lansing, Michigan Dec 2006 - present

- Restructured company, reducing operating costs by 30% while diversifying funding sources, maintaining project momentum and retaining core managers.
- Developed a new long term strategy focused on bridging biobased research and commercial application in close alignment with Michigan State University.

Transition Consulting

Consulted for acquirer DFB Pharmaceuticals until October 2005 during post-merger transition. Advised CellFor, a Canadian forestry biotechnology company in 2006.

President, Phyton, Inc., Ithaca, New York May 2002 – Dec 2003; Mar 2000 – Sep 2001

- Executed a $50M all-cash merger deal with Texas-based specialty pharmaceutical company, DFB Pharmaceuticals following negotiations with multiple suitors. Engaged investment bank, experienced interim CFO, and ensured retention of core managers and employees.
- Negotiated win/win licensing settlement to a significant patent dispute with Japanese conglomerate Mitsui, paving way for merger closure and expanded market potential.
- Marshaled expertise to restructure and negotiate foundational technology-license- and manufacturing-supply agreements with Bristol Myers Squibb. This transformative deal brought $27M in upfront cash plus lucrative long-term manufacturing and royalty revenues.
- Managed company's transition from development to commercial stage by negotiating interim supply agreement, exceeding production targets at German manufacturing facility and maintaining strong year-on-year revenue growth and profit margins until merger.
- Marketing Taxol® made via Phyton plant-cell-paclitaxel process earned Bristol Myers Squibb the prestigious Presidential "Green Chemistry" Award from the US Environmental Protection Agency in 2004.

Vice President, Phyton, Inc., Ithaca, New York 1991 – 2000

Managed R&D programs, day-to-day operations and partnership alliances during rapid growth from a start-up in 1991 to a headcount of 45 people and budget of $3.5M.

- Steered U.S. FDA and European regulatory-approval processes in collaboration with Bristol Myers Squibb. Presented plant cell technology at FDA meetings, addressed questions from European regulators, and wrote critical technical chapters of the supplemental New Drug Application filing with BMS regulatory experts.
- Ensured $15M in funding by delivering ongoing milestones during 7-year partnership with Bristol Myers Squibb. Added Pfizer to client base by setting up R&D collaboration to produce an early-stage Pfizer drug candidate.
- Managed Phyton intellectual property portfolio in a competitive international field.

- Architect of plant cell fermentation technology; led concerted multidisciplinary R&D program to develop premier commercial paclitaxel production process.
  - Achieved 1000-fold increase in paclitaxel productivity through high-throughput strain screening, biosynthetic manipulation, and environmental optimization.
  - Elucidated critical segments of taxane biosynthetic pathway in plant cell cultures using isotope-labeling, kinetic analysis and tandem mass spectrometry.
  - Conceived and executed a comprehensive strain-banking solution to address strain stability, previously a regulatory and operational Achilles heel for plant cell technology.
  - Served as technical expert on the team scaling up the production process to 75,000-L commercial scale at the company's German manufacturing facility.
  - Lead inventor on foundational patent covering paclitaxel production technology.
- Secured financial support from Government agencies, including NSF and NIH. Obtained a $1M NIH grant for research alliance with Cornell University, Colorado State University, US Dept of Agriculture, and Phyton; set-up and managed Co-operative R&D Agreement with USDA in conjunction with exclusive patent license.

Member of the Board of Directors, Phyton, Inc., Ithaca, New York 1991 – 2003

EDUCATION

Ph.D. (1991) Cornell University, School of Chemical Engineering, Ithaca, New York. Multi-disciplinary background in biochemical engineering, biochemistry, and plant cell biology.
M.S. (1985) Colorado State University, Department of Chemical Engineering, Fort Collins Colorado. Major in biochemical engineering with microbiology focus.
B.S. (1983) Institute of Technology, Department of Chemical Engineering, Varanasi, India.

SELECTED PUBLICATIONS AND PRESENTATIONS

- ***Biobased Building Blocks and Bio-Transformation***. S. Kleff, R.J. Hanchar, and V. Bringi. Plenary invited lecture presented at the Huntsman Corporation Biorenewables Conference, The Woodlands, TX, April 2, 2008.
- ***Assessing the Component Costs of Producing Cellulosic Ethanol***. Panel discussion chaired by V. Bringi, J. Beaudry-Losique (US Department of Energy/Biomass Program) and K. Creamer (Novozymes). Future Fuels 2007 Conference Workshop, December 5, 2007.
- ***Enhanced production of taxol and taxanes by cell cultures of Taxus species***. V. Bringi, P. Kadkade, C.L. Prince, B.F. Schubmehl, E. Kane and B.L. Roach, US patent 5,407,816 (1995). V. Bringi, C.L. Prince, P. Kadkade and B.L. Roach, European Application EP 1538214 (1997).
- ***Metabolic Inhibitors, Elicitors, and Precursors as Tools for Probing Yield Limitations in Taxane Production by Taxus chinensis Cell Cultures***. V. Srinivasan, V. Ciddi, V. Bringi and M.L. Shuler (1996). *Biotechnology Progress* 12, 457-465.
- ***Plant Cell and Tissue Culture in Liquid Systems***. G.F. Payne, V. Bringi, C.L. Prince, and M.L. Shuler (1991) Hanser Publishers, Munich, and John Wiley, New York. (*This is an advanced treatise and the first book to integrate engineering and biological aspects of plant cell and tissue culture.)*
- ***Convective Mass Transfer in Large Porous Biocatalysts: Plant Organ Cultures***. C.L. Prince, V. Bringi, and M.L. Shuler (1991) *Biotechnology Progress* 7, 195-199.
- ***Studies on Differentiation in Plant Cell Cultures***. V. Bringi (1991), Invited Speaker, Gordon Conference Session on Plant Cell and Tissue Culture, Plymouth, New Hampshire.
- ***A Framework for Understanding the Effects of Immobilization on Plant Cells***. V. Bringi and M.L. Shuler (1990). In "Physiology of Immobilized Cells" J.A.M. de Bont *et al.* (Eds) Elsevier, 161-172.
- ***Experimental and Theoretical Evidence for Convective Nutrient Transport in an Immobilized Cell Support***. V. Bringi and B.E. Dale (1990) *Biotechnology Progress* 6, 205-209.

Timothy J. Campbell

6053 Horizon Dr. **(517) 336-4631 (office)**
East Lansing, MI 48823 **(517) 242-3656 (cell)**
campbell@mbi.org

Summary

Chemical engineer with 20+ years experience in research and technology development. Expertise in reactor design, fuel chemistry and analysis, surface chemistry and catalyst development, and separation and purification processes.

Education

University of Florida Gainesville, Florida
Master of Engineering, Chemical Engineering, 1999

Northern Michigan University Marquette, Michigan
Bachelor of Science, Biochemistry, 1983

Experience

MBI International **Lansing, MI**

Process Development Engineer 2007 – present

Development and de-risking of the Ammonia Fiber Expansion (AFEX) process for pretreatment of lignocellulosic biomass.

Specific accomplishments include:

- Studies of ammonia thermodynamics and transport in biomass pretreatment systems.
- Development and testing of a continuous AFEX reactor system.

Applied Research Associates, Inc. **Tyndall AFB, FL**

Research Chemical Engineer 1994 - 2007

In support of Air Force Research Laboratory client, designed and executed experiments for a number of research projects. Specific projects included development of the Logistic Fuel Processor (LFP), a deployable reformer system for conversion of JP-8 to hydrogen for use with fuel cells, and investigation of chloro-organic groundwater contaminant reduction using zero-valent iron.

Specific accomplishments include:

- Design and testing of compact reactors, fuel fractionators, heat exchangers, and sulfur adsorption beds for the LFP system.
- Development of novel coated-wall catalysts for use in the LFP system, including cracking, steam reforming, and combustion catalysts.

University of Florida, Dept. of Civil Engineering **Tyndall AFB, FL**

Research Chemical Engineer 1999 - 2001

Lead researcher on a project to develop the Passive Flux Monitor (PFM), a novel device for in-situ monitoring of groundwater contaminant flux and specific discharge.

EnviroLab, Inc. **Ormond Beach, FL**

Chemist 1993 - 1994

Bench chemist performing routine analyses of water samples by HPLC, using EPA methods.

BioEnergy International, LLC **Gainesville, FL**

Research Asssistant 1992-1993

Performed bench-scale experiments on fermentation of cellulosic feedstocks to ethanol using novel genetically-modified microbes.

PCR, Inc. **Gainesville, FL**

Chemist 1989-1992

Analytical laboratory chemist for ISO-9000 certified specialty chemicals manufacturer.

Cuno, Inc. **Meriden, CT**

Research Assistant 1983 - 1988

Assistant in R&D laboratory of filtration and chromatography media manufacturer.

Publications and Patents

- Shaaban, A.H. and T.J. Campbell. Compact distillates fuel processor with effective sulfur removal process. U.S. Patent No. 7,318,845, January 15, 2008.
- Campbell, T.J., D.T. Vu, and F. Teymouri. Ammonia phase equilibrium in vapor-water-biomass pretreatment systems. Poster presentation at 30th Symposium on Biotechnology for Fuels and Chemicals, New Orleans, LA, May 4-7, 2008.
- Campbell, T.J., K. Hatfield, P.S.C. Rao, and M.D. Annable. Magnitude and Directional Measures of Water and Cr(VI) Fluxes by Passive Flux Meter. *Environ. Sci. and Technol*., **40**, 2006, p 6392-97. Selected "2006 Technology Paper of the Year" by the editors of *ES&T.*
- Campbell, T.J., A.H. Shaaban, F.H. Holcomb, R. Salavani, and M.J. Binder. JP-8 catalytic cracking for compact fuel processors. *J. Power Sources*, **129**, 2004, p 81-89.
- Hatfield, K., P.S.C. Rao, M.D. Annable, and T.J. Campbell. Device and method for measuring fluid and solute fluxes in flow systems. U.S. Patent No. 6,401,547, June 11, 2002.
- Burris, D.R., R.M. Allen-King, V.S. Manoranjan, T.J. Campbell, G.A. Loraine, and B. Deng. . Chlorinated ethene reduction by cast iron: Sorption and mass transfer. *J. Environ. Eng.*, **124**, 1998, p 1012-19.
- Deng, B., T.J. Campbell, and D.R. Burris. Hydrocarbon formation in metallic iron/water systems. *Environ. Sci. and Technol.*, **31**, 1997, p 1185-90.

Synergistic Activities

- Modification and operation of a continuous AFEX reactor system at MBI International.
- Design and execution of experiments to study ammonia/water equilibrium and transport in biomass pretreatment systems at MBI International.
- Design, fabrication, and testing of novel separations and purifications systems at ARA, Inc.
- Studied bench-scale conversion of cellulosic biomass to ethanol at BioEnergy International LLC.

DAVID K. JONES

jones@mbi.org 517-336-4613 (office)
517-515-4322 (cell)

SUMMARY

Chemical/Bioproducts industry executive with 25 years of experience in commercializing new technologies. Experience includes large chemical company divisional global management in sales and business unit management with P&L responsibility and oversight for sales, marketing, technical and customer service. Proven record of success in developing and articulating a vision, building a global action-oriented team, and implementing focused objectives.

EDUCATION

PURDUE UNIVERSITY West Lafayette, Indiana
Bachelors of Science, Chemical Engineering, 1982
Bachelors of Science, Chemistry, 1982

Kelly School of Business, INDIANA UNIVERSITY Bloomington, Indiana
Executive Management & Leadership, 2004

PROFESSIONAL EXPERIENCE

MBI INTERNATIONAL Lansing, Michigan 2009- present
Not-for-profit organization
Senior Vice President – Business Development and Commercialization
Leads sales, marketing and new business development for MBI.

- Implementing new strategies to grow organization via external licensing, fee for service work and other partnerships with corporations

ASHLAND INC. Dublin, Ohio 1984-2009
$11B specialty chemical company
Director of Bioproducts (2006-2009)

Reporting to Chief Growth Officer, led new effort to diversify away from petrochemicals moving toward renewable and sustainable chemistries. Selected to launch company's strategic plan for bioproduct initiatives, successfully securing approval of chairman.

- Created over 20 partnership opportunities with biotechnology start-ups, universities, chemical companies and agricultural companies that were under development for external investment or internal research projects. Areas of focus included enzymes, bioderived polyols, starch derivatives, biobased lubricants, fillers and organic acids. Filed seven records of invention.
- Led development of a $100MM investment in a European joint venture project with Cargill, focusing on the conversion of glycerin into propylene glycol.
- Team leader for company's Sustainability Initiative reporting out to the Board of Directors. Managed project from conception through implementation of the Global Reporting Initiative G3 indicators, achieving clarity and consensus around a previously hazy concept. Completed company's first sustainability report.

Director, Growth Office (2005-2006)

Appointed by President as initial member of an innovative, corporate team assembled to develop a new strategic direction for the company in addition to clarifying investment opportunities for the

$1B resulting from sale of petroleum refining operations. Accessed market opportunities and recommended specialty chemicals as the direction for the company. Led analysis and early due diligence of large acquisition candidates.

Global Director of Sales – Specialty Polymers (2003-2005)

Global responsibility for $250MM of specialty chemical revenue. Managed staff of 60 with five direct reports. End use markets included automotive, building and construction, packaging, assembly, electronic, and medical.

- Achieved all time sales record in 2004 and 2005, representing a 16% increase in sales in 2005.
- Chairman's Award, 2005; President's Award, 2003.
- Implemented design for six sigma process and new strategic account management process.
- Reorganized business unit structure to a matrix functional organization.

Global Business Director – Packaging and Converting Adhesives (1999-2003)

Global profit and loss responsibility for three business units totally $150MM in revenue, overseeing 130 employees in sales, marketing, product management, technical, customer service and toll manufacturing. Markets included pressure sensitive adhesives, flexible packaging adhesives and hot melt adhesives.

- Achieved record income in 2000 and 2002 through geographic and product line growth, managing internal organic efforts and external alliances.
- Achieved significant competitive position via a systematic segmentation marketing approach. Aligned sales and technical around customer segmentation patterns.

Business Unit Manager – Building and Construction Adhesives (1997-1999)

Full profit and loss responsibility for this $35MM specialty business, with sales, marketing, product management, technical, customer service, and toll manufacturing. Markets served include engineered wood, panel lamination, millwork, and general assembly.

Divisional Market Development Manager – Specialty Polymers and Adhesives (1995-1997)

Duties included strategic plan development, acquisitions (closed 2), technology licensing, capital investment justification, joint ventures, and competitive analysis.

Senior Technical Sales Representative – Acrylic Adhesives (1991-1995)

Technical Sales Representative – Urethane Coatings (1988-1991)

Chemist / Technical Service Representative – Urethane Coatings (1984-1988)

.

UNITED TECHNOLOGIES INMONT (NOW BASF) 1983-1984

Laboratory chemist developing topcoats for Ford, GM and Chrysler.

AMOCO OIL (NOW BP) 1981-1982

Summer co-op chemical engineer at Texas City, Texas Oil refinery.

PATENTS

Chen, Gang-Fung; Day, David; Jones, David. Heat and radio frequency-curable two-pack soy protein-base polyurethane adhesive compositions. US Patents 6,231,985 in 2001 and 6,265,650 in 2002.

SYNERGISTIC ACTIVITIES

Strategic Planning – Wharton Business School, UNIVERSITY OF PENNSYLVANIA
Business to Business Marketing – Kellogg Business School, NORTHWESTERN UNIVERSITY
Transformational Leadership – Ashland Inc.
Ohio Bioproducts Innovation Center, Board of Directors, current
Governor's Ohio Job Stimulus Advisory Committee, current

Darold F. McCalla, DVM

553 Southlawn **(517) 351-2152**
East Lansing, MI 48823 **(517) 749-6916 (cell)**

Summary

Professional executive in operations, marketing and finance with domestic and international experience. Successful people and project manager in commodity livestock-oriented business as well as product development, research and animal health.

Education

Michigan State University East Lansing, Michigan
Doctor of Veterinary Medicine, 1960
Bachelor of Science, 1958

Experience

MBI International **Lansing, MI**
Consultant – Senior Advisor/Corporate Development 2002 – present

Project manager for various projects including Ethanol Biorefinery Development and Modeling, Improved Uses for Distillers Grains, Pilot Plant Development for Ammonia Fiber Expansion.

Specific accomplishments include:

- Technologies for the production of Succinic Acid from mixed sugars and for lignocellulosic pretreatment have been licensed to commercial partners.

Private consultant to agricultural businesses 1996 – present

Client list includes: MBI International, ConAgra Beef, Southern States Cooperative, Thorn Apple Valley, Upjohn Corporation, S & B Cattle Company, Swine, Dairy and Beef Cattle Producers.

Michigan Livestock Exchange **East Lansing, MI**
Senior Vice President 1992 - 1996

Operating responsibility for hog procurement and agricultural lending ; administrative responsibility for legal, office facilities and special projects.

Specific accomplishments include:

- Hog procurement covered the Midwestern states and purchased in excess of three million hogs per year.
- Lending activity exceeds $45 million loaned to livestock producers.

Granada Corporation **Houston, TX**
Vice President 1982 – 1992

Operating responsibility for cattle feeding, cattle breeding, technical services and research. Managed company internal and external biotechnology research program with

annual budget in excess of $10 million. Developed and marketed embryo technologies in domestic and international markets. Developed and managed the company contracts and risk management programs to feed 800,000 cattle per year. Planned and managed company breeding programs for Angus, Brangus and Holstein cattle.

Self employed **Williamston, MI**
1979 – 1982

Owned and operated a meat business with two retail outlets, wholesale HRI business and cattle slaughter. Provided consulting in cattle feeding meat marketing and embryo transfer.

Premier Corporation **Fowlerville, MI**
Vice President 1965 – 1979

Corporate operating responsibility for cattle breeding, meat packing and cattle feeding. Served as Chairman of the company's meat packing subsidiary, Dugdale Packing Company, and feeding subsidiary, Colorado Beef Producers. Operated purebred and commercial cattle ranches in seven states.

Private veterinary practice **McLean, IL**
1960 – 1965

Livestock practice: 60% swine, 30% cattle, 10% small animals

Synergistic Activities

- Convention speaker, Michigan Livestock Exchange
- Convention speaker, American Veterinary Association
- Advisory member on panel for Agricultural Technologies, U.S. Congress
- Michigan Bioeconomy Summit 2007, 2008

Publications and Patents

- S. Rajagopalan, T. Tiedje and McCalla, D. Process for Treatment of Biomass Feedstocks. US Patent Application 11/719,158. May 11, 2007
- R. Hanchar, F. Teymouri, C. Nielson, McCalla, D. and M. Stowers. Separation of Glucose and Pentose Sugars by Selective Enzyme Hydrolysis of AFEX-treated Corn Fiber. *Appl. Biochem. Biotechnol.,* **137-140(1-12)**, 2007, p 313-25.
- F. Teymouri and McCalla, D. Production of Fermentable Sugars and High Protein Animal Feed from Dried Distiller's Grain (DDG). *Unpublished.*
- S. Rajagopalan, E. Ponnampalam, McCalla, D. and M. Stowers. Enhancing Profitability of Dry Mill Ethanol Plants. *App. Biochem. Biotechnol.*, **120(1)**, 2005, p 37-50.
- F. Teymouri, M. Guettler, McCalla, D. and M. Stowers. Fed batch SSF of AFEX-treated corn fiber, corn stover, bagasse and cane leaf matter. Presentation at AIChE Annual Meeting, Cincinnati, OH, November 1, 2005.
- E. Ponnampalam, D.B. Steele, D. Burgdorf and McCalla, D. The Effect of Germ and Fiber Removal on the Production of Ethanol from Corn. *Appl. Biochem. Biotechnol.*, **115**, 2004, P 837-842.

David Senyk

8821 Corrison Road **(517) 336-4605 (office)**
Grand Ledge, MI 48837 **senyk@mbi.org**

Summary

20+ years experience in nearly all facets of biotech manufacturing, including process and project engineering, operations, process development, facility maintenance, and quality control. Expert level knowledge in fermentation manufacturing and enzyme technology and applications.

Education

University of Michigan Ann Arbor, Michigan
Bachelor of Science, Chemical Engineering (Biochemical option) 1980

Experience

MBI International **Lansing, MI**
Vice President - Engineering 2006-present
Overall responsibilities for facilities, engineering, pilot plant operations, and contract manufacturing. Key efforts at MBI have focused on biomass pretreatment and fermentation, and organic acid and biofuel process development.
Specific accomplishments include:

- Inventor on a patent application for a continuous reactor for the ammonia fiber expansion biomass pretreatment process.
- Project manager and technical lead for a process scale up contract services project with a major chemical company. Authored the proposal, developed the scale up strategy, and negotiated the terms of the contract.

Diversa Corporation **San Diego, CA**
Director of Engineering and Manufacturing 2004-2006
Responsible for all manufacturing, capital projects, process transfers, and cost reduction efforts at company's toll manufacturing site. Products produced include industrial biochemicals for the pulp and paper, fuel ethanol, and animal feed industries. Projects have included a $2.2 million expansion of fermentation and recovery capacity, introduction of 4 new products, and significant improvements in downstream processing yields.
Specific accomplishments include:

- Established strong project management techniques on the capacity expansion project resulting in clear lines of responsibility and less duplication of effort for design engineering contractor, contract manufacturer, and company's engineering group.

Bioport Corporation **Lansing, MI**
Senior Manufacturing Manager 2002- 2004
Led a team of manufacturing associates, team leaders, and production supervisors in all aspects of the manufacture of a bacterial vaccine. Responsible for fermentation and aseptic processing, cGMP compliance, failure investigations and process improvements.
Specific accomplishments include:

- Design team member for the expansion of manufacturing capacity.
- Manufacturing lead during FDA inspections.

Genencor International Inc. **Cedar Rapids, IA**

Manager Engineering Technology Group 1997- 2002

Led a team of engineers and technicians in a high performance work team environment that was responsible for the manufacturing process development, facility maintenance, project and process engineering, and process control functions. Group activities included predictive and preventative equipment maintenance; capital project identification, estimation, evaluation, installation and startup; process optimization and troubleshooting; and new product/process introduction. Unit operation experience includes batch, fed batch, and continuous fermentations, centrifugation, membrane processes, crystallization, filtration, and fluidized bed granulation. My specific responsibilities included: departmental budget management, site capital management, and coordination of process performance improvement efforts and project prioritization.

Specific accomplishments include:

- Capital projects completed include: three new membrane separation processes ($3.1 million capital), downstream processing CIP modifications ($550 k capital) to meet cGMP requirements, new fermentation SIP installation ($200k capital) and significant modifications ($350k capital) to fermentation equipment to improve process performance.
- Led engineering technology team in meeting aggressive (averaging >9%per year) annual variable cost reduction targets. Techniques included total plant optimization; use of advanced statistical tools; process sensitivity analyses; and coordination of experiments and efforts with research and pilot facilities.
- Leader of a worldwide manufacturing engineering team. Group was responsible for identification of global improvement projects; evaluation of new technologies, coordination of continuous improvement efforts between manufacturing, research, and pilot plant; and setting the direction for manufacturing within the company.

Senior Engineer 1993-1997

Site lead process engineer on manufacturing process development. Projects included both fermentation and downstream processing. Worked with plant engineering staff and pilot plant engineers to identify, evaluate, and implement cost reduction projects.

Specific accomplishments include:

- Optimization of an enzyme hydrolysis process to improve fermentation substrate availability and reduce substrate viscosity.
- Key contributor awards for a fermentation optimization program that resulted in sustainable productivity improvements of >5-10%/yr for all products and a simplification of downstream process that resulted in a 5-10% yield improvement for all granular products.

Novozymes **Franklinton, NC**

Production Manager 1982-1993

Responsible for all production operations in an industrial biochemical manufacturing facility. My specific responsibilities included managing a staff of engineers, supervisors, technicians and operators; production scheduling; operating budget management; new product/process introductions; new process equipment design and selection; and GMP compliance.

Specific accomplishments include:

- Helped company achieve the highest productivity within corporation for all key products.
- Selected as the first engineer from company to participate in an engineer exchange program with the corporate headquarters.

Farzaneh Teymouri

Office Phone: 517-336-4622 E-mail: teymouri@mbi.org

Summary

8+ years experience in pretreatment and bioconversion of lignocellulosic biomass to value added products such as fuels and specialty chemicals. Extensive experience in ammonia fiber expansion (AFEX) pretreatment. Fairly familiar with the leading biomass pretreatment technologies such as dilute acid, steam explosion, hot water, ammonia percolation and lime treatment.

Education

Michigan State University East Lansing, MI
Ph.D. in Chemical Engineering, 2003

Sharif University of Technology Tehran, Iran
BS in Chemical Engineering, 1991

Experience

MBI **Lansing, MI**
Senior Scientist 2004 – present
Coordinating and Leading the lignocellulosic biomass pretreatment and processing research activities
Specific accomplishments:

- Bench scale process development: Scaling up the AFEX process from 1 gallon to 5 gallon reactor
- Defined operating parameters/conditions for AFEX pretreatment of several different biomass
- Integrated AFEX with enzyme hydrolysis and fermentation steps
- Developed methods to increase ethanol concentration in fermentation processes.
- Developed methods for selective hydrolysis of cellulose and hemicellulose portion of biomass and separation of C6 and C5.
- Development and testing of a continuous AFEX reactor system.

Michigan State University
Chemical Engineering and Material science Department **East Lansing, MI**
Research Associate (Postdoctoral) 2003 - 2004
Conducted research includes:

- Understanding factors that limit the enzymatic hydrolysis of biomass such as corn stover
- Ammonia Fiber Explosion (AFEX) treatment of switchgrass and evaluating its digestibility via enzymatic hydrolysis and fermentation.
- Study inhibitory effect of xylose and its oligomers on cellulase activity.
- Modifying the AFEX treatment to use ammonium hydroxide as the pretreatment reagent and evaluating the results.

Publications

- Zhong, H., **Teymouri, F**., Chapman, B., Maqbool, S. B., Sabzikar R., El-Maghraby, Y., Dale, B. and Sticklen, M. B. 2002. *The dicot pea (Pisum sativum L.) rbcS transit peptide directs the Alcaligenes eutrophus polyhydroxybutyrate enzymes into the monocot maize (Zea mays L.) chloroplasts. Plant Science* 165(3): 455-462.

- **Teymouri, F**., Alizadeh, H., Laureano-Perez, L., Dale, B. E. and Sticklen, M. B. "Effects of Ammonia Fiber Explosion Treatment on Activity of Endoglucanase from *Acidothermus cellulolyticus* in Transgenic Plants" *Applied. Biochemistry and Biotechnology.* Vol. 113-116. pgs. 1183-1191 (2004)
- **Teymouri, F**., Laureano-Perez, L., Alizadeh, H. and Dale, B. E. "Ammonia Fiber Explosion Treatment of Corn Stover" *Applied. Biochemistry and Biotechnology.* Vol. 113-116. pgs. 951-963 (2004)
- **Teymouri, F**.; Laureano-Perez, L.; Alizadeh, H.; Dale, B. E.; "Optimization of the ammonia fiber explosion (AFEX) treatment parameters for enzymatic hydrolysis of corn stover" *Bioresource Technology* 96, 2014-2018, (2005).
- Alizadeh, H.; **Teymouri, F**.; Gilbert, T. I.; Dale, B. E.; "Pretreatment of switchgrass by ammonia fiber explosion (AFEX)" *Applied Biochemistry and Biotechnology* 121, 1133-1142, (2005).
- Laureano-Perez, L.; **Teymouri, F**.; Alizadeh, H.; Dale, B. E.; "Understanding factors that limit enzymatic hydrolysis of biomass" *Applied Biochemistry and Biotechnology* 121, 1081-1100, (2005).
- Hanchar R.; **Teymouri F**.; Nielson Ch.; McCalla D.; and Stowers D.; "Separation of Glucose and Pentose Sugars by Selective Enzyme Hydrolysis of AFEX-treated Corn Fiber" *Applied Biochemistry and Biotechnology* 136-140, 313-325, (2007)
- Bradshaw T., Alizadeh H., **Teymouri F**., Balan V., and Dale B., "AFEX and Enzymatic hydrolysis on two different stages of Reed Canarygrass" *Applied Biochemistry and Biotechnology* (In press).

Presentations:

- **Teymouri F**.; Guettler M.; McCalla D.; Stowers M.; "Fed batch SSF of AFEX treated corn fiber, corn stover, bagasse and cane leaf matter (CLM)" AIChE Annual meeting Nov 1st 2005,Cincinnati, OH
- **Teymouri F**.; Selig M.; Decker S.; Dale B.; "Hydrolysis of ground and unground AFEX treated corn stover with different combinations of cellulase and xylanase" 27th Symposium on Biotechnology for Fuels and Chemicals, Denver, Colorado, May 1-4, 2005
- Tiedje T.; **Teymouri F**.; McCalla D.; Stowers M.; Chung C.; Day D.; Rein P.; **"**Separation of cellulose from hemicellulose and lignin from sugarcane bagasse and cane leaf matter" 27th Symposium on Biotechnology for Fuels and Chemicals, Denver, Colorado, May 1-4, 2005
- **Teymouri F**.; Guettler M.; Saffron Ch.; Kleff S.; "Ethanol and Succinic Acid Production from AFEX treated Sugarcane Bagasse and Cane Leaf Matter (CLM)" 29th Symposium on Biotechnology for Fuels and Chemicals, Denver, Colorado, April 29th- May 2, 2007
- Campbell T., Vu D., T**eymouri** F.; "Ammonia Phase Equilibrium in Vapor-Water-Biomass Pretreatment Systems" 30th Symposium on Biotechnology for Fuels and Chemicals, New Orleans, LA, May 4-7, 2008
- Moore J., Kleff S., Headman Van Vleet J., Jeffries T., **Teymouri F.; "**Fermentation of biomass derived glucose/xylose mixture to ethanol using *Pichia stipitis*" 30th Symposium on Biotechnology for Fuels and Chemicals, New Orleans, LA, May 4-7, 2008

Synergistic Activities

- Design and execution of experiments to study AFEX process at bench scale
- Design and execution of experiments to develop efficient methods for integration of AFEX process with hydrolysis and fermentation steps.
- Analyze lignocellulosic biomass structure
- Participate in the CAFI (Consortium for applied fundamentals and innovation) study and currently serve as one of their advisory board members
- Develop continuous AFEX process
- Collaborate with other entities to evaluate the value of the by-product generated from fermentation of AFEX treated biomass

Dung-Thi Vu

Office: 517-336-4658 E-mail: vu@mbi.org

Summary

Research chemical engineer with strong background in thermodynamics, phase equilibria, organic chemistry, process engineering, process modeling and optimization. Highly skilled in computer programming, including molecular dynamic simulations. Team leader with experience supervising and directing technical staff in polymerization process.

Education

Michigan State University East Lansing, Michigan
Doctor of Philosophy, Chemical Engineering, 2007
Bachelor of Science, Chemical Engineering, 1998
University of Saigon Ho Chi Minh City, Vietnam
Bachelor of Science, Organic Chemistry, 1990

Experience

MBI International **Lansing, MI**
Post Doctoral Research Associate 2007-present

- Provided economic evaluations and process modeling for the development and scale-up of sustainable bioprocesses.
- Studied phase equilibria of ammonia-water-biomass systems involved in the continuous Ammonia Fiber Expansion (AFEX) process.

Michigan State University **East Lansing, MI**
Research Associate/ Research Assistant/ Teaching Assistant 2000-2007

- Studied phase equilibria of systems involved in reactive distillations producing plant-derived esters and bio-diesel. Received the award in 2006 from Sigma Xi.
- Designed and built a simple pressure-compositions apparatus to measure vapor-liquid equilibrium of binary and multiple component systems.
- Collaborated in molecular simulations to optimize parameters of new chemical engineering software (SPEAD) for estimating vapor pressure of bio-derived products.
- Successfully developed a novel process for isolation and purification of a specialized plant lipid for medical and industrial applications, without using chlorinated solvents.
- Investigated separation of vegetable oils and lipids based on functionality, using fixed-bed adsorption with various adsorbents.
- Mentored chemical and mechanical engineering students in Process Design and Optimization, Chemical Engineering Thermodynamics, Transport Phenomena, Differential Equations, Statics and MatLab courses.

General Motors Technical Center **Warren, MI**
R&D Graduate Summer Intern Summer 2001

- Designed and built a very compact, efficient gas adsorption system to test zeolites for Sulfur Hexafluoride (SF_6) retention.
- Developed an accurate model of the process to reproduce the experimental measurements, and provide basis for scale-up.
- Evaluated the impact of SF_6 emissions on GM's environmental performance.

Norplas Industries **Northwood, OH**

Paint Process Engineer 1999-2000

- Developed Fanuc-R200 robotic paint path motions and operating parameters of new products in a start-up plant. Improved the 30 colors paint system to 300^{+} colors system.
- Provided a computer program to monitor and optimize paint transfer efficiency.
- Implemented control system and processes to improve paint system performance.
- Initiated, recommended and provided solution to prevent the occurrence of any non-conformities relating to the products, paint process and quality system.

Allied Signal, Burdick & Jackson **Muskegon, MI**

R&D Scientist Assistant 1998-1999

- Identified parameters to study stability of new DNA products.
- Refined method and developed new synthesis procedures to Quality Control.
- Completed lab scale process improvements to pass on to plant.
- Experimented with distillation, HPLC, GC, UV, analytical methods and chemical syntheses.

Trifonco Plastic Industries **Ho Chi Minh City, Vietnam**

Process Engineer/ Supervisor 1990-1993

- Experienced with rubber and plastic molding injection.
- Supervised and scheduled for 85 employees in a plastic plant.
- Analyzed incoming materials. Wrote formulas and instructions for daily production runs.
- Wrote procedure for pilot testing and producing of new products.
- Successfully developed recycling process for Ethylene Vinyl Acetate Polymer.
- Consultant to manufacturers with problems in the EVA polymerization process.

Publications and Patents

1. Kolah, A. K.; Asthana, N. S.; Vu, D.T; Lira, C. T.; Miller, D.J. "Reaction Kinetics for the Heterogeneously Catalyzed Esterification of Succinic Acid with Ethanol," Ind. Eng. Chem. Res, (2008), 47(15), 5313-5317.
2. Kolah, A. K.; Asthana, N. S.; Vu, D.T; Lira, C. T.; Miller, D.J. "Triethyl Citrate Synthesis by Reactive Distillation," Ind. Eng. Chem. Res, (2008), 47(4), 1017-1025.
3. Vu, Dung Thi. "Properties and separations of plant-derived chemicals," Michigan State Univ., East Lansing, MI, USA. Avail. UMI, Order No. DA3264248. (2007), 228 pp. From: Diss. Abstr. Int., B 2007, 68(5), 3231.
4. Kolah, A. K.; Asthana, N. S..; Vu, D.T; Lira, C.T.; Miller, D.J. "Reaction Kinetics of the Catalytic Esterification of Citric Acid with Ethanol," Ind. Eng. Chem. Res, (2007), 46(10), 3180-3187.
5. Miller, D.J.; Asthana, N.; Kolah, A.; Vu, D.T.; Lira, C. T., Preparation of Org. Acid Di- and Tri-Esters by Reactive Esterification Distillation for Use as Solvents and Plasticizers., in U.S. Pat. Appl. Publ. 2006, (Board of Trustees of Michigan State University, USA): US. 83pp.
6. Vu, D.T.; Lira, C.T.; Asthana, N.S.; Kolah, A.K.; Miller, D.J. "Vapor-Liquid Equilibria in the Systems Ethyl Lactate + Ethanol and Ethyl Lactate + Water," J. Chem. Eng. Data 51(4), 1220-1225, (2006).
7. Asthana, N. S.; Kolah, Aspi K.; Vu, D.T.; Lira, Carl T.; Miller, D.J. "A Kinetic Model for the Esterification of Lactic Acid and Its Oligomers," Ind. Eng. Chem. Res, (2006), 45(15), 5251-5257.
8. Vu, D.T.; Kolah, A. ; Asthana, N.; Peereboom, L.; Lira, C.T.; Miller, D.J. "Oligomer Distribution in Concentrated Lactic Acid Solutions," Fluid Phase Equilibria 236, 125-135 (2005).
9. Asthana, N.; Kolah, A.; Vu, D.T.; Lira, C.T.; Miller D.J. "A Continuous Reactive Separation Process for Ethyl Lactate Formation," J. Org. Process Res. Dev. 9(5), 599-607, (2005).
10. Baber, T. M.; Vu, D.T.; Lira, C.T. "Liquid-Liquid Equilibrium of the Castor Oil + Soybean Oil + Hexane Ternary System," J. Chem. Eng. Data 47(6), 1502-1505, (2002).

Jim Wynn, PhD

wynn@mbi.org

(517) 336-4620 (office)
(517) 755-6933 (cell)

Summary

Microbial physiologist/molecular biologist with over 15 years experience in developing commercially important products from micro-organisms. Experienced Project and Team Leader, who has lead multidisciplinary research programs to develop and expand commercial potential of microbial products from nutritional products to therapeutic proteins. A proven track record for successful research, hitting milestones on time and within budget.

Education

University of Hull — Hull, United Kingdom
Doctor of Philosophy, Biological Sciences (microbial biochemistry), 1994

University of Wales — Cardiff, United Kingdom
Bachelor of Science, Applied Biology, 1986

Experience

MBI International — Lansing, MI
Director, Process Development and Integration — May 2009 – present

- Responsible for debottlenecking MBI's process development capacity and driving concurrent research programs to commercialization.
- Developing and implementing MBI's Research and Development strategy
- Developing collaborations with MSU faculty and industrial partners.

Martek Biosciences Corporation — Columbia, MD
Principal Scientist — 2005-2009
Senior Scientist — 2001-2004

- Project Leader for Therapeutic Proteins Research program, developed project scope, milestones and timelines. Established collaborations with two industrial partners to evaluate and develop the production platform. Liaised with IP tea to capture key technology developments.
- Chairman of the R&D Subcommittee for the "Arachidonic Acid" Joint Venture between Martek and DSM. Responsible for multidisciplinary research team to develop production process and expand the market of nutritional oil product (ARASCO), which constitutes >60 % of Martek's revenue. Achieved $3MM/annum cost saving, in 2005, by process improvements alone.
- Led scientific team that identified novel biochemical pathways for lipid biosynthesis in marine micro-algae (*Crypthecodinium cohnii*).

- Inventor on two key process patents for the commercial production of a DHA algal-oil that is included in >90 % of infant formula in USA (and >30 % of infant formula globally).
- Recognized as an "Innovator" in the "New Product Opportunities" initiative
- Played an active role in the development of Martek's Strategic Five Year Plan.

Publications and Patents

- Behrens, P.W., Thompson, J.M., Apt, K., Pfeifer, J.W., Wynn, J.P., Lippmeier, J.C. and Hansen, J. Production of DHA in microalgae at low pH. US2006/0100279 A1 Publication date 11 May 2006 (http://v3.espacenet.com/publicationDetails/biblio?adjacent=true&KC=A1&date=20060511&NR=2006100279A1&DB=EPODOC&locale=en_EP&CC=US&FT=D)
- Behrens, P.W., Thompson, J.M., Apt, K., Pfeifer, J.W., Wynn, J.P., Lippmeier, J.C. and Hansen, J. The production of high levels of DHA in microalgae using modified amounts of chloride and potassium. WO 2005/035775 Publication date April 21 2005 (http://v3.espacenet.com/publicationDetails/biblio?adjacent=true&KC=A&date=20060913&NR=20060097009A&DB=EPODOC&locale=en_EP&CC=KR&FT=D)
- Li Y, Adams IP, Wynn JP, Ratledge C. Cloning and characterization of a gene encoding a malic enzyme involved in anaerobic growth in *Mucor circinelloides*. *Mycol Res.* 109 461-8, 2005
- Ratledge C, Wynn JP. The biochemistry and molecular biology of lipid accumulation in oleaginous microorganisms. *Adv Appl Microbiol.* 51:1-51, 2002
- Wynn JP, Hamid AA, Li Y, Ratledge C. Biochemical events leading to the diversion of carbon into storage lipids in the oleaginous fungi *Mucor circinelloides* and *Mortierella alpina*. *Microbiology.* 147 2857-64, 2001 (http://mic.sgmjournals.org/cgi/reprint/147/10/2857)
- Song Y, Wynn JP, Li Y, Grantham D, Ratledge C. A pre-genetic study of the isoforms of malic enzyme associated with lipid accumulation in *Mucor circinelloides*. *Microbiology.* 1471507-15, 2001(http://mic.sgmjournals.org/cgi/reprint/147/6/1507)
- Wynn JP, Ratledge C. Evidence that the rate-limiting step for the biosynthesis of arachidonic acid in *Mortierella alpina* is at the level of the 18:3 to 20:3 elongase. *Microbiology.* 146 2325-31, 2000 (http://mic.sgmjournals.org/cgi/reprint/146/9/2325)
- Wynn JP, bin Abdul Hamid A, Ratledge C. The role of malic enzyme in the regulation of lipid accumulation in filamentous fungi. *Microbiology*. 145 1911-7, 1999 (http://mic.sgmjournals.org/cgi/reprint/145/8/1911)
- Wynn JP, Kendrick A, Hamid AA, Ratledge C. Malic enzyme: a lipogenic enzyme in fungi. Biochem Soc Trans. Nov;25 S669, 1997
- Wynn JP, Kendrick A, Ratledge C. Sesamol as an inhibitor of growth and lipid metabolism in *Mucor circinelloides via* its action on malic enzyme. *Lipids*. 32 605-10, 1997

Synergistic Activities

- Grant application reviewer for the Mississippi-Alabama Sea Grant Consortium

John H. Ashworth, Ph.D.

National Renewable Energy Laboratory (NREL)
Phone: 303-384-6858
Email: john.ashworth@nrel.gov

Education & Training

B.A., Government, 1968 – Wesleyan University
Ph.D., Government, 1977 – Harvard University

Summary of Work Experience

Dr. Ashworth has more than 30 years of experience in environmentally friendly biomass-based energy systems, including ethanol production from lignocellulosic biomass, biomass gasification, and biomass pyrolysis. He currently heads up NREL's partnership development work with industrial partners, Dr. Ashworth has provided technical assistance to the U.S. Department of Energy, the U.S. Army RD&E Command, the U.S. Environmental Protection Agency, the World Bank, the U.S. Agency for International Development, several California and Arizona-based electric utilities, and several large private sector manufacturing corporations. He has designed, conducted, and managed market assessments of a range of renewable and environmentally sensitive technologies for private clients.

Professional Experience

National Renewable Energy Laboratory **October 2007 - Present**
Principal Scientist & Team Leader, Partnership Development
Responsible for all cooperative research and development activities of the NREL National Bioenergy Center (NBC) with industrial partners and other federal agencies. Also assists the Department of Energy Office of Biomass Programs in outreach to industrial firms and groups that are interested in the conversion of cellulosic biomass to fuels.

National Renewable Energy Laboratory **May 2007 – October 2007**
Acting Center Director, National Bioenergy Center
Responsible for managing a staff of 100 scientists and engineers, including recruitment, retention, $30 million budget, and research progress.

National Renewable Energy Laboratory **September 2001 – May 2007**
Team Leader, Partnership Development, National Bioenergy Center
Responsible for all cooperative research and development activities of the NREL National Bioenergy Center (NBC) with industrial partners and other federal agencies. Also assists the Department of Energy Office of Biomass Programs in outreach to industrial firms and groups that are interested in the conversion of cellulosic biomass to fuels.

Power & Performance Solutions, Inc. **1998 – September 2001**
President and CEO
Founder and CEO of this Arizona-based firm, providing market research, management consulting, training, and professional services to the renewable energy industry, electric and water utilities, and governmental agencies in the U.S. Southwest. Key projects included:

- Technical support to Salt River Project, Arizona State University, and the Hopi Nation to develop an environmentally sustainable remote community for 100 households.
- Manager for a three-person P&PSI team responsible for commercialization and direct sales of the

Arizona Public Service (APS) Remote Solar Electric Service to Arizona remote rural households and ranches.

- Confidential consulting support to start-up renewable energy company to locate funding for technology scale-up and to create multi-year business plan.

EcoGroup (now Nexus Energy Software) **1994 – 1998**
Vice President, Energy & Environmental Services
Directed a multi-disciplinary staff of 15 energy and environmental analysts, computer programmers, energy modelers, and market research specialists for this fast-growing product development company. Responsible for developing and managing numerous major projects with electric, water and gas utilities throughout the United States. Responsible for developing project budgets, negotiating contracts with suppliers and subcontractors, managing deliverables and expenditures, and reporting progress to utility, governmental agency, and private sector clients.

Meridian Corporation **1987 – 1994**
Associate Partner & Director of Technology Applications Operation
Associate partner and senior manager for multi-disciplinary, diversified consulting firm with staff of more than 200. Complete responsibility for Technology Applications Operation (TAO), which focused largely on renewable energy technologies and energy conservation. Responsibilities included program and project design; policy advice to senior policy makers in private sector manufacturing firms as well as U.S. Department of Energy Office of Transportation Technologies (DOE/OTT), U.S. Environmental Protection Agency and international agencies; directing staff of 17 professionals; day-to-day operations; business development; project management; and coordination with other divisions of the corporation. Projects included: Director of Biofuels Tiger Team, a multi-disciplinary team of scientists and analysts providing technical and policy support to senior managers of the U.S. Department of Energy Office of Transportation Technologies in alternative transportation fuels.

AID Staff Strengthening through Environmental Training (ASSET) Program **1990 – 1994**
Core Faculty Member

Associates in Rural Development (ARD) **1982 – 1987**
Senior Associate
Technical director and senior manager for research and consulting firm with staff of 26. Offices in Burlington, Vermont; Washington, D.C.; Mogadishu, Somalia; and Gabarone, Botswana. Sole responsibility for management of support contracts with U.S. Agency for International Development (AID), as well as research and policy development program for the U.S. Solar++ Energy Research Institute (SERI).

Solar Energy Research Institute (now NREL) **1981 – 1982**
Manager, International Development Group, Solar Electric Technology Program Office

Solar Energy Research Institute (now NREL) **1977 – 1981**
Senior Policy Analyst, International and Policy Analysis Division

Massachusetts Institute of Technology **1977 – 1978**
Post-Doctoral Research Fellow, Energy Policy Analysis Division, Energy Laboratory

Publications & Presentations

Two book chapters, over 50 papers, technical reports and countless technical presentations.

Richard T. Elander

National Renewable Energy Laboratory (NREL)
Phone: 303-384-6841
Email: richard.elander@nrel.gov

Education & Training

B.S., Chemical Engineering, 1984 – University of Pennsylvania
M.S., Chemical Engineering (emphasis in Biochemical Engineering), 1988 – Colorado State University

Professional Experience

National Renewable Energy Laboratory, Research Supervisor/Senior Engineer II 2007 – Present
Supervise a R&D staff of ~10 engineers, scientists, and post-doctoral researchers. Manage multiple research and development projects involving biomass pretreatment and enzymatic hydrolysis with a combined annual budget of $5-10 million. Led a multi-year $38 million industrial R&D collaboration with DuPont that culminated in a successful pilot plant demonstration of novel pretreatment, hydrolysis, and fermentation technology. Provide expertise to international groups on biomass conversion process and pilot plant design. Manage an ongoing university and industrial subcontract portfolio. Deliver technical presentations and invited lectures and serve as technical session chair/co-chair at prestigious scientific conferences.

National Renewable Energy Laboratory, Senior Engineer II and Team/Project Leader 1999 - 2007
Team leader for pretreatment technology research and development efforts. Manage multiple research and development projects. Led efforts to install and operate unique pilot scale pretreatment and solid-liquid separation equipment. Develop and manage a university and industrial subcontract portfolio. Deliver technical presentations and serve as technical session chair/co-chair at prestigious scientific conferences.

National Renewable Energy Laboratory, Senior Engineer/Team Leader 1995 – 1999
Led efforts to develop and evaluate a unique biomass pretreatment and fractionation process, culminating in a unique pilot scale reactor design with a major pulp and paper equipment supplier. Led an industrial collaboration project with a major Midwestern corn dry-milling ethanol manufacturer.

National Renewable Energy Laboratory, Process Engineer 1991 – 1995
Technoeconomic evaluation biomass-to-ethanol conversion processes, including industrial collaborations. Research and development activities in biomass pretreatment and corn dry-mill enhancement projects.

Genencor International, Inc., Process Development Engineer 1988 – 1991
Conducted laboratory and pilot plant process development projects for several enzyme recovery and purification unit operations, including centrifugation, filtration, membrane concentration, and chromatographic purification. Implemented process improvements in several enzyme manufacturing facilities. Participated in the equipment selection and design of all protein recovery operations for an $80 million state-of-the-art enzyme manufacturing facility.

Allied Corporation, Water Treatment Polymers Pilot Plant, Research Engineer 1984 – 1985
Responsible for the operation of an emulsion polymerization process. Supervised a work crew of process operators and maintenance personnel.

Publications & Presentations

Two book chapters, nine published patent applications (pending), over 30 published papers, reports and technical presentations.

Synergistic Activities

Founding Member and PI, Biomass Refining Consortium for Applied Fundamentals and Innovation (CAFI)
Invited Lecturer, MIT Professional Education Short Course, “Biofuels from Biomass”, 2008
Invited Participant to National Academy of Engineering Frontiers of Engineering Symposium, 2005
Federal Laboratory Consortium Mid-Continent Region Outstanding Technology Development Award, 2005
R&D 100 Award team member, Ethanol from Corn Fiber, 1993

Nicholas J. Nagle

National Renewable Energy Laboratory (NREL)
Phone: 303-384-6837
Email: Nicholas.nagle@nrel.gov

Education & Training

B.S., Microbiology, 1976 – Colorado State University
M.S., Environmental Engineering, 1990 – Colorado School of Mines

Professional Experience

Over twenty years of experience in the field of biomass conversion via anaerobic digestion, growth of microalgae and pretreatment and enzymatic hydrolysis of biomass for bioethanol productions. Breadth of work has been conducted at bench to pilot plant to production scale. Designed, planned and executed experimental tasks at the project level leading to understanding the biomass recalcitrance to enzymatic and thermochemical conversion. Work conducted with a number of collaborations spanning, USDA, DOE laboratories, universities, and industrial partners. Skilled at technical organization, project management and project presentation.

Work Experience

National Renewable Energy Laboratory, Senior Engineer **2001 – Present**
Senior engineer in the Pretreatment and Enzymatic Hydrolysis task. Manages subtasks related to the pretreatment of biomass for bioethanol production.

National Renewable Energy Laboratory, Staff Scientist **1996 - 2001**
Worked in the Biotechnology Center for the development of pretreatment technology for bioethanol production Project leader for the installation, shakedown, operation and data analysis for a novel pretreatment reactor. Work has lead to a Record of Invention filling of a (ROI) based on novel technology and operation. Specific contributions include providing the initial engineering data for process analysis as well and accessing biodegradability for residual material. Results of work lead to a Team of the Quarter Award.

National Renewable Energy Laboratory, Scientist **1990 - 1996**
Worked to establish a waste-to-energy facility in the Pacific American Territories. Major contribution was conducting the treatability studies of the island waste, develop the preliminary engineering, and process design of the waste treatment process using a biological treatment system. Projects goals were to develop on site technology to reduce waste streams that will avoid waste transfer or land filling. Results of work have led to several patents regarding biosolids disposal. Results of work led to Employee of the Month Citation.

Solar Energy Research Institute, Research Technician **1984 – 1990**
Managed and operated a demonstration facility for the production of biodiesel from microalgae. Specific duties included growth and harvesting of microalgae and product recovery by solvent extraction. Results of work demonstrated a unique integrated process using microalgae. Results of work led to a publication, Master Thesis, and demonstration fuel for engine testing. Received a letter of acknowledgment from the Department of Energy, and Employee of the Month Citation.

Robinson Dairy, QA/QC Inspector **1981 – 1984**
Developed bacterial cultures for fermented food products. Tested all milk products for health and product specifications. Interacted with state, city and federal inspectors for compliance with product and production standards.

Colorado State University, Microbiologist **1976 – 1979**
Tested new pesticides to determine toxicity data as a requirement by the Environmental Protection Agency. Tested new filter designs, for the Teledyne Company, to determine their capacity for water purification.

Publications & Presentations

Dien, Bruce; Nagle, Nick. International Sugar Journal (Mar. 2005)

Fermentation of "Quick Fiber" Produced from a Modified Corn-Milling Process into Ethanol and Recovery of Corn Fiber Dien, Bruce; Nagle, Nick; Hicks, Kevin; Singh, Vijay; Moreau, Robert; Tucker, Melvin; Nichols, Nancy; Johnston, David; Cotta, Michael; Nguyen, Quang; Bothast, Rodney Applied Biochemistry and Biotechnology. Spring 2004, Volume 115, Issue 1-3 ien, B. and Nagle, N.

Conversion of Distiller's Grain into Fuel Alcohol and a Higher-Value Animal Feed by Dilute-Acid Pretreatment Tucker, Melvin; Nagle, Nicholas; Jennings, Edward; Ibsen, Kelly; Aden, Andy; Nguyen, Quang; Kim, Kyoung; Noll, Sally. Twenty-Fifth Symposium on Biotechnology for Fuels and Chemicals Published 5/15/2004

Efficacy of a Hot Washing Process for Pretreated Yellow Poplar to Enhance Bioethanol Production. Nagle, N. J.; Elander, R. T.; Newman, M. M.; Rohrback, B. T.; Ruiz, R. O.; Torget, R. W. Biotechnol. Prog.; (Note); 2002; 18(4); 734-738.

Process Economic Approach to Develop a Dilute Acid Cellulose Hydrolysis Process to Produce Ethanol from Biomass. Nagle, N., Ibsen, K., Jennings, E. Applied Biochemistry and Biotechnology Spring 1999, Volume 79, Issue 1-3 Appl. Biochem and Biotech.

Don L. Higgins, M.S.
Novozymes North America
77 Perry's Chapel Rd., Franklinton, NC 27525
dohi@novozymes.com 919-494-3381

Professional Experience:

NOVOZYMES North America, Franklinton, NC, *2001- Present*

- **Senior Scientist, Biomass R&D** *May 2006-Present*.
- Project Leader, Soluble Biomass Inhibitor Remediation Aug 2006-Present. Coordinated a team of 4 scientists for the characterization of soluble biomass enzyme inhibitors and cellulase inhibition. Provided input for high-throughput enzyme screening.
- **Senior Scientist,** Feed Application Unit, Bagsvaerd, Denmark *April 2005-May2006*. Screened novel hemicellulases for improvement of animal feed digestability using a monogastric *in vitro* model.
- **Senior Scientist, BioFuels R&D** *2003 – 2005.* Enzyme application development for 1st and 2nd generation bioethanol production. Developed a method for screening amylases on raw starch. Automated a cellulase screening method utilizing a pretreated corn stover substrate.
- **Research Scientist, Food Enzyme Development,** *2001-2003*. Developed an enzyme application screening method which resulted in the identification of a novel phospholipase resulting in a commercial product for the dairy industry.

TRIMERIS, Incorporated, Durham, NC 1999-2001

- **Senior Scientist,** Developed and validated immunologic methods to support pharma clinical trials. Developed quantitative HPLC methods utilizing flourescence detection of peptides and small molecules in plasma. Optimized methods for antibody/enzyme conjugation and labeled antibodies with various fluorescent molecules. Transferred an ELISA to a contract facility and supervised the successful validation of the assay.

ORGANON TEKNIKA Corporation, Durham, NC *1990-1999*

- **Research Scientist I and II**, Developed ELISA products for the detection HTLV I/II retroviruses, hemorrhagic *E. coli* and pathogenic *Salmonella* sp. Developed conjugation protocols for preparation of antibody/antibody or antibody/enzyme conjugates. Optimized protein purification of antibodies, conjugates, and viral antigens. Assisted in product scale-up and transfer to manufacturing including writing validation protocols, manufacturing directions, and release documents.

Education:

- **NORTH CAROLINA STATE UNIVERSITY**, M.S. Food Microbiology 1988. *Summa cum laude*. Thesis title: Characterization of conjugative plasmids encoding restriction and modification activities from *Streptococcus lactis* ME2. Specialized in the improvement of bacterial fermentations through genetic modification.
- **VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY**, B.S. Food Science, minor in Chemistry, 1985. *Magna cum laude*. Includes two years of chemical engineering classes.

Selected Publications and Presentations:

- Jin, Q., Liu, J., Cassland, A. and D.L.Higgins. 2008. Detoxifying pre-treated lignocellulose-containing materials. WO 134259 PCT application filed November 6, 2008.
- Durmaz, E., **Higgins, D.L.**, and T.R. Klaenhammer. 1994. Molecular characterization of a second abortive phage resistance gene present in *Lactococcus lactic* subsp. *lactis* ME2. J. Bacteriol. 174:7463-7469.
- Sarngadharan, M.G., Romano, J.W., Chetty, C., Schreiber, S.M. and **D.L. Higgins**. 1993. Molecular similarities and immunological cross-reactivities between HTLV-I and HTLV-II: implications in diagnosis. Abstract for the IXth International Conference on AIDS, Berlin, Germany.
- **Higgins, D.L**. and B.J. Robinson. 1993. Comparison of MICRO-ID Listeria to conventional biochemical methods for identification of members of the genus *Listeria*: collaborative study. J. Assoc. Anal. Chem. 76:831-838.
- **Higgins, D.L**., Durham, R., Butman, B., and B. Robison. 1992. Detection of *Salmonella* in nonfat dry milk within 24 hours using a tube immunocapture method. 1992 Annual International Symposium on *Salmonella* and Salmonellosis, Pflagren, France.
- **Higgins, D.L**., Bryant, D.H., and B.J. Robison. 1992. Rapid estimation of the number of microorganisms in raw meat using an automated colorimetric microbial detection system. 1992 Annual Meeting of the Institute of Food Technologists, New Orleans, LA.
- Francois, J., **Higgins, D**., and K. Tatchell. 1991. Inhibition of glycogen synthesis in *S. cerevisiae* by the mating pheremone □-factor. J. Biol. Chem. 266:6174-6180.
- **Higgins, D.L**., Sanozky-Dawes, R.B., and T.R. Klaenhammer. 1988. Restriction and modification activities from *Streptococcus lactis* ME2 are encoded by a self-transmissible plasmid, pTN20, that forms cointegrates during mobilization of lactose-fermenting ability. J. Bacteriol. 170:3435-3442.

Synergistic Activities.

- Member, Society for Industrial Microbiology, 2006-Present
- Member, American Chemical Society, 2005-Present

Name **Bruce E. Dale**	**Position Title** Professor of Chemical Engineering	
Institution and Location	Degree *& Date*	Field of Study
University of Arizona, Tucson	*B.S. 1974*	Chemical Engineering (magna cum laude)
University of Arizona, Tucson	*M.S. 1976*	Chemical Engineering
Purdue University, West Lafayette, Indiana	*Ph. D. 1979*	Chemical Engineering

PROFESSIONAL EXPERIENCE & HONORS

University Distinguished Professor, Dept. of Chemical Engineering & Materials Science, Michigan State University, East Lansing, MI, 2001-present
Professor and Chair, Dept. of Chemical Engineering, Michigan State University, 1996 – 2001

Professor, Chemical Engineering & Agricultural Engineering, Texas A&M University, 1991 – 1995
Director, Food Protein Research and Development Center, Texas A&M University, 1991 – 1993
Director, Engineering Biosciences Research Center, Texas A&M University, 1990 - 1995
Associate Professor, Chemical and Agricultural Engineering, Texas A&M University, 1988 – 1991

Professor, Chemical Engineering, Colorado State University, 1988 – 1988
Associate Professor Chemical Engineering, Colorado State University, 1983– 1988
Assistant Professor, Chemical Engineering, Colorado State University, 1979 – 1983

Halliburton Outstanding Young Faculty Award (1982)
Abell Young Faculty Research Award (1984)
Colorado State University Research Foundation Researcher of the Year (1986)
Engineering Dean's Council Award (1987)
Editorial Board, *Biotechnology Progress* (1989-present)
Editorial Board, *Biotechnology and Bioengineering* (2002-present)
Editor, *Bioresource Technology* (1991-1996)
Editor in Chief, *Biofuels, Bioproducts & Biorefineries* (2007-present)
Co-Chair, National Research Council Committee on Biobased Industrial Products (1994-2000)
Charles D. Scott Award (1996)
Sterling Hendricks Award (2007)
Distinguished University Faculty Award (2008)

EXPERTISE SUMMARY

My research expertise is the integrated conversion of cellulosic biomass to fuels and chemicals via pretreatment and enzymatic hydrolysis to fermentable sugars. I also have expertise in the use of life cycle analysis to understand the environmental impacts of these bioconversion systems. I have a strong administrative background with almost 10 years experience directing a department of 20 faculty members at Michigan State in addition to directing two multimillion dollar per year research centers at Texas A&M. During the past 5 years I have been actively

involved with MBI, International to commercialize the AFEX process that I invented. I have received 17 total U. S. and foreign patents, three of them in the past three years and have filed 10 patent disclosures over the past two years. I believe it is fair to say I am one of a very small handful of internationally recognized leaders in the field of cellulose conversion to ethanol. I am also a leading public advocate for biofuels and bioproducts.

ABBREVIATED LIST OF PROFESSIONAL PUBLICATIONS

1. Lau, M. W., Dale, B. E. and Balan, V. (2008). Ethanolic Fermentation of Hydrolysates from AFEX Treated Corn Stover and Distillers Grains without Detoxification and External Nutrient Supplementation. Biotech. Bioengr. Vol. 99: 529-539.
2. Carolan, J. E., Joshi, S. V. and Dale, B. E. "Technical and Financial Feasibility Analysis of Distributed Bioprocessing Using Biomass Pre-processing Centers" J. of Agricultural and Food Industrial Organization. Vol. 5, Issue 2, Article 10 (2007)
3. Murnen, H. K., Balan, V., Chundawat, S., Bals, B., da Costa Sousa, L. and Dale, B. E. "Optimization of AFEX Pretreatment and Enzymatic Hydrolysis of *Miscanthus x giganteus* to Fermentable Sugars. Biotechnol. Prog. 23: 846-850 (2007)
4. Dale, B. E. (2008). Biofuels: Thinking Clearly about the Issues. J. Agric. Food Chem. 56: 3885-3891.
5. Lynd, L. R., Laser, M. S., Bransby, D., Dale, B. E., Davison, B., Hamilton, R., Himmel, M., Keller, M., McMillan, J. D., Sheehan, J. and Wyman, C. E. (2008). How Biotech can Transform Biofuels. Nature Biotechnology. Vol. 26: 169-172.
6. Laureano-Perez, L., Dale, B. E., O'Dwyer, J. P. and Holtzapple, M. "Statistical Correlation of Spectroscopic Analysis and Enzymatic Hydrolysis of Poplar Samples" Biotechnology Progress 22, 835-841, (2006).
7. Kim, S.; Dale, B. E.; "Life cycle assessment study of biopolymers derived from no-tilled corn" International Journal of Life Cycle Assessment 10, 200-210, (2005).
8. Kim, S.; Dale, B. E.; "Life cycle assessment of various cropping systems utilized for producing biofuels. Biomass & Bioenergy 29, 426-439, (2005).
9. Kim, S. and B. E. Dale. "Cumulative Energy and Global Warming Impact from the Production of Biomass for Biobased Products" *J. of Industrial Ecology.* Vol. 7, No. 3-4. pgs. 147-162. (2004)
10. Kim, S. and B. E. Dale. "Global Potential Bioethanol Production from Wasted Crops and Crop Residues" *Biomass & Bioenergy.* Vol. 26. pgs. 361-375 (2004)

SYNERGISTIC ACTIVITIES

- Leading member of the CAFI (Consortium for Applied Fundamentals and Innovation) that is working to rigorously compare and develop advanced biomass pretreatments
- Member of a project team of the Northeast Sun Grant (headed by Dr. Tom Richard of Penn State) to model bioenergy systems in terms of environmental, landscape and social/community economic impacts.
- Active member of the Midwest Consortium for Biobased Products and Bioenergy. The Consortium is currently working to develop value-added products from distillers grains.
- Leader of the Biomass Processing thrust of the recently established Great Lakes Regional Bioenergy Center funded by the U. S. Dept. of Energy ($25 million per year for 5 years), participating the Sustainability thrust of this Center also.
- Active collaborations with MSU agricultural economics and animal science faculty to explore viable process designs for distributed or regional biomass processing.

Curriculum Vitae of David Hodge

Address Department of Chemical Engineering and Materials Science
Michigan State University
2527 Engineering Building
East Lansing, MI 48824
Telephone (517) 353-4508
E-mail hodgeda@msu.edu

Education and Training

2005-2006 **Postdoctoral Researcher,** National Bioenergy Center, National Renewable Energy Laboratory, Golden, Colorado

Aug 2005 **Ph.D. in Chemical Engineering**, Colorado State University, Ft. Collins, Colorado. Dissertation: O*ptimization of High Solids Lignocellulosic Biomass Conversion for Ethanol Production.*

June 2002 **M.S. in Chemical Engineering**, Colorado State University, Ft. Collins, Colorado. Thesis: *Modeling and Predictive Control of Recombinant Zymomonas mobilis Fed-Batch Fermentation.*

June 1999 **B.S. in Chemical Engineering**, (*cum laude*). Auburn University, Auburn, Alabama. Specialization in Pulp and Paper Engineering

Professional Experience

Nov. 2008-present
Assistant Professor, Department of Chemical Engineering and Materials Science, joint appointment with Biosystems and Agricultural Engineering, Michigan State University, East Lansing Michigan

Feb 2006-Oct 2008
Research Assistant Professor, Department of Chemical Engineering, Luleå University of Technology, Luleå, Sweden

- Developed media and feed protocol for aerobic cultivation on spruce acid hydrolyzates by *Saccharomyces cerevisiae* metabolically engineered for pentose fermentation
- Investigated and tested microbial processes for conversion of lignocellulosic biomass sugars to higher value organic acids (succinic acid, itaconic acid, xylonic acid)
- Evaluated and tested feedstocks and industrial processes for the fractionation of lignocellulosic biomass for the production of fuels and chemicals
- Performed transcriptional and proteomic profiling on *Escherichia coli* metabolically engineered to convert lignocellulosic biomass sugars to succinic acid

Nov 2003-Feb 2006
Postdoctoral Scientist, Research Engineer, National Bioenergy Center, National Renewable Energy Laboratory (NREL), Golden, Colorado

- Evaluated, tested, and optimized reactor configurations for solid-phase enzymatic hydrolysis of cellulose from lignocellulosic biomass
- Optimized reaction conditions to obtain exceptionally high monomeric sugar product titers (greater than 150 g/L) and yields from the enzymatic depolymerization of cellulose from dilute acid pretreated corn stover in high insoluble solid concentration reactors
- Investigated the effect inhibitors generated during pretreatment on cellulases

Aug 1999-Nov 2003
Research/Teaching Assistant, Department of Chemical Engineering, Colorado State University, Ft. Collins, Colorado

- Developed kinetic models and control algorithms for online optimization of fed-batch ethanol fermentation from lignocellulosic sugars by a *Z. mobilis* metabolically engineered to ferment xylose
- Used 2-D SDS PAGE to monitor protein expression in response to substrates and environmental conditions in metabolically engineered *Z. mobilis*
- Developed principle component models for industrial recombinant protein fermentation data for the purpose of process monitoring, fault detection, and analysis

June 1996-Mar 1998
Control Systems Engineering Cooperative Education Student, Mead Coated Board (a Kraft paper mill, currently Mead WestVaco), Phenix City, Alabama

Publications

Peer-Reviewed Journal Articles

1. Hodge DB, Andersson CA, Berglund KA, Rova U (in press 2009). Detoxification Requirements for Bioconversion of Softwood Dilute Acid Hydrolyzates to Succinic Acid. *Enz Microb Technol.* http://dx.doi.org/10.1016/j.enzmictec.2008.11.007
2. Andersson CA, Helmerius J, Hodge DB, Berglund K, Rova U (2009) Inhibition of Succinic Acid Production in Metabolically Engineered *Escherichia coli* by Neutralizing Agent, Organic Acids, and Osmolarity. *Biotech Prog.* 25(1):116-23. http://www3.interscience.wiley.com/journal/121683629/abstract
3. Hodge DB, Karim MN, Schell DJ, McMillan JD (2009). Model-Based Fed-Batch for High-Solids Enzymatic Cellulose Hydrolysis. *Appl Biochem Biotech*. 152(1):88-107. http://www.springerlink.com/content/k115163555u57504/
4. Hodge DB, Karim MN, Schell DJ, McMillan JD (2008). Soluble and Insoluble Solids Contributions to High-Solids Enzymatic Hydrolysis of Lignocellulose. *Biores Technol.* 99(18):8940-8948. http://dx.doi.org/10.1016/j.biortech.2008.05.015
5. Enman J, Hodge DB, Berglund K, Rova U (2008). Production of the Bioactive Compound Eritadenine by Submerged Cultivation of Shiitake (*Lentinus edodes*) Mycelia. *J Ag Food Chem*. 56(8):2609–2612. http://pubs.acs.org/doi/abs/10.1021/jf800091a
6. Andersson CA, Hodge DB, Berglund KA, Rova U (2007). Effect of Different Carbon Sources on the Production of Succinic Acid Using Metabolically Engineered *Escherichia coli*. *Biotech Prog*. 23(2):381-388. http://www3.interscience.wiley.com/journal/121399061/abstract
7. Karim NM, Hodge DB, Simon L (2003). Data-Based Modeling and Analysis of Bioprocesses: Some Real Experiences. *Biotech Prog* 19(5):1591-1605. http://www3.interscience.wiley.com/journal/121400476/abstract
8. Hodge DB and Karim MN (2002). Modeling and Advanced Control of Recombinant *Zymomonas mobilis* Fed-Batch Fermentation. *Biotech Prog* 18(3):572-579. http://www3.interscience.wiley.com/journal/121399751/abstract

Book Chapters

1. Berglund KA, Rova U, Hodge DB (in press 2009). Microbial metabolites as building blocks for renewable resource based surfactants. Ed. In: *Surfactants from Renewable Resources*. M. Kjellin, Ed. John Wiley & Sons.

Synergistic Activities

Journal Reviewer: *Biotechnology & Bioengineering, Applied Biochemistry & Biotechnology, Bioresource Technology, Energy & Fuels, Applied Energy, Journal of Environmental Engineering, Letters in Applied Microbiology*

Since 1995 American Institute of Chemical Engineers (AIChE)

KENNETH KEEGSTRA

Education:
1967 BA, cum laude (Chemistry), Hope College, Holland, MI

1971 PhD, (Biochemistry) University of Colorado, Boulder, CO
Thesis Advisor: Peter Albersheim

1971-1973 Postdoctoral Fellow, Department of Biology, MIT, Cambridge, MA
Advisor: Phillips Robbins

Positions Held:
1973-1977 Assistant Professor
Department of Microbiology
State University of New York at Stony Brook

1977-1979 Assistant Professor
1979-1983 Associate Professor
1983-1991 Professor
1991-1992 Professor and Chair
Department of Botany
University of Wisconsin-Madison

1993-2006 Director, MSU-DOE Plant Research Laboratory
2006-present University Distinguished Professor
MSU-DOE Plant Research Laboratory
Department of Biochem and Mol Biol, Department of Plant Biol.
Michigan State University

10 Publications most relevant to this proposal:
Perrin, RM, DeRocher, AE, Bar-Peled, M, Zeng, W, Norambuena, L, Orellana, A, Raikhel, NV, and Keegstra, K (1999) Xyloglucan fucosyltransferase, an enzyme involved in plant cell wall biosynthesis. Science 284:1976-1979.

Faik A, Price NJ, Raikhel NV, Keegstra K (2002) An *Arabidopsis* gene encoding an α-xylosyltransferase involved in xyloglucan biosynthesis. Proc Natl Acad Sci USA 99: 7797-7802.

Vanzin GF, Madson M, Carpita NC, Raikhel NV, Keegstra K, Reiter W-D (2002) The mur2 mutant of Arabidopsis thaliana lacks fucosylated xyloglucan due to a lesion in fucosyltransferase AtFUT1. Proc Natl Acad Sci USA 99:3340-3345.

Liepman AH, Wilkerson CG, Keegstra K (2005) Expression of cellulose synthase-like (Csl) genes in insect cells reveals that CslA family members encode mannan synthases. Proc Natl Acad Sci USA 102:2221-2226.

Cavalier DM, Keegstra K (2006) Two xyloglucan xylosyltransferases catalyze the addition of multiple xyosyl residues to cellohexaose. J Biol Chem 281: 34197-34207.

Lerouxel O, Cavalier DM, Liepman AH, Keegstra K (2006) Biosynthesis of plant cell wall polysaccharides-a complex process. Curr Opin Plant Biol 9:621-630.

Cocuron J-C, Lerouxel O, Drakakaki G, Alonso AP, Liepman AH, Keegstra K, Raikhel N, Wilkerson CG (2007) A gene from the cellulose synthase-like C family encodes a β-1,4 glucan

synthase. Proc Natl Acad Sci USA, 104:8550-8555.

Pauly M, Keegstra K (2008) Cell wall carbohydrates and their modification as a resource for biofuels. Plant J, 54:559-568..

Zabotina OA, van de Ven, WTG, Freshour, G, Drakakaki, G, Cavalier D, Mouille G, Hahn, MG, Keegstra, K, Raikhel, NV (2008) The Arabidopsis XT5 protein encodes a putative α-1,6-xylosyltransferase that is involved in xyloglucan biosynthesis. Plant J, 56:101-115.

Cavalier, DM, Lerouxel, O, Neumetzler, L, Yamauchi, K, Reinecke, A, Freshour, G, Zabotina, O, Hahn, MG, Burgert, I, Pauly, M, Raikhel NV, Keegstra, K (2008) Disruption of two *Arabidopsis thaliana xylosyltransferase* genes results in plants deficient in xyloglucan, a major primary cell wall component. Plant Cell, 20:1519-1537.

Synergistic activities:
I currently serve on the editorial board of two scientific journals; in 1997-98, I served as president of the American Soceity of Plant Physiologists (ASPB). I am currently Scientific Director for the Great Lakes Bioenergy Research Center, one of three Bioenergy Research Centers funded by DOE.

Collaborators & Other Affiliations:
Collaborators within the last 48 months: G Budziszewski (Syngenta), N. Carpita (Purdue U), M-L Chou (Academia Sinica, Taiwan), J Davila-Aponte (Washington U), T Girke (UC-Riverside), PJ Green (U Delaware), RA Gutierrez (New York U), P Jarvis (U Leicester, UK), Z Jia (U of Georgia), H-M Li (Academia Sinica, Taiwan), J Lauricha (UC-Riverside), JZ Levin (Syngenta), M Madson (Purdue U), J Ohlrogge (Michigan State U), R Patel (U Leicester, UK), N. Price (UC-Riverside), S Potter-Lewis (Syngenta), N. Raikhel (UC-Riverside), W-D Reiter (U of Conn), S Reumann (U Gottingen), D. Schnell (Univ of Mass), M. Smith (Waterloo U), H Tran (UC-Riverside), SL Tu (Academia Sinica, Taiwan), G. Vanzin (U of Conn), W. York (U of Georgia),

Thesis advisor: Peter Albersheim (now retired)
Postdoctoral mentor: Phillips Robbins (now retired)

PhD students (18 total): Jonathan Davis is a current PhD student.

Postdoctoral associates (21 total): John Froehlich (research assistant professor at MSU), David Cavalier, and Yan Wang are current postdoctoral associates.

Seungdo Kim

Department of Chemical Engineering and Materials Science, Michigan State University
East Lansing, Michigan 48824-1226 Phone 517-355-4621, Email: kimseun@msu.edu

EDUCATION

Hanyang University, Seoul, Korea, Chemical Engineering, B.S., 1984
Hanyang University, Seoul, Korea, Chemical Engineering, M.S., 1986
Louisiana State University, Chemical Engineering, Ph.D., 1993
North Carolina State University, Life Cycle Assessment, Post-doc, 1998 - 2001

RESEARCH and PROFESSTIONAL EXPERIENCE

Visiting Associated Professor, Department of Chemical & Materials Science, Michigan State University, 2005 - Present
Visiting research associate at Chemical Engineering, Michigan State Univ., 2001-2005
Post-doc at Chemical Engineering, North Carolina State Univ., 1998-2001
Project Manager at Samsung Electronics Co., Ltd., Korea 1994-1998

CURRENT PROJECTS

Title: Life Cycle Assessment of Corn Based Ethanol
Source of Support: Poet
Total Award Period Covered: 02/1/09 – 12/31/09
PI: Dale, Bruce E.
Title: Life Cycle Assessment of Cellulosic Biorefinery
Source of Support: GLBRC
Total Award Period Covered: 12/1/08 – 11/31/09
PI: Dale, Bruce E.
Title: Life Cycle Assessment to Improve the Sustainability and Competitive Position of Biobased Chemicals: A Local Approach
Source of Support: Department of Energy
Total Award Period Covered: 01/1/07 – 12/31/09
PI: Dale, Bruce E. Co-PI: Kim, Seungdo
Title: Life Cycle Assessment of Polyhydroxyalkanoates derived from corn grain: Energy and Greenhouse Gas Impacts
Source of Support: Metabolix, Inc.
Total Award Period Covered: 9/1/07 – 3/31/08
PI: Dale, Bruce E
Title: Integrated Corn Based Biorefinery
Source of Support: Department of Energy/DuPont Biobased Materials, Inc.
Total Award Period Covered: 11/1/03 – 10/31/07
PI: Bruce, Dale E.
Title: PREMISE II: Design and Engineering of Green Composites from Biofibers and Bioplastics
Source of Support: NSF

Total Award Period Covered: 07/1/04 – 06/30/07
PI: Drzal, Lawrence et al.
Title: Development of Sustainable Biobased Products and Bioenergy in Cooperation with Midwest Consortium for Sustainable Biobased Products
Source of Support: Department of Energy
Total Award Period Covered: 11/1/04 – 10/31/06
PI: Bruce, Dale E.

SELECTED PUBLICATIONS
Related to Project

- Kim, H., Kim, S. and Dale, B. E., Biofuels, Land Use Change, and Greenhouse Gas Emissions: Some Unexplored Variables, Environmental Science & Technology, 43 (3), 961–967, 2009.
- Kim, S., Dale, B. E. and Jenkins, R., Life Cycle Assessment of Corn Grain and Corn Stover, accepted in International Journal of Life Cycle Assessment, 2009.
- Kim, S. and Dale, B. E., Energy and Greenhouse Gas Profiles of Polyhydroxybutyrates derived from corn grain: A Life Cycle Perspective, Environmental Science & Technology, 42 (20), 7690–7695, 2008.
- Kim, S. and Dale, B. E., Effects of Nitrogen Fertilizer Application on Greenhouse Gas Emissions and Economics of Corn Production, Environmental Science & Technology, 42 (16), 6028–6033, 2008.
- Kim, S. and Dale, B. E., Life Cycle Assessment of Fuel Ethanol Derived from Corn Grain via Dry Milling, Bioresource Technology, 99, 5250 – 5260, 2008.
- Kim, S. and Dale, B. E., Ethanol Fuels: E10 or E85 – Life Cycle Perspectives, International Journal of Life Cycle Assessment, 11 (2), 117 – 121, 2006.
- Kim, S. and Dale, B. E., Life Cycle Assessment of Various Cropping Systems Utilized for Producing Biofuels: Bioethanol and Biodiesel, Biomass & Bioenergy, 29, 426 – 439, 2005.
- Kim, S. and Dale, B. E., Life Cycle Inventory Information of the United States Electricity System, International Journal of Life Cycle Assessment, 10 (4), 294 – 304, 2005.
- Kim, S. and Dale, B. E., Environmental aspects of ethanol derived from no-tilled corn grain: nonrenewable energy consumption and greenhouse gas emission, Biomass & Bioenergy, 28, 475–489, 2005.
- Kim, S. and Dale, B. E., Cumulative Energy and Global Warming Impact Associated with Producing Biomass for Biobased Industrial Products, Journal of Industrial Ecology, 7 (3-4), 147–162, 2004.

SYNERGISTIC ACTIVITIES

- Member of editorial board in International Journal of Life Cycle Assessment, 2003 – Present
- Journal reviewer: International Journal of Life Cycle Assessment, Journal of Industrial Ecology, Resources Conservation and Recycling, 2003 – Present

CARL T. LIRA

Department of Chemical Engineering and Materials Science, 2527 Engineering Building, Michigan State University, East Lansing, MI 48824-1226, 517/355-9731, FAX: 517/432-1105; lira@egr.msu.edu; http://www.egr.msu.edu/~lira

EDUCATION

Ph.D.	Chemical Engineering, University of Illinois at Urbana-Champaign, 1986.
M.S.	Chemical Engineering, University of Illinois at Urbana-Champaign, 1984.
B.S.	Chemical Engineering, Cum Laude, Kansas State University, 1981.

PROFESSIONAL EXPERIENCE

1/92 — present	Associate Professor, Michigan State University.
5/94 — 12/03	National Technological University, Chemical Engineering Faculty
1/86 — 1/92	Assistant Professor, Michigan State University.
1/84 — 5/84	Instructor — Senior Project Lab, University of Illinois.
5/81 — 8/81	Research Engineer, Conoco, Ponca City, OK.

RESEARCH INTERESTS

Property Measurements	Molecular Simulation for Property Prediction
High Pressure Phase Equilibria	Adsorption and Interfacial Phenomena
Supercritical Fluid Extractions	Extraction and Purification of Natural Products

AWARDS, HONORS

Amoco Foundation Excellence in Teaching Award, Michigan State University, 1999.

Withrow Teaching Excellence Award, College of Engineering, Michigan State University, 1992, 2004, 2008.

DuPont Young Faculty Award, Michigan State University, 1986.

National Science Foundation Minority Graduate Fellowship, University of Illinois, 8/82-8/85.

BOOKS

"Introductory Chemical Engineering Thermodynamics", J.R. Elliott, C. T. Lira, Prentice-Hall. 1999.

TEN PUBLICATIONS RECENT PUBLICATIONS

Kolah, A.K.; Asthana, N.S.; Vu, D.T.; Lira, C.T.; Miller, D.J. "Reaction Kinetics for the Heterogeneously Catalyzed Esterification of Succinic Acid with Ethanol", Ind. Eng. Chem. Res., 47, 5313-5317 (2008).

Kolah, A.K.; Asthana, N.S.; Vu, D.T.; Lira C.T.; Miller, D.J. “Tri-ethyl Citrate Synthesis by Reactive Distillation”, Ind.Eng.Chem. Res. 47,1017-1025, (2008).

Kolah, A.K.; Asthana, N.S.; Vu, D.T.; Lira, C.T.; Miller, D.J. "Reaction Kinetics of the Catalytic Esterification of Citric Acid with Ethanol", Ind. Eng. Chem. Res. 46, 3180-3187, (2007).

Asthana, N.S.; Kolah, A.K.; Vu, D.T.; Lira, C.T.; Miller, D.J. "A Kinetic Model for Esterification of Lactic Acid and Its Oligomers," Ind. Eng. Chem. Res. 45, 5251-5257 (2006).

Vu, D.T.; Lira, C.T.; Asthana, N.S.; Kolah, A.K. Miller D.J. "Vapor-liquid Equilibria in the Systems Ethyl Lactate + Ethanol and Ethyl Lactate + Water," J. Chem. Eng. Data. 51, 1220-1225, (2006).

Yang, X.; Lira, C.T. “Theoretical Study of Adsorption on Activated Carbon from Supercritical Fluids by the SLD-ESD Approach”, J. Supercritical Fluids 37, 191-200, (2006).

Vu, D. T.; Kolah, A. K.; Asthana, N. S.; Peereboom, L.; Lira, C. T.; Miller, D. J. "Oligomer distribution in concentrated lactic acid solutions," Fluid Phase Equilib. 236, 125-135, (2005).

Asthana, N.; Kolah, A.; Vu, D. T.; Lira, C.T. ; Miller D.J. “A Continuous Reactive Separation Process for Ethyl Lactate Formation”, Org. Proc. Res. Dev. 9, 599-607, (2005).

Baber, T.M.; Graiver, D. ; Lira, C. T. ; Narayan, R. “A Novel Application of Catalytic Ozone Chemistry for Improved Biodiesel Synthesis”, Biomacromolecules 6 (3), 1334-1344, (2005).

Guyer D.E; Saengcharoenrat, C; Lira, C.T. “Onion Flavor Recovery in the Process of Adsorption and Supercritical Carbon Dioxide Desorption”, J. Food Process Eng. 28, 205-218, (2005).

SYNERGISTIC ACTIVITIES

Professor Lira extends enthusiasm for his research through classroom discussions and routinely incorporates research topics into homework problems for classes, broadening the impact of knowledge. For example, he has recently developed a short module for molecular simulations based on code developed for research funded by a USDA project. He has also used the chemical reactions for creating fresh, relevant problems.

Professor Lira is coauthor of an undergraduate thermodynamics chemical engineering textbook used at some of the top departments globally. A draft of the 2nd edition is in classroom testing spring semester 2009, and will be further revised to include increased content of biology and biobased fuels and chemicals. Examples and homework developed from research-related material will be widely distributed beyond the immediate organization by this mechanism.

Miller, D.J.; Peereboom, L.; Kolah, A.K.; Asthana, N.S.; Lira, C.T., “Process for Production of a Composition Useful as a Fuel,“ U.S. Patent 7,321,052, Jan. 22, (2008).

Miller, D.J.; Asthana, N.; Kolah, A.; Lira C.T. “Process for Production of Organic Acid Esters”, US Patent Application A1,20060014977, January 19, 2006.

Asthana, N.; Kolah, A.; Vu, D.T.; Lira, C.T.; Miller, D.J.; “Process for reactive esterification distillation,” US Patent Application A1, 20060252956.

Bryan K. Ritchie

February, 2009

James Madison College
Michigan State University
East Lansing, MI 48825
Phone: (517) 353-8614
Fax: (517)-432-1804
e-mail: ritchieb@msu.edu

Home Address
4396 Manitou Dr.
Okemos, MI 48864
Phone: (517) 381-5130
e-mail:bkritchie@gmail.com

Education

- Ph.D. Political Science, Emory University, 2001
- Master of Business Administration, Marriott School, Brigham Young University, 1995
- Bachelor of Arts, University of Nevada, Las Vegas, 1990

Professional Experience

- Associate Director for Technology Alliances 7/07 – Present
  - Office of Bio-based Technology
- Associate Professor of International Relations
  - James Madison College, Michigan State University 8/06 – Present
  - Core Faculty, Asian Studies Center
- Co-director
  - Michigan Center for Innovation and Economic Prosperity 5/06 – Present
- Assistant Professor of International Relations 8/01 – 7/06
  - James Madison College, Michigan State University
  - Core Faculty, Asian Studies Center
- Consultant 1995-1997
  - Oversaw the product development process for the introduction of video communication products at USRobotics (now 3Com Corporation). I also consulted with Iomega for the launch of their Zip, Jaz, and Ditto products.
- Director of Strategic Markets, Novell, Inc. 1995-1997
  - Developed product marketing and development plans and oversaw product development for the embedded systems technology (NEST) division's home- and office-based networking products. This division was an entrepreneurial startup within Novell.
- Senior Program Leader, Dayna Communications—1993-1995
  - I led the product and business development team responsible for wireless networking and communication products. I was responsible for product development, strategic alliances, worldwide sales and marketing, and manufacturing. The team successfully developed new wireless PDA products (based on cellular, CDPD, and RF 2.4 Ghz technologies). My management purview included program product line strategy, profit, loss and budget. I traveled extensively worldwide to promote the products and work with distribution and development partners.
- Owner, Teleologic—1992-1994
  - I was the primary software designer of Marco Polo, an international business information software program. Achievements include product conception, design, and development
  - (Developed product in C++). Product was featured in Inc. and Success Magazines.
- Vice President of World-wide Sales and Marketing, Century Software—1990-1992

    - I developed the company's OEM, international, national and major account sales infrastructure. I led seven sales and three marketing representatives and their production. I directed marketing and marketing communications for all products and was responsible for high level product, marketing, and sales planning
- Owner, MB Technology—1988-1990
    - I created and managed a custom database and network programming company, which I diversified to include computer reselling and hardware configuration. I configured and installed multi-user operating systems, networks, and computer hardware (Novell, Unix, and Theos) and also developed vertical market database software applications in Paradox.

Publications

- Forthcoming. *Relationship Economics: The Social Capital Paradigm and its Application to Business, Politics, and other Transactions*. With Lindon Robison. Gower (Ashgate): London.
- 2008. "Political Challenges of Innovation in the Developing World." Forthcoming in *Journal of Policy Research*, fall 2008.
- 2008. "Economic Upgrading in a State-Coordinated, Liberal Market Economy." *Asia Pacific Journal of Management.* Available at http://www.springerlink.com/content/h39300971t16nn90/
- 2008. With Ross B. Emmett and John T. Fournier. "Changing Horses: Recreating Entrepreneurial Economies in the Mid-Western United States." (L'avenir du Midwest, de la rust belt aux start-ups?) Politique Americaine, Number 10 - Printemps (Spring) 2008 Pp. 105-116 2005. "Progress Through Setback or Mired in Mediocrity? Crisis and institutional change in Southeast Asia." *Journal of East Asian Studies.* Vol. 5, No 2 (June), pp. 273-314.
- 2005. "Coalitional Politics, Economic Reform, and Technological Upgrading in Malaysia." *World Development.* Vol. 33, No. 5 (May), pp. 745-762.
- 2005. "Systemic Vulnerability and the Origins of Developmental States: Northeast and Southeast Asia in Comparative Perspective." With Richard F. Doner and Dan Slater. *International Organization.* Vol. 59:2 (Spring), pp. 327-361.
- 2004. "Politics and Economic Reform in Malaysia." *William Davidson Institute Working Paper Series*. No. 655. February 2004. University of Michigan.
- 2003. "Economic Crisis and Technological Trajectories: Hard Disk Drive Production in Southeast Asia." With Richard F. Doner. In Richard Samuels and William Keller, eds., *Crisis and Innovation in Asian Technology.* New York: Cambridge University Press.
- 2002. "Foreign Direct Investment and Intellectual Capital Formation in Southeast Asia." Technical paper number 194 (August, 2002). Organization of Economic Cooperation and Development (OECD) Paris: OECD Development Centre.
- 2001. "Innovation Systems, Collective Dilemmas, and the Formation of Technical Intellectual Capital in Malaysia, Singapore, and Thailand." *International Journal of Business and Society.* Vol. 2 No.2, July 2001, pg. 21-48.

Professional and Scholarly Activities

As co-director of the Center for Innovation and Economic Prosperity, I am working to help Michigan learn from other rapidly developing countries, like Singapore. The point is to figure out how to transform the institutions of this region to support entrepreneurial and innovative companies. Next generation industries, including those in biofuels, will only be possible as we resolve not only the technical hurdles, but also the supply chain, social, and political ones as well.

KURT D. THELEN, Ph.D. Rm. 512 PSSB
East Lansing, MI 48824
517-355-0271 ext: 1232
thelenk3@msu.edu

EDUCATION

Ph.D. Crop & Soil Sciences, May 1994. Michigan State University, East Lansing. Dissertation: Characterizing Herbicide Interactions with Nuclear Magnetic Resonance.

M.S. Crop & Soil Sciences, September 1987. Michigan State University, East Lansing. Thesis: Velvetleaf Control and Off-Target Injury With Clomazone. GPA: 3.9 of 4.0

B.S. with High Honors, Crop & Soil Sciences, June 1985. Michigan State University, East Lansing. GPA: 3.9 of 4.0

EXPERIENCE

July 1, 1999 to present:

Michigan State University, Department of Crop and Soil Sciences, Assistant Professor (1999-2004); Associate Professor (2004 to present). Cropping systems agronomist, specializing in energy crops, corn and soybean production systems. Co-chair of Extension Field Crops Area of Expertise Team. Also, oversee corn hybrid variety testing program and teach CSS 467 BioEnergy Feedstock Production, and CSS 212 Advanced Crop Production.

October 1997 to June 30, 1999:

Michigan Department of Agriculture, Director, Environmental Stewardship Division. Responsibilities include oversight of a $9.2 million budget, supervision of 40 MDA staff implementing agricultural-environmental programs including: Right to Farm; Intercounty Drains; Groundwater Stewardship; Spill Response; Pesticide State Management Plans; Groundwater Monitoring; Forestry; Migrant Labor Housing; Pesticide Container Recycling; Biosolids; and, Clean Sweeps. Represent the Michigan Department of Agriculture on national and regional work groups on agricultural and environmental issues. Integrate agricultural and environmental research implications into state agriculture policy. Coordinate numerous interagency committees, task forces, and work groups; and, work with the legislature on proposed legislation.

September 1988 to December 1997:

Instructor, Michigan State University, Taught CSS 204, Corn & Soybean Production, and CSS 072 Advanced Crop Production in the MSU Department of Crop & Soil Sciences and the Institute of Agricultural Technology. Course work focused on a systems approach to field crop production.

July 1990 to October 1997:

Michigan Department of Agriculture, Manager, Office of Pollution Prevention. Responsibilities include supervision of 15 MDA staff implementing agricultural-environmental programs. Work with the agricultural industry on the development of agricultural best management practices for pesticide use, turfgrass management, forestry, livestock operations, and fertilizer use; represent the Michigan Department of Agriculture on national and regional work groups on great lakes issues, confined animal feeding operations, and pesticide disposal. Solicit and procure federal grant dollars; conduct educational programs on environmental-agricultural issues; advise departmental staff on agricultural-environmental issues including minor use crops, pesticide resistance, food safety, biosolids, and contamination remediation.

September 1986 to July 1990:
Soil Scientist, Department of Natural Resources, Waste Management Division. Responsibilities: Evaluate and monitor land application of biological wastes to agricultural and forest land. Assisted in procurement of interagency policy; drafted rule language amending environmental law. Appointed Contract Administrator for 3-yr cooperative study with the University of Notre Dame to evaluate environmental effects of surface applied ice and dust control agents. Assigned to Great Lakes States Governors' Task Force to evaluate effect of wastewater applications to agricultural land. Gave numerous presentations on environmental topics and participated in public hearings concerning environmental issues.

June 1978 to January 1990:
Partner with parents in a 500 acre, 100 cow, crop and dairy farm. Currently own and manage a 40 acre cash crop and beef cattle operation.

RECENT RELEVANT PUBLICATIONS
Gao, J. X. Hao, K.D. Thelen, and G.P. Robertson. 2009. Agronomic Management System and Precipitation Effects on Soybean Oil and Fatty Acid Profiles. Crop Science. Accepted Oct. 2008.

Fronning, B., K.D. Thelen, and D.H. Min. 2008. Use of Manure, Compost, and Cover Crops to Supplant Crop Residue Carbon in Corn Stover Removed Cropping Systems. Agron. J. 100:1703-1710.

Baributsa, D., E. F. Foster, K. Thelen, A. Kravchenko, D. Mutch and M. Ngouajio. 2008. Corn and Cover Crop Response to Corn Density in an Interseeding System. Agron J 100:981-987.

Schulz, T.J., and K.D. Thelen. 2008. Soybean seed inoculant and fungicidal seed treatment effects on soybean. Crop Sci (accepted 4/08).

Thelen, K.D. and D. Penner. 2007. Yield environment affects glyphosate-resistant hybrid response to glyphosate. Crop Sci. 47:2098-2107.

Kravchenko, A., and K. D. Thelen. 2007. Effect of winter wheat crop residue on no-till corn growth and development. Agron J. Accepted 9/06.

Huang, X., S. Senthilkumar, A. Kravchenko, K.D. Thelen and J. Qi. 2007. Total carbon mapping in glacial till soils using near infrared spectroscopy, landsat imagery and topographical information. Geoderma accepted 12/06

Grandy, A. S., G. P. Robertson, and K. D. Thelen. 2006. Do productivity and environmental tradeoffs justify periodically cultivating no-till cropping systems? Agron J 98:1377-1383.

Thelen, K. D. 2006. Interaction between row spacing and yield: Why it works. Online. Crop Management doi:10.1094/CM-2006-02XX-01-RV.

Jewett, M.R., and K.D. Thelen. 2006. Winter cereal cover crop removal strategy affects spring soil nitrate levels. J. Sustainable Ag 29(3): 55-68.

SYNERGISTIC ACTIVITIES
Thrust leader for the Great Lakes BioEnergy Research Center, a US DOE BioEnergy Center grant awarded to Michigan State University and the University of Wisconsin. Lead research efforts evaluating novel production systems for bioenergy feedstock production.

Received Chrysler Corp. 2007 Environmental Achievement Award for research project evaluating the use of regulatory brownfields for growing bioenergy crops.

Current chair of the American Society of Agronomy, C-3 Crop Ecology Physiology & Management Div.

Scott Rempe

Vermeer Corporation **Business telephone: 641-621-7373**
1410 Vermeer Rd E, Pella, IA 50219 **Alternate telephone: 641-780-3721**
E-mail: srempe@vermeer.com

Summary

Engineer with over 20 years of experience in design and development of mobile agricultural equipment including tractors and balers. Expertise in harvest technology for agricultural crops, and practical considerations related to the logisitics of harvest, transport, storage and processing of a variety of bio-materials.

Education

Iowa State University Ames, IA
BSME, BSAgE, 1984

Experience

Current Employer **Pella, Iowa**

Sr Project Engineer 2007 – present

Research and development of technology for Bio-Energy markets.
Specific accomplishments include:

- Development of a corn cob harvesting machine.
- Research and development of biomass size reduction technology.

Product Safety Engineer 2006 – 2007

Evaluation of issues related to product safety of Vermeer machines.
Specific accomplishments include:

- Participated on a development team to develop operator presence technology for Stump Grinders.
- Participated on a development team to develop a winch interlock system for Brush Chippers.

Patent Agent / Intellectual Property Manager 1999 – 2006

Variety of tasks for management of Vermeer Corporation's Patent portfolio..
Specific accomplishments include:

- Development of several patent applications, including co-inventor of 7 patents .
- Patent prosecution.
- Involvement in prior art research for patent litigation.

Project Engineer/Engineering Manager 1990 – 1999

Design and development of round baler technology and machines.
Specific accomplishments include:

- Managed development of and market introduction of several models of Vermeer Round Balers.
- Managed engineering department responsible for Vermeer's Agricultural products

Employer 1 **City, State**

Ford Motor Company (Tractor Division) / Ford New Holland 1984 - 1990

Design and Development of Ford Tractors
Specific accomplishments include:

- Design and launch support for transmissions and final drives for a new family of tractors.

Synergistic Activities

- Development of a new machine for harvesting a biomass feedstock – corn cobs.
- Market introduction of the corn cob harvest machine, developing distribution options for a new agricultural machine.
- Research and development of equipment for size reduction of bio-materials.
- Current knowledge related to a variety of aspects of energy crops and processing options currently being developed.

Jay Van Roekel

1210 Vermeer Rd East **641-621-7116**
Pella, IA 50219 **641-780-0440**
jvanroekel@vermeer.com

Summary

Segment Manager with over 21 years experience in the farm implement business. Strengths include OEM to dealer /customer relations, sales application, product training, product evaluation and product launch plans.

Education

Truman State University Kirksville, Missouri
BSE Industrial Arts Education, 1984

Experience

Vermeer Manufacturing **Pella, IA**

Segment Manager 2001 – present

Responsible for long-term product plans, competitive product evaluation, product launch plans and training tools. Additionally managed all international relationships with key whole good alliance partners, evaluated future alliances and managed Vermeer Forage Segment international sales.
Specific accomplishments include:

- Managed gross margin at or above company averages in a mature market
- Defined the project then launched the most successful (sales and market share) round baler project in recent history at Vermeer – M series.
- Established new product sales training manuals including features/benefits, product walk around guide, competitive comparison and demonstration guide

Territory Manager 1987 - 2001

Responsible for factory to dealer relationship including: communication, training, ordering, inventory management, basic service and warranty. Recruited new dealers, promoted equipment sales with dealers at farm shows, demonstrations and customer events.
Specific accomplishments include:

- Successfully implemented new one-level dealer network.
- Improved and maintained over 25% market share in 5x4 baler market in my area
- Built a dealer network that worked together vs. as competitors

Synergistic Activities

- Industry Activities
  - FEMA – regular attendee of the bi-annual Farm Equipment Manufacturer Association. Member of the International Relations Committee.
  - AEM – regular attendee of the Agricultural Marketing meetings
- Managing the market introduction of a new machine for harvesting corn cobs, the Vermeer CX-770.
  - Development of distribution options for a new agricultural machine.
  - Development of tools to inform agricultural producers of the new business opportunity.
- Current on the status of development of energy crops

Peilin Yang, Ph.D

1710 Vermeer Road East **(641) 621-8068**
PO Box 170, Pella, IA 50219 **(530) 219-9786**
pyang@vermeer.com

Summary

Agricultural & Biological Systems Engineer with 20+ years experience in research, technology development, and design. Expertise in environmental machine design, biological conversion and analysis, biofuel and bioenergy technologies, and waste/wastewater treatment and air quality control

Education

Ph.D., Biological Systems Engineering, June 2006. Department of Biological and Agricultural Engineering, University of California, Davis

Ph.D. candidate, Agricultural and Biosystems Engineering, **Civil and Environmental Engineering**, June 2001. (1.5 years, transferred), Department of Agricultural and Biosystems Engineering, Department of Civil, Construction and Environmental Engineering, Iowa State University

M.S., Agricultural and Biosystems Engineering, December 1999. Department of Agricultural and Biosystems Engineering, Iowa State University

Diploma, International Course on Pig Husbandry and Animal Feed Milling Technology, May 1991. IPC Livestock Barneveld College, the Netherlands

B.S., Agricultural Engineering, July 1983. Department of Agricultural Engineering, Inner Mongolia University of Technology, China

Experience

Vermeer Corporation **Pella, IA**

Design Engineer 2007 – present

Participated in design and research projects for biomass size reduction & field collection

Mississippi State University **Starkville, MS**

Postdoctoral research Associate 2006 - 2007

Designed and executed experiments for a number of research projects in the areas of biofuel and bioenergy production. *Specific accomplishments include:*

- Glucose Production for Ethanol Fermentation from Enzymatic Hydrolysis of Cellulose at a Reduced Enzyme Loading Rate and Shortened Retention Time
- Creating New Utilization Opportunities for Crude Glycerol: Anaerobic Conversion of Crude Glycerol to Green Energy
- Evaluation of Synthesis Gas Storage under Different Pressures and Temperatures

University of California **Davis, CA**

Research Assistant 2001 - 2006

Designed and completed several research projects including:

- Biohydrogen and Methane Production from Food Wastes by Anaerobic Fermentation Using Mixed Microbial Cultures
- Production of Wood Residues from Sawmills in California
- Treatment of Flushed Dairy Manure by Solid-Liquid Separation and Aeration
- Computer Modeling of Ammonia Emission from Dairy Feedlots
- Swine Wastewater Treatment with Anaerobic and Aerobic Processing, Filtration, and Membrane Separation Technologies

Iowa State University **Ames, IA**

Research Assistant 1997 - 2001

Designed and completed several research projects including:

- Volume and Nutrients of Manure Production from High-Rise Laying Hen Houses
- Evaluation of Anaerobic Digester for Destruction of Pathogens and Mineralization of Nutrients
- Soil Infiltration and Wetland Treatment of Open Beef Feedlot Runoff

Unisono B.V. Beijing Office **Beijing, China**

Sales Manager & Group Head 1993 - 1997

Sales and services of turn-key projects and machines: animal feedmill, cattle slaughter house, meat coldstorage, poultry houses with facilities, hatchery, meat and dairy processing equipment, waste/wastewater treatment equipment

Chinese Academy of Agricultural & Mechanization Sciences **Beijing, China**

Project Engineer 1983-1993

As a technical director leading a factory to develop & manufacture pipeline dairy milking machines based on Germen technologies. Designed and installed a number of animal feed mill projects, dairy milking systems, swine and poultry feeding and drinking equipment, and dairy waste management facilities

Design & Research Engineer

Completed several research projects for the products of a series of vacuum pump, vacuum regulator, bucket milking and self-cleaning elevator, which were used for dairy farms and animal feedmills

Selected Publications

P.Yang, E. Columbus, J Wooten, W. Batchelor, P. Buchireddy, X. Ye, and L. Wei. 2009. Evaluation of Syngas Storage Under Different Pressures and Temperatures, *Applied Engineering in Agriculture, 25(1):121-128.*

P. Yang and B.M. Jenkins. 2008. Wood Residues from Sawmills in California, *Biomass and Bioenergy, 32:101-108.*

P. Yang, R. Zhang, J. McGarvey, and J. Benemann. 2007. Biohydrogen Production from Cheese Processing Wastewater by Anaerobic Fermentation Using Mixed Microbial Communities, *International Journal of Hydrogen Energy, 32(18):4761-4771.*

Zhang, R., **P. Yang**, Z. Pan, T.D. Wolf. J.H. Turnbull. 2004. Treatment of Swine Wastewater with Anaerobic and Aerobic Processing, Filtration, and Reverse Osmosis: a Laboratory Study, *Trans. of ASAE* 47(1):243-250

Yang, P., J. Lorimor, and H. Xin. 2000. Nitrogen Loss from Layer Manure in Commercial High-Rise Laying Hen Facilities, *Trans. of ASABE* 43(6): 1771-1780 (**Honorable Mention Award from ASABE**)

Yang, P. and F. Gao. 1989. 9ZT2000 Vacuum Regulator for Milking Machine. *Agriculture and Food Machinery*, 1989:3

Yang, P., F. Gao, and M. Xiao. 1988. ZDT10 Self-Cleaning Elevator for Premix and Concentration Production in Animal Feedmill*, Agriculture and Food Machinery*, 1988:2

Xiao, M., **P. Yang**, and F. Gao. 1985. Series of 9NZ Vacuum Pump Systems, *Agriculture and Food Machinery*, 1985:4

Xiao, M. and **P. Yang**. 1984. 9NZ90 Vacuum Pump, *Rural Sciences*, 1984:12

Professional Activities

Member of the American Society of Agricultural and Biological Engineers

Member of Alpha Epsilon – The Honor Society of Agricultural, Food, and Biological Engineering

Panelist of the 2009 & 2008 EPA Peer Review Panel for Grants: People, Prosperity and the Planet (P3) National Student Design Competition

Panelist of the 2007 EPA SBIR Peer Review Panel for Animal Waste and Waste to Energy

Panelist of the 2006 EPA SBIR Peer Review Panel for Agriculture and Rural Community Improvement and Management of Animal Feeding Operations

Applicant Name: MBI International

Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Total Cumulative Budget

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Budget Period 1	81.087			$2,407,879	$601,761	$3,009,640
2. Budget Period 2	81.087			$15,036,410	$3,759,251	$18,795,661
3. Budget Period 3	81.087			$1,345,949	$336,547	$1,682,496
4.						$0
5. Totals		$0	$0	$18,790,237	$4,697,559	$23,487,796

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 1	(2) Budget Period 2	(3) Budget Period 3	(4)	
a. Personnel	$591,927	$1,548,561	$278,941		$2,419,429
b. Fringe Benefits	$239,849	$627,477	$113,027		$980,353
c. Travel	$15,800	$56,600	$22,800		$95,200
d. Equipment	$162,624	$5,319,550	$0		$5,482,174
e. Supplies	$19,800	$30,565	$15,578		$65,943
f. Contractual	$870,562	$8,312,365	$720,199		$9,903,126
g. Construction	$0	$0	$0		$0
h. Other	$2,200	$32,400	$2,224		$36,824
i. Total Direct Charges (sum of 6a-6h)	$1,902,762	$15,927,518	$1,152,769	$0	$18,983,049
j. Indirect Charges	$1,106,878	$2,868,143	$529,727		$4,504,748
k. Totals (sum of 6i-6j)	$3,009,640	$18,795,661	$1,682,496	$0	$23,487,796
7. Program Income					$0

Section C - Non-Federal Resources					
(a) Grant Program		(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 1		$520,416		$81,345	$601,761
9. Budget Period 2		$3,552,573		$206,678	$3,759,251
10. Budget Period 3		$269,751		$66,796	$336,547
11.					$0
12. Total (sum of lines 8 - 11)		$4,342,740	$0	$354,819	$4,697,559
Section D - Forecasted Cash Needs					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter /Budget Period 2
13. Federal	$4,246,364	802626	802626	802626	$1,838,485
14. Non-Federal	$1,170,855	$200,587	$200,587	$200,587	$569,094
15. Total (sum of lines 13 and 14)	$5,417,219	$1,003,213	$1,003,213	$1,003,213	$2,407,579
Section E - Budget Estimates of Federal Funds Needed for Balance of the Project					
		Future Funding Periods			
(a) Grant Program		(b) First	(c) Second	(d) Third	(e) Fourth
16.		$2,407,879	$15,036,410	$1,345,949	
17.					
18.					
19.					
20. Total (sum of lines 16-19)		$2,407,879	$15,036,410	$1,345,949	$0
Section F - Other Budget Information					
21. Direct Charges		22. Indirect Charges Provisional rate = 129.98% Base (Salary, Fringe, Materials): $3,465,725 x 129.98% = $4,504,748			
23. Remarks					

Applicant Name: MBI International

Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Budget Period 1

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Budget Period 1	81.087			$2,407,879	$601,761	$3,009,640
2.						$0
3.						$0
4.						$0
5. Totals		$0	$0	$2,407,879	$601,761	$3,009,640

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 1	(2)	(3)	(4)	
a. Personnel	$591,927				$591,927
b. Fringe Benefits	$239,849				$239,849
c. Travel	$15,800				$15,800
d. Equipment	$162,624				$162,624
e. Supplies	$19,800				$19,800
f. Contractual	$870,562				$870,562
g. Construction	$0				$0
h. Other	$2,200				$2,200
i. Total Direct Charges (sum of 6a-6h)	$1,902,762			$0	$1,902,762
j. Indirect Charges	$1,106,878				$1,106,878
k. **Totals** (sum of 6i-6j)	$3,009,640	$0	$0	$0	$3,009,640
7. Program Income					$0

Section C - Non-Federal Resources					
(a) Grant Program		(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 1		$520,416		$81,345	$601,761
9.					$0
10.					$0
11.					$0
12. Total (sum of lines 8 - 11)		$520,416	$0	$81,345	$601,761
Section D - Forecasted Cash Needs					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter /Budget Period 2
13. Federal	$4,246,364	802,626	802,626	802,626	1,838,485
14. Non-Federal	$1,170,855	200,587	200,587	200,587	569,094
15. Total (sum of lines 13 and 14)	$5,417,219	$1,003,213	$1,003,213	$1,003,213	$2,407,579
Section E - Budget Estimates of Federal Funds Needed for Balance of the Project					
		Future Funding Periods			
(a) Grant Program		(b) First	(c) Second	(d) Third	(e) Fourth
16.		$15,036,410	$1,345,949		
17.					
18.					
19.					
20. Total (sum of lines 16-19)		$15,036,410	$1,345,949	$0	$0
Section F - Other Budget Information					
21. Direct Charges		22. Indirect Charges Provisional rate = 129.98% Base (Salary, Fringe, Materials): $851,576 x 129.98% = $1,106,878			
23. Remarks					

Applicant Name: MBI International

Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Budget Period 2

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Budget Period 2	81.087			$15,036,410	$3,759,251	$18,795,661
2.						$0
3.						$0
4.						$0
5. Totals		$0	$0	$15,036,410	$3,759,251	$18,795,661

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 2	(2)	(3)	(4)	
a. Personnel	$1,548,561				$1,548,561
b. Fringe Benefits	$627,477				$627,477
c. Travel	$56,600				$56,600
d. Equipment	$5,319,550				$5,319,550
e. Supplies	$30,565				$30,565
f. Contractual	$8,312,365				$8,312,365
g. Construction	$0				$0
h. Other	$32,400				$32,400
i. Total Direct Charges (sum of 6a-6h)	$15,927,518			$0	$15,927,518
j. Indirect Charges	$2,868,143				$2,868,143
k. Totals (sum of 6i-6j)	$18,795,661	$0	$0	$0	$18,795,661
7. Program Income					$0

Section C - Non-Federal Resources					
(a) Grant Program		(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 2		$3,552,573		$206,678	$3,759,251
9.					$0
10.					$0
11.					$0
12. Total (sum of lines 8 - 11)		$3,552,573	$0	$206,678	$3,759,251
Section D - Forecasted Cash Needs					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter /Budget Period 2
13. Federal	$4,246,364	802,626	802,626	802,626	1,838,485
14. Non-Federal	$1,170,855	200,587	200,587	200,587	569,094
15. Total (sum of lines 13 and 14)	$5,417,219	$1,003,213	$1,003,213	$1,003,213	$2,407,579
Section E - Budget Estimates of Federal Funds Needed for Balance of the Project					
		Future Funding Periods			
(a) Grant Program		(b) First	(c) Second	(d) Third	(e) Fourth
16.		$1,345,949			
17.					
18.					
19.					
20. Total (sum of lines 16-19)		$1,345,949	$0	$0	$0
Section F - Other Budget Information					
21. Direct Charges		22. Indirect Charges Provisional rate = 129.98% Base (Salary, Fringe, Materials): $2,206,603 x 129.98% = $2,868,143			
23. Remarks					

Applicant Name: MBI International

Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Budget Period 3

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Budget Period 3	81.087			$1,345,949	$336,547	$1,682,496
2.						$0
3.						$0
4.						$0
5. Totals		$0	$0	$1,345,949	$336,547	$1,682,496

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 3	(2)	(3)	(4)	
a. Personnel	$278,941				$278,941
b. Fringe Benefits	$113,027				$113,027
c. Travel	$22,800				$22,800
d. Equipment	$0				$0
e. Supplies	$15,578				$15,578
f. Contractual	$720,199				$720,199
g. Construction	$0				$0
h. Other	$2,224				$2,224
i. Total Direct Charges (sum of 6a-6h)	$1,152,769			$0	$1,152,769
j. Indirect Charges	$529,727				$529,727
k. **Totals** (sum of 6i-6j)	$1,682,496	$0	$0	$0	$1,682,496
7. Program Income					$0

Section C - Non-Federal Resources					
(a) Grant Program		(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 3		$269,751		$66,796	$336,547
9.					$0
10.					$0
11.					$0
12. Total (sum of lines 8 - 11)		$269,751	$0	$66,796	$336,547
Section D - Forecasted Cash Needs					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter /Budget Period 2
13. Federal	$4,246,364	802,626	802,626	802,626	1,838,485
14. Non-Federal	$1,170,855	200,587	200,587	200,587	569,094
15. Total (sum of lines 13 and 14)	$5,417,219	$1,003,213	$1,003,213	$1,003,213	$2,407,579
Section E - Budget Estimates of Federal Funds Needed for Balance of the Project					
		Future Funding Periods			
(a) Grant Program		(b) First	(c) Second	(d) Third	(e) Fourth
16.		$0			
17.					
18.					
19.					
20. Total (sum of lines 16-19)		$0	$0	$0	$0
Section F - Other Budget Information					
21. Direct Charges		22. Indirect Charges Provisional rate = 129.98% Base (Salary, Fringe, Materials): $407,546 x 129.98% = $529,727			
23. Remarks					

Instructions and Summary

Award Number: DE-FOA-0000096
Award Recipient: Michigan Biotechnology Institute

Date of Submission: 25-Jun-09
Form submitted by: International
(May be award recipient or sub-recipient)

Please read the instructions on each page before starting.
If you have any questions, please ask your DOE contact. It will save you time!

On this form, provide detailed support for the estimated project costs identified on the SF-424A form (Budget).

- **The dollar amounts on this page must match the amounts on the associated SF-424A.**
- **The award recipient and each sub-recipient with estimated costs of $100,000 or more must complete this form and a SF-424A form.**
- **The total budget presented on this form and on the SF424A must include both Federal (DOE), and Non-Federal (cost share) portions, thereby reflecting TOTAL PROJECT COSTS proposed.**
- **For costs in each Object Class Category on the SF-424A, complete the corresponding worksheet on this form (tab at the bottom of the page).**
- **All costs incurred by the preparer's sub-recipients, vendors, contractors, consultants and Federal Research and Development Centers (FFRDCs), should be entered only in section f. Contractual. All other sections are for the costs of the preparer only.**

SUMMARY OF BUDGET CATEGORY COSTS PROPOSED

(Note: The values in this summary table are from entries made in each budget category sheet.)

CATEGORY	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Total Costs	Project Costs %	Comments (Add comments as needed)
a. Personnel	$591,927	$1,548,561	$278,941	**$2,419,429**	**10.3%**	
b. Fringe Benefits	$239,849	$627,477	$113,027	**$980,353**	**4.2%**	
c. Travel	$15,800	$56,600	$22,800	**$95,200**	**0.4%**	
d. Equipment	$162,624	$5,319,550	$0	**$5,482,174**	**23.3%**	Vendor quotes attached as "VendorQuotesBudgetJust" in Optional Attachments.
e. Supplies	$19,800	$30,565	$15,578	**$65,943**	**0.3%**	
f. Contractual						
Sub-recipient	*$124,076*	*$334,862*	*$107,175*	*$566,113*	*2.4%*	
FFRDC	*$467,536*	*$2,414,503*	*$591,274*	*$3,473,313*	*14.8%*	
Vendor	*$278,950*	*$5,563,000*	*$21,750*	*$5,863,700*	*25.0%*	
Total Contractual	$870,562	$8,312,365	$720,199	**$9,903,126**	**42.2%**	
g. Construction	$0	$0	$0	**$0**	**0.0%**	
h. Other Direct Costs	$2,200	$32,400	$2,224	**$36,824**	**0.2%**	
i. Indirect Charges	$1,106,878	$2,868,143	$529,727	**$4,504,748**	**19.2%**	
Total Project Costs	**$3,009,640**	**$18,795,661**	**$1,682,496**	**$23,487,796**	**100.0%**	

Additional Explanations/Comments (as necessary)

Affirmation of compliance with Davis-Bacon Act attached as "MBI-DavisBaconAffirm" in Optional Other Attachments.

a. Personnel

PLEASE READ!!!

List costs solely for employees of the entity completing this form (award recipient or sub-recipient). All other personnel costs (of subrecipients or other contractual efforts of the entity preparing this) must be included under f., Contractual. This includes all consultants and FFRDCs.

Identify positions to be supported. Key personnel should be identified by title. All other personnel should be identified either by title or a group category. State the amounts of time (e.g., hours or % of time) to be expended, the composite base pay rate, total direct personnel compensation and identify the rate basis (e.g., actual salary, labor distribution report, technical estimate, state civil service rates, etc.).

Add rows as needed. Formulas/calculations will need to be entered by the preparer of this form. Please enter formulas as shown in the example.

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
1. Generation 2A Receiver Design		10000		$423,000	600		$24,000	800		$31,000	11400	$478,000	Actual Salary
EXAMPLE	Sr. Engineer	2000	$85.00	$170,000	200	$50.00	$10,000	200	$50.00	$10,000	2400	$190,000	Actual Salary
ONLY!!!	Electrical engineers	6200	$35.00	$217,000	400	$35.00	$14,000	600	$35.00	$21,000	7200	$252,000	Actual Salary
	Technician	1800	$20.00	$36,000	0	$0.00	$0	0	$0.00	$0	1800	$36,000	Actual Salary
Pilot Scale Integrated AFEX Biorefinery													
1.1 Design													
1.1.2 Select Engineering, Procurment & Cons		666		$38,979									
	Director - Operations	160	$57.34	$9,174							160	$9,174	Actual Salary
	Business Development												
	Senior Scientist (a)	120	$80.00	$9,600							120	$9,600	Actual Salary
	VP - Engineering	119	$76.36	$9,087							119	$9,087	Actual Salary
	Senior Scientist (b)	80	$43.35	$3,468							80	$3,468	Actual Salary
	Process Development Engineer	27	$65.74	$1,775							27	$1,775	Actual Salary
	Process Development Engineer	160	$36.72	$5,875							160	$5,875	Actual Salary
1.1.3 Preliminary Process Design		974		$59,767									
	Director - Operations	96	$57.34	$5,505							96	$5,505	Actual Salary
	Senior Scientist (a)	120	$80.00	$9,600							120	$9,600	Actual Salary
	VP - Engineering	235	$76.67	$18,017							235	$18,017	Actual Salary
	Senior Scientist (b)	168	$43.35	$7,283							168	$7,283	Actual Salary
	Process Development Engineer	211	$66.70	$14,074							211	$14,074	Actual Salary
	Process Development Engineer	144	$36.72	$5,288							144	$5,288	Actual Salary
1.1.5 NREL Design Review of Pilot Scale AFE		125		$7,168									
	Director - Operations	125	$57.34	$7,168							125	$7,168	Actual Salary
1.2 AFEX Pilot Plant New Construction-Bids & Permits													
1.2.1 Complete Final Site Plan		412		$24,958									
	Director - Operations	85	$57.56	$4,893							85	$4,893	Actual Salary
	Senior Scientist (a)	68	$79.78	$5,425							68	$5,425	Actual Salary
	VP - Engineering	80	$76.51	$6,121							80	$6,121	Actual Salary
	Senior Scientist (b)	36	$43.17	$1,554							36	$1,554	Actual Salary
	Process Development Engineer	107	$52.79	$5,649							107	$5,649	Actual Salary
	Director - Facilities	36	$36.56	$1,316							36	$1,316	Actual Salary
1.2.2 Complete Final Construction Plan		232		$14,289									
	Director - Operations	75	$58.43	$4,382							75	$4,382	Actual Salary
	VP - Engineering	63	$77.97	$4,912							63	$4,912	Actual Salary
	Process Development Engineer	47	$68.60	$3,224							47	$3,224	Actual Salary
	Process Development Engineer	47	$37.68	$1,771							47	$1,771	Actual Salary
1.2.3 Bid Preparation and Responses		120		$8,034									
	Director - Operations	64	$59.06	$3,780							64	$3,780	Actual Salary
	VP - Engineering	40	$78.80	$3,152							40	$3,152	Actual Salary
	Process Development Engineer	16	$68.88	$1,102							16	$1,102	Actual Salary
1.2.4 Building Permit Applications		200		$14,174									
	Director - Operations	40	$59.05	$2,362							40	$2,362	Actual Salary
	VP - Engineering	80	$78.80	$6,304							80	$6,304	Actual Salary
	Process Development Engineer	80	$68.85	$5,508							80	$5,508	Actual Salary
1.2.6 Complete NEPA Determination		480		$23,452									
	Director - Operations	240	$58.64	$14,073							240	$14,073	Actual Salary
	Research Associate (b)	120	$24.00	$2,880							120	$2,880	Actual Salary
	Director - Facilities	120	$54.16	$6,499							120	$6,499	Actual Salary
1.3 R&D													
1.3.2.1 Measure Heat & Mass Transfer Coeffi		2838		$73,409									
	Director - Operations	32	$57.34	$1,835							32	$1,835	Actual Salary
	Divisonal Administrator-Grants &	149	$24.17	$3,602							149	$3,602	Actual Salary
	Research Associate (c)	480	$20.47	$9,826							480	$9,826	Actual Salary
	Research Associate (e)	480	$32.19	$15,451							480	$15,451	Actual Salary
	Senior Scientist (b)	80	$43.35	$3,468							80	$3,468	Actual Salary
	Research Associate (a)	332	$22.68	$7,530							332	$7,530	Actual Salary
	Research Associate (b)	629	$23.47	$14,764							629	$14,764	Actual Salary
	Pilot Plant Specialist	32	$29.09	$931							32	$931	Actual Salary
	Research Associate (d)	400	$19.44	$7,777							400	$7,777	Actual Salary
	Process Development Engineer	224	$36.72	$8,225							224	$8,225	Actual Salary
1.3.2.2 Aspen Model of NH3 Recovery Proces		484		$17,288									
	Research Associate (e)	260	$32.35	$8,412							260	$8,412	Actual Salary
	Senior Scientist (b)	92	$43.36	$3,989							92	$3,989	Actual Salary
	Process Development Engineer	132	$37.02	$4,887							132	$4,887	Actual Salary
1.3.2.3 Design or Specify NH3 Recovery Equ		640		$24,679									
	VP - Engineering	32	$78.81	$2,522							32	$2,522	Actual Salary
	Research Associate (e)	320	$33.15	$10,608							320	$10,608	Actual Salary
	Senior Scientist (b)	96	$44.65	$4,286							96	$4,286	Actual Salary
	Process Development Engineer	192	$37.83	$7,263							192	$7,263	Actual Salary
1.3.3 AFEX Integration with Saccharification		4714		$117,812									

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
	Research Associate (c)	1030	$20.63	$21,249							1030	$21,249	Actual Salary
	Senior Scientist (b)	443	$43.70	$19,358							443	$19,358	Actual Salary
	Research Associate (a)	973	$22.86	$22,246							973	$22,246	Actual Salary
	Research Associate (b)	550	$23.67	$13,019							550	$13,019	Actual Salary
	Senior Maintenance Mechanic	64	$30.20	$1,933							64	$1,933	Actual Salary
	Pilot Plant Specialist	392	$29.09	$11,403							392	$11,403	Actual Salary
	Research Associate (d)	1004	$19.57	$19,644							1004	$19,644	Actual Salary
	Electrician	64	$31.19	$1,996							64	$1,996	Actual Salary
	Purchasing Administrator	32	$29.44	$942							32	$942	Actual Salary
	Process Development Engineer	162	$37.17	$6,022							162	$6,022	Actual Salary
1.4 Complete Risk Mitigation Plan		**540**		**$30,403**									
	Director - Operations	67	$57.06	$3,823							67	$3,823	Actual Salary
	Senior Scientist (a)	100	$80.00	$8,000							100	$8,000	Actual Salary
	VP - Engineering	80	$76.51	$6,121							80	$6,121	Actual Salary
	Senior Scientist (b)	133	$43.46	$5,780							133	$5,780	Actual Salary
	Process Development Engineer	27	$66.04	$1,783							27	$1,783	Actual Salary
	Process Development Engineer	133	$36.81	$4,896							133	$4,896	Actual Salary
1.5 Business & Commercializtion Plan Updat		**530**		**$43,684**									
	Director - Operations	120	$57.89	$6,947							120	$6,947	Actual Salary
	President/CEO	80	$120.99	$9,679							80	$9,679	Actual Salary
	Business Development	80	$88.23	$7,058							80	$7,058	Actual Salary
	Senior Scientist (a)	250	$80.00	$20,000							250	$20,000	Actual Salary
1.6	**Project Management Support**	**1560**		**$27,692**									
	Admin Project Support	1560	$17.75	$27,692							1560	$27,692	Actual Salary
1.7 Reporting													
1.7.1 Reporting Q1		**320**		**$15,160**									
	Director - Operations	40	$57.35	$2,294							40	$2,294	Actual Salary
	Divisonal Administrator-Grants &	80	$24.21	$1,937							80	$1,937	Actual Salary
	Senior Scientist (a)	40	$80.00	$3,200							40	$3,200	Actual Salary
	Senior Scientist (b)	40	$43.35	$1,734							40	$1,734	Actual Salary
	VP - Finance & Administration	40	$46.30	$1,852							40	$1,852	Actual Salary
	Process Development Engineer	40	$66.85	$2,674							40	$2,674	Actual Salary
	Process Development Engineer	40	$36.73	$1,469							40	$1,469	Actual Salary
1.7.2 Reporting Q2		**156**		**$7,195**									
	Director - Operations	40	$57.35	$2,294							40	$2,294	Actual Salary
	Divisonal Administrator-Grants &	24	$24.21	$581							24	$581	Actual Salary
	Senior Scientist (a)	4	$80.00	$320							4	$320	Actual Salary
	Senior Scientist (b)	40	$43.35	$1,734							40	$1,734	Actual Salary
	VP - Finance & Administration	40	$46.30	$1,852							40	$1,852	Actual Salary
	Process Development Engineer	4	$66.75	$267							4	$267	Actual Salary
	Process Development Engineer	4	$36.75	$147							4	$147	Actual Salary
1.7.3 Reporting PH1 Final		**152**		**$7,203**									
	Director - Operations	24	$59.04	$1,417							24	$1,417	Actual Salary
	Divisonal Administrator-Grants &	24	$24.92	$598							24	$598	Actual Salary
	Senior Scientist (a)	8	$80.00	$640							8	$640	Actual Salary
	Senior Scientist (b)	40	$44.65	$1,786							40	$1,786	Actual Salary
	VP - Finance & Administration	40	$47.70	$1,908							40	$1,908	Actual Salary
	Process Development Engineer	8	$68.88	$551							8	$551	Actual Salary
	Process Development Engineer	8	$37.88	$303							8	$303	Actual Salary
1.8 Meetings/Communications													
1.8.1 Meeting - Budget Period 1 Kickoff		**86**		**$5,835**									
	Director - Operations	15	$57.07	$856							15	$856	Actual Salary
	President/CEO	7	$127.86	$895							7	$895	Actual Salary
	Business Development	15	$86.13	$1,292							15	$1,292	Actual Salary
	Divisonal Administrator-Grants &	7	$25.86	$181							7	$181	Actual Salary
	Senior Scientist (a)	7	$85.29	$597							7	$597	Actual Salary
	VP - Engineering	7	$81.57	$571							7	$571	Actual Salary
	Senior Scientist (b)	7	$46.29	$324							7	$324	Actual Salary
	VP - Finance & Administration	7	$49.43	$346							7	$346	Actual Salary
	Process Development Engineer	7	$71.29	$499							7	$499	Actual Salary
	Process Development Engineer	7	$39.14	$274							7	$274	Actual Salary
1.8.2 Meeting - Budget Period 1 Stage Gate R		**162**		**$10,276**									
	Director - Operations	16	$57.31	$917							16	$917	Actual Salary
	President/CEO	16	$119.81	$1,917							16	$1,917	Actual Salary
	Business Development	16	$86.56	$1,385							16	$1,385	Actual Salary
	Divisonal Administrator-Grants &	9	$23.22	$209							9	$209	Actual Salary
	Senior Scientist (a)	16	$80.00	$1,280							16	$1,280	Actual Salary
	VP - Engineering	16	$76.50	$1,224							16	$1,224	Actual Salary
	Senior Scientist (b)	16	$43.38	$694							16	$694	Actual Salary
	Pilot Plant Specialist	9	$27.89	$251							9	$251	Actual Salary
	VP - Finance & Administration	16	$46.31	$741							16	$741	Actual Salary
	Process Development Engineer	16	$66.88	$1,070							16	$1,070	Actual Salary
	Process Development Engineer	16	$36.75	$588							16	$588	Actual Salary
1.8.3 Meeting - Budget Period 1 Final Review		**155**		**$10,235**									
	Director - Operations	16	$59.06	$945							16	$945	Actual Salary
	President/CEO	16	$123.44	$1,975							16	$1,975	Actual Salary
	Business Development	16	$91.81	$1,469							16	$1,469	Actual Salary
	Divisonal Administrator-Grants &	9	$23.89	$215							9	$215	Actual Salary
	Senior Scientist (a)	16	$80.00	$1,280							16	$1,280	Actual Salary
	VP - Engineering	16	$78.81	$1,261							16	$1,261	Actual Salary
	Senior Scientist (b)	16	$44.63	$714							16	$714	Actual Salary
	Pilot Plant Specialist	9	$28.67	$258							9	$258	Actual Salary
	VP - Finance & Administration	9	$45.67	$411							9	$411	Actual Salary
	Process Development Engineer	16	$68.88	$1,102							16	$1,102	Actual Salary
	Process Development Engineer	16	$37.81	$605							16	$605	Actual Salary
1.8.4 Meeting - Budget Period 1 Stage Gate R		**155**		**$10,235**									
	Director - Operations	16	$59.06	$945							16	$945	Actual Salary

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
	President/CEO	16	$123.44	$1,975							16	$1,975	Actual Salary
	Business Development	16	$91.81	$1,469							16	$1,469	Actual Salary
	Divisonal Administrator-Grants &	9	$23.89	$215							9	$215	Actual Salary
	Senior Scientist (a)	16	$80.00	$1,280							16	$1,280	Actual Salary
	VP - Engineering	16	$78.81	$1,261							16	$1,261	Actual Salary
	Senior Scientist (b)	16	$44.63	$714							16	$714	Actual Salary
	Pilot Plant Specialist	9	$28.67	$258							9	$258	Actual Salary
	VP - Finance & Administration	9	$45.67	$411							9	$411	Actual Salary
	Process Development Engineer	16	$68.88	$1,102							16	$1,102	Actual Salary
	Process Development Engineer	16	$37.81	$605							16	$605	Actual Salary
2. Construction, Shakedown and Operation													
2.1.2 Management Review					80		$5,500						
	Director - Operations				16	$59.06	$945				16	$945	Actual Salary
	President/CEO				16	$123.43	$1,975				16	$1,975	Actual Salary
	VP - Engineering				16	$78.80	$1,261				16	$1,261	Actual Salary
	Senior Scientist (b)				16	$44.65	$714				16	$714	Actual Salary
	Process Development Engineer				16	$37.83	$605				16	$605	Actual Salary
2.1.3 Contract Negotiation					48		$4,181						
	Director - Operations				16	$59.06	$945				16	$945	Actual Salary
	President/CEO				16	$123.43	$1,975				16	$1,975	Actual Salary
	VP - Engineering				16	$78.80	$1,261				16	$1,261	Actual Salary
2.2 Procurement - Major Equipment													
2.2.1 Finalize Spec & Order Feeder/Reactor/Discharge Equipment					48		$2,291						
	Director - Operations				16	$59.06	$945				16	$945	Actual Salary
	VP - Engineering				6	$74.55	$447				6	$447	Actual Salary
	Senior Scientist (b)				6	$42.24	$253				6	$253	Actual Salary
	Purchasing Administator				14	$30.75	$430				14	$430	Actual Salary
	Process Development Engineer				6	$35.79	$215				6	$215	Actual Salary
2.2.2 Finalize Spec & Order NH3 Recovery Equipment					104		$4,739						
	Director - Operations				16	$59.06	$945				16	$945	Actual Salary
	VP - Engineering				16	$78.80	$1,261				16	$1,261	Actual Salary
	Senior Scientist (b)				16	$44.65	$714				16	$714	Actual Salary
	Purchasing Administator				40	$30.33	$1,213				40	$1,213	Actual Salary
	Process Development Engineer				16	$37.83	$605				16	$605	Actual Salary
2.2.3 Finalize Spec & Order Densification Equipment					77		$3,553						
	Director - Operations				16	$59.06	$945				16	$945	Actual Salary
	VP - Engineering				11	$78.80	$867				11	$867	Actual Salary
	Senior Scientist (b)				11	$44.65	$491				11	$491	Actual Salary
	Purchasing Administator				28	$30.33	$834				28	$834	Actual Salary
	Process Development Engineer				11	$37.83	$416				11	$416	Actual Salary
2.3 Engineering													
2.3.1 Finalize P&ID's					80		$4,340						
	Senior Scientist (a)				16	$80.00	$1,280				16	$1,280	Actual Salary
	VP - Engineering				16	$78.80	$1,261				16	$1,261	Actual Salary
	Senior Scientist (b)				16	$44.65	$714				16	$714	Actual Salary
	Pilot Plant Specialist				16	$29.96	$479				16	$479	Actual Salary
	Process Development Engineer				16	$37.83	$605				16	$605	Actual Salary
2.3.2 Finalize Equipment Layouts					60		$3,255						
	Senior Scientist (a)				12	$80.00	$960				12	$960	Actual Salary
	VP - Engineering				12	$78.80	$946				12	$946	Actual Salary
	Senior Scientist (b)				12	$44.65	$536				12	$536	Actual Salary
	Pilot Plant Specialist				12	$29.96	$360				12	$360	Actual Salary
	Process Development Engineer				12	$37.83	$454				12	$454	Actual Salary
2.3.8 Final Engineering Review					48		$3,071						
	Director - Operations				8	$59.06	$472				8	$472	Actual Salary
	Senior Scientist (a)				8	$80.00	$640				8	$640	Actual Salary
	VP - Engineering				16	$81.17	$1,299				16	$1,299	Actual Salary
	Senior Scientist (b)				8	$44.65	$357				8	$357	Actual Salary
	Process Development Engineer				8	$37.83	$303				8	$303	Actual Salary
2.5 AFEX Pilot Plant Equiment Intallation													
2.5.1 Install Feeder/Reactor/Discharge Equipment					96		$4,152						
	VP - Engineering				16	$81.17	$1,299				16	$1,299	Actual Salary
	Senior Maintenance Mechanic				16	$31.22	$500				16	$500	Actual Salary
	Pilot Plant Specialist				16	$30.05	$481				16	$481	Actual Salary
	Electrician				32	$31.18	$998				32	$998	Actual Salary
	Director - Facilities				16	$54.71	$875				16	$875	Actual Salary
2.5.2 Install NH3 Recovery Equipment					96		$4,152						
	VP - Engineering				16	$81.17	$1,299				16	$1,299	Actual Salary
	Senior Maintenance Mechanic				16	$31.22	$500				16	$500	Actual Salary
	Pilot Plant Specialist				16	$30.05	$481				16	$481	Actual Salary
	Electrician				32	$31.18	$998				32	$998	Actual Salary
	Director - Facilities				16	$54.71	$875				16	$875	Actual Salary
2.5.3 Install Densification Equipment					96		$2,679						
	Senior Maintenance Mechanic				8	$31.12	$249				8	$249	Actual Salary
	Pilot Plant Specialist				8	$29.96	$240				8	$240	Actual Salary
	Electrician				40	$31.09	$1,244				40	$1,244	Actual Salary
	Maintenance Mechanic				40	$23.68	$947				40	$947	Actual Salary
2.5.4 Piping & Electrical					288		$9,314						
	Senior Maintenance Mechanic				64	$31.68	$2,028				64	$2,028	Actual Salary
	Pilot Plant Specialist				64	$30.46	$1,949				64	$1,949	Actual Salary
	Electrician				64	$31.61	$2,023				64	$2,023	Actual Salary
	Director - Facilities				32	$55.45	$1,774				32	$1,774	Actual Salary
	Maintenance Mechanic				64	$24.07	$1,541				64	$1,541	Actual Salary

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
2.5.5 Install Instrumentation					**112**		**$3,595**						
	Pilot Plant Specialist				32	$30.05	$962				32	$962	Actual Salary
	Electrician				32	$31.18	$998				32	$998	Actual Salary
	Director - Facilities				16	$54.71	$875				16	$875	Actual Salary
	Maintenance Mechanic				32	$23.75	$760				32	$760	Actual Salary
2.5.7 Commissioning and Startup					**194**		**$6,997**						
	Director - Operations				8	$60.84	$487				8	$487	Actual Salary
	Research Associate (c)				33	$21.92	$723				33	$723	Actual Salary
	VP - Engineering				8	$81.17	$649				8	$649	Actual Salary
	Senior Scientist (b)				40	$45.99	$1,840				40	$1,840	Actual Salary
	Pilot Plant Specialist				16	$30.86	$494				16	$494	Actual Salary
	Research Associate (d)				33	$20.82	$687				33	$687	Actual Salary
	Electrician				16	$32.03	$512				16	$512	Actual Salary
	Process Development Engineer				40	$40.13	$1,605				40	$1,605	Actual Salary
2.5.8 Write & Issue SOPS for all New Equipment					**272**		**$10,397**						
	Director - Operations				16	$60.84	$973				16	$973	Actual Salary
	Research Associate (c)				40	$21.70	$868				40	$868	Actual Salary
	VP - Engineering				32	$81.17	$2,597				32	$2,597	Actual Salary
	Senior Scientist (b)				40	$45.99	$1,840				40	$1,840	Actual Salary
	Research Associate (b)				48	$24.90	$1,195				48	$1,195	Actual Salary
	Pilot Plant Specialist				16	$30.86	$494				16	$494	Actual Salary
	Research Associate (d)				40	$20.61	$824				40	$824	Actual Salary
	Process Development Engineer				40	$40.13	$1,605				40	$1,605	Actual Salary
2.5.9 Operator safety Training for all New Equipment					**42**		**$1,955**						
	Director - Operations				8	$60.84	$487				8	$487	Actual Salary
	Research Associate (c)				4	$21.67	$96				4	$96	Actual Salary
	VP - Engineering				8	$81.17	$649				8	$649	Actual Salary
	Senior Scientist (b)				4	$45.92	$204				4	$204	Actual Salary
	Research Associate (b)				4	$24.86	$111				4	$111	Actual Salary
	Pilot Plant Specialist				4	$30.81	$137				4	$137	Actual Salary
	Research Associate (d)				4	$20.58	$92				4	$92	Actual Salary
	Process Development Engineer				4	$44.58	$178				4	$178	Actual Salary
2.6 NREL PDU/IBRF Saccharification & Fermentation Equipment Modification					**672**		**$36,067**						
	Director - Operations				448	$59.61	$26,704				448	$26,704	Actual Salary
	Senior Scientist (b)				112	$45.06	$5,047				112	$5,047	Actual Salary
	Process Development Engineer				112	$38.54	$4,316				112	$4,316	Actual Salary
2.7 Equiment Shakeddown trials													
2.7.1 Produce Stover for Shakedown Trials													
2.7.1.4 Stover Receiving & Storage at MBI					**384**		**$8,537**						
	Research Associate (c)				128	$21.67	$2,774				128	$2,774	Actual Salary
	Research Associate (a)				64	$24.03	$1,538				64	$1,538	Actual Salary
	Research Associate (b)				64	$24.86	$1,591				64	$1,591	Actual Salary
	Research Associate (d)				128	$20.58	$2,634				128	$2,634	Actual Salary
2.7.2 AFEX Plant Equipment Shakedown Trials													
2.7.2.1 Stover Throughput Trial, Atmos P					**442**		**$16,911**						
	Director - Operations				18	$60.84	$1,095				18	$1,095	Actual Salary
	Research Associate (c)				64	$21.70	$1,381				64	$1,381	Actual Salary
	VP - Engineering				24	$81.17	$1,948				24	$1,948	Actual Salary
	Senior Scientist (b)				120	$45.99	$5,519				120	$5,519	Actual Salary
	Pilot Plant Specialist				51	$30.85	$1,571				51	$1,571	Actual Salary
	Research Associate (d)				64	$20.61	$1,311				64	$1,311	Actual Salary
	Process Development Engineer				102	$40.13	$4,086				102	$4,086	Actual Salary
2.7.2.2 Reactor P Test (air or N2)					**184**		**$6,561**						
	Director - Operations				6	$60.84	$365				6	$365	Actual Salary
	Research Associate (c)				40	$21.70	$868				40	$868	Actual Salary
	VP - Engineering				10	$81.17	$812				10	$812	Actual Salary
	Senior Scientist (b)				40	$45.99	$1,840				40	$1,840	Actual Salary
	Pilot Plant Specialist				8	$30.86	$247				8	$247	Actual Salary
	Research Associate (d)				40	$20.61	$824				40	$824	Actual Salary
	Process Development Engineer				40	$40.13	$1,605				40	$1,605	Actual Salary
2.7.2.3 Stover Throughput Trial, Design P (air or N2)					**360**		**$11,509**						
	Research Associate (c)				80	$21.70	$1,736				80	$1,736	Actual Salary
	Senior Scientist (b)				80	$45.99	$3,679				80	$3,679	Actual Salary
	Pilot Plant Specialist				40	$30.86	$1,234				40	$1,234	Actual Salary
	Research Associate (d)				80	$20.61	$1,649				80	$1,649	Actual Salary
	Process Development Engineer				80	$40.13	$3,210				80	$3,210	Actual Salary
2.7.2.4 Stover Mixing Trial					**438**		**$14,007**						
	Director - Operations				18	$60.84	$1,095				18	$1,095	Actual Salary
	Research Associate (c)				120	$21.70	$2,604				120	$2,604	Actual Salary
	VP - Engineering				18	$81.17	$1,461				18	$1,461	Actual Salary
	Senior Scientist (b)				60	$45.99	$2,759				60	$2,759	Actual Salary
	Pilot Plant Specialist				51	$30.85	$1,571				51	$1,571	Actual Salary
	Research Associate (d)				120	$20.61	$2,473				120	$2,473	Actual Salary
	Process Development Engineer				51	$40.12	$2,043				51	$2,043	Actual Salary
2.7.2.5 Stover NH3 Trials with NH3 Recovery					**835**		**$28,038**						
	Director - Operations				46	$60.84	$2,799				46	$2,799	Actual Salary
	Research Associate (c)				105	$21.68	$2,266				105	$2,266	Actual Salary
	VP - Engineering				40	$81.17	$3,247				40	$3,247	Actual Salary
	Senior Scientist (b)				100	$45.99	$4,599				100	$4,599	Actual Salary
	Research Associate (a)				120	$24.07	$2,888				120	$2,888	Actual Salary
	Research Associate (b)				120	$24.90	$2,988				120	$2,988	Actual Salary
	Pilot Plant Specialist				100	$30.86	$3,086				100	$3,086	Actual Salary
	Research Associate (d)				104	$20.61	$2,152				104	$2,152	Actual Salary
	Process Development Engineer				100	$40.13	$4,013				100	$4,013	Actual Salary
2.7.2.6 AFEX Independent Engineer Performance Test					**223**		**$8,932**						

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
	Director - Operations				8	$60.84	$487				8	$487	Actual Salary
	Research Associate (c)				40	$21.70	$868				40	$868	Actual Salary
	VP - Engineering				40	$81.17	$3,247				40	$3,247	Actual Salary
	Senior Scientist (b)				15	$45.93	$667				15	$667	Actual Salary
	Pilot Plant Specialist				40	$30.86	$1,234				40	$1,234	Actual Salary
	Research Associate (d)				40	$20.61	$824				40	$824	Actual Salary
	Process Development Engineer				40	$40.13	$1,605				40	$1,605	Actual Salary
2.7.3 Densification Equipment Shakedown													
2.7.3.1 Densification Equipment Shakedown					304		$10,809						
	Director - Operations				40	$60.84	$2,434				40	$2,434	Actual Salary
	Research Associate (c)				80	$21.70	$1,736				80	$1,736	Actual Salary
	VP - Engineering				16	$81.17	$1,299				16	$1,299	Actual Salary
	Senior Scientist (b)				40	$45.99	$1,840				40	$1,840	Actual Salary
	Pilot Plant Specialist				8	$30.86	$247				8	$247	Actual Salary
	Research Associate (d)				80	$20.61	$1,649				80	$1,649	Actual Salary
	Process Development Engineer				40	$40.13	$1,605				40	$1,605	Actual Salary
2.7.3.2 Densification Equipment Independent Engineer Test					160		$6,255						
	Director - Operations				20	$60.84	$1,217				20	$1,217	Actual Salary
	Research Associate (c)				40	$21.70	$868				40	$868	Actual Salary
	VP - Engineering				20	$81.17	$1,623				20	$1,623	Actual Salary
	Senior Scientist (b)				20	$45.99	$920				20	$920	Actual Salary
	Research Associate (d)				40	$20.61	$824				40	$824	Actual Salary
	Process Development Engineer				20	$40.13	$803				20	$803	Actual Salary
2.7.3.4 Monitor Hydrolysis & Fermentation Yields of Densified AFEX Treated S					992		$29,795						
	Director - Operations				160	$60.84	$9,734				160	$9,734	Actual Salary
	Research Associate (c)				160	$21.70	$3,472				160	$3,472	Actual Salary
	Senior Scientist (b)				32	$45.99	$1,472				32	$1,472	Actual Salary
	Research Associate (a)				160	$24.07	$3,851				160	$3,851	Actual Salary
	Research Associate (b)				320	$24.90	$7,968				320	$7,968	Actual Salary
	Research Associate (d)				160	$20.61	$3,298				160	$3,298	Actual Salary
2.7.4 NREL Saccharification & Fermentation Equipment Shakedown Trials													
2.7.4.1 NREL Saccharification & Fermentation Equipment Shakedown					792		$46,214						
	Director - Operations				288	$61.31	$17,656				288	$17,656	Actual Salary
	VP - Engineering				144	$82.47	$11,875				144	$11,875	Actual Salary
	Senior Scientist (b)				360	$46.34	$16,683				360	$16,683	Actual Salary
2.8 Capstone Runs													
2.8.1 AFEX Equipment Capstone Runs					14257		$583,955						
	Director - Operations				1536	$61.49	$94,452				1536	$94,452	Actual Salary
	President/CEO				49	$128.50	$6,255				49	$6,255	Actual Salary
	Research Associate (c)				1536	$21.93	$33,689				1536	$33,689	Actual Salary
	VP - Engineering				1920	$82.55	$158,490				1920	$158,490	Actual Salary
	Senior Scientist (b)				1920	$46.48	$89,250				1920	$89,250	Actual Salary
	Research Associate (a)				1920	$24.59	$47,219				1920	$47,219	Actual Salary
	Research Associate (b)				1920	$25.17	$48,324				1920	$48,324	Actual Salary
	Pilot Plant Specialist				384	$31.19	$11,977				384	$11,977	Actual Salary
	Research Associate (d)				1536	$20.83	$31,998				1536	$31,998	Actual Salary
	Process Development Engineer				1536	$40.56	$62,300				1536	$62,300	Actual Salary
2.8.4 Densification Capstone Runs					1824		$62,313						
	Director - Operations				192	$60.84	$11,681				192	$11,681	Actual Salary
	Research Associate (c)				480	$21.70	$10,416				480	$10,416	Actual Salary
	VP - Engineering				96	$81.90	$7,862				96	$7,862	Actual Salary
	Senior Scientist (b)				192	$45.99	$8,830				192	$8,830	Actual Salary
	Pilot Plant Specialist				192	$30.86	$5,925				192	$5,925	Actual Salary
	Research Associate (d)				480	$20.61	$9,893				480	$9,893	Actual Salary
	Process Development Engineer				192	$40.13	$7,705				192	$7,705	Actual Salary
2.12.1 NREL Saccharification & Fermentation Demonstration Runs					621		$38,150						
	Director - Operations				388	$62.66	$24,312				388	$24,312	Actual Salary
	VP - Engineering				78	$83.60	$6,487				78	$6,487	Actual Salary
	Senior Scientist (b)				155	$47.37	$7,352				155	$7,352	Actual Salary
2.9	Afex Shake down & Capstone				1989		$51,405						
	Senior Scientist (b)				193	$44.65	$8,622				193	$8,622	Actual Salary
	Research Associate (c)				464	$21.92	$10,171				464	$10,171	Actual Salary
	Research Associate (e)				402	$24.07	$9,666				402	$9,666	Actual Salary
	Research Associate (a)				462	$24.40	$11,278				462	$11,278	Actual Salary
	Research Associate (b)				469	$24.90	$11,668				469	$11,668	Actual Salary
2.1	Project mangemnt Support				5120		$93,385						
	Admin Project Support				5120	$18.24	$93,385				5120	$93,385	Actual Salary
2.11 Update Techno-economic Model Using Data From Demonstration Runs					208		$10,723						
	Director - Operations				16	$62.66	$1,003				16	$1,003	Actual Salary
	Senior Scientist (a)				32	$80.00	$2,560				32	$2,560	Actual Salary
	VP - Engineering				16	$83.60	$1,338				16	$1,338	Actual Salary
	Research Associate (e)				80	$37.31	$2,985				80	$2,985	Actual Salary
	Senior Scientist (b)				32	$47.37	$1,516				32	$1,516	Actual Salary
	Process Development Engineer				32	$41.33	$1,323				32	$1,323	Actual Salary
2.12 Business & Commercialization Plan Update					2400		$209,657						
	President/CEO				160	$128.38	$20,541				160	$20,541	Actual Salary
	Business Development				640	$95.49	$61,115				640	$61,115	Actual Salary
	Senior Scientist (a)				1600	$80.00	$128,000				1600	$128,000	Actual Salary
2.15 Reporting													
2.15.1 Reporting - Budget Period 2 Q1					280		$14,128						
	Director - Operations				80	$59.05	$4,724				80	$4,724	Actual Salary
	Divisonal Administrator-Grants &				40	$24.93	$997				40	$997	Actual Salary
	Senior Scientist (a)				40	$80.00	$3,200				40	$3,200	Actual Salary
	Senior Scientist (b)				40	$44.65	$1,786				40	$1,786	Actual Salary

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
	VP - Finance & Administration				40	$47.69	$1,908				40	$1,908	Actual Salary
	Process Development Engineer				40	$37.83	$1,513				40	$1,513	Actual Salary
2.15.2 Reporting - Budget Period 2 Q2					280		$14,129						
	Director - Operations				80	$59.06	$4,725				80	$4,725	Actual Salary
	Divisonal Administrator-Grants &				40	$24.93	$997				40	$997	Actual Salary
	Senior Scientist (a)				40	$80.00	$3,200				40	$3,200	Actual Salary
	Senior Scientist (b)				40	$44.65	$1,786				40	$1,786	Actual Salary
	VP - Finance & Administration				40	$47.69	$1,908				40	$1,908	Actual Salary
	Process Development Engineer				40	$37.83	$1,513				40	$1,513	Actual Salary
2.15.3 Reporting - Budget Period 2 Q3					280		$14,166						
	Director - Operations				80	$59.24	$4,739				80	$4,739	Actual Salary
	Divisonal Administrator-Grants &				40	$25.01	$1,000				40	$1,000	Actual Salary
	Senior Scientist (a)				40	$80.00	$3,200				40	$3,200	Actual Salary
	Senior Scientist (b)				40	$44.78	$1,791				40	$1,791	Actual Salary
	VP - Finance & Administration				40	$47.83	$1,913				40	$1,913	Actual Salary
	Process Development Engineer				40	$38.06	$1,522				40	$1,522	Actual Salary
2.15.4 Reporting - Budget Period 2 Q4					280		$14,504						
	Director - Operations				80	$60.84	$4,867				80	$4,867	Actual Salary
	Divisonal Administrator-Grants &				40	$25.68	$1,027				40	$1,027	Actual Salary
	Senior Scientist (a)				40	$80.00	$3,200				40	$3,200	Actual Salary
	Senior Scientist (b)				40	$45.99	$1,840				40	$1,840	Actual Salary
	VP - Finance & Administration				40	$49.12	$1,965				40	$1,965	Actual Salary
	Process Development Engineer				40	$40.13	$1,605				40	$1,605	Actual Salary
2.15.5 Reporting - Budget Period 2 Q5					240		$12,070						
	Director - Operations				40	$60.84	$2,434				40	$2,434	Actual Salary
	Divisonal Administrator-Grants &				40	$25.68	$1,027				40	$1,027	Actual Salary
	Senior Scientist (a)				40	$80.00	$3,200				40	$3,200	Actual Salary
	Senior Scientist (b)				40	$45.99	$1,840				40	$1,840	Actual Salary
	VP - Finance & Administration				40	$49.12	$1,965				40	$1,965	Actual Salary
	Process Development Engineer				40	$40.13	$1,605				40	$1,605	Actual Salary
2.15.6 Reporting - Budget Period 2 Q6					240		$12,070						
	Director - Operations				40	$60.84	$2,434				40	$2,434	Actual Salary
	Divisonal Administrator-Grants &				40	$25.68	$1,027				40	$1,027	Actual Salary
	Senior Scientist (a)				40	$80.00	$3,200				40	$3,200	Actual Salary
	Senior Scientist (b)				40	$45.99	$1,840				40	$1,840	Actual Salary
	VP - Finance & Administration				40	$49.12	$1,965				40	$1,965	Actual Salary
	Process Development Engineer				40	$40.13	$1,605				40	$1,605	Actual Salary
2.15.7 Reporting - Budget Period 2 Q7					280		$14,504						
	Director - Operations				80	$60.84	$4,867				80	$4,867	Actual Salary
	Divisonal Administrator-Grants &				40	$25.68	$1,027				40	$1,027	Actual Salary
	Senior Scientist (a)				40	$80.00	$3,200				40	$3,200	Actual Salary
	Senior Scientist (b)				40	$45.99	$1,840				40	$1,840	Actual Salary
	VP - Finance & Administration				40	$49.12	$1,965				40	$1,965	Actual Salary
	Process Development Engineer				40	$40.13	$1,605				40	$1,605	Actual Salary
2.15.8 Reporting - Budget Period 2 Q8					280		$14,842						
	Director - Operations				80	$62.66	$5,013				80	$5,013	Actual Salary
	Divisonal Administrator-Grants &				40	$26.45	$1,058				40	$1,058	Actual Salary
	Senior Scientist (a)				40	$80.00	$3,200				40	$3,200	Actual Salary
	Senior Scientist (b)				40	$47.37	$1,895				40	$1,895	Actual Salary
	VP - Finance & Administration				40	$50.59	$2,024				40	$2,024	Actual Salary
	Process Development Engineer				40	$41.33	$1,653				40	$1,653	Actual Salary
2.15.9 Reporting - Final Budget Period 2 Report					576		$31,780						
	Director - Operations				160	$62.66	$10,026				160	$10,026	Actual Salary
	President/CEO				16	$130.95	$2,095				16	$2,095	Actual Salary
	Divisonal Administrator-Grants &				80	$26.45	$2,116				80	$2,116	Actual Salary
	Senior Scientist (a)				80	$80.00	$6,400				80	$6,400	Actual Salary
	Senior Scientist (b)				80	$47.37	$3,790				80	$3,790	Actual Salary
	VP - Finance & Administration				80	$50.59	$4,047				80	$4,047	Actual Salary
	Process Development Engineer				80	$41.33	$3,306				80	$3,306	Actual Salary
2.16 Meetings/Communications													
2.16.1 Meeting - Budget Period 2 Kickoff					120		$4,445						
	Director - Operations				16	$59.12	$946				16	$946	Actual Salary
	President/CEO				8	$123.43	$987				8	$987	Actual Salary
	Divisonal Administrator-Grants &				8	$24.93	$199				8	$199	Actual Salary
	Construction Contractor				8	$0.00	$0				8	$0	
	Senior Scientist (a)				8	$80.00	$640				8	$640	Actual Salary
	VP - Engineering				8	$78.80	$630				8	$630	Actual Salary
	Engineering Contractor				8	$0.00	$0				8	$0	
	Senior Scientist (b)				8	$44.65	$357				8	$357	Actual Salary
	VP - Finance & Administration				8	$47.69	$382				8	$382	Actual Salary
	MSU				8	$0.00	$0				8	$0	
	NREL				16	$0.00	$0				16	$0	
	Process Development Engineer				8	$0.00	$0				8	$0	
	Process Development Engineer				8	$37.83	$303				8	$303	Actual Salary
2.16.2 Meeting - Quarterly Review					85		$5,734						
	Director - Operations				13	$61.69	$802				13	$802	Actual Salary
	President/CEO				8	$127.13	$1,017				8	$1,017	Actual Salary
	Divisonal Administrator-Grants &				8	$25.68	$205				8	$205	Actual Salary
	Senior Scientist (a)				8	$80.00	$640				8	$640	Actual Salary
	VP - Engineering				16	$81.17	$1,299				16	$1,299	Actual Salary
	Senior Scientist (b)				16	$45.99	$736				16	$736	Actual Salary
	VP - Finance & Administration				8	$49.12	$393				8	$393	Actual Salary
	Process Development Engineer				8	$80.26	$642				8	$642	Actual Salary
2.16.3 Meeting - Quarterly Review					85		$5,734						
	Director - Operations				13	$61.69	$802				13	$802	Actual Salary

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
	President/CEO				8	$127.13	$1,017				8	$1,017	Actual Salary
	Divisonal Administrator-Grants &				8	$25.68	$205				8	$205	Actual Salary
	Senior Scientist (a)				8	$80.00	$640				8	$640	Actual Salary
	VP - Engineering				16	$81.17	$1,299				16	$1,299	Actual Salary
	Senior Scientist (b)				16	$45.99	$736				16	$736	Actual Salary
	VP - Finance & Administration				8	$49.12	$393				8	$393	Actual Salary
	Process Development Engineer				8	$80.26	$642				8	$642	Actual Salary
2.16.4 Meeting - Quarterly Review					80		$5,419						
	Director - Operations				8	$60.84	$487				8	$487	Actual Salary
	President/CEO				8	$127.13	$1,017				8	$1,017	Actual Salary
	Divisonal Administrator-Grants &				8	$25.68	$205				8	$205	Actual Salary
	Senior Scientist (a)				8	$80.00	$640				8	$640	Actual Salary
	VP - Engineering				16	$81.17	$1,299				16	$1,299	Actual Salary
	Senior Scientist (b)				16	$45.99	$736				16	$736	Actual Salary
	VP - Finance & Administration				8	$49.12	$393				8	$393	Actual Salary
	Process Development Engineer				8	$80.26	$642				8	$642	Actual Salary
2.16.5 Meeting - Quarterly Review					80		$5,419						
	Director - Operations				8	$60.84	$487				8	$487	Actual Salary
	President/CEO				8	$127.13	$1,017				8	$1,017	Actual Salary
	Divisonal Administrator-Grants &				8	$25.68	$205				8	$205	Actual Salary
	Senior Scientist (a)				8	$80.00	$640				8	$640	Actual Salary
	VP - Engineering				16	$81.17	$1,299				16	$1,299	Actual Salary
	Senior Scientist (b)				16	$45.99	$736				16	$736	Actual Salary
	VP - Finance & Administration				8	$49.12	$393				8	$393	Actual Salary
	Process Development Engineer				8	$80.26	$642				8	$642	Actual Salary
2.16.6 Meeting - Budget Period 2 Stage Gate Review					65		$4,888						
	Director - Operations				9	$62.81	$565				9	$565	Actual Salary
	President/CEO				8	$130.95	$1,048				8	$1,048	Actual Salary
	Divisonal Administrator-Grants &				8	$26.45	$212				8	$212	Actual Salary
	Senior Scientist (a)				8	$160.00	$1,280				8	$1,280	Actual Salary
	VP - Engineering				8	$83.60	$669				8	$669	Actual Salary
	Senior Scientist (b)				8	$47.37	$379				8	$379	Actual Salary
	VP - Finance & Administration				8	$50.59	$405				8	$405	Actual Salary
	Process Development Engineer				8	$41.33	$331				8	$331	Actual Salary
2.16.7 Meeting - Quarterly Review					80		$5,419						
	Director - Operations				8	$60.84	$487				8	$487	Actual Salary
	President/CEO				8	$127.13	$1,017				8	$1,017	Actual Salary
	Divisonal Administrator-Grants &				8	$25.68	$205				8	$205	Actual Salary
	Senior Scientist (a)				8	$80.00	$640				8	$640	Actual Salary
	VP - Engineering				16	$81.17	$1,299				16	$1,299	Actual Salary
	Senior Scientist (b)				16	$45.99	$736				16	$736	Actual Salary
	VP - Finance & Administration				8	$49.12	$393				8	$393	Actual Salary
	Process Development Engineer				8	$80.26	$642				8	$642	Actual Salary
2.16.8 Meeting - Quarterly Review					80		$5,562						
	Director - Operations				8	$62.66	$501				8	$501	Actual Salary
	President/CEO				8	$130.95	$1,048				8	$1,048	Actual Salary
	Divisonal Administrator-Grants &				8	$26.45	$212				8	$212	Actual Salary
	Senior Scientist (a)				8	$80.00	$640				8	$640	Actual Salary
	VP - Engineering				16	$83.60	$1,338				16	$1,338	Actual Salary
	Senior Scientist (b)				16	$47.37	$758				16	$758	Actual Salary
	VP - Finance & Administration				8	$50.59	$405				8	$405	Actual Salary
	Process Development Engineer				8	$82.66	$661				8	$661	Actual Salary
2.16.9 Meeting - Independent Engineer Review at MBI					88		$4,888						
	Director - Operations				16	$60.84	$973				16	$973	Actual Salary
	Divisonal Administrator-Grants &				8	$25.68	$205				8	$205	Actual Salary
	Senior Scientist (a)				8	$80.00	$640				8	$640	Actual Salary
	VP - Engineering				16	$81.17	$1,299				16	$1,299	Actual Salary
	Senior Scientist (b)				16	$45.99	$736				16	$736	Actual Salary
	VP - Finance & Administration				8	$49.12	$393				8	$393	Actual Salary
	Process Development Engineer				16	$40.13	$642				16	$642	Actual Salary
2.16.10 Meeting - Independent Engineer Review at NREL					48		$3,098						
	Director - Operations				16	$62.66	$1,003				16	$1,003	Actual Salary
	VP - Engineering				16	$83.60	$1,338				16	$1,338	Actual Salary
	Senior Scientist (b)				16	$47.37	$758				16	$758	Actual Salary
2.16.11 Meeting - Budget Period 2 Stage gate Review					128		$8,367						
	Director - Operations				16	$62.66	$1,003				16	$1,003	Actual Salary
	President/CEO				16	$130.95	$2,095				16	$2,095	Actual Salary
	Divisonal Administrator-Grants &				16	$26.45	$423				16	$423	Actual Salary
	Senior Scientist (a)				16	$80.00	$1,280				16	$1,280	Actual Salary
	VP - Engineering				16	$83.60	$1,338				16	$1,338	Actual Salary
	Senior Scientist (b)				16	$47.37	$758				16	$758	Actual Salary
	VP - Finance & Administration				16	$50.59	$809				16	$809	Actual Salary
	Process Development Engineer				16	$41.33	$661				16	$661	Actual Salary
3. Operation													
3.1.1 MBI Pilot Scale AFEX & Densification Extended Operations								4090		$128,923			
	Director - Operations							100	$64.54	$6,454	100	$6,454	Actual Salary
	Research Associate (c)							600	$23.03	$13,818	600	$13,818	Actual Salary
	Senior Scientist (b)							520	$50.26	$26,135	520	$26,135	Actual Salary
	Research Associate (a)							640	$25.53	$16,339	640	$16,339	Actual Salary
	Research Associate (b)							640	$26.41	$16,902	640	$16,902	Actual Salary
	Pilot Plant Specialist							600	$32.74	$19,644	600	$19,644	Actual Salary
	Research Associate (d)							600	$22.52	$13,512	600	$13,512	Actual Salary
	Process Development Engineer							390	$41.33	$16,119	390	$16,119	Actual Salary

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
3.1.2 NREL PDU/IBRF Pilot Scale Saccharification & Fermentation Extended Operations								200		$12,908			
	Director - Operations							200	$64.54	$12,908	200	$12,908	Actual Salary
2. Modeling & BCP Development													
3.2.1 Economic Modeling								1177		$48,182			
	Director - Operations							57	$64.54	$3,679	57	$3,679	Actual Salary
	Research Associate (e)							800	$37.31	$29,848	800	$29,848	Actual Salary
	Senior Scientist (b)							160	$50.26	$8,042	160	$8,042	Actual Salary
	Process Development Engineer							160	$41.33	$6,613	160	$6,613	Actual Salary
3.2.3 Business & Commercialization Plan Development								548		$41,101			
	Director - Operations							68	$64.54	$4,389	68	$4,389	Actual Salary
	President/CEO							80	$134.88	$10,790	80	$10,790	Actual Salary
	Business Development							80	$100.33	$8,026	80	$8,026	Actual Salary
	Senior Scientist (a)							80	$80.00	$6,400	80	$6,400	Actual Salary
	Senior Scientist (b)							80	$50.26	$4,021	80	$4,021	Actual Salary
	VP - Finance & Administration							80	$52.11	$4,169	80	$4,169	Actual Salary
	Process Development Engineer							80	$41.33	$3,306	80	$3,306	Actual Salary
3.3 Project Managemnt Support								1081		$20,308			
	Admin Project Support							1081	$18.79	$20,308	1081	$20,308	Actual Salary
3.4 Reporting													
3.4.1 Reporting - Budget Period 3 Q1								38		$2,211			
	Director - Operations							14	$64.56	$904	14	$904	Actual Salary
	Divisonal Administrator-Grants &							4	$28.00	$112	4	$112	Actual Salary
	Senior Scientist (a)							4	$80.00	$320	4	$320	Actual Salary
	Senior Scientist (b)							4	$50.25	$201	4	$201	Actual Salary
	VP - Finance & Administration							4	$52.00	$208	4	$208	Actual Salary
	Process Development Engineer							4	$75.25	$301	4	$301	Actual Salary
	Process Development Engineer							4	$41.25	$165	4	$165	Actual Salary
3.4.2 Reporting - Budget Period 3 Final Report								176		$10,395			
	Director - Operations							80	$64.54	$5,163	80	$5,163	Actual Salary
	Divisonal Administrator-Grants &							16	$28.06	$449	16	$449	Actual Salary
	Senior Scientist (a)							16	$80.00	$1,280	16	$1,280	Actual Salary
	Senior Scientist (b)							16	$50.25	$804	16	$804	Actual Salary
	VP - Finance & Administration							16	$52.13	$834	16	$834	Actual Salary
	Process Development Engineer							16	$75.25	$1,204	16	$1,204	Actual Salary
	Process Development Engineer							16	$41.31	$661	16	$661	Actual Salary
3.5 Meetings/Communications													
3.5.1 Meeting - Budget Period 3 Kickoff								78		$5,288			
	Director - Operations							14	$64.56	$904	14	$904	Actual Salary
	President/CEO							8	$134.88	$1,079	8	$1,079	Actual Salary
	Divisonal Administrator-Grants &							8	$28.00	$224	8	$224	Actual Salary
	Senior Scientist (a)							8	$80.00	$640	8	$640	Actual Salary
	VP - Engineering							8	$86.13	$689	8	$689	Actual Salary
	Senior Scientist (b)							8	$50.25	$402	8	$402	Actual Salary
	VP - Finance & Administration							8	$52.13	$417	8	$417	Actual Salary
	Process Development Engineer							8	$75.25	$602	8	$602	Actual Salary
	Process Development Engineer							8	$41.38	$331	8	$331	Actual Salary
3.5.2 Meeting - Budget Period 3 Stage Gate Review								70		$4,209			
	Director - Operations							14	$64.56	$904	14	$904	Actual Salary
	Divisonal Administrator-Grants &							8	$28.00	$224	8	$224	Actual Salary
	Senior Scientist (a)							8	$80.00	$640	8	$640	Actual Salary
	VP - Engineering							8	$86.13	$689	8	$689	Actual Salary
	Senior Scientist (b)							8	$50.25	$402	8	$402	Actual Salary
	VP - Finance & Administration							8	$52.13	$417	8	$417	Actual Salary
	Process Development Engineer							8	$75.25	$602	8	$602	Actual Salary
	Process Development Engineer							8	$41.38	$331	8	$331	Actual Salary
3.5.3 Meeting - Budget Period 3 Stage Gate Review								80		$5,417			
	Director - Operations							16	$64.56	$1,033	16	$1,033	Actual Salary
	President/CEO							8	$134.88	$1,079	8	$1,079	Actual Salary
	Divisonal Administrator-Grants & Contracts							8	$28.00	$224	8	$224	Actual Salary
	Construction Contractor							0	$0.00	$0	0	$0	
	Senior Scientist (a)							8	$80.00	$640	8	$640	Actual Salary
	VP - Engineering							8	$86.13	$689	8	$689	Actual Salary
	Enigneering Contractor							0	$0.00	$0	0	$0	
	Senior Scientist (b)							8	$50.25	$402	8	$402	Actual Salary
	VP - Finance & Administration							8	$52.13	$417	8	$417	Actual Salary
	MSU							0	$0.00	$0	0	$0	
	NREL							0	$0.00	$0	0	$0	
	Process Development Engineer							8	$75.25	$602	8	$602	Actual Salary
	Process Development Engineer							8	$41.38	$331	8	$331	Actual Salary
	Total Personnel Costs	15701		591927	37620		1548561	7538		278941	60859	$2,419,429	

Additional Explanations/Comments (as necessary)

b. Fringe Benefits

	Budget Period 1	Budget Period 2	Budget Period 3	Total
Rate applied:	40.52%	40.52%	40.52%	
Total fringe requested:	$239,849	$627,477	$113,027	**$980,353**

A federally approved fringe benefit rate agreement, or a proposed rate supported and agreed upon by DOE for estimating purposes is required if reimbursement for fringe benefits is requested. Please check (X) one of the options below and provide the requested information, if it has not already been provided to the Contracting Officer, OR if it has changed since it was. Calculate the fringe rate and enter the total amount in Section B, line 6.b. ("Fringe Benefits") of form SF-424A.

_____ **A fringe benefit rate has been negotiated with, or approved by, a federal government agency. A copy of the latest rate agreement is included with this application, and will be provided electronically to the Contracting Officer for this project.**
(When this option is selected, a presentation of the budget that demonstrates the appliction of the approved rate, to arrive at the proposed fringes benefits dollars should also be provided.)

x **There is not a current, federally approved rate agreement negotiated and available.**
(When this option is checked, the entity preparing this form shall submit a rate proposal in the format provided at the following website, or a format that provides the same level of information and which will support the rates being proposed for use in performance of the proposed project. Go to https://www.eere-pmc.energy.gov/forms.aspx and select PMC 400.2 Sample Rate Proposal.)

Additional explanation/comments (as necessary)

Rate proposal attached as "MBIICRP" in Other Optional Attachments.

c. Travel

PLEASE READ!!!

Provide travel detail as requested below, identifying total Foreign and Domestic Travel as separate items. Purpose of travel are items such as professional conference, DOE sponsored meeting, project management meeting, etc. The Basis for Estimating Costs are items such as past trips, current quotations, Federal Travel Regulations, etc.

All listed travel must be necessary for performance of the Statement of Projecct Objectives.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Purpose of travel	No. of Travelers	Depart From (not required for domestic travel)	Destination (not required for domestic travel)	No. of Days	Cost per Traveler	Cost per Trip	Basis for Estimating Costs
Budget Period 1							
Domestic Travel							
EXAMPLE ONLY!!! Visit to PV cell mfr. to set up vendor agreement	2			2	$650	$1,300	Internet prices
Professional Conference	2			4	$1,200	$2,400	Internet Prices
Travel to NREL for collaboration work	3			5	$1,600	$4,800	Previous history
Vist to equipment vendors	3			2	$650	$1,950	Internet Prices
Project management meetings	3			2	$950	$2,850	Internet Prices
StageGate meeting	4			2	$950	$3,800	Internet Prices
						$0	
						$0	
						$0	
Domestic Travel subtotal						$15,800	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 1 Total						**$15,800**	

Purpose of travel	No. of Travelers	Depart From (not required for domestic travel)	Destination (not required for domestic travel)	No. of Days	Cost per Traveler	Cost per Trip	Basis for Estimating Costs
Budget Period 2							
Domestic Travel							
Professional conference	2			4	$1,200	$2,400	Internet Prices
Professional conference	3			4	$1,200	$3,600	Internet Prices
Professional conference	3			4	$1,200	$3,600	Internet Prices
Professional conference	2			4	$1,200	$2,400	Internet Prices
Project Management Meeting	3			2	$950	$2,850	Internet Prices
Project Management Meeting	3			2	$950	$2,850	Internet Prices
Project Management Meeting	3			2	$950	$2,850	Internet Prices
Collaboration on Site at NREL	4			5	$1,600	$6,400	Internet Prices
Collaboration on Site at NREL	4			5	$1,600	$6,400	Internet Prices
Vendor Visits	2			2	$825	$1,650	Internet Prices
DOE Peer Review	4			3	$1,200	$4,800	Internet Prices
DOE Peer Review	4			3	$1,200	$4,800	Internet Prices
StageGate meeting	6			2	$1,000	$6,000	Internet Prices
StageGate meeting	6			2	$1,000	$6,000	Internet Prices
						$0	
						$0	
						$0	
Domestic Travel subtotal						$56,600	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 2 Total						**$56,600**	
Budget Period 3							
Domestic Travel							
Collaboration on site at NREL	2			5	$1,700	$3,400	Internet Prices
Project Management Meeting	3			2	$1,000	$3,000	Internet Prices
Professional Conference	4			4	$1,400	$5,600	Internet Prices
StageGate meeting	6			2	$1,000	$6,000	Internet Prices
DOE Peer Review	4			3	$1,200	$4,800	Internet Prices
						$0	
						$0	
Domestic Travel subtotal						$22,800	
International Travel							
						$0	

Purpose of travel	No. of Travelers	Depart From (not required for domestic travel)	Destination (not required for domestic travel)	No. of Days	Cost per Traveler	Cost per Trip	Basis for Estimating Costs
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 3 Total						**$22,800**	
PROJECT TOTAL						**$95,200**	

Additional Explanations/Comments (as necessary)

d. Equipment

PLEASE READ!!!

Equipment is generally defined as an item with an acquisition cost greater than $5,000 and a useful life expectancy of more than one year. Further definitions can be found at 10 CFR 600 found on the PMC Recipient Resources Forms page at https://www.eere-pmc.energy.gov/Forms.aspx#regs .

List all proposed equipment below, providing a basis of cost such as vendor quotes, catalog prices, prior invoices, etc., and briefly justifying its need as it applies to the Statement of Project Objectives. If it is existing equipment, and the value of its contribution to the project budget is being shown as cost share, provide logical support for the estimated value shown. If it is new equipment which will retain a useful life upon completion of the project, provide logical support for the estimated value shown.

For equipment over $50,000 in price, also include a copy of the associated vendor quote or catalog price list.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 1					
EXAMPLE ONLY!!! Thermal shock chamber	2	$20,000	$40,000	Vendor Quote	Reliability testing of PV modules- Task 4.3
Vacuum Oven	1	$ 9,100	$9,100	Catalog pricing	Drying of AFEX treated corn stover samples
HPLC	1	$ 54,074	$54,074	Vendor Quote (1)	Compositional analysis of feedstock and products
ASE Extractor	1	$ 65,000	$65,000	Vendor Quote (2)	Extraction of samples for compostional analysis
Auto Titrator	1	$ 5,655	$5,655	Catalog pricing	Quantitation of ammonia in process streams
Fermentation Vessels	1	$ 28,795	$28,795	Vendor Quote	Supplement existing equipment for fermentability of treated
			$0		
			$0		
			$0		
Budget Period 1 Total			$162,624		
Budget Period 2					
AFEX Reactor System	1	$ 3,410,000	$3,410,000	Vendor Quote (3)	Core equipment of AFEX treatment
Ammonia System	1	$ 1,337,856	$1,337,856	Vendor Quote (4)	Core equipment of ammonia recovery
Dryer	1	$ 275,000	$275,000	Vendor Quote (5)	Core equipment of ammonia recovery
Feedsystem	1	$ 92,400	$92,400	Vendor Quote (6)	Core equipment for biomass feed system
Ammonia Solution Heat Exchanger	1	$ 5,000	$5,000	Engineer Estimate	Core equipment of ammonia recovery
Feedstock weighing conveyor	1	$ 30,494	$30,494	Vendor Quote (7)	Key component of feed system
Product conveyor	1	$ 26,400	$26,400	Vendor Quote	Key component of product delivery system
Anhydrous ammonia vaporizer	1	$ 5,000	$5,000	Engineer Estimate	Core equipment of ammonia recovery
Weighing conveyor rotary airlock valve	1	$ 3,500	$3,500	Engineer Estimate	Key component of feed system
Feedstock feeder conveyor	1	$ 5,000	$5,000	Engineer Estimate	Key component of feed system
Discharge chamber	1	$ 2,000	$2,000	Engineer Estimate	Key component of product delivery system
Ammonia discharge safety flare	1	$ 5,000	$5,000	Engineer Estimate	Ammonia safety system
Liquid knockdown pot	1	$ 5,000	$5,000	Engineer Estimate	Core equipment of ammonia recovery
Fork Lift	1	$ 26,900	$26,900	Vendor Quote	Key equipment for feedstock handling

Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Laboratory Furniture	1	$ 30,000	$30,000	Catalog pricing	Required for new laboratory setup
Densification/Compaction System	1	$60,000	$60,000	Vendor Quote (8)	Required to densify/compact AFEX-treated corn stover
Budget Period 2 Total			$5,319,550		
Budget Period 3					
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 3 Total			$0		
PROJECT TOTAL			**$5,482,174**		

Additional Explanations/Comments (as necessary)

e. Supplies

PLEASE READ!!!

Supplies are generally defined as an item with an acquisition cost of $5,000 or less and a useful life expectancy of less than one year. Supplies are generally consumed during the project performance. Further definitions can be found at 10 CFR 600 found on the PMC Recipient Resources Forms page at https://www.eere-pmc.energy.gov/Forms.aspx#regs.

List all proposed supplies below, providing a bases of cost such as vendor quotes, catalog prices, prior invoices, etc., and briefly justifying the need for the Supplies as they apply to the Statement of Project Objectives. Note that Supply items must be direct costs to the project at this budget category, and not duplicative of supply costs included in the indirect pool that is the basis of the indirect rate applied for this project.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

General Category of Supplies	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 1					
EXAMPLE ONLY!!! Wireless DAS components	10	$360.00	$3,600	Catalog price	For Alpha prototype - Task 2.4
Various chemicals (acid, purified sugars, base, fermentation media components, enzymes…)	1	$2,500.00	$2,500	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
Glassware	1	$2,000.00	$2,000	Prior Experience	Used in hydrolysis, fermentation, and composition analysis
Various laboratory supplies (pipets, tubes, syringes, filters, sterilized fiters, HPLC vials…)	1	$7,500.00	$7,500	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
High Speed Microcentrifuge	1	$1,900.00	$1,900	Prior Experience	
Safety gear (i.e., lab coats, gloves, goggles, ammonia masks, ammonia cartridges, fitting test)	1	$1,000.00	$1,000	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
storage racks	1	$2,900.00	$2,900	Quote From global	
Ammonia Tank Rental	1	$2,000.00	$2,000	Prior Experience	
			$0		
			$0		
			$0		
Budget Period 1 Total			**$19,800**		
Budget Period 2					
Various chemicals (acid, purified sugars, base, fermentation media components, enzymes…)	1	$6,900.00	$6,900	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
Glassware	1	$3,100.00	$3,100	Prior Experience	Used in hydrolysis, fermentation, and composition analysis
Various laboratory supplies (pipets, tubes, syringes, filters, sterilized fiters, HPLC vials…)	1	$9,525.00	$9,525	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
Office Supply	1	$800.00	$800	Prior Experience	
Floor Scale	1	$1,300.00	$1,300	Quote From Arlyn	

General Category of Supplies	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Self Contained Breathing	1	$1,500.00	$1,500	Catalog	
Encapsulated Suit	2	$620.00	$1,240	Catalog	
Ammonia Tank Rental	1	$3,700.00	$3,700	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
Ammonia Tank Refill	1	$1,500.00	$1,500	Prior Experience	
Safety gear (i.e., lab coats, gloves, goggles, ammonia masks, ammonia cartridges, fitting test)	1	$1,000.00	$1,000	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
			$0		
Budget Period 2 Total			$30,565		
Budget Period 3					
Various chemicals (acid, purified sugars, base, fermentation media components, enzymes…)	1	$3,678.00	$3,678	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
Glassware	1	$3,000.00	$3,000	Prior Experience	Used in hydrolysis, fermentation, and composition analysis
Various laboratory supplies (pipets, tubes, syringes, filters, sterilized fiters, HPLC vials…)	1	$4,500.00	$4,500	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
Office Supply	1	$1,000.00	$1,000	Prior Experience	
Ammonia Tank Rental	1	$2,400.00	$2,400	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
Safety gear (i.e., lab coats, gloves, goggles, ammonia masks, ammonia cartridges, fitting test)	1	$1,000.00	$1,000	Prior Experience	Running AFEX and hydrolysis, fermentation, and composition analysis
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 3 Total			$15,578		
PROJECT TOTAL			**$65,943**		

Additional Explanations/Comments (as necessary)

f. Contractual

PLEASE READ!!!

The entity completing this form must provide all costs related to sub-recipients, vendors, contractors, consultants and FFRDC partners in the applicable boxes below.

Sub-recipients (partners, sub-awardees):
For each sub-recipient with total project costs of $100,000 or more, a separate SF-424A budget and PMC123.1 budget justification form must be submitted. These sub-recipient forms may be completed by either the sub-recipients themselves or by the preparer of this form. The budget totals on the sub-recipient's forms must match the sub-recipeint entries below.

The preparer of this form need only provide further support of the completed sub-recipient budget forms as they deem necessary. The support to justify the budgets of sub-recipients with estimated costs less than $100,000 may be in any format, and at a minimum should provide what Statement of Project Objectives task(s) are being performed, the purpose/need for the effort, and a basis of the estimated costs that is considered sufficient for DOE evaluation.

Vendors (includes contractors and consultants):
List all vendors, contractors and consultants supplying commercial supplies or services used to support the project. The support to justify vendor costs (in any amount) should provide the purpose for the products or services and a basis of the estimated costs that is considered sufficient for DOE evaluation.

Federal Research and Development Centers (FFRDCs):
For FFRDC partners, award recipient will provide a Field Work Proposal (if not already provided with the original application), along with the FFRDC labor mix and hours, by category and FFRDC major purchases greater than $25,000, including Quantity, Unit Cost, Basis of Cost, and Justification. The award recipient may allow the FFRDC to provide this information directly to DOE.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Sub-Recipient Name/Organization	Purpose/Tasks in SOPO	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
EXAMPLE ONLY!!! XYZ Corp.	Partner to develop optimal fresnel lens for Gen 2 product - Task 2.4	$48,000	$32,000	$16,000	**$96,000**
Michigan State University	Design (Task 1.1) , Research & Development (Task 1.3) ,NH3 Recovery (with MBI), AFEX Integration with Saccharification and Fermentation (with MBI, NREL), Densification (with MBI), Techno-economic Model Update (Tasks 2.11 and 3.2.1), Business and Commercialization Plan Update (Tasks 2.12 and 3.2.2), Project Meeting/Communications (Tasks 1.8, 2.16 and 3.5)	$80,836	$252,299	$89,541	**$422,676**

Sub-Recipient Name/Organization	Purpose/Tasks in SOPO	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
Novozymes	Task 1.3.3.10.1: Hemicellulase screening on AFEX-treated corn stover, Task 1.3.3.10.2: Analysis of soluble enzyme inhibitors formed during AFEX pretreatment, Task 2.7.4: NREL PDU/IBRF Saccharification and Fermentation Shakedown trials, Task 2.8.4: NREL PDU/IBRF Saccharification and Fermentation Capstone Runs, Tasks 2.11 and 3.2.1 : Techno-economic modeling and Life Cycle Analysis, Task 1.8; 2.16 and 3.5: Project Review Meetings	$43,240	$82,563	$17,634	**$143,437**
					$0
					$0
					$0
					$0
					$0
					$0
	Sub-total	**$124,076**	**$334,862**	**$107,175**	**$566,113**

Vendor Name/Organization	Product or Service, Purpose/Need and Basis of Cost (Provide additional support at bottom of page as needed)	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
EXAMPLE ONLY!!! ABC Corp.	Vendor for developing custom robotics to perform lens inspection, alignment, and placement (Task 4). Required for expanding CPV module mfg. capacity. Cost is from competitive quotes.	$32,900	$86,500		**$119,400**
Vermeer	Vermeer will procure, harvest and preprocess (grind) corn stover for use as feedstock for the proposed biorefinery. Vermeer will then ship the prepared biomass to MBI in Lansing, MI for AFEX treatment. Vermeer personnel will report on all process steps, including equipment used, power/fuel usage and other pertinent data required to adequately model the process. Key Vermeer personnel will participate in quarterly meetings, reporting and StageGate reviews as required.	$8,950	$38,000	$21,750	**$68,700**

Sub-Recipient Name/Organization	Purpose/Tasks in SOPO	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
Engineering, Procurement and Construction (EPC) Firm	Design, construction and installation of equipment of the proposed pilot plant at MBI will be outsourced to an engineering, procurement and construction (EPC) firm. This firm will interface with key project teams to facilitate a design and construct effort that meets the project objectives aimed at successful demonstration of the technology in a timely manner and within budget. The contract(s) for design and construction will be competitively solicited and awarded. Awards will not be made on cost alone, but rather a combination of cost, experience and capability. This firm will participate in all meetings/reviews and reporting activities during the course of all design, construction and installation tasks.	$270,000	$5,525,000		**$5,795,000**
					$0
					$0
					$0
					$0
					$0
		$278,950	**$5,563,000**	**$21,750**	**$5,863,700**

FFRDC Name/Organization	Purpose	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
National Renewable Energy Laboratory (NREL)	Phase Ia. Bench Scale Enzymatic Saccharification and Fermentation Process Validation, Phase *Ib. NREL Design Review of Pilot-Scale AFEX Pretreatment Equipment and Other Systems at MBI,Phase 2a. Pilot Scale Enzymatic Saccharification and Fermentation Equipment Modification at NREL PDU/IBRF, Phase 2b. Pilot Scale Enzymatic Saccharification and Fermentation Shakedown, Optimization, and Demonstration Runs at NREL PDUIIBRF,Phase 3. Additional Pilot Scale Enzymatic Saccharification and Fermentation Demonstration Runs at NREL PDU/1BRF	$467,536	$2,414,503	$591,274	**$3,473,313**
					$0
					$0
		$467,536	**$2,414,503**	**$591,274**	**$3,473,313**

Total Contractual		**$870,562**	**$8,312,365**	**$720,199**	**$9,903,126**

AdditionalExplanations/Comments (as necessary)

Sub-Recipient Name/Organization	Purpose/Tasks in SOPO	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total

g. Construction

PLEASE READ!!!

Construction, for the purpose of budgeting, is defined as all types of work done on a particular building, including erecting, altering, or remodeling. Construction conducted by the award recipient is entered on this page. Any construction work that is performed by a vendor or subrecipient to the award recipient should be entered under f. Contractual.

List all proposed construction below, providing a basis of cost such as engineering estimates, prior construction, etc., and briefly justify its need as it applies to the Statement of Project Objectives.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Overall description of construction actiivities:

Example Only!!! - Build wind turbine platform

General Description	Cost	Basis of Cost	Justification of need
Budget Period 1			
Three days of excavation for platform site EXAMPLE ONLY!!!	$28,000	Engineering estimate	Site must be prepared for construction of platform.
Budget Period 1 Total	**$0**		
Budget Period 2			

General Description	Cost	Basis of Cost	Justification of need
Budget Period 2 Total	$0		
Budget Period 3			
Budget Period 3 Total	$0		
PROJECT TOTAL	**$0**		

Additional Explanations/Comments (as necessary)

h. Other Direct Costs

PLEASE READ!!!

Other direct costs are direct cost items required for the project which do not fit clearly into other categories, and are not included in the indirect pool for which the indirect rate is being applied to this project. Examples are meeting costs, postage, couriers or express mail, telephone/fax costs, printing costs, etc.

Basis of cost are items such as vendor quotes, prior purchases of similar or like items, published price list, etc.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

General description	Cost	Basis of Cost	Justification of need
Budget Period 1			
EXAMPLE ONLY!!! Grad student tuition	$16,000	Established UCD costs	Support of graduate students working on project
Postage/Express Mail	$600	previous experience	
Printing Cost	$1,000	previous experience	
Meeting Costs	$600	previous experience	
Budget Period 1 Total	$2,200		
Budget Period 2			
Postage/Express Mail	$1,200	previous experience	
Printing Cost	$2,000	previous experience	
Meeting Costs	$1,200	previous experience	
Shipping to NRELL	$28,000	previous experience	Shipping of materials to NRELL
Budget Period 2 Total	$32,400		
Budget Period 3			
Postage/Express Mail	$624	previous experience	
Printing Cost	$1,000	previous experience	
Meeting Costs	$600	previous experience	
Budget Period 3 Total	$2,224		
PROJECT TOTAL	**$36,824**		

Additional Explanations/Comments (as necessary)

i. Indirect Costs

	Budget Period 1	Budget Period 2	Budget Period 3	Total
Rate applied:	129.98%	129.98%	129.98%	
Total indirect costs requested:	$1,106,878	$2,868,143	$529,727	**$4,504,748**

A federally approved indirect rate agreement, or rate proposed supported and agreed upon by DOE for estimating purposes is required if reimbursement of fringe benfits is requested. Please check (X) one of the options below and provide the requested information if it has not already been provided as requested, or has changed. Calculate the indirect rate dollars and enter the total in the Section B., line 6.j. (Indirect Charges) of form SF 424A.

____ **There is a federally approved indirect rate agreement. A copy is provided with this application and will be provided electronically to the Contracting Officer for this project.**
(When this option is selected, a presentation of the budget that demonstrates the application of the approved rate, to arrive at the proposed indirect charges proposed should also be provided.)

X **There is no current, federally-approved indirect rate agreement.**
(When this option is checked, the entity preparing this form shall submit an indirect cost rate proposal in the format provided at the following website, or in a format that provides the same level of information and which supports the rate(s) being proposed for use in estimating the project. Go to https://www.eere-pmc.energy.gov/forms.aspx and select PMC 400.2 Sample Rate Proposal.)

Additional Explanations/Comments (as necessary)

MBI's cognizant/oversight agency is Defense Contract Audit Agency. Dianna Eldridge is the individual responsible for MBI's indirect rate and she can be reached at 734.805.1000. Indirect cost rate proposal attached as "MBIICRP" in Other Optional Attachments.

Cost Share

PLEASE READ!!!

A detailed presentation of the cash or cash value of all cost share proposed for the project must be provided in the table below. Identify the source & amount of each item of cost share proposed by the award recipient and each sub-recipient or vendor. Letters of committment must be submitted for all third party cost share (other than award recipient).

Note that "cost-share" is not limited to cash investment. Other items that may be assigned value in a budget as incurred as part of the project budget and necessary to performance of the project, may be considered as cost share, such as: contribution of services or property; donated, purchased or existing equipment; buildings or land; donated, purchased or existing supplies; and/or unrecovered personnel, fringe benefits and indirect costs, etc. For each cost share contribution identified as other than cash, identify the item and describe how the value of the cost share contribution was calculated.

Funds from other Federal sources MAY NOT be counted as cost share. This prohibition includes FFRDC sub-recipients. Non-Federal sources include private, state or local Government, or any source not originally derived from Federal funds. Documentation of cost sharing commitments must be provided, if not already provided with the original application and they have not changed since its submission.

Fee or profit will not be paid to the award recipients or subrecipients of financial assistance awards. Additionally, foregone fee or profit by the applicant shall not be considered cost sharing under any resulting award. Reimbursement of actual costs will only include those costs that are allowable and allocable to the project as determined in accordance with the applicable cost principles prescribed in 10 CFR 600.127, 10 CFR 600.222 or 10 CFR 600.317. Also see 10 CFR 600.318 relative to profit or fee.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Organization/Source	Type (cash or other)	Cost Share Item	Budget Period 1 Cost Share	Budget Period 2 Cost Share	Budget Period 3 Cost Share	Total Project Cost Share
ABC Company **EXAMPLE ONLY!!!**	Cash	Project partner ABC Company will provide 40 PV modules for product development at 50% off the of the retail price of $680	$13,600			**$13,600**
Michigan State University (MSU)	Cash	Unrrecoved personnel, fringe benefits and indirect cost	$33,812	$105,889	$38,730	**$178,431**
Novozymes	Cash	Unrrecoved personnel, fringe benefits and indirect cost	$43,240	$82,563	$17,634	**$143,437**
MBI/MSUF	Cash	Unrrecoved personnel, fringe benefits and indirect cost	$520,416	$3,552,573	$269,751	**$4,342,740**
Vermeer	Cash/Services	Vermeer will ship and procure,harvest and preprocess (grind) corn stover. Key Vermeer personnel will participate in quarterly meeting, reporting and StageGate reviews as needed. Services where calculated at their market value	$4,293	$18,226	$10,432	**$32,951**
						$0

Organization/Source	Type (cash or other)	Cost Share Item	Budget Period 1 Cost Share	Budget Period 2 Cost Share	Budget Period 3 Cost Share	Total Project Cost Share
						$0
						$0
						$0
						$0
						$0
		Totals	$601,761	$3,759,251	$336,547	$4,697,559

Total Project Cost: $23,487,796 **Cost Share Percent of Award: 20.0%**

Additional Explanations/Comments (as necessary)

VENDOR QUOTE (1)

Agilent Technologies

Dayle Frame

Agilent Technologies, Inc.
(c/o Analytical Sciences Group)
DeWitt, MI 48820

517.889.1100 (o)
517.575.9450 (c)
frameh@msu.edu

Ms. Heather Hodge
MBI International
3900 Collins Rd
Lansing, MI 48910
United States
Office Phone: 517.337.3181
Email: hodge@mbi.org

04.05.2009 (May 4, 2009)

AM1111254-02

Here are the details of the quote:

Item	Model	Description	US List Price	Quantity	Net Price
1	**G1354A**	1200 Series Quaternary Pump w/ degasser	16,486.00	1	16,486.00
2	**G1329A**	1200 Series Standard Autosampler	11,980.00	1	11,980.00
3	**G1316B**	1200 Series Thermost. Col. Compartm. SL	5,006.00	1	5,006.00
4	**G1362A**	1200 Series Refractive Index Detector	10,029.00	1	10,029.00
5	**G6700AA**	EZChrom Elite Workstation	7,321.00	1	7,321.00
6	**SYS-LC-1200 8D2**	Extended Warranty 2yr	3,252.00	1	3,252.00
				USD	**54,074.00**

Call me if you have any questions. Thank you for your time.

Dayle Frame

DIONEX

VENDOR QUOTE (2)

To Janet Moore
MBI International
517-337-3181
moore@mbi.org

Address 3900 Collins Road
LANSING
MI 48910
United States

Quote Date 22-JUN-2009

Quotation Number 138439

Quotation Name 1304_MBI_ASE350_Moore

WE ARE PLEASED TO SUBMIT THE FOLLOWING QUOTATION SUBJECT TO CONDITIONS SHOWN:

Item	Qty	Product	Unit Price	Discount	Total Price
1	1	066050 ASE 350 Accelerated Solvent Extractor	48,000.00	0.00	48,000.00
2	1	057794 Installation Service, ASE	2,000.00	-2,000.00	0.00
3	2	960708 Power Cord US	0.01	0.00	0.02
4	2	053848 Bottle Set (Three 2 L Bottles Plus Caps and Tubing)	805.00	0.00	1,610.00
5	1	068255 ASE 350 Starter Kit for 34 mL Cells	1,600.00	0.00	1,600.00
6	4	068099 Extraction Cell Kit, Stainless Steel, 34 mL, Pkg of 6 for ASE 350	3,100.00	0.00	12,400.00
7	4	056284 250 mL Clear Collection Bottles for ASE 300/100, Pkg of 12, VOC Cert.	36.00	0.00	144.00
8	3	049463 ASE Collection Bottle Lids, Pkg of 72	21.50	0.00	64.50
9	3	056775 Frits, 10 µm SST, ASE 300/100 Cells, Pkg of 50	320.00	0.00	960.00
10	2	049457 O-Rings, Teflon, ASE Cell Cap, Pkg of 50	40.00	0.00	80.00
11	1	056699 Aluminum Funnel (28.3 mm) for ASE 300/100	57.00	0.00	57.00
12	3	056780 Filters, Cellulose for 34, 66 or 100 mL Cells, Pkg of 100, ASE 300/100	25.00	0.00	75.00
				Quotation Total	64,990.52

Notes :

Quote Expires	18-AUG-2009	**Respectfully Submitted:**	**Dionex Corporation** Ms. Tyla N. Brown 3000 Lakeside Drive Suite 116N Bannockburn, IL 60015 Rep Phone : 248-930-4850 Main Phone : 847-295-7500 Main Fax : 847-283-0722 E-Mail id : Tyla.Brown@dionex.com
Estimated Delivery	Within 90 Days ARO		
Freight	Prepaid and Added		
FOB Point	Sunnyvale, California		
Terms	30 NET		

Ordering: Order should be made out to Dionex Corporation and sent to the North American sales office in Bannockburn, Illinois.

The above prices and terms are valid for final destination within the Continental U.S., Alaska, Hawaii and Washington, D.C.

RETURN POLICY
AND
LIMITED WARRANTY STATEMENT

Limited Warranty. Subject to the terms and conditions of this warranty statement, and for the applicable limited period of time specified below (the "Warranty Period"), Dionex Corporation **(DIONEX)** warrants that (a) its products will be free of material defects in materials and workmanship; and (b) with respect to products that consist of software and instrumentation designed by **DIONEX**, such software and instrumentation will operate in substantial conformity with its published documentation when properly installed and used in accordance with its documentation.

PRODUCT	WARRANTY PERIOD
All DIONEX ASE, HPLC, IC, MSQ, Integral, instruments/modules and associated accessories (excluding columns, ICS-900, ICS-1000, ICS-1100, ICS-1500, ICS-1600, ASE 150)	One Year
ICS-900, ICS-1000, ICS-1100, ICS-1500, ICS-1600, ASE 150, with purchased installation	One Year
ICS-900, ICS-1000, ICS-1100, ICS-1500, ICS-1600, ASE 150 without purchased installation	90 Days
Chromatography columns and consumables	90 Days (exclusive of breakage during shipment)
Any products repaired or replaced by DIONEX	90 Days (limited to only the item repaired or replaced)
Instruments previously used for demonstrations	90 Days
Instrument spare parts	90 Days
Software applications	90 Days and limited solely to replacement of the defective item

New analytical instruments and accessories (excluding software, columns and consumables) that are installed by **DIONEX** are warranted from the earlier of (a) the installation date; or (b) the sixty-first (61st) day after the date of shipment. All other products are warranted from the shipment date.

Warranty Remedies. Any product that fails to conform to the foregoing warranty during its stated Warranty Period will be repaired or replaced at the sole discretion of **DIONEX** at its facilities in Sunnyvale, California, or at another location specified by **DIONEX,** *provided that* Buyer:

(1) Provides written notice of the defect to DIONEX promptly after BUYER discovers or should have discovered the defect, AND

(2) Returns the defective article, properly packed with all freight charges prepaid, to the DIONEX factory in Sunnyvale, California (or to an alternative location designated by DIONEX), in accordance with DIONEX's return process described below.

Buyer's sole and exclusive remedy, and **DIONEX's** sole liability, for any nonconformity to this limited warranty is repair or replacement of defective articles or parts, or, if **DIONEX** determines that it is commercially infeasible to repair or replace such defective items, to issue a refund equal to the net price paid for such defective articles or parts. For the avoidance of doubt, minor deviations from specification, which do not affect performance of the articles, shall not constitute material defects in breach of the foregoing warranty.

Installation and on-site warranty services may be available, but only in the **DIONEX** service travel area (as defined below), and only in the country of initial purchase unless **BUYER** pays **DIONEX** international prices for the product and services. For installation and on-site warranty services outside of the **DIONEX** service travel area, **DIONEX** will provide a quotation for the applicable additional services. If products eligible for installation and on-site warranty services are moved from the initial installation point, the warranty will remain in effect only if the **BUYER** purchased additional inspection or installation services at the new site. The travel service area in North America shall include the United States and Canada. For the travel service area outside of North America please contact the local **DIONEX** subsidiary or your local distributor.

This warranty is limited to the original **BUYER** and is not transferable.
Exclusions. The foregoing warranty shall not apply to defects resulting from:

(1) Improper or inadequate maintenance, adjustment, calibration or operation by **BUYER.**

(2) **BUYER**-supplied software, hardware, interfacing, or consumables.

(3) Modification, servicing, or repair of the articles by any party other than **DIONEX.**

(4) Misuse or failure to install or operate the products except in the manner expressly described in the applicable documentation.

(5) Operation outside of the environmental and electrical specifications for the product.

(6) Improper site preparation and maintenance; or **BUYER**-induced contamination or leaks.

This warranty shall not apply to complete assemblies purchased from other manufacturers and incorporated into **DIONEX** products. In case of failure of such assemblies, **DIONEX** will honor the specific warranty terms of the original manufacturers involved.

DISCLAIMERS. THE EXPRESS WARRANTIES IN THIS LIMITED WARRANTY STATEMENT ARE IN LIEU OF ALL OTHER WARRANTIES, WHETHER EXPRESS, IMPLIED, OR STATUTORY, REGARDING THE PRODUCTS PURCHASED FROM **DIONEX**. **DIONEX** EXPRESSLY DISCLAIMS ALL SUCH OTHER WARRANTIES, INCLUDING ANY WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, TITLE, AND NON-INFRINGEMENT OF THIRD-PARTY RIGHTS. WITHOUT LIMITING THE FOREGOING, **DIONEX** DOES NOT WARRANT THAT THE OPERATION OF ANY SOFTWARE OR INSTRUMENTATION COMPRISING THE PRODUCTS WILL BE UNINTERRUPTED OR ERROR-FREE.

Statements made by any person, including by representatives of **DIONEX**, which are inconsistent or in conflict with the terms of this warranty shall not be binding upon **DIONEX** unless reduced to writing and signed by an officer of **DIONEX.**

Limitation of Liability. In no event shall **DIONEX** be liable for indirect, incidental, EXEMPLARY, SPECIAL, or consequential damages, OR FOR LOSS OF PROFITS OR LOSS OF USE, ARISING FROM OR RELATING TO ANY OF THE PRODUCTS PURCHASED FROM **DIONEX.** in no event shall any liability of **DIONEX** arising in connection with any article sold hereunder (whether such liability arises from a claim based on contract, warranty, tort, indemnity, or

otherwise) exceed the actual amount paid by **BUYER** to **DIONEX** for such article. The remedies provided herein are **BUYER'S** sole and exclusive remedies, AND **DIONEX** shall not be liable for any other claim or damages of any kind RELATED TO THE PRODUCTS.

Return Policy and Process. Under no circumstances may articles be returned by the **BUYER** unless advance written authorization and shipping instructions have been secured from **DIONEX**. Before returning any item in the United States or Canada, contact **DIONEX**'s Order Administration Department for a Return Material Authorization (RMA) number at 1-800-**DIONEX**-0 or 1-800-346-6390. Countries other than United States or Canada, please contact the local **DIONEX** subsidiary or your local distributor for processing. **BUYER** may need to complete a RMA Form which includes a Hazard Free Form and/or Instrument Contamination Data Form.

BUYER must return items to **DIONEX** in their original or equivalent packaging, prepay shipping charges, and insure the shipment or accept the risk if the item is lost or damaged in shipment. In addition, **DIONEX** reserves the right to charge the **BUYER** the list price for missing components or subassemblies when incomplete items are returned to **DIONEX**.

No replacements for articles or parts claimed to be defective will be shipped by **DIONEX** unless the alleged defect is established to its satisfaction after suitable test and/or inspection. Replacements will be on an exchange basis without further credit and all replaced parts or articles will become the property of **DIONEX**.

Returns of any unused items which are free from material defects, to **DIONEX**, if such return is accepted by **DIONEX** in its sole discretion, may be subject to a twenty-five (25) percentage restocking charge.

SunOpta BioProcess Inc.

Budgetary Quotation

To Supply

SunOpta Pretreatment System

January 12, 2009

Proposal submitted by:
SunOpta BioProcess Inc.
2838 Bovaird Drive West
Brampton, Ontario
L7A 0H2

Submitted to:
MBI International
3900 Collins Road
Lansing, MI
48910-8596

2838 Bovaird Drive West, Brampton, Ontario, Canada L7A 0H2
T: 905-455-2528 ext 128 F: 905-455-5744
www.sunopta.com/bioprocess

1. Background

MBI International (the "Buyer") desires to incorporate a SunOpta BioProcess (the "Seller") Pretreatment System in their pilot facility capable of treating 40-100 kg/hr of agricultural residues on a dry matter basis. The Buyer has requested that the Pretreatment System be able to handle aqueous ammonia. The Buyer has requested a price estimate for budgetary purposes.

In order to estimate the overall capital cost for budgetary purposes, equipment sizing was based on the following parameters:

- Feedstock moisture content upon harvesting (~50%)
- Fibre length (< 1 inch)
- Fibre potential air dried density ~60 kg/m^3.
- Aqueous ammonia addition in the SunOpta Hydrolyzer
- Operating Temperature 90-140 deg C
- Operating Pressure 100-400 psig
- Residence time of 10-30 min

2. Purpose

This proposal is a budgetary price quotation for Engineering, Procurement, Manufacturing and Equipment Supply of a SunOpta Pretreatment System for the subsequent production of cellulosic ethanol.

3. Scope of Supply

The Seller is making this budgetary quotation for supplying the equipment listed below:

3.1 Fibre Pretreatment System includes:

3.1.1 SunOpta feeder
- 3.1.1.1 Capability to feed biomass continuously into hydrolyzer at up to 400 PSIG
- 3.1.1.2 All wetted parts ANSI SS 316L or equivalent

3.1.2 SunOpta continuous hydrolyzer
- 3.1.2.1 ASME pressure vessel rated for 400 PSIG and 225°C for non acid use
- 3.1.2.2 All wetted components ANSI SS 316L
- 3.1.2.3 Blow valve ANSI SS 316L
- 3.1.2.4 Blow line ANSI SS 316L

3.1.3 SunOpta blow cyclone
- 3.1.3.1 ASME pressure vessel rated for 100 PSIG and 170°C
- 3.1.3.2 All wetted components ANSI SS 316L
- 3.1.3.3 Additional nozzles for temperature(s) and pressure(s)

2838 Bovaird Drive West, Brampton, Ontario, Canada L7A 0H2
T: 905-455-2528 ext 128 F: 905-455-5744
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4. Budgetary Estimate

Based on the Scope of Supply summarized in Section 3 and detailed in Appendix I, the Seller is pleased to submit a budgetary estimate of **$3,410,000 (USD)**. This estimate covers the following:

1) SunOpta Hydrolyzer System manufactured with Stainless Steel, suitable for non-acid service.

Seller emphasizes that this information is a budgetary estimate only. A firm price quote will be provided upon completion of Basic Engineering which will enables Seller to determine specific equipment sizing and request quotation from multiple vendors. Also, prices outlined in the document are based upon December 23, 2008 exchange rate of 1.21313 Canadian dollar per US dollar.

5. Seller Services

The budgetary estimate for equipment supply includes the following items:

- Basic engineering
- Procurement and manufacturing management
- Equipment supply for Fibre Pretreatment System
- Instrumentation and controls
- Project management
- Shipping

6. Items Excluded From Seller's Scope of Supply

The aforementioned cost does not include the following items:

- Detailed civil/structural engineering
- Plant construction and equipment installation
- Construction management
- Detailed piping design
- Detailed equipment layouts
- Field engineering
- Commissioning and start-up assistance
- Onsite support
- Site training
- Supply of electrical systems such variable frequency drives (VFD's) and MCC's
- Equipment insulation

2838 Bovaird Drive West, Brampton, Ontario, Canada L7A 0H2
T: 905-455-2528 ext 128 F: 905-455-5744
www.sunopta.com/bioprocess

7. Process and Mechanical Guarantees

The Seller is willing to provide process and mechanical guarantees for all systems within the Seller's scope of supply that have a known process outcome that Seller has been able to previously confirm in our labs and pilot plants.

8. Payment Terms and Conditions

In consideration of full and proper performance of its contractual obligations by Seller, the Buyer will pay the Seller the total contract price by telegraphic transfer (T/T) through the Buyer's Bank to the Seller's Bank. The Contract shall be paid as follows:

- Twenty percent (20%) shall be paid by the Buyer to the Seller within ten (10) days of the effective date of the Contract
- The remaining payments will be invoiced monthly to the client in 4 equal installments
- All invoices will be issued in US dollars and payable within thirty (30) days
- All invoices will be paid in US dollars.

9. Delivery

Delivery of equipment is approximately from 9 to12 months from the date of order placement.

2838 Bovaird Drive West, Brampton, Ontario, Canada L7A 0H2
T: 905-455-2528 ext 128 F: 905-455-5744
www.sunopta.com/bioprocess

Appendix I: Equipment List

2838 Bovaird Drive West, Brampton, Ontario, Canada L7A 0H2
T: 905-455-2528 ext 128 F: 905-455-5744
www.sunopta.com/bioprocess

SunOpta BioProcess Inc.

Table 1: Equipment List (1)

Item No.	Description
	Fibre Pretreatment
1	Feeder Hopper
2	Sight Glass
3	6" SunOpta Feeder
4	24" SunOpta Hydrolyzer
5	Hydrolyzer Headers and Valves
6	Hydrolyzer Retention Screw
7	Hydrolyzer Discharge Screw
8	Mechanical Seals
9	26" SunOpta Blow Cyclone
10	SunOpta Blow Cyclone Internal Components
11	SunOpta Blow Cyclone Discharge Chute
12	SunOpta Blow Valve
13	SunOpta Blow Line
14	Lubrication Unit
15	Metering Pump for the increase/mixing of Ammonia in the hydrolyzer

2838 Bovaird Drive West, Brampton, Ontario, Canada L7A 0H2
T: 905-455-2528 ext 128 F: 905-455-5744
www.sunopta.com/bioprocess

Rowald Refrigeration Systems, Inc.

515 Grable Street Rockford, IL USA 61109-2001
Phone 815 397-7733 Fax 815 397-5936
E-mail rwrowald@rowald.com Web site www.rowald.com

March 23, 2009

Zaheer Khalfan
DICK ENGINEERING INC.
Suite 500
One Concorde Gate
Toronto, Ontario M3C 3N6

Budget Quotation QA031909 Rev 01

Zaheer:

This is the ballpark budgetary quote for the ammonia recovery system. I am still waiting for many prices from vendors. Stainless ammonia parts are not common and many of the items will be specially made for this system. The system consists of two oil free piston compressors sections raising the pressure of two ammonia streams, condensing these streams and then placing them into a receiver. This revision adds additional instrumentation to the unit and VFDs to all pump and compressor motors. See concept drawing below.

We will provide the following items.

- Design
- Ammonia handling equipment as detailed below
- Cooling tower system as detailed below
- Motors
- Instrumentation and control systems
- Control systems interface to the plants system
- Electrical systems (starters, VFD drives, and wiring) in electrical enclosures and on skids
- Wiring and conduits between skids will be called out but not provided, as we do not know the distances between the skids or building details.
- Piping and valuing
- Piping will end at the edge of the skids with flanged or screwed connections
- Connection to the plant process streams by others
- Ammonia leak detection system
- Startup supervision

The system consists of the following major components.

Strong Ammonia Stream

Dual filter for inlet ammonia stream
25-Hp oil free piston compressor package
Ammonia condenser, water-cooled
Ammonia receiver tank
Air purger system with multi point connections
Interconnecting piping
Control and shut off service valves
Electrical control system
Instrumentation (the mass flow meter is not included)

Dilute Ammonia Stream

Dual filter for inlet ammonia stream
Ammonia cooler, water-cooled
Ammonia cooler, ammonia-cooled
Dilute ammonia receiver
Dilute ammonia pump
30-Hp oil free piston compressor package
Ammonia condenser, water-cooled
Interconnecting piping
Control and shut off service valves
Electrical control system
Instrumentation

Ammonia Supply System

Ammonia supply pump
Electrical control system
Instrumentation

Cooling Tower System

One 126 GPM cooling tower with 2 HP fan
Winterizing of piping, heat traced
Three supply pumps each with 50% flow capacity
Indoor reservoir
Three-way diverting valve, temperature operated
Tower fan speed control, temperature operated
Electrical control system

Instrumentation

Note: piping between the tower and pump skid is not included as distances are unknown. Return piping is 6" schedule 40, 316L or PVC, Supply piping is 3" schedule 40, 316L or PVC.

Stainless steel piping will be used throughout these units as much as possible. The compressors are 316 SS, 400 series SS and nickel/TFE coated. Some of the refrigeration specialties valves are steel or iron as they are not available in stainless. All of the vessels, piping and pumps are 316L stainless steel or other non-ferrous metal. All pumps are equipped with isolation valves for servicing. Electrical enclosures are NEMA 7 or NEMA 12 purged to meet Class 1, Div 1, Group D.

COST

Ammonia recovery system $1,337,856.00
Cooling tower system $248,947.00

BUILD AND SHIPPING

Design time 4 to 6 months. Build time is currently 26 to 30 weeks after print approval. Prices are exworks our plant. All freight charges are the responsibility of the customer.

DOMESTIC TERMS

Orders less than $25,000.00 are net 30 from day of shipment with PRIOR approved credit; otherwise Cash in Advance or COD shipment. Over $25,000.00 requires down and progress payments, which are negotiable. Requested terms are: 10% with purchase order, 20% payment after drawing approval, 40% progress payment 30 days after drawing approval, balance of 30% due 30 days after shipment. The first progress payment is due with the purchase order. The second and third progress payments are due upon receipt of invoice. The final payment is due net 30 days from day of shipment.

LATE PAYMENT CHARGES

A 1½-percent late charge will be assessed 30 days after the billing date if full payment has not been received and an additional 1½-percent per month thereafter, except when

otherwise mandated by law. Any attorney fees, court costs, or other costs required to collect any outstanding portion of any invoice will be paid for by the customer.

WARRANTY of WORKMANSHIP and MATERIAL

ROWALD guarantees all machinery and materials of its manufacture against defects in workmanship and material for eighteen (18) months from date of manufacture, or one (1) year from date of initial start-up, whichever shall occur first, and will repair or replace F.O.B. point of manufacture such products or components as ROWALD finds defective. This warranty does not include the cost of labor to remove or reinstall any defective components; nor does it include cost of handling, shipping, or transaction involved in supplying replacement for defective components. This warranty does not include the replacement of refrigerant lost from the unit after shipment from the point of manufacture. On machinery and materials furnished by ROWALD, but manufactured by others, ROWALD will extend the same warranty it receives from the manufacturer. No liability shall be attached to ROWALD until said ROWALD machinery or materials have been paid for, and then said liability shall be limited to the cost of repairing or replacing said defective products or components.

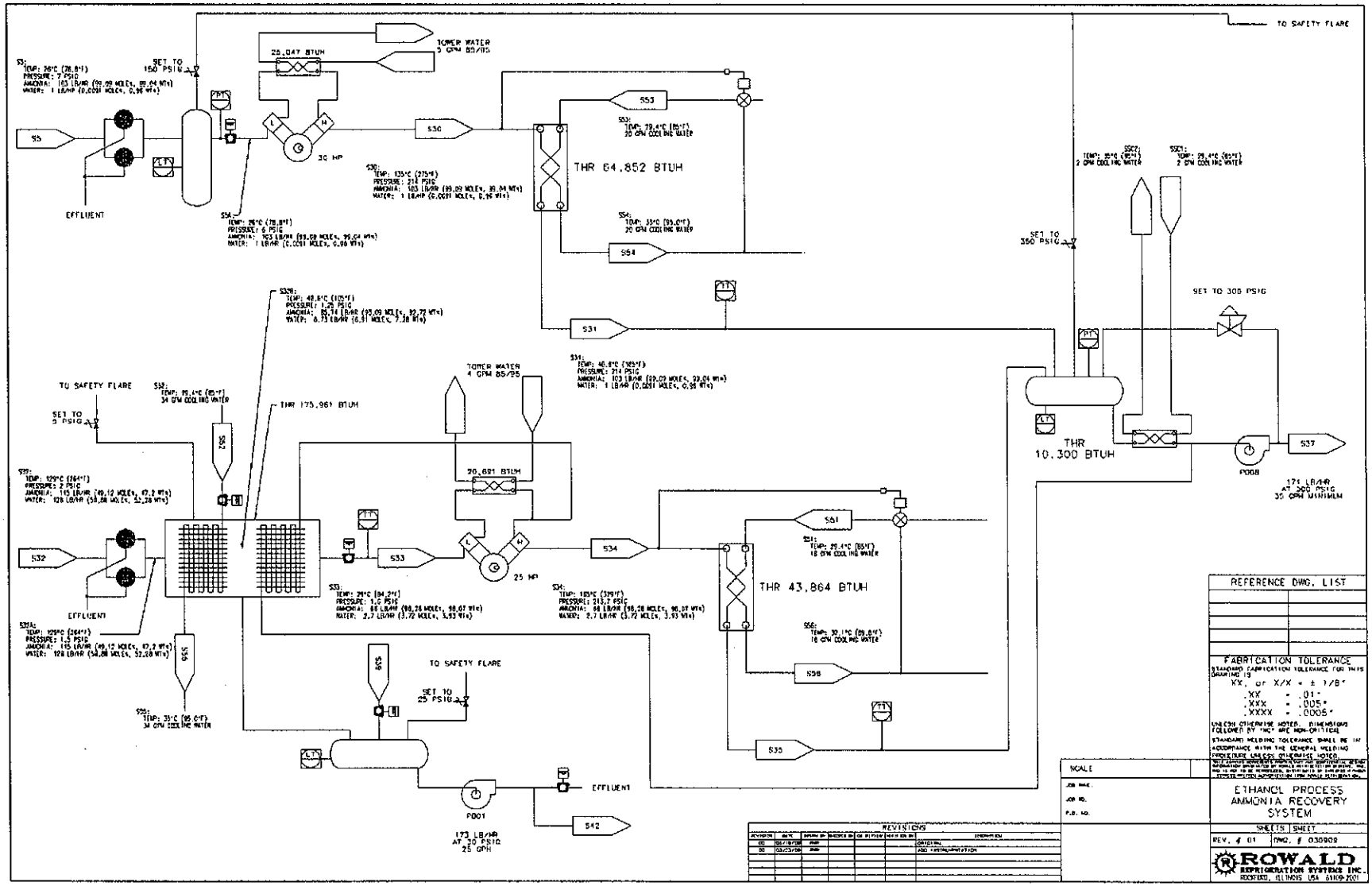
THE WARRANTY AND LIABILITY SET FORTH ABOVE ARE IN LIEU OF ALL OTHER WARRANTIES AND LIABILITIES EXPRESSED OR IMPLIED, IN LAW OR IN FACT, INCLUDING THE WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, IN NO EVENT SHALL ROWALD BE LIABLE FOR ANY INCIDENTAL OR CONSEQUENTIAL DAMAGES.

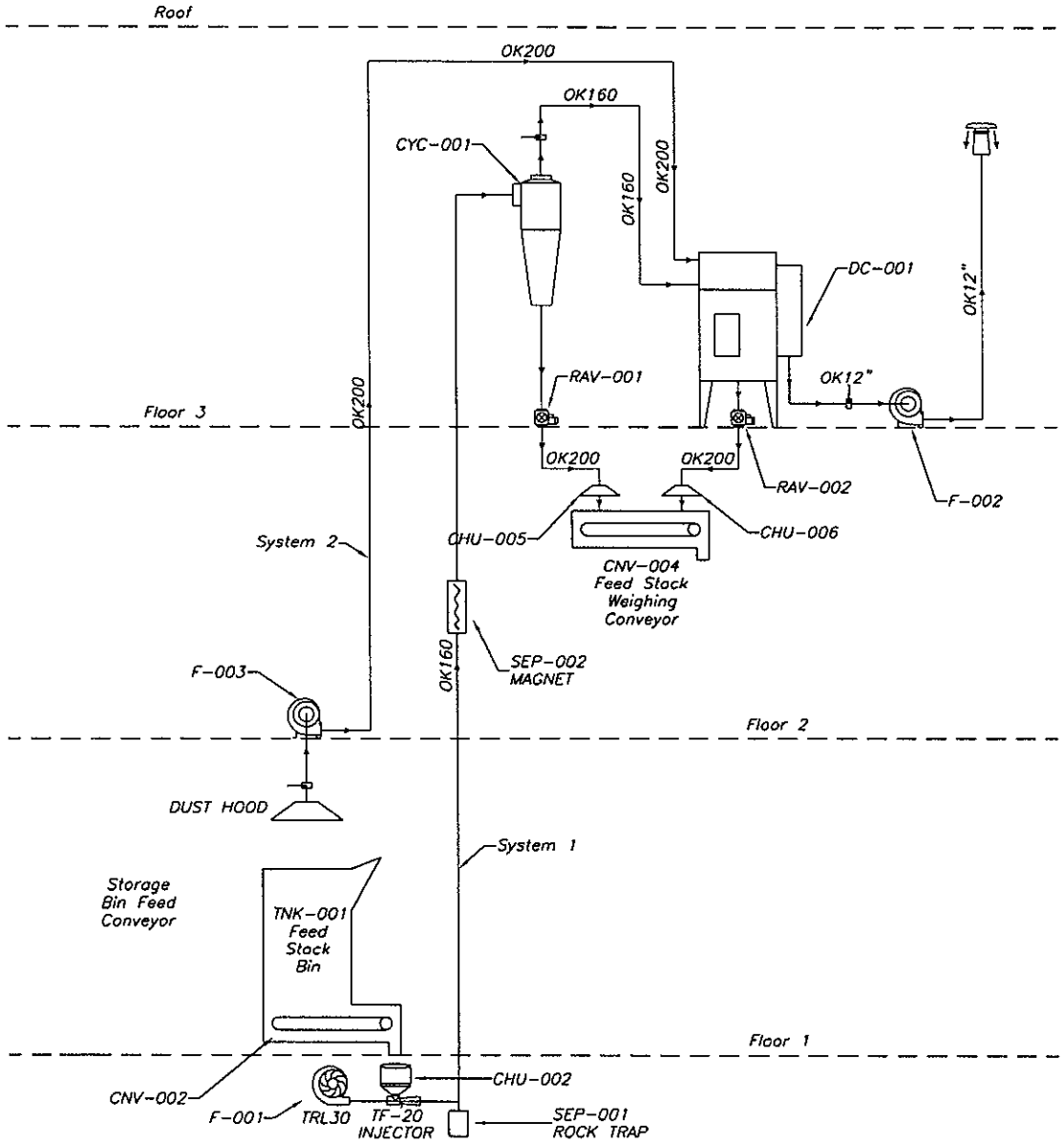
ROWALD REFRIGERATION reserves the right to change or supersede products or part numbers of any product ordered due to changes in design, processing, or material content.

Thank you for your consideration,

Robert W. Rowald

Robert W. Rowald


TO SAFETY FLARE
TOWER WATER
3 GPM 85/95
28,047 BTUH
SET TO
150 PSIG
S5
EFFLUENT
30 HP
S30
THR 64,852 BTUH
S53
S54
SET TO
350 PSIG
SET TO 300 PSIG
S31
TOWER WATER
4 GPM 85/95
THR 175,961 BTUH
TO SAFETY FLARE
SET TO
5 PSIG
S32
S37
THR
10,300 BTUH
P008
171 LB/HR
AT 300 PSIG
35 GPM MINIMUM
20,691 BTUH
S61
S33
S34
25 HP
THR 43,864 BTUH
S58
S35
TO SAFETY FLARE
SET TO
25 PSIG
EFFLUENT
P001
173 LB/HR
AT 20 PSIG
25 GPM
S42
REFERENCE DWG. LIST
FABRICATION TOLERANCE
SCALE
ETHANOL PROCESS
AMMONIA RECOVERY
SYSTEM
REVISIONS
ROWALD
REFRIGERATION SYSTEMS INC.
ROCKFORD, ILLINOIS USA 61109-2021



Blower TRL30 – 3hp

Blower MTD25 – 5hp

KM35 Cyclone

RFE20 Rotary Valve

Torit DFO2-4 Dust Collector w. Explosion Vent

Manual Slide Gate

Explosion Vent Exit

Air Diffuser

6" INLINE MAGNET

CHU-002 HOPPER EXT. CHUTE

ROCKTRAP

Material Specifications:

System 1:
Material: Corn Stover
Bulk density: 4 lbs/cu.ft.
Rate: 220 lbs/hr

System 2:
Material: Dust

System Specifications:

System 1:
Max. vertical conveying distance: 30'
Max. horizontal conveying distance: 10'
Max. no. of bends: 3 pcs.

System 2:
Max. vertical conveying distance: 30'
Max. horizontal conveying distance: 10'
Max. no. of bends: 3 pcs.

Rev.:	Date:	Ini.:	Revision:
A	19.03.09	JSG	COSMETIC CHANGES

Approved for Construction by: Date:

Approved by Customer: Date:

KONGSKILDE

KONGSKILDE INDUSTRIES INC.
EXETER, ONTARIO, CANADA
TEL: 519-235-0540
FAX: 519-235-2931

Project name:

Scale: –

Format: A2

Plant:
Pneumatic Conveying System
for Loose Bulk Corn Fibre
Flow Diagram

Drawn: JSG

Check:

Date: 19.03.09

Replaces:

Replaced by:

Client:
Dick Engineering
USA

Project No.: KUSI.840.555.02

Drawing No.:

Rev.:

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Bēpex

March 11, 2009

Dick Engineering Inc.
1 Concorde Gate, Suite 500
Toronto, Ontario
Canada M3C 3N6
Attn: Zaheer Khalfan

Reference: Our Budget Quotation M-09-B-13576-F

Zaheer,

Thank you for your interest in Bepex processing equipment. As per your request, we have updated the previous budgetary pricing for a Bepex dryer and vacuum pump to extract ammonia from your corn stover treatment process. To review, our equipment sizing was based on the following information.

Feed Material:	Corn Stover
Feed Rate:	556 lb/hr
Feed Temperature:	26 °C
Feed Moisture:	40% water / 20% ammonia
Product Temperature:	80 °C
Operating Pressure:	- 0.2 atm
Product Moisture:	15% water / 2% ammonia
Steam Pressure/Temperature:	125 psig / 350°F

For this application we recommended our Solidaire model SJS 30-12, with the following design parameters:

Heat Transfer Area:	94 ft2
Motor Size (each):	75 hp
Vessel Pressure Rating:	+/- 5 psig
Jacket Pressure Rating:	150 psig
Estimated Dimensions:	215 inches long
(w/o drive)	48 inches wide
	48 inches high
Estimated Weight (w/o drive):	5,500 lbs

Bepex International LLC
333 Taft Street NE, Minneapolis, MN 55413 USA
p: +1.612.331.4370 f: +1.612.627.1444 www.bepex.com

Bēpex

Updated budgetary pricing for our SJS 30-12, manufactured in 316L stainless steel, is $275,000 (±20%). This budget pricing includes the vacuum blower with variable frequency drive, discharge rotary airlock, drive, gas purged seals, and an OSHA approved guard.

To confirm this budgetary pricing we require testing of your material in Bepex's pilot laboratory located in Minneapolis, MN.

Please note the following items are not included in this quotation:

Feeding and Product Collection Equipment	Installation
Insulation	Controls
Piping and Ductwork	Start-up Support
Steam Boilers	Spare Parts

If you have any questions or need additional information, please don't hesitate to contact me at 612-627-1449 or via email at sanderson@bepex.com.

Regards,

Spencer Anderson
Application Engineer

Bepex International LLC
333 Taft Street NE, Minneapolis, MN 55413 USA
p: +1.612.331.4370 f: +1.612.627.1444 www.bepex.com

KONGSKILDE

March 20, 2009
Area: 213
QT#DR09-164-**01 Revised**

Mr. Zaheer Khalfan
Dick Engineering Inc.
Suite 500
Concorde Gate
Toronto, Ontario
M3C 3N6
Ph: # (416) 391-2322
Fax: # (416) 391-3133

Zaheer,

We are pleased to have this opportunity to present you with this proposal for a pneumatic conveyor system to transport corn stover from your TNK-001 feed stock bin to the CNV-004 feed stock weighing conveyor.

	Material to be conveyed:	Corn Stover
	Capacity:	220 lbs/hr.
	Bulk Density:	4 lbs/cubic/ft.
Criteria:	Vertical Distance:	30'
	Horizontal Distance:	10'
	Elbows in Line:	3
	Pipe Size:	160mm"
	Type of System:	# 1 Pressure / # 2 Vacuum

System consists of the following equipment:

EDP#	QUANTITY	DESCRIPTION	TAG #
121220045	1	TRL-30 BLOWER c/w **3HP**, 3ph, **460 volt**	F-001
125300025	2	MTD-25 BLOWER c/w **5HP** 3ph, **460 volt**	F-002 / F-003
9254335224	1	KM35 CYCLONE	CYC-001
9254335022	2	RFE-20 ROTARY VALVE c/w **1HP**, 3ph, **460 volt**, 53RPM	RAV-001 / RAV-002
699116974	1	DFO 2-4 DUST COLLECTION UNIT	DC-001
121111010	1	OK160 TF-20 INJECTOR	CHU-002
699117xxx	1	OK160 ROCK TRAP	SEP-001
699117xxx	2	CUSTOM CHUTES	CHU-005 / CHU-006
699117xxx	1	OK160 INLINE MAGNET SECTION OF PIPE	SEP-002
699117xxx	1	FEED STOCK STORAGE BIN W/ 340 FT3 CAPACITY	TNK-001
699117xxx	1	STORAGE BIN DISCHARGE SCREW AUGER	CNV-002
699117xxx	2	**1hp** VFD FOR: RFE-20 ROTARY VALVES	RAV-001 / RAV-002
699117xxx	1	**2hp** VFD FOR: STORAGE BIN DISCHARGE AUGER	CNV-002
		Heavy Equipment Total:	**$70,263.00**

Kongskilde Industries Inc
2439 South Main Unit 2
Bloomington Illinois 61704
USA

Phone 309 820 1090
Fax 309 820 1364
E-mail mail@kus.kongskilde.com
Web www.kongskilde.com

QT#DR09-164-**01** Dick Engineering Inc. – Page 2

One (1) Lot of Kongskilde Piping, Elbows, Clamps, Transitions, Pipe supports and hangers. Plus Engineering. Total: **$22,137.00**

As Per Attached Flow Drawing # KUSI.840.555.02 US Funds Net Total: $92,400.00

Exclusions: motor starters, electrical and mechanical Installations.

Terms: Subject to credit approval
Delivery Time: 4 to 6 weeks subject to stock at time of order.
F.O.B.: Bloomington IL. USA

Taxes: Extra as applicable in your area

Quotation valid for 30 days

Once again, thank you for the quotation opportunity and we look forward to working with you. In the meantime if you have any questions please do not hesitate to contact us.

Regards,

Derek Regier
***KONGSKILDE* INDUSTRIES INC.**
Regional Manager - Central Canada
Ph # 519-263-2610
Fax # 519-263-2622
E-mail: dr@kongskilde.com

KONGSKILDE

March 20, 2009
Area: 212
QT#DR09-165-**01 Revised**

Mr. Zaheer Khalfan
Dick Engineering Inc.
Suite 500
Concorde Gate
Toronto, Ontario
M3C 3N6
Ph: # (416) 391-2322
Fax: # (416) 391-3133

Zaheer,

We are pleased to have this opportunity to present you with this proposal for Mechanical Installation Labor to install a pneumatic conveyor system to transport corn stover from the TNK-001 feed stock bin to the CNV-004 feed stock weighing conveyor.

Re: Mechanical Installation Labor:

All necessary Kongskilde non-union labor for the mechanical installation of the attached proposal **QT#DR09-164 only and drawing # KUSI.840.555.02**

Exclusion of Damages:

Kongskilde Industries Inc. shall not be Liable in contract, in tort, or otherwise, for special, indirect, incidental or consequential damages, such as, but no limited to, damage to or loss of other property or equipment, loss of use of any property or equipment, loss of profits or revenue, loss of capital or claims for business interruption.

Note: Labor is based on an uninterrupted work schedule until the system is completed. Interruptions by Dick Engineering Inc. or delays which cause return trips or unexpected amounts of extra time may necessitate additional labor charges. Kongskilde must be allowed unrestricted access to the project area. Electric power (460 & 110 volt) must be provided in order to complete the installation.

Installation Prices quoted DO NOT INCLUDE any electrical connections.

Quantities shown on the installation lists attached are an estimate on information provided at time of the latest quotation. Should these quantities change due to after purchase design changes, extra charges may apply.

Should these quantities change due to estimating error, no extra charges will apply.

Overages if any are returned to Kongskilde no credits apply.

QT#DR09-165-**01** Dick Engineering Inc.- Page 2

Note: "A" Kongskilde Industries Inc. will supply 2 men for approximately (15) days to install proposal **QT#DR09-164-01 only.**
"B" Dick Eng. Inc. will supply scissor lift and or forklift required to install the system in a safe conduct.
"C" Hole perforations through inside or outside walls, floors or ceilings for piping installation if needed will be preformed by others.
"D" Price is based on clear access above and around the installation location.

Mechanical Labor to Install System QT#DR09-164-01 US Funds Net Total: $23,850.00

Optional:
One Day Start-up and training consists of the following. Installation Location: Michigan USA.

Once everything is installed and operating, Kongskilde will send one (1) qualified technician. This will include one (1) day trial test run and training to debug the system. Plus all travel expenses.

One Day Start-up/per system, Training & Travel Expenses US Funds Net Total: $1,800.00/ea.

Terms: See QT#DR09-164-01 terms of payment
Delivery Time: 4 to 6 weeks
F.O.B.: Bloomington, IL. USA

Taxes: Extra as applicable in your area

Quotation valid for 30 days

Thank you for the quotation opportunity and we look forward to being of service to you.

Sincerely,

Derek Regier
***KONGSKILDE* INDUSTRIES INC.**
Regional Manager
Ph # 519-263-2610
Fax # 519-263-2622

E-mail: dr@kongskilde.com

ThermoFisher
SCIENTIFIC

The world leader
in serving science

March 9, 2009

Dick Engineering
1 Concorde Gate, Suite 500
Toronto, Ontario, Canada
M3C 3N6

Attention: Zaheer Khalfan
Email: zk@dickeng.com

Subject: Thermo Quotation I-6183
Mini Weigh Belt Feeder

We are pleased to quote on the Model 90-150 Mini Weigh Belt Feeder for your consideration:

ITEM	QTY	APPLICATION SPECIFICATIONS:			
1	1	Conveyor Length:	* 6 ft.	Belt Width:	17"
		Capacity:	253 PPF	Material:	Corn Stover
		Belt Speed:	8 FPM	Bulk Density:	4 PCF

* Centerline of inlet to centerline of discharge.

EQUIPMENT PROPOSED:

1.0 Unitized, pre-assembled, belt conveyor complete with:
- 1.1 Steel formed channel frame with legs.
- 1.2 All items will be supplied with premium grade belting with corrugated edge.
- 1.3 6-1/2" diameter knurled, trapazoidal crowned, head pulley with 1-3/16" diameter shaft and Linkbelt or equal, flange bearing.
- 1.4 6-1/2" diameter smooth, trapazoidal crowned tail pulley with 1" diameter shaft and Linkbelt or equal TB Series pillow blocks.
- 1.5 Screw type, tail pulley take-up with 6" of travel.
- 1.6 5/8" diameter stainless steel rod slide bed arrangement.
- 1.7 load hopper with adjustable profile gate.
- 1.8 or equal shaft-mounted gear reducer.
- 1.9 Speed sensor mounted on tail pulley shaft.
- 1.10 Fixed speed ½ HP motor drive 220 VAC, 3PH
- 1.11 Weighted tension roll to provide constant belt tension and provide a guide for belt take-up adjustments.

2.0 Model Single Idler Suspension, unitized carriage/weighbridge assembly to include:
- 2.1 Strain gauge load cell.
- 2.2 Polycarbonate junction box designed to meet NEMA-4X.

3.0 Model 2001 MicroTech Integrator.
- 3.1 (NEMA-4X wall or panel) mount enclosure.
- 3.2 120/240 VAC power
- 3.3 Microprocessor based.
- 3.4 Four line by twenty character alpha-numeric display.
- 3.5 4-20 mA analog output.
- 3.6 Pulse output.
- 3.7 Eight (8) digit totalizer.
- 3.8 Other optional communications available.

4.0 Two (2) instruction manuals for installation, calibration, operation and maintenance of system including all necessary drawings and recommended spare parts lists. Additional manuals at $30.00 each.

Total Price Item 1, Each..... $30,494.00

NOTES TO QUOTATION:

1. Prices quoted are firm subject to receipt of your order within 60 days from the date of this proposal.

2. Field technical assistance available as specified in the attached "Conditions of Service".

3. Thermo warrants the Model 90-150 Feeder System to weigh & totalize to a value of ±1/2% on factory approved installations. Reference brochure for test requirements.

4. This quotation is subject to the terms and conditions on the attachment labeled "Terms and Conditions of Sale" which shall constitute the exclusive terms governing the contracts between us for your order. Also, if applicable, a valid export license may be required for shipment of goods outside the territories of the U.S.A.

5. Thermo Fisher Scientific requires that the following information appear on all purchase orders:
   - Order Addressed to:
     Thermo Ramsey, Inc., 501 90th Avenue N.W., Minneapolis, MN 55433.
   - Your Company Name and Contact Information.
   - Correct Invoicing Information.
   - Net 30 Day Payment Terms.
   - Ex. Works Minneapolis, MN, USA.
   - Freight Prepaid and Added to Invoice.
   - Order Total.
   - Include Tax Certificate if Exempt.
   - Authorized Signature.
   - Remit by Check to:
     Thermo Ramsey, Inc., P.O. Box 711983, Cincinnati, OH 45271-1983.

6. Approximate shipping: 12-14 weeks after receipt of order and release to manufacturing.

Thank you for your interest in Thermo manufactured products and for the opportunity to provide you with this quotation. If after review of the enclosed information you find that you have questions or require additional information, please do not hesitate to contact our office or our representative for your area listed below.

Regards,

John Towers
Sales Application Specialist
Thermo Fisher Scientific
john.towers@thermofisher.com

cc: Thermo Fisher Scientific
P.O. Box 100
14 Gormley Industrial Avenue, Unit #4
Gormley, Ontario
Canada L0H 1G0
Ph: 905-888-8808
Fx: 905-888-8828
Email: john.simpson@thermofisher.com

Thermo Fisher Scientific
If accepted, please furnish the above quoted items at the specified prices.

PURCHASER: _____

BY: _____ DATE: _____

SEE TERMS & CONDITIONS ON THE FOLLOWING PAGES

THERMO RAMSEY

TERMS AND CONDITIONS OF SALE

UNLESS OTHERWISE EXPRESSLY AGREED IN WRITING, ALL SALES ARE SUBJECT TO THE FOLLOWING TERMS AND CONDITIONS:

1. GENERAL. **Thermo Ramsey** ("Seller") hereby offers for sale to the buyer named on the face hereof ("Buyer") the products listed on the face hereof (the "Products") on the express condition that Buyer agrees to accept and be bound by the terms and conditions set forth herein. Any provisions contained in any document issued by Buyer are expressly rejected and if the terms and conditions in this Agreement differ from the terms of Buyer's offer, this document shall be construed as a counter offer and shall not be effective as an acceptance of Buyer's document. Buyer's receipt of Products or Seller's commencement of the services provided hereunder will constitute Buyer's acceptance of this Agreement. This is the complete and exclusive statement of the contract between Seller and Buyer with respect to Buyer's purchase of the Products. No waiver, consent, modification, amendment or change of the terms contained herein shall be binding unless in writing and signed by Seller and Buyer. Seller's failure to object to terms contained in any subsequent communication from Buyer will not be a waiver or modification of the terms set forth herein. All orders are subject to acceptance in writing by an authorized representative of Seller.

2. PRICE. All prices published by Seller or quoted by Seller's representatives may be changed at any time without notice. All prices quoted by Seller or Seller's representatives are valid for thirty (30) days, unless otherwise stated in writing. All prices for the Products will be as specified by Seller or, if no price has been specified or quoted, will be Seller's price in effect at the time of shipment. All prices are subject to adjustment on account of specifications, quantities, raw materials, cost of production, shipment arrangements or other terms or conditions which are not part of Seller's original price quotation.

3. TAXES AND OTHER CHARGES. Prices for the Products exclude all sales, value added and other taxes and duties imposed with respect to the sale, delivery, or use of any Products covered hereby, all of which taxes and duties must by paid by Buyer. If Buyer claims any exemption, Buyer must provide a valid, signed certificate or letter of exemption for each respective jurisdiction.

4. TERMS OF PAYMENT. Seller may invoice Buyer upon shipment for the price and all other charges payable by Buyer in accordance with the terms on the face hereof. If no payment terms are stated on the face hereof, payment shall be net thirty (30) days from the date of invoice. If Buyer fails to pay any amounts when due, Buyer shall pay Seller interest thereon at a periodic rate of one and one-half percent (1.5%) per month (or, if lower, the highest rate permitted by law), together with all costs and expenses (including without limitation reasonable attorneys' fees and disbursements and court costs) incurred by Seller in collecting such overdue amounts or otherwise enforcing Seller's rights hereunder. Seller reserves the right to require from Buyer full or partial payment in advance, or other security that is satisfactory to Seller, at any time that Seller believes in good faith that Buyer's financial condition does not justify the terms of payment specified. All payments shall be made in U.S. Dollars.

5. DELIVERY; CANCELLATION OR CHANGES BY BUYER. The Products will be shipped to the destination specified by Buyer, F.O.B. Seller's shipping point. Seller will have the right, at its election, to make partial shipments of the Products and to invoice each shipment separately. Seller reserves the right to stop delivery of Products in transit and to withhold shipments in whole or in part if Buyer fails to make any payment to Seller when due or otherwise fails to perform its obligations hereunder. All shipping dates are approximate only, and Seller will not be liable for any loss or damage resulting from any delay in delivery or failure to deliver which is due to any cause beyond Seller's reasonable control. In the event of a delay due to any cause beyond Seller's reasonable control, Seller reserves the right to terminate the order or to reschedule the shipment within a reasonable period of time, and Buyer will not be entitled to refuse delivery or otherwise be relieved of any obligations as the result of such delay. Products as to which delivery is delayed due to any cause within Buyer's control may be placed in storage by Seller at Buyer's risk and expense and for Buyer's account. Orders in process may be canceled only with Seller's written consent and upon payment of Seller's cancellation charges. Orders in process may not be changed except with Seller's written consent and upon agreement by the parties as to an appropriate adjustment in the purchase price therefor. Credit will not be allowed for Products returned without the prior written consent of Seller.

6. TITLE AND RISK OF LOSS. Notwithstanding the trade terms indicated above and subject to Seller's right to stop delivery of Products in transit, title to and risk of loss of the Products will pass to Buyer upon delivery of possession of the Products by Seller to the carrier; provided, however, that title to any software incorporated within or forming a part of the Products shall at all times remain with Seller or the licensor(s) thereof, as the case may be.

7. WARRANTY. Seller warrants that the Products will operate or perform substantially in conformance with Seller's published specifications and be free from defects in material and workmanship, when subjected to normal, proper and intended usage by properly trained personnel, for the period of time set forth in the product documentation, published specifications or package inserts. If a period of time is not specified in Seller's product documentation, published specifications or package inserts, the warranty period shall be one (1) year from the date of shipment to Buyer for equipment and ninety (90) days for all other products (the "Warranty Period"). Seller agrees during the Warranty Period, to repair or replace, at Seller's option, defective Products so as to cause the same to operate in substantial conformance with said published specifications; provided that Buyer shall (a) promptly notify Seller in writing upon the discovery of any defect, which notice shall include the product model and serial number (if applicable) and details of the warranty claim; and (b) after Seller's review, Seller will provide Buyer with service data and/or a Return Material Authorization ("RMA"), which may include biohazard decontamination procedures and other product-specific handling instructions, then, if applicable, Buyer may return the defective Products to Seller with all costs prepaid by Buyer. Replacement parts may be new or refurbished, at the election of Seller. All replaced parts shall become the property of Seller. Shipment to Buyer of repaired or replacement Products shall be made in accordance with the Delivery provisions of the Seller's Terms and Conditions of Sale. Consumables are expressly excluded from this warranty.

Notwithstanding the foregoing, Products supplied by Seller that are obtained by Seller from an original manufacturer or third party supplier are not warranted by Seller, but Seller agrees to assign to Buyer any warranty rights in such Product that Seller may have from the original manufacturer or third party supplier, to the extent such assignment is allowed by such original manufacturer or third party supplier.

In no event shall Seller have any obligation to make repairs, replacements or corrections required, in whole or in part, as the result of (i) normal wear and tear, (ii) accident, disaster or event of force majeure, (iii) misuse, fault or negligence of or by Buyer, (iv) use of the Products in a manner for which they were not designed, (v) causes external to the Products such as, but not limited to, power failure or electrical power surges, (vi) improper storage and handling of the Products or (vii) use of the Products in combination with equipment or software not supplied by Seller. If Seller determines that Products for which Buyer has requested warranty services are not covered by the warranty hereunder, Buyer shall pay or reimburse Seller for all costs of investigating and responding to such request at Seller's then prevailing time and materials rates. If Seller provides repair services or replacement parts that are not covered by this warranty, Buyer shall pay Seller therefor at Seller's then prevailing time and materials rates. ANY INSTALLATION, MAINTENANCE, REPAIR, SERVICE, RELOCATION OR ALTERATION TO OR OF, OR OTHER TAMPERING WITH, THE PRODUCTS PERFORMED BY ANY PERSON OR ENTITY OTHER THAN SELLER WITHOUT SELLER'S PRIOR WRITTEN APPROVAL, OR ANY USE OF REPLACEMENT PARTS NOT SUPPLIED BY SELLER, SHALL IMMEDIATELY VOID AND CANCEL ALL WARRANTIES WITH RESPECT TO THE AFFECTED PRODUCTS.

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Notwithstanding the above, Seller's infringement related indemnification obligations shall be extinguished and relie if Seller, at its discretion and at its own expense (a) procures for Buyer the right, at no additional expense to Buyer continue using the Product; (b) replaces or modifies the Product so that it becomes non-infringing, provided modification or replacement does not adversely affect the specifications of the Product; or (c) in the event (a) and (b) not practical, refund to Buyer the amortized amounts paid by Buyer with respect thereto, based on a five (5) y amortization schedule. THE FOREGOING INDEMNIFICATION PROVISION STATES SELLER'S ENTI LIABILITY TO BUYER FOR THE CLAIMS DESCRIBED HEREIN.

8.2 By Buyer. Buyer shall indemnify, defend with competent and experienced counsel and hold harml Seller, its parent, subsidiaries, affiliates and divisions, and their respective officers, directors, shareholders employees, from and against any and all damages, liabilities, actions, causes of action, suits, claims, demands, loss costs and expenses (including without limitation reasonable attorneys' fees and disbursements and court costs) to extent arising from or in connection with (i) the negligence or willful misconduct of Buyer, its agents, employe representatives or contractors; (ii) use of a Product in combination with equipment or software not supplied by Sel where the Product itself would not be infringing; (iii) Seller's compliance with designs, specifications or instructi supplied to Seller by Buyer; (iv) use of a Product in an application or environment for which it was not designed; or modifications of a Product by anyone other than Seller without Seller's prior written approval.

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10. LIMITATION OF LIABILITY. NOTWITHSTANDING ANYTHING TO THE CONTRARY CONTAIN HEREIN, THE LIABILITY OF SELLER UNDER THESE TERMS AND CONDITIONS (WHETHER BY REAS OF BREACH OF CONTRACT, TORT, INDEMNIFICATION, OR OTHERWISE, BUT EXCLUDING LIABIL OF SELLER FOR BREACH OF WARRANTY (THE SOLE REMEDY FOR WHICH SHALL BE AS PROVID UNDER SECTION 7 ABOVE)) SHALL NOT EXCEED AN AMOUNT EQUAL TO THE LESSER OF (A) T TOTAL PURCHASE PRICE THERETOFORE PAID BY BUYER TO SELLER WITH RESPECT TO T PRODUCT(S) GIVING RISE TO SUCH LIABILITY OR (B) ONE MILLION DOLLARS ($1,000,0 NOTWITHSTANDING ANYTHING TO THE CONTRARY CONTAINED HEREIN, IN NO EVENT SHA SELLER BE LIABLE FOR ANY INDIRECT, SPECIAL, CONSEQUENTIAL OR INCIDENTAL DAMAG (INCLUDING WITHOUT LIMITATION DAMAGES FOR LOSS OF USE OF FACILITIES OR EQUIPMENT, LO OF REVENUE, LOSS OF DATA, LOSS OF PROFITS OR LOSS OF GOODWILL), REGARDLESS OF WHETH SELLER (a) HAS BEEN INFORMED OF THE POSSIBILITY OF SUCH DAMAGES OR (b) IS NEGLIGENT.

11. EXPORT RESTRICTIONS Buyer acknowledges that each Product and any related software and technolo including technical information supplied by Seller or contained in documents (collectively "Items"), is subject to exp controls of the U.S. government. The export controls may include, but are not limited to, those of the Exp Administration Regulations of the U.S. Department of Commerce (the "EAR"), which may restrict or require licen for the export of Items from the United States and their re-export from other countries. Buyer shall comply with EAR and all other applicable laws, regulations, laws, treaties, and agreements relating to the export, re-export, import of any Item. Buyer shall not, without first obtaining the required license to do so from the appropriate U government agency; (i) export or re-export any Item, or (ii) export, re-export, distribute or supply any Item to restricted or embargoed country or to a person or entity whose privilege to participate in exports has been denied restricted by the U.S. government. Buyer shall cooperate fully with Seller in any official or unofficial audit or inspect related to applicable export or import control laws or regulations, and shall indemnify and hold Seller harmless from, in connection with, any violation of this Section by Buyer or its employees, consultants, agents, or customers.

12. MISCELLANEOUS. (a) Buyer may not delegate any duties nor assign any rights or claims hereunder without Seller's prior written consent, and any such attempted delegation or assignment shall be void. (b) The rights and obligations of the parties hereunder shall be governed by and construed in accordance with the laws of the State of Seller's manufacturing location, without reference to its choice of law provisions. Each party hereby irrevocably consents to the exclusive jurisdiction of the state and federal courts located in the county and state of Seller's manufacturing location, in any action arising out of or relating to this Agreement and waives any other venue to which it may be entitled by domicile or otherwise. (c) In the event of any legal proceeding between the Seller and Buyer relating to this Agreement, neither party may claim the right to a trial by jury, and both parties waive any right they may have under applicable law or otherwise to a right to a trial by jury. Any action arising under this Agreement must be brought within one (1) year from the date that the cause of action arose. (d) The application to this Agreement of the U.N. Convention on Contracts for the International Sale of Goods is hereby expressly excluded. (e) In the event that any one or more provisions contained herein shall be held by a court of competent jurisdiction to be invalid, illegal or unenforceable in any respect, the validity, legality and enforceability of the remaining provisions contained herein shall remain in full force and effect, unless the revision materially changes the bargain. (f) Seller's failure to enforce, or Seller's waiver of a breach of, any provision contained herein shall not constitute a waiver of any other breach or of such provision. (g) Unless otherwise expressly stated on the Product or in the documentation accompanying the Product, the Product is intended for research only and is not to be used for any other purpose, including without limitation, unauthorized commercial uses, *in vitro* diagnostic uses, *ex vivo* or *in vivo* therapeutic uses, or any type of consumption by or application to humans or animals. (h) Buyer agrees that all pricing, discounts and technical information that Seller provides to Buyer are the confidential and proprietary information of Seller. Buyer agrees to (1) keep such information confidential and not disclose such information to any third party, and (2) use such information solely for Buyer's internal purposes and in connection with the Products supplied hereunder. Nothing herein shall restrict the use of information available to the general public. (i) Any notice or communication required or permitted hereunder shall be in writing and shall be deemed received when personally delivered or three (3) business days after being sent by certified mail, postage prepaid, to a party at the address specified herein or at such other address as either party may from time to time designate to the other.

Farzaneh Teymouri

From: Norm Miller [normm@fedmac.com]
Sent: Friday, April 10, 2009 11:50 AM
To: Farzaneh Teymouri
Subject: Re: pelletizer

Farzaneh Teymouri wrote:
>
> Dear Norm,
>
> This is Farzaneh Teymouri from MBI. I got your contact information
> from Dr. Dale's group. MBI and MSU are planning to send a proposal to
> DOE in respond to their recent FOA for almost $22.5 million for
> building a pilot plant scale biorefinery for conversion of corn stover
> to ethanol using AFEX process. Pelletizing the AFEX treated biomass is
> part of our proposed process. We need to estimate the capitol cost for
> that portion. The required capacity for the pilot plant is minimum of
> 1 ton per day.
>
> If you don't mind I would like to call you and discuss some detail
> about our proposal and see if you can provide us with a quote for a
> pelletizer in our capacity range.
>
> Would you please let me know how and when I can contact you.
>
> Thank you in advance
>
> Farzaneh Teymouri
>
Hello:
Yes do call me - mid day is about the best.
What we are building are "ComPAKers" (2 different styles 3 different series) These are Biomass compaction machines. Our main unit will do 10 tons per hour.
I have designed "PAK's" for 2 and 1/2 years. There are MANY uses for corn stover and many other Biomass materials.
You call me and we will visit. I would guess we have a smaller proto-type here we could delivery in about 6 weeks at approx. $60,000
But lets talk and see what is needed.

Norm Miller
Plant Superintendent / HR
Federal Machine Company

Director of Sales and Marketing
Chief Researcher - BioPAKs
ComPAKco LLC.

701-282-8134

.E OF CONTENTS

HEDULE A	Schedule A - Summary of Claimed Indirect Rates
PROFIT & LOSS	Profit & Loss for FY2008
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Summary Sched H	Summary Schedule H - Direct Grant/Contract/Subcontract Costs/FUND/B&P SUMMARIZES SCHEDULE H DIRECT COSTS AND LINKS TO OTHER SCHEDULES
SCHEDULE H	Schedule H- Direct Cost by Grant/Contract/Subcontract,FUND/B&P Direct Incurred, and Indirect Expense Applied at Claimed Rates (USE SUMMARY SCHEDULE H TO SUMMARIZE DIRECT COSTS USED IN BASES TO COMPUTE RATES)
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SCHEDULE K	Schedule K- Not Included; No T&M/Labor Hour Contracts
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SCHEDULE P	Schedule P- Not Included

SCHEDULE A

Schedule A is linked to the following schedules:
Schedule C, Overhead
Schedule B, G&A
Schedule E
Schedule E-1

MBI INTERNATIONAL
LANSING, MI

Summary of Claimed Indirect Rates
Fiscal Year End 6/30/08

COST ELEMENT	CLAIMED	REFERENCE
O/H		
POOL	1,067,240	SCHED C
BASE	1,559,658	SCHED E
O/H RATE	68.43%	
G & A		
POOL	959,902	SCHED B
BASE	1,559,658	SCHED E
G& A RATE	61.55%	
COMMON FRINGE		
POOL	264,127	SCHED E-1
BASE	1,885,368	SCHED E
FRINGE RATE	14.01%	
FULL TIME FRINGE		
POOL	490,046	SCHED E-1
BASE	1,848,435	SCHED E
FRINGE RATE	26.51%	

Schedule B is linked to the following schedules:
P&L
SCHED E

SCHEDULE B

MBI INTERNATIONAL
LANSING, MI

General & Administrative (G&A) Expenses
Fiscal Year End 6/30/08

ACCOUNT NUMBER	DESCRIPTION	G&A TOTAL PER G/L	ADJUSTMENT	CLAIMED	NOTES	Reference
	Salaries and Wages	501,575		501,575		P&L
	Fringe Rate Applied to Labor	203,241		203,241		SCHED E
	Bonuses	23,787		23,787		P&L
	Travel	6,316	(998)	5,318	1	"
	Supplies	7,101		7,101		"
	Consulting	179,686		179,686		"
	Bank/Payroll Fees	6,760		6,760		"
	Printing	3,963		3,963		"
	Computer Data Info Services	3,920		3,920		"
	Freight/Courier	901		901		"
	Legal	5,016	(5,016)	-	2	"
	Maintenance Agreements	3,634		3,634		"
	Equipment Rental	883		883		"
	Other Services	11,286		11,286		"
	Insurance	2,688		2,688		"
	Utilities	5,043		5,043		"
	Amortization	45,796	(45,796)	-	2	"
	Provision for loan Loss	249,092	(249,092)	-	3	"
	Abandon Technology	88,601	(88,601)	-	4	"
	Equity in Loss of Subsidiaries	(51,958)	51,958	-	5	"
	Bad Debt	5,000	(5,000)	-	6	"
	Gain/Loss Asset Disposal	667	(667)	-	7	"
	Miscellaneous	(327)	443	116	8	"
	Royalties	36,972	(36,972)	-	9	"
	SUBTOTAL	1,339,641	(379,739)	959,902		
	Bus Dev/Mkt Mat'l,Trvl,ODC	83,628	(83,628)	-	10	P&L
	Bus Dev/Mkt Labor	29,456	(29,456)	-	10	"
	Bus Dev/Mkt Benefit on Labor	7,423	(7,423)	-	10	SCHED E
	TOTAL G & A EXPENSE POOL	1,460,149	(500,247)	959,902		

Explanatory Notes:

1. Unallowable Entertainment costs per FAR 31.205-14
2. Unallowabe patent costs per FAR 31.205-30
3. Unallowable Provision for Loan Loss per OMB Circular A122
4. Unallowabe patent costs per FAR 31.205-30
5. Unallowable Equity in Loss of Subsidiaries per OMB Circular A122
6. Unallowable Bad Debt costs per FAR 31.205-3
7. Unallowable Gain/Loss Asset Disposal costs per FAR 31.205-16
8. Unallowable Late Fees and Miscellaneous per OMB Circular A122
9. Unallowable Royalty costs per FAR 31.205-37
10. Unallowabe marketing and public relations costs per FAR 31.205-1

Schedule C is linked to the following schedules:
P&L

SCHEDULE C

MBI INTERNATIONAL
LANSING, MI

Overhead Expenses
Fiscal Year End 6/30/08

ACCOUNT NUMBER	DESCRIPTION	TOTAL PER G/L & TRIAL BAL/FS	ADJUSTMENTS	CLAIMED	Notes	Ref.
	Salaries and Wages	240,667		240,667		P&L
	Fringe Rate Applied to Labor	97,520		97,520		"
	Travel	2,475		2,475		"
	Supplies	86,962		86,962		"
	Consulting	15,402		15,402		"
	Printing	(4,876)		(4,876)		"
	Computer Data Info Services	1,271		1,271		"
	Freight/Courier	4,037		4,037		"
	Maintenance Agreements	2,956		2,956		"
	Equipment Rental	9,379		9,379		"
	Other Services	8,999		8,999		"
	Insurance	25,362		25,362		"
	Rent	500,000		500,000		"
	Utilities	8,446		8,446		"
	Depreciation	247,104	(182,477)	64,627	1	"
	Facilities expense	3,358		3,358		"
	Miscellaneous	656		656		"
	Total Overhead Pool	1,249,717	(182,477)	1,067,240		

Explanatory Notes:

1. Unallowable Gov't Depreciation costs per FAR 31.205-11

Schedule E is linked to the following schedules:
P&L
Schedule C, Overhead
Schedule B, G&A
SCHED E-1
Summary SCHED H
SCHED H

MBI INTERNATIONAL
LANSING, MI

SCHEDULE E

CLAIMED ALLOCATION BASES
Fiscal Year End 6/30/08

	PER G/L, F/S & TRIAL BAL/FS	PER G/L ADJUSTMENTS	CLAIMED	Notes	Ref.
Overhead Pool	1,249,717	(182,477)	1,067,240		SCHED C
Overhead Base:					
Total Contract/Grant Labor	1,106,827		1,106,827		Summary SCHED H
Total Contract/Grant Benefit	443,215		443,215		"
FUND Labor	2,315		2,315		"
FUND Benefit	938		938		"
B&P Labor	4,528		4,528		"
B&P Benefit	1,835		1,835		"
Total Overhead Base	1,559,658	-	1,559,658		
Overhead Rate	80.13%		68.43%		
G & A Pool	1,460,149	(500,247)	959,902		SCHED B
G & A Base:					
Total Contract/Grant Labor	1,106,827		1,106,827		Summary SCHED H
Total Contract/Grant Benefit	443,215		443,215		"
FUND Labor	2,315		2,315		"
FUND Benefit	938		938		"
B&P Labor	4,528		4,528		"
B&P Benefit	1,835		1,835		"
Subtotal = DIRECT COSTS	1,559,658	-	1,559,658		
G&A Rate			61.55%		
Common Fringe Benefit Pool	264,127	-	264,127		SCHED E-1
Full Time Fringe Benefit Pool	490,046	-	490,046		SCHED E-1
Common Fringe Benefit Base:					
Direct Full-Time Labor			1,086,915		SCHED H
Direct Part-Time Labor			19,912		"
G&A Full-Time Labor			499,223		SCHED B
G&A Part-Time Labor			2,351		
Overhead Full-Time Labor			240,667		P&L
Overhead Part-Time Labor			-		"
FUND Full-Time Labor			2,315		SCHED H
IR&D Full-Time Labor			12,435		P&L
IR&D Part-Time Labor			17,021		"
B&P Full-Time Labor			4,528		SCHED H
Total Benefit Base			1,885,368		
Benefit Rate			14.01%		
Full Time Benefit Base:					
Direct Labor			1,086,915		SCHED H
G&A Labor			501,575		SCHED B
Overhead Labor			240,667		SCHED C
FUND Labor			2,315		SCHED H
IR&D Labor			12,435		P&L
B&P Labor			4,528		SCHED H
Total Benefit Base			1,848,435		
Benefit Rate			26.51%		

Schedule E-1 is linked to the following schedules:
P&L

MBI INTERNATIONAL
LANSING, MI

SCHEDULE E-1

Benefit Expenses
Fiscal Year End 6/30/08

ACCOUNT	DESCRIPTION	PER G/L	ADJUSTMENTS	CLAIMED COSTS	Notes	Ref.
8100-01-100:	Workers Comp Insurance	19,744		19,744		P&L
8100-01-101:	Unemployment Insurance	22,350		22,350		"
8100-01-102:	Employer FICA Tax	153,275		153,275		"
8100-01-103:	Pension Expense	62,753		62,753		"
8100-02-100:	Holiday Gala	2,790		2,790		"
8100-02-102:	Other Employee Events	365		365		"
8100-03-101	Service Awards	2,550		2,550		"
8100-03-102	Patent Awards	300		300		"
	Total Common Fringe Benefit Pool	264,127	-	264,127		
8120-01-101:	Health Insurance	186,412		186,412		"
8120-01-102:	Dental Insurance	21,751		21,751		"
8120-01-103:	Life Insurance	7,732		7,732		"
8120-01-104:	Long Term Disability Ins	(1)		(1)		"
8120-02-101:	Leave	184,990		184,990		"
8120-02-102:	Personal Holiday	7,348		7,348		"
8120-02-103:	Company Holiday	64,322		64,322		"
8120-02-200:	ST Disability Wages	12,949		12,949		"
8120-03-102	FSA Expenses	3,059		3,059		"
8120-03-103	Jury Duty	192		192		"
8120-03-150	Other Benefits	1,291		1,291		"
	Total Full Time Fringe Benefit Pool	490,046	-	490,046		
		754,173	-	754,173		

Schedule G is linked to the following schedule:
P&L
SCHED H

SCHEDULE G

MBI INTERNATIONAL
LANSING, MI

RECONCILIATION OF BOOKS OF ACCOUNT AND CLAIMED DIRECT COSTS
Fiscal Year End 6/30/08

ACCT	DESCRIPTION*	AMOUNT PER GENERAL LEDGER	ADJUSTMENTS	AMOUNT CLAIMED	Notes	Ref.
50XX	Direct Labor	1,106,827		1,106,827		P&L
52XX	Travel	23,158		23,158		"
53XX	Material	165,485		165,485		"
1700-04-XXX	Equipment	98,801		98,801		SCHED H
54XX, 59XX, 56XX	Other Direct Cost	137,564		137,564		P&L
55XX	Subcontracts	-		-		"
	TOTAL DIRECT COSTS	1,531,834	-	1,531,834		

Summary Schedule H is linked from the following schedules:
Schedule H

MBI INTERNATIONAL
LANSING, MI

Summary Schedule H of Direct Grant/Contract/Subcontract/FUND/B&P Costs
Fiscal Year End 6/30/08

DIRECT COST ELEMENTS	CONTRACT/GRANT TOTAL	FUND/B&P TOTAL	GRAND TOTAL	Ref.	Notes
Contract Labor	1,106,827	6,843	1,113,670	SCHED H	
Direct Material	165,353	-	165,353	"	
Travel	23,158	1,253	24,411	"	
Other Direct Costs (ODC)	110,046	183	110,229	"	
Equipment	98,801	-	98,801	"	
Subcontracts	27,565	123,682	151,247	"	
TOTAL DIR. GRANT/CONT COSTS	1,531,749	131,961	1,663,710		
FUND AND B&P COSTS					
FUND Labor	2,315		2,315	SCHED H	
B&P Labor	4,528		4,528	"	
Subtotal FUND&B&P Labor	6,843		6,843		
FUND Benefit	938		938	"	
B&P Benefit	1,835		1,835	"	
FUND Overhead	-		-	"	
B&P Overhead	-		-	"	
FUND Other Costs	121,264		121,264	"	
B&P Other Costs	3,853		3,853	"	
TOTAL IR&D/B&P	134,734		134,734		
TOTAL DIRECT LABOR					
TOTAL GRANT/CONTRACT LABOR			1,106,827		
Total FUND/B&P Labor			6,843		
TOTAL DIRECT/FUND/B&P LABOR			1,113,670		

Schedule H is linked to the following schedules:
Schedule A - Applied Overhead, G&A, & COM Rates
Summary Schedule H
Schedule H-1

Schedule H

MBI INTERNATIONAL
LANSING, MI

Contract Direct Costs by Grant/Contract/Subcontract
And Indirect Expense Applied at Claimed Rates
Fiscal Year End 6/30/08

GRANT/CONTRACT NUMBER		JOB ORDER	LABOR	TRAVEL	MATERIAL	EQUIP	ODCs	CONSULT/ SUBCONT	TOTAL DIRECT COSTS	SCHED A CLAIMED BENEFIT APPLIED	DIRECT COSTS PLUS BENEFIT	UNALLOW	DIRECT COSTS PLUS BENEFIT LESS UNALLOW	SCHED A CLAIMED OVERHEAD APPLIED	DIRECT COSTS PLUS O/H & BENEFIT	SCHED A CLAIMED G &A APPLIED	TOTAL COSTS
A. COST TYPE																	
58-5447-2-315	USDA	1500	104	-	-	-	20	-	124	42	166	-	166	71	237	64	301
DE-FG36-04GO14236	DOE-LSU	1534	191	-	-	-	33	-	225	77	302	-	302	131	433	118	551
DE-FG36-05GO85007	DOE	1550	189	-	-	-	212	-	401	76	478	-	478	129	607	116	723
EM-83295401-0	EPA	1565	631	-	-	-	-	-	631	256	886	-	886	432	1,318	388	1,706
DE-FG36-06GO86031	DOE	1575	1,744	821	1,769	-	1,019	-	5,344	707	6,051	-	6,051	2,414	8,465	2,163	10,628
2006-34524-17132	NDSU	1603	18,356	4,120	266	-	1,695	-	24,436	7,438	31,874	(64)	31,810	12,743	44,553	11,462	56,015
2006-34189-17124	USDA	1607	51,987	6,093	10,660	90,438	6,571	-	165,749	20,984	186,733	(696)	186,037	42,869	228,906	38,559	267,465
58-5447-7-336	USDA-ARS	1615	216,172	5,638	15,549	8,363	1,630	-	247,352	87,582	334,934	(232)	334,702	158,567	493,269	142,624	635,893
DE-FG36-07GO87005	DOE	1618	117,516	2,568	12,912	-	1,546	-	134,543	46,326	180,869	(174)	180,695	89,252	269,947	80,279	350,226
A. TOTAL COST TYPE			406,890	19,240	41,156	98,801	12,728		578,814	163,489	742,303	(1,166)	741,137	306,598	1,047,735	275,773	1,323,508
B. VARIOUS COMMERCIAL WORK																	
	GRT	1007	1,627	-	-	-	1,723	-	3,351	659	4,010	-	4,010	1,114	5,124	1,002	6,126
	Poet	1600	6,070	78	-	-	42	-	6,190	2,460	8,650	-	8,650	4,154	12,804	3,736	16,540
	Overby Farm, LLC	1604	379	-	-	-	-	-	379	154	532	-	532	259	791	233	1,024
	DuPont	1605	149,784	2,592	74,314	-	55,903	-	282,592	60,693	343,286	-	343,286	153,350	496,636	137,932	634,568
	Pasteria Bioscience	1613	10,001	-	1,756	-	435	-	12,193	4,053	16,245	-	16,245	8,046	24,291	7,237	31,528
	UCRP-K	1616	214,301	-	6,077	-	3,238	-	223,616	86,836	310,453	-	310,453	150,805	461,258	135,643	596,901
	MSUF	1617	301,202	1,248	34,801	-	30,619	27,565	395,436	118,156	513,592	-	513,592	229,927	743,519	206,810	950,329
	Poet	1620	14,090	-	1	-	67	-	14,158	5,709	19,867	-	19,867	9,642	29,509	8,673	38,182
	SunEthanol	1627	1,777	-	29	-	-	-	1,807	720	2,527	-	2,527	1,236	3,763	1,112	4,875
	BBIM - General	5100	558	-	-	-	524	-	1,082	226	1,308	-	1,308	382	1,690	343	2,033
	BBIM - Ecosynthetix	5118	40	-	456	-	-	-	496	16	512	-	512	339	851	305	1,156
	BBIM - AFID	5129	-	-	6,634	-	4,590	-	11,224		11,224	-	11,224	4,540	15,764	4,083	19,847
	BBIM - MSU	5131	107	-	33	-	79	-	219	43	262	-	262	95	357	86	443
	BBIM - Rapid Biosense	5135	-	-	95	-	98	-	193		193	-	193	65	258	59	317
B. TOTAL VARIOUS COMMERCIAL WORK			699,937	3,918	124,196		97,319	27,565	952,935	279,726	1,232,661		1,232,661	563,954	1,796,615	507,254	2,303,869
TOTAL GRANT/CONTRACT COSTS			1,106,827	23,158	165,353	98,801	110,046	27,565	1,531,749	443,215	1,974,964	(1,166)	1,973,798	870,552	2,844,350	783,027	3,627,377
FUNDRAISING			2,315	1,253	-	-	-	120,011	123,580	938	124,518	25	124,543				
B& P			4,528	-	-	-	183	3,670	8,381	1,835	10,216	-	10,216				
TOTAL FUND/B&P			6,843	1,253			183	123,682	131,961	2,773	134,734	25	134,759				
GRAND TOTAL			1,113,670	24,411	165,353	98,801	110,229	151,247	1,663,710	445,988	2,109,698	(1,141)	2,108,557				

Explanatory Notes:

1. Unallowable Travel/Entertainment per OMB Circular A122

Schedule H-1 is linked to the following schedules:
Schedule H

MBI INTERNATIONAL
LANSING, MI

Government Participation in Indirect Cost Pools
Fiscal Year End 6/30/08

Contract Type	Overhead Base Amount	%	G&A Base Amount	%	Benefit Base Amount	%	Ref.
Cost Plus FF	-	0.00%	-	0.00%	-	0.00%	SCHED H
Cost-Type	406,890	36.54%	1,047,735	36.84%	406,890	36.54%	"
Commercial	699,937	62.85%	1,796,615	63.16%	699,937	62.85%	"
FUND/B&P	6,843	0.61%	-	0.00%	6,843	0.61%	"
Total	1,113,670	100.00%	2,844,350	100.00%	1,113,670	100.00%	

Schedule I is linked to the following schedules:
Schedule H, Grant/Contract Costs

MBI INTERNATIONAL
LANSING, MI

SCHEDULE I

SCHEDULE OF CUMULATIVE DIRECT AND INDIRECT COSTS CLAIMED AND BILLED
ON COST/FLEXIBLY PRICED AND T&M GRANTS/CONTRACTS AND SUBCONTRACTS
Fiscal Year End 6/30/08

Grant/Contract No.	Order No.	Subject To Penalty Clause note (2)	Prior Years Settled Total Costs note (3)	Unsettled/Claimed Direct And Indirect Costs Using Claimed Prior Year(s) Costs FYE note (4)	Current Year Costs FYE note (4)	Total Cumulative Settled or Claimed	Less Contract Limitations Rebates/Cred note (5)	Net Cumulative Settled or Claimed note (6)	PV No.	Cumulative Billed (Manual Entry) Date Cost Billed Through	Amount	Over (Under) Billing	Physcially Complete
SCHED H					SCHED H								
Cost Type:													
58-5447-2-315	1500	No	-	1,794,350	301	1,794,651	301	1,794,350		4/30/2007	1,794,350	(0)	YES
DE-FG36-04GO14236	1534	No	-	740,625	551	741,176	551	740,625		6/30/2007	740,625	0	YES
DE-FG36-05GO85007	1550	No	-	1,239,500	723	1,240,223	723	1,239,500		6/30/2007	1,239,500	(0)	YES
EM-83295401-0	1565	No	-	193,400	1,706	195,107	1,706	193,400		4/30/2007	193,400	(0)	YES
DE-FG36-06GO86031	1575	No	-	978,846	10,628	989,473	(527)	990,000		10/31/2007	990,000	(0)	YES
2006-34524-17132	1603	No	-	24,643	56,015	80,658	24,205	56,453		6/30/2008	56,596	142	
2006-34189-17124	1607	No	-	189,690	267,465	457,155	81,428	375,727		6/30/2008	377,942	2,215	
58-5447-7-336	1615	No	-	-	635,893	635,893	268,838	367,055		6/30/2008	367,055	(0)	
DE-FG36-07GO87005	1618	No	-	-	350,226	350,226	(122,008)	472,234		6/30/2008	473,989	1,755	
Total-Cost				5,161,054	1,323,508	6,484,562		6,229,345			6,233,457	4,112	

Schedule not linked to other schedules.

MBI INTERNATIONAL
LANSING, MI

SCHEDULE J

SUBCONTRACT INFORMATION
Fiscal Year End 6/30/08

SUBCONTRACT NO.	PRIME CONTRACT NO.	SUBCONTRACTOR'S NAME & ADDRESS	POINT OF CONTACT AND PHONE NO.	SUBCONTRACT VALUE	COSTS INCURRED IN FY	AWARD TYPE
2006-34524-17132	12230	Michigan State University East Lansing, MI	Diane Cox	$ 18,211.00	$ -	Cost Type

Note : Subject schedule is to provide identification of subcontracts you have awarded to companies for which you are the prime or upper-tier contractor. This information is required for all cost type, flexibly priced, T & M , and labor hour subcontract awards.

Schedule L is linked to the following schedules:
Schedule C, Overhead
Schedule B, G&A
Summary Schedule H

SCHEDULE L

MBI INTERNATIONAL
LANSING, MI

Reconciliation of Total Payroll
to Total Labor Distributed
Fiscal Year End 6/30/08

Acct No.	Description	General Ledger	Reference
	Direct Labor	1,113,670	Summary SCHED H
	G&A Wages	501,575	SCHED B
	Overhead Wages	240,667	SCHED C
	IR&D Wages	29,456	SCHED B
	Bonuses	160,438	P&L
	Fringe:		
	Holiday Wages	64,322	"
	PTO	185,242	"
	Disabillity	12,949	"
	Other	3,042	"
	TOTAL LABOR DISTRIBUTION	2,311,361	

	PER IRS FORM 941
1st Qtr - Sept 2007	539,549
2nd Qtr - Dec 2007	549,529
3rd Qtr - March 2008	642,535
4th Qtr - June 2008	527,955
Plus: Current Year Accrual	-
Minus: Prior Year Accrual	-
Café 125 Benefits	71,573
Group Term Life	(5,393)
Health Waiver	(14,324)
Other Adjustments	(63)
TOTAL PAYROLL	2,311,361

SCHEDULE M

MBI INTERNATIONAL
LANSING, MI

Listing of Decisions/Agreements, or
Approvals Affecting Direct/Indirect Cost
And Description of Accounting or Organization Changes
Fiscal Year End 6/30/08

None

This Schedule does not contain any links to other schedules.

SCHEDULE O

MBI INTERNATIONAL
LANSING, MI

SCHEDULE OF GRANT/CONTRACT CLOSING INFORMATION
FOR THOSE CONTRACTS WHICH WORK EFFORT WAS COMPLETED DURING
Fiscal Year End 6/30/08

Grant/Contract No.	Order No.	Performance Period From	Performance Period To	Ready To Close(1)	Contract Ceiling Amount (2)	Contract Ceiling Fee(3)	(if applicable) Level of Effort Cumulative Hours Required	(if applicable) Level of Effort Cumulative Hours Actual	Notes
Cost Type:									
58-5447-2-315	1500	7/1/2002	4/30/2007	YES	1,794,350	-			
DE-FG36-04G014236	1534	7/1/2004	6/30/2007	YES	740,625	-			
DE-FG36-05GO85007	1550	7/1/2005	6/30/2007	YES	1,239,500	-			
EM-83295401-0	1565	5/1/2006	4/30/2007	YES	193,400	-			
DE-FG36-06GO86031	1575	6/1/2006	11/30/2007	YES	990,000	-			

Explanatory Notes:

SCHEDULE N

MBI INTERNATIONAL
LANSING, MI

Certificate of Final Indirect Costs
Fiscal Year End 6/30/08

This is to certify that I have reviewed this proposal to establish final indirect cost rates and to the best of my knowledge and belief:

1. All costs included in the proposal FY2008 6/30/08 to establish final indirect cost rates for Fiscal Year 2008
are allowable in accordance with the cost principles of the Federal Acquisition Regulation (FAR) and its supplements applicable to the contracts to which the final indirect cost rates will apply; and

2. This proposal does not include any costs which are expressly unallowable under applicable cost principles of the FAR or its supplements.

Firm: MBI International

Signature: Kevin Fitzgerald 12-30-08

Name of Certifying Official: Kevin Fitzgerald

Title: VP, Finance & Administration

Date of Execution: December 30, 2008

FAR Part 52.242-4-- Certification of Final Indirect Costs.
As prescribed in 42.703-2(f), insert the following clause:
Certification of Final Indirect Costs (Jan 1997)
(a) The Contractor shall --
(1) Certify any proposal to establish or modify final indirect cost rates;
(2) Use the format in paragraph (c) of this clause to certify; and
(3) Have the certificate signed by an individual of the Contractor's organization at a level no lower than a vice president or chief financial officer of the business segment of the Contractor that submits the proposal.
(b) Failure by the Contractor to submit a signed certificate, as described in this clause, may result in final indirect costs at rates unilaterally established by the Contracting Officer.
(c) The certificate of final indirect costs shall read as follows: (see above)

De-Risking and Scale-Up
of Bio-Based Technologies

June 25, 2009

US Department of Energy
Golden Field Office

RE: DE-FOA-0000096 – Demonstration of Integrated Biorefinery Operations

To Whom It May Concern:

The undersigned certifies that as a grantee under DE-FOA-0000096, Michigan Biotechnology Institute d/b/a MBI International will comply with the regulations under subchapter IV of Chapter 31 of Title 40, United States Code (Davis-Bacon Act).

Venkataraman Bringi, Ph.D.
President & CEO

Applicant Name: Michigan State University (MSU) Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Total Cumulative Budget

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Budget Period 1	81.087			$47,023	$33,812	$80,835
2. Budget Period 2	81.087			$146,410	$105,889	$252,299
3. Budget Period 3	81.087			$50,812	$38,730	$89,542
4.						$0
5. Totals		$0	$0	$244,245	$178,431	$422,676

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1)Budget Period 1	(2)Budget Period 2	(3)Budget Period 3	(4)	
a. Personnel	$40,845	$127,483	$45,245		$213,573
b. Fringe Benefits	$12,336	$38,503	$13,665		$64,504
c. Travel	$0	$0	$0		$0
d. Equipment	$0	$0	$0		$0
e. Supplies	$0	$0	$0		$0
f. Contractual	$0	$0	$0		$0
g. Construction	$0	$0	$0		$0
h. Other	$0	$0	$0		$0
i. Total Direct Charges (sum of 6a-6h)	$53,181	$165,986	$58,910	$0	$278,077
j. Indirect Charges	$27,654	$86,313	$30,633		$144,600
k. Totals (sum of 6i-6j)	$80,835	$252,299	$89,542	$0	$422,676
7. Program Income					$0

Section C - Non-Federal Resources				
(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 1	$33,812			$33,812
9. Budget Period 2	$105,889			$105,889
10. Budget Period 3	$38,730			$38,730
11.				$0
12. Total (sum of lines 8 - 11)	$178,431	$0	$0	$178,431

Section D - Forecasted Cash Needs					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter /Budget Period 2
13. Federal	$65,323	$ 15,674	$ 15,674	$ 15,674	$ 18,301
14. Non-Federal	$47,048	$ 11,271	$ 11,271	$ 11,271	$ 13,236
15. Total (sum of lines 13 and 14)	$112,371	$26,945	$26,945	$26,945	$31,537

Section E - Budget Estimates of Federal Funds Needed for Balance of the Project				
	Future Funding Periods			
(a) Grant Program	(b) First	(c) Second	(d) Third	(e) Fourth
16.	$47,023	$146,410	$50,812	
17.				
18.				
19.				
20. Total (sum of lines 16-19)	$47,023	$146,410	$50,812	$0

Section F - Other Budget Information	
21. Direct Charges	22. Indirect Charges Predetermined Base:IDC calculated at 52% MTDC
23. Remarks	

Applicant Name: Michigan State University (MSU) Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Budget Period 1

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Budget Period 1	81.087			$47,023	$33,812	$80,835
2.						$0
3.						$0
4.						$0
5. Totals		$0	$0	$47,023	$33,812	$80,835

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 1	(2)	(3)	(4)	
a. Personnel	$40,845				$40,845
b. Fringe Benefits	$12,336				$12,336
c. Travel	$0				$0
d. Equipment	$0				$0
e. Supplies	$0				$0
f. Contractual	$0				$0
g. Construction	$0				$0
h. Other	$0				$0
i. Total Direct Charges (sum of 6a-6h)	$53,181			$0	$53,181
j. Indirect Charges	$27,654				$27,654
k. **Totals** (sum of 6i-6j)	$80,835	$0	$0	$0	$80,835
7. Program Income					$0

Section C - Non-Federal Resources					
(a) Grant Program		(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 1		$33,812			$33,812
9.				$0	$0
10.				$0	$0
11.				$0	$0
12. Total (sum of lines 8 - 11)		$0	$0	$0	$33,812
Section D - Forecasted Cash Needs					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter /Budget Period 2
13. Federal	$65,323	$ 15,674	$ 15,674	$ 15,674	$ 18,301
14. Non-Federal	$47,048	$ 11,271	$ 11,271	$ 11,271	$ 13,236
15. Total (sum of lines 13 and 14)	$112,371	$26,945	$26,945	$26,945	$31,537
Section E - Budget Estimates of Federal Funds Needed for Balance of the Project					
		Future Funding Periods			
(a) Grant Program		(b) First	(c) Second	(d) Third	(e) Fourth
16.		$146,410	$50,812		
17.					
18.					
19.					
20. Total (sum of lines 16-19)		$146,410	$50,812	$0	$0
Section F - Other Budget Information					
21. Direct Charges		22. Indirect Charges Predetermined Base:IDC calculated at 52% MTDC			
23. Remarks					

Applicant Name: Michigan State University (MSU) Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Budget Period 2

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Budget Period 2	81.097			$146,410	$105,889	$252,299
2.						$0
3.						$0
4.						$0
5. Totals		$0	$0	$146,410	$105,889	$252,299

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 2	(2)	(3)	(4)	
a. Personnel	$127,483				$127,483
b. Fringe Benefits	$38,503				$38,503
c. Travel	$0				$0
d. Equipment	$0				$0
e. Supplies	$0				$0
f. Contractual	$0				$0
g. Construction	$0				$0
h. Other	$0				$0
i. Total Direct Charges (sum of 6a-6h)	$165,986			$0	$165,986
j. Indirect Charges	$86,313				$86,313
k. **Totals** (sum of 6i-6j)	$252,299	$0	$0	$0	$252,299
7. Program Income					$0

Section C - Non-Federal Resources					
(a) Grant Program		(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 2		$105,889			$105,889
9.				$0	$0
10.				$0	$0
11.				$0	$0
12. Total (sum of lines 8 - 11)		$0	$0	$0	$105,889
Section D - Forecasted Cash Needs					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
13. Federal	$65,323	$ 15,674	$ 15,674	$ 15,674	$ 18,301
14. Non-Federal	$47,048	$ 11,271	$ 11,271	$ 11,271	$ 13,236
15. Total (sum of lines 13 and 14)	$112,371	$26,945	$26,945	$26,945	$31,537
Section E - Budget Estimates of Federal Funds Needed for Balance of the Project					
		Future Funding Periods			
(a) Grant Program		(b) First	(c) Second	(d) Third	(e) Fourth
16.		$50,812			
17.					
18.					
19.					
20. Total (sum of lines 16-19)		$50,812	$0	$0	$0
Section F - Other Budget Information					
21. Direct Charges		22. Indirect Charges Predetermined Base:IDC calculated at 52% MTDC			
23. Remarks					

Applicant Name: Michigan State University (MSU) Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Budget Period 3

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Budget Period 3	81.087			$50,812	$38,730	$89,542
2.						$0
3.						$0
4.						$0
5. Totals		$0	$0	$50,812	$38,730	$89,542

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 3	(2)	(3)	(4)	
a. Personnel	$45,245				$45,245
b. Fringe Benefits	$13,665				$13,665
c. Travel	$0				$0
d. Equipment	$0				$0
e. Supplies	$0				$0
f. Contractual	$0				$0
g. Construction	$0				$0
h. Other	$0				$0
i. Total Direct Charges (sum of 6a-6h)	$58,910			$0	$58,910
j. Indirect Charges	$30,633				$30,633
k. **Totals** (sum of 6i-6j)	$89,542	$0	$0	$0	$89,542
7. Program Income					$0

Section C - Non-Federal Resources					
(a) Grant Program		(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 3		$38,730			$38,730
9.					$0
10.					$0
11.					$0
12. Total (sum of lines 8 - 11)		$38,730	$0	$0	$38,730
Section D - Forecasted Cash Needs					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
13. Federal	$65,323	$ 15,674	$ 15,674	$ 15,674	$ 18,301
14. Non-Federal	$47,048	$ 11,271	$ 11,271	$ 11,271	$ 13,236
15. Total (sum of lines 13 and 14)	$112,371	$26,945	$26,945	$26,945	$31,537
Section E - Budget Estimates of Federal Funds Needed for Balance of the Project					
		Future Funding Periods			
(a) Grant Program		(b) First	(c) Second	(d) Third	(e) Fourth
16.		$0			
17.					
18.					
19.					
20. Total (sum of lines 16-19)		$0	$0	$0	$0
Section F - Other Budget Information					
21. Direct Charges		22. Indirect Charges Predetermined Base:IDC calculated at 52% MTDC			
23. Remarks					

Instructions and Summary

Award Number: DE-FOA-0000096
Award Recipient: Michigan State University (MSU)

Date of Submission: 25-Jun-09
Form submitted by: MBI International
(May be award recipient or sub-recipient)

Please read the instructions on each page before starting.
If you have any questions, please ask your DOE contact. It will save you time!

On this form, provide detailed support for the estimated project costs identified on the SF-424A form (Budget).

- **The dollar amounts on this page must match the amounts on the associated SF-424A.**
- **The award recipient and each sub-recipient with estimated costs of $100,000 or more must complete this form and a SF-424A form.**
- **The total budget presented on this form and on the SF424A must include both Federal (DOE), and Non-Federal (cost share) portions, thereby reflecting TOTAL PROJECT COSTS proposed.**
- **For costs in each Object Class Category on the SF-424A, complete the corresponding worksheet on this form (tab at the bottom of the page).**
- **All costs incurred by the preparer's sub-recipients, vendors, contractors, consultants and Federal Research and Development Centers (FFRDCs), should be entered only in section f. Contractual. All other sections are for the costs of the preparer only.**

SUMMARY OF BUDGET CATEGORY COSTS PROPOSED

(Note: The values in this summary table are from entries made in each budget category sheet.)

CATEGORY	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Total Costs	Project Costs %	Comments (Add comments as needed)
a. Personnel	$40,845	$127,483	$45,245	**$213,573**	**50.5%**	
b. Fringe Benefits	$12,336	$38,503	$13,665	**$64,504**	**15.3%**	
c. Travel	$0	$0	$0	**$0**	**0.0%**	
d. Equipment	$0	$0	$0	**$0**	**0.0%**	
e. Supplies	$0	$0	$0	**$0**	**0.0%**	
f. Contractual						
Sub-recipient	*$0*	*$0*	*$0*	*$0*	*0.0%*	
FFRDC	*$0*	*$0*	*$0*	*$0*	*0.0%*	
Vendor	*$0*	*$0*	*$0*	*$0*	*0.0%*	
Total Contractual	$0	$0	$0	**$0**	**0.0%**	
g. Construction	$0	$0	$0	**$0**	**0.0%**	
h. Other Direct Costs	$0	$0	$0	**$0**	**0.0%**	
i. Indirect Charges	$27,654	$86,313	$30,633	**$144,600**	**34.2%**	
Total Project Costs	**$80,836**	**$252,299**	**$89,542**	**$422,676**	**100.0%**	

Additional Explanations/Comments (as necessary)

a. Personnel

PLEASE READ!!!

List costs solely for employees of the entity completing this form (award recipient or sub-recipient). All other personnel costs (of subrecipients or other contractual efforts of the entity preparing this) must be included under f., Contractual. This includes all consultants and FFRDCs.

Identify positions to be supported. Key personnel should be identified by title. All other personnel should be identified either by title or a group category. State the amounts of time (e.g., hours or % of time) to be expended, the composite base pay rate, total direct personnel compensation and identify the rate basis (e.g., actual salary, labor distribution report, technical estimate, state civil service rates, etc.).

Add rows as needed. Formulas/calculations will need to be entered by the preparer of this form. Please enter formulas as shown in the example.

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
1. Generation 2A Receiver Design		**10000**		**$423,000**	**600**		**$24,000**	**800**		**$31,000**	**11400**	**$478,000**	**Actual Salary**
EXAMPLE	Sr. Engineer	2000	$85.00	$170,000	200	$50.00	$10,000	200	$50.00	$10,000	**2400**	**$190,000**	Actual Salary
ONLY!!!	Electrical engineers	6200	$35.00	$217,000	400	$35.00	$14,000	600	$35.00	$21,000	**7200**	**$252,000**	Actual Salary
	Technician	1800	$20.00	$36,000	0	$0.00	$0	0	$0.00	$0	**1800**	**$36,000**	Actual Salary
1.1 Preliminary Process Design													
	University Distinguished Professor	21	$85.00	$1,800									
	Associate Professor	19	$44.00	$856									
1.3.1 Produce Stover Feedstock													
	Associate Professor	6	$60.00	$330									
1.3.2.1.1 Design bench scale NH3 recovery exp.													
	University Distinguished Professor	21	$85.00	$1,800									
	Associate Professor	19	$44.00	$856									
1.3.2.2 Aspen model of NH3 design													
	University Distinguished Professor	29	$85.00	$2,500									
	Assistant Professor	235	$44.00	$10,326									
1.3.2.3 Spec. or design NH3 recovery equipment													
	University Distinguished Professor	24	$85.00	$2,000									
	Associate Professor	19	$44.00	$856									
1.3.3.4 Shakedown high solids enzyme reactor													
	Assistant Professor	50	$40.00	$2,000									
1.3.3.5 NREL bench scale enzymatic													
	Assistant Professor	50	$40.00	$2,000									
1.3.3.6 SSF trials Using NREL org at MBI													
	University Distinguished Professor	18	$85.00	$1,500									
1.3.3.7 SSF trials using other org at MBI													
	University Distinguished Professor	12	$85.00	$1,000									
1.3.3.8 SSF trials using improved enzymes													
	University Distinguished Professor	18	$85.00	$1,500									
	Assistant Professor	22	$44.00	$980									
1.4 risk mitigation plan													
	Associate Professor	12	$66.00	$786									

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
1.5 Business and commercialization plan													
	Associate Professor	45	$66.00	$3,000									
	Professor	3	$96.00	$302									
1.8 Meeting and communication													
	University Distinguished Professor	14	$85.00	$1,202									
	Associate Professor	20	$44.00	$901									
	Associate Professor	20	$66.00	$1,350									
	Professor	13	$96.00	$1,200									
	Associate Professor	10	$60.00	$600									
	Assistant Professor	30	$40.00	$1,200									
2.3.1 Finalize P&IDs													
	University Distinguished Professor				31	$87.55	$2,718						
	Associate Professor				29	$45.32	$1,327						
2.6 NREL PDU/IBRF sacc & ferm equipment shakedown													
	University Distinguished Professor				34	$87.55	$3,000						
	Assistant Professor				85	$41.20	$3,500						
2.7.2.5.1 Stover NH3 trial no steam													
	University Distinguished Professor				40	$87.55	$3,500						
	Associate Professor				72	$45.32	$3,250						
2.7.2.5.2 Stover NH3 trial steam													
	University Distinguished Professor				40	$87.55	$3,500						
	Associate Professor				72	$45.32	$3,250						
2.7.3 Densification equip. shakedown													
	University Distinguished Professor				46	$87.55	$4,000						
	Assistant Professor				24	$41.20	$1,000						
2.7.4 Nrel sacc & ferm shakedown													
	University Distinguished Professor				34	$87.55	$3,000						
	Assistant Professor				243	$41.20	$10,000						
2.11 update techno-economic model													
	University Distinguished Professor				40	$87.55	$3,500						
	Assistant Professor				19	$41.20	$790						
	Assistant Professor				654	$45.32	$29,629						
2.12 Business and commercialization plan													
	University Distinguished Professor				114	$87.55	$10,000						
	Associate Professor				114	$67.98	$7,730						
	Professor				32	$98.88	$3,187						
	Associate Professor				24	$61.80	$1,500						
2.16 Meetings													
	University Distinguished Professor				95	$87.55	$8,300						
	Associate Professor				66	$45.32	$3,000						
	Associate Professor				122	$67.98	$8,300						
	Professor				15	$98.88	$1,502						

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
	Associate Professor				23	$61.80	$1,400						
	Assistant Professor				97	$41.20	$4,000						
	Assistant Professor				57	$45.32	$2,600						
3.1.1 AFEX and densification													
	University Distinguished Professor							51	$90.10	$4,562			
	Associate Professor							53	$46.64	$2,474			
	Assistant Professor							57	$42.40	$2,433			
3.1.2 NREL													
	Assistant Professor							61	$42.40	$2,588			
3.2.1 Economic modeling													
	University Distinguished Professor							34	$90.10	$3,041			
	Assistant Professor							226	$46.64	$10,525			
3.22 BCP development													
	University Distinguished Professor							46	$90.10	$4,166			
	Associate Professor							49	$69.96	$3,409			
	Professor							6	$101.76	$639			
3.5 Meeting													
	University Distinguished Professor							33	$90.10	$2,965			
	Associate Professor							29	$46.64	$1,368			
	Associate Professor							33	$69.96	$2,281			
	Professor							10	$101.76	$1,026			
	Associate Professor							16	$63.60	$1,029			
	Assistant Professor							43	$42.40	$1,825			
	Assistant Professor							20	$46.64	$914			
	Total Personnel Costs	**731.254**		**$40,845**	**2223**		**$127,483**	**766**		**$45,245**	**0**	**$213,573**	

$0

Additional Explanations/Comments (as necessary)

b. Fringe Benefits

	Budget Period 1	Budget Period 2	Budget Period 3	Total
Rate applied:	30.2%	30.2%	30.2%	
Total fringe requested:	$12,336	$38,503	$13,665	**$64,504**

A federally approved fringe benefit rate agreement, or a proposed rate supported and agreed upon by DOE for estimating purposes is required if reimbursement for fringe benefits is requested. Please check (X) one of the options below and provide the requested information, if it has not already been provided to the Contracting Officer, OR if it has changed since it was. Calculate the fringe rate and enter the total amount in Section B, line 6.b. ("Fringe Benefits") of form SF-424A.

X **A fringe benefit rate has been negotiated with, or approved by, a federal government agency. A copy of the latest rate agreement is included with this application, and will be provided electronically to the Contracting Officer for this project.**
(When this option is selected, a presentation of the budget that demonstrates the appliction of the approved rate, to arrive at the proposed fringes benefits dollars should also be provided.)

____ **There is not a current, federally approved rate agreement negotiated and available.**
(When this option is checked, the entity preparing this form shall submit a rate proposal in the format provided at the following website, or a format that provides the same level of information and which will support the rates being proposed for use in performance of the proposed project. Go to https://www.eere-pmc.energy.gov/forms.aspx and select PMC 400.2 Sample Rate Proposal.)

Additional explanation/comments (as necessary)

Approved rate agreement is attached as "MSUApprovedRates" in Optional Other Attachments

c. Travel

PLEASE READ!!!

Provide travel detail as requested below, identifying total Foreign and Domestic Travel as separate items. Purpose of travel are items such as professional conference, DOE sponsored meeting, project management meeting, etc. The Basis for Estimating Costs are items such as past trips, current quotations, Federal Travel Regulations, etc.

All listed travel must be necessary for performance of the Statement of Projecct Objectives.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Purpose of travel	No. of Travelers	Depart From (not required for domestic travel)	Destination (not required for domestic travel)	No. of Days	Cost per Traveler	Cost per Trip	Basis for Estimating Costs
Budget Period 1							
Domestic Travel							
EXAMPLE ONLY!!! Visit to PV cell mfr. to set up vendor agreement	2			2	$650	$1,300	Internet prices
						$0	
						$0	
						$0	
						$0	
						$0	
						$0	
						$0	
						$0	
Domestic Travel subtotal						$0	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 1 Total						**$0**	

Purpose of travel	No. of Travelers	Depart From (not required for domestic travel)	Destination (not required for domestic travel)	No. of Days	Cost per Traveler	Cost per Trip	Basis for Estimating Costs
Budget Period 2							
Domestic Travel							
						$0	
						$0	
						$0	
						$0	
						$0	
						$0	
Domestic Travel subtotal						$0	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 2 Total						**$0**	
Budget Period 3							
Domestic Travel							
						$0	
						$0	
						$0	
						$0	
						$0	
						$0	
Domestic Travel subtotal						$0	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 3 Total						**$0**	
PROJECT TOTAL						**$0**	

Additional Explanations/Comments (as necessary)

d. Equipment

PLEASE READ!!!

Equipment is generally defined as an item with an acquisition cost greater than $5,000 and a useful life expectancy of more than one year. Further definitions can be found at 10 CFR 600 found on the PMC Recipient Resources Forms page at https://www.eere-pmc.energy.gov/Forms.aspx#regs .

List all proposed equipment below, providing a basis of cost such as vendor quotes, catalog prices, prior invoices, etc., and briefly justifying its need as it applies to the Statement of Project Objectives. If it is existing equipment, and the value of its contribution to the project budget is being shown as cost share, provide logical support for the estimated value shown. If it is new equipment which will retain a useful life upon completion of the project, provide logical support for the estimated value shown.

For equipment over $50,000 in price, also include a copy of the associated vendor quote or catalog price list.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 1					
EXAMPLE ONLY!!! Thermal shock chamber	2	$20,000	$40,000	Vendor Quote	Reliability testing of PV modules- Task 4.3
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 1 Total			$0		
Budget Period 2					

Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
			$0		
			$0		
Budget Period 2 Total			$0		
Budget Period 3					
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 3 Total			$0		
PROJECT TOTAL			**$0**		

Additional Explanations/Comments (as necessary)

e. Supplies

PLEASE READ!!!

Supplies are generally defined as an item with an acquisition cost of $5,000 or less and a useful life expectancy of less than one year. Supplies are generally consumed during the project performance. Further definitions can be found at 10 CFR 600 found on the PMC Recipient Resources Forms page at https://www.eere-pmc.energy.gov/Forms.aspx#regs.

List all proposed supplies below, providing a bases of cost such as vendor quotes, catalog prices, prior invoices, etc., and briefly justifying the need for the Supplies as they apply to the Statement of Project Objectives. Note that Supply items must be direct costs to the project at this budget category, and not duplicative of supply costs included in the indirect pool that is the basis of the indirect rate applied for this project.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

General Category of Supplies	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 1					
EXAMPLE ONLY!!! Wireless DAS components	10	$360.00	$3,600	Catalog price	For Alpha prototype - Task 2.4
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 1 Total			**$0**		
Budget Period 2					
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 2 Total			$0		

General Category of Supplies	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 3					
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 3 Total			$0		
PROJECT TOTAL			**$0**		

Additional Explanations/Comments (as necessary)

f. Contractual

PLEASE READ!!!

The entity completing this form must provide all costs related to sub-recipients, vendors, contractors, consultants and FFRDC partners in the applicable boxes below.

Sub-recipients (partners, sub-awardees):
For each sub-recipient with total project costs of $100,000 or more, a separate SF-424A budget and PMC123.1 budget justification form must be submitted. These sub-recipient forms may be completed by either the sub-recipients themselves or by the preparer of this form. The budget totals on the sub-recipient's forms must match the sub-recipeint entries below.

The preparer of this form need only provide further support of the completed sub-recipient budget forms as they deem necessary. The support to justify the budgets of sub-recipients with estimated costs less than $100,000 may be in any format, and at a minimum should provide what Statement of Project Objectives task(s) are being performed, the purpose/need for the effort, and a basis of the estimated costs that is considered sufficient for DOE evaluation.

Vendors (includes contractors and consultants):
List all vendors, contractors and consultants supplying commercial supplies or services used to support the project. The support to justify vendor costs (in any amount) should provide the purpose for the products or services and a basis of the estimated costs that is considered sufficient for DOE evaluation.

Federal Research and Development Centers (FFRDCs):
For FFRDC partners, award recipient will provide a Field Work Proposal (if not already provided with the original application), along with the FFRDC labor mix and hours, by category and FFRDC major purchases greater than $25,000, including Quantity, Unit Cost, Basis of Cost, and Justification. The award recipient may allow the FFRDC to provide this information directly to DOE.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Sub-Recipient Name/Organization	Purpose/Tasks in SOPO	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
EXAMPLE ONLY!!! XYZ Corp.	Partner to develop optimal fresnel lens for Gen 2 product - Task 2.4	$48,000	$32,000	$16,000	**$96,000**
					$0
					$0
					$0
					$0
					$0

Sub-Recipient Name/Organization	Purpose/Tasks in SOPO	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
					$0
					$0
					$0
	Sub-total	$0	$0	$0	$0

Vendor Name/Organization	Product or Service, Purpose/Need and Basis of Cost (Provide additional support at bottom of page as needed)	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
EXAMPLE ONLY!!! ABC Corp.	Vendor for developing custom robotics to perform lens inspection, alignment, and placement (Task 4). Required for expanding CPV module mfg. capacity. Cost is from competitive quotes.	$32,900	$86,500		**$119,400**
					$0
					$0
					$0
					$0
					$0
					$0
					$0
		$0	$0	$0	$0

FFRDC Name/Organization	Purpose	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
					$0
					$0
					$0
		$0	$0	$0	$0

Total Contractual		$0	$0	$0	$0

AdditionalExplanations/Comments (as necessary)

g. Construction

PLEASE READ!!!

Construction, for the purpose of budgeting, is defined as all types of work done on a particular building, including erecting, altering, or remodeling. Construction conducted by the award recipient is entered on this page. Any construction work that is performed by a vendor or subrecipient to the award recipient should be entered under f. Contractual.

List all proposed construction below, providing a basis of cost such as engineering estimates, prior construction, etc., and briefly justify its need as it applies to the Statement of Project Objectives.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Overall description of construction actiivities:

Example Only!!! - Build wind turbine platform

General Description	Cost	Basis of Cost	Justification of need
Budget Period 1			
Three days of excavation for platform site EXAMPLE ONLY!!!	$28,000	Engineering estimate	Site must be prepared for construction of platform.
Budget Period 1 Total	**$0**		
Budget Period 2			
Budget Period 2 Total	$0		

General Description	Cost	Basis of Cost	Justification of need
Budget Period 3			
Budget Period 3 Total	$0		
PROJECT TOTAL	**$0**		

Additional Explanations/Comments (as necessary)

h. Other Direct Costs

PLEASE READ!!!

Other direct costs are direct cost items required for the project which do not fit clearly into other categories, and are not included in the indirect pool for which the indirect rate is being applied to this project. Examples are meeting costs, postage, couriers or express mail, telephone/fax costs, printing costs, etc.

Basis of cost are items such as vendor quotes, prior purchases of similar or like items, published price list, etc.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

General description	Cost	Basis of Cost	Justification of need
Budget Period 1			
EXAMPLE ONLY!!! Grad student tuition	$16,000	Established UCD costs	Support of graduate students working on project
Budget Period 1 Total	$0		
Budget Period 2			
Budget Period 2 Total	$0		
Budget Period 3			
Budget Period 3 Total	$0		
PROJECT TOTAL	**$0**		

Additional Explanations/Comments (as necessary)

i. Indirect Costs

	Budget Period 1	Budget Period 2	Budget Period 3	Total
Rate applied:	52.0%	52.0%	52.0%	
Total indirect costs requested:	$27,654	$86,313	$30,633	**$144,600**

A federally approved indirect rate agreement, or rate proposed supported and agreed upon by DOE for estimating purposes is required if reimbursement of fringe benfits is requested. Please check (X) one of the options below and provide the requested information if it has not already been provided as requested, or has changed. Calculate the indirect rate dollars and enter the total in the Section B., line 6.j. (Indirect Charges) of form SF 424A.

X **There is a federally approved indirect rate agreement. A copy is provided with this application and will be provided electronically to the Contracting Officer for this project.**
(When this option is selected, a presentation of the budget that demonstrates the application of the approved rate, to arrive at the proposed indirect charges proposed should also be provided.)

____ **There is no current, federally-approved indirect rate agreement.**
(When this option is checked, the entity preparing this form shall submit an indirect cost rate proposal in the format provided at the following website, or in a format that provides the same level of information and which supports the rate(s) being proposed for use in estimating the project. Go to https://www.eere-pmc.energy.gov/forms.aspx and select PMC 400.2 Sample Rate Proposal.)

Additional Explanations/Comments (as necessary)

Approved rate agreement is attached as "MSUApprovedRates" in Optional Other Attachments

Cost Share

PLEASE READ!!!

A detailed presentation of the cash or cash value of all cost share proposed for the project must be provided in the table below. Identify the source & amount of each item of cost share proposed by the award recipient and each sub-recipient or vendor. Letters of committment must be submitted for all third party cost share (other than award recipient).

Note that "cost-share" is not limited to cash investment. Other items that may be assigned value in a budget as incurred as part of the project budget and necessary to performance of the project, may be considered as cost share, such as: contribution of services or property; donated, purchased or existing equipment; buildings or land; donated, purchased or existing supplies; and/or unrecovered personnel, fringe benefits and indirect costs, etc. For each cost share contribution identified as other than cash, identify the item and describe how the value of the cost share contribution was calculated.

Funds from other Federal sources MAY NOT be counted as cost share. This prohibition includes FFRDC sub-recipients. Non-Federal sources include private, state or local Government, or any source not originally derived from Federal funds. Documentation of cost sharing commitments must be provided, if not already provided with the original application and they have not changed since its submission.

Fee or profit will not be paid to the award recipients or subrecipients of financial assistance awards. Additionally, foregone fee or profit by the applicant shall not be considered cost sharing under any resulting award. Reimbursement of actual costs will only include those costs that are allowable and allocable to the project as determined in accordance with the applicable cost principles prescribed in 10 CFR 600.127, 10 CFR 600.222 or 10 CFR 600.317. Also see 10 CFR 600.318 relative to profit or fee.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Organization/Source	Type (cash or other)	Cost Share Item	Budget Period 1 Cost Share	Budget Period 2 Cost Share	Budget Period 3 Cost Share	Total Project Cost Share
ABC Company **EXAMPLE ONLY!!!**	Cash	Project partner ABC Company will provide 40 PV modules for product development at 50% off the of the retail price of $680	$13,600			**$13,600**
Michigan State University (MSU)	Cash	Salary and wages, fringe benefits and undercovered indirect charges	$33,812	$105,889	$38,730	**$178,431**
						$0
						$0
						$0
						$0
						$0

Organization/Source	Type (cash or other)	Cost Share Item	Budget Period 1 Cost Share	Budget Period 2 Cost Share	Budget Period 3 Cost Share	Total Project Cost Share
						$0
						$0
						$0
						$0
		Totals	$33,812	$105,889	$38,730	$178,431

Total Project Cost: $422,676 **Cost Share Percent of Award: 42.2%**

Additional Explanations/Comments (as necessary)

COLLEGES AND UNIVERSITIES RATE AGREEMENT

EIN #: 1386005984A1

DATE: March 8, 2007

INSTITUTION:
Michigan State University
Contract and Grant Administration
301 Administration Building
East Lansing MI 48824-1046

FILING REF.: The preceding Agreement was dated May 27, 2004

The rates approved in this agreement are for use on grants, contracts and other agreements with the Federal Government, subject to the conditions in Section III.

SECTION I: FACILITIES AND ADMINISTRATIVE COST RATES*

RATE TYPES: FIXED FINAL PROV.(PROVISIONAL) PRED.(PREDETERMINED)

TYPE	EFFECTIVE PERIOD FROM	TO	RATE(%)	LOCATIONS	APPLICABLE TO
PRED.	07/01/04	06/30/08	51.0	On Campus	Organized Research
PRED.	07/01/04	06/30/08	40.0	On Campus	Other Spon Act
PRED.	07/01/03	06/30/08	26.0	Off Campus	All Programs
PRED.	07/01/08	06/30/11	52.0	On Campus	Organized Research
PRED.	07/01/08	06/30/11	41.0	On Campus	Other Spon Act
PRED.	07/01/08	06/30/11	26.0	Off Campus	All Programs
PROV.	07/01/11	UNTIL AMENDED	Use same rates and conditions as those cited for fiscal year ending June 30, 2011.		

*BASE:
Modified total direct costs, consisting of all salaries and wages, fringe benefits, materials, supplies, services, travel and subgrants and subcontracts up to the first $25,000 of each subgrant or subcontract (regardless of the period covered by the subgrant or subcontract). Modified total direct costs shall exclude equipment, capital expenditures, charges for patient care, tuition remission, rental costs of off-site facilities, scholarships, and fellowships as well as the portion of each subgrant and subcontract in excess of $25,000.

INSTITUTION:
Michigan State University
Contract and Grant Administration

AGREEMENT DATE: March 8, 2007

SECTION II: SPECIAL REMARKS

TREATMENT OF FRINGE BENEFITS:
Fringe benefits are specifically identified to each employee and are charged individually as direct costs. The directly claimed fringe benefits are listed below.

TREATMENT OF PAID ABSENCES:
Vacation, holiday, sick leave pay and other paid absences are included in salaries and wages and are claimed on grants, contracts and other agreements as part of the normal cost for salaries and wages. Separate claims for the costs of these paid absences are not made.

OFF-CAMPUS DEFINITION: For all activities performed in facilities not owned by the institution and to which rent is directly allocated to the project(s), the off-campus rate will apply. Grants or contracts will not be subject to more than one F&A cost rate. If more than 50% of a project is performed off-campus, the off-campus rate will apply to the entire project.

Equipment Definition -
Equipment means an article of nonexpendable, tangible personal property having a useful life of more than one year and an acquisition cost of $5,000 or more per unit.

FRINGE BENEFITS:

FICA	Retirement	Disability Insurance
Worker's Compensation	Life Insurance	Unemployment Insurance
Health Insurance	Longevity Pay Increments	Tuition Remission
Dental Insurance		

INSTITUTION:
Michigan State University
Contract and Grant Administration

AGREEMENT DATE: March 8, 2007

SECTION III: GENERAL

A. LIMITATIONS:
The rates in this Agreement are subject to any statutory or administrative limitations and apply to a given grant, contract or other agreement only to the extent that funds are available. Acceptance of the rates is subject to the following conditions: (1) Only costs incurred by the organization were included in its facilities and administrative cost pools as finally accepted; such costs are legal obligations of the organization and are allowable under the governing cost principles; (2) The same costs that have been treated as facilities and administrative costs are not claimed as direct costs; (3) Similar types of costs have been accorded consistent accounting treatment; and (4) The information provided by the organization which was used to establish the rates is not later found to be materially incomplete or inaccurate by the Federal Government. In such situations the rate(s) would be subject to renegotiation at the discretion of the Federal Government.

B. ACCOUNTING CHANGES:
This Agreement is based on the accounting system purported by the organization to be in effect during the Agreement period. Changes to the method of accounting for costs which affect the amount of reimbursement resulting from the use of this Agreement require prior approval of the authorized representative of the cognizant agency. Such changes include, but are not limited to, changes in the charging of a particular type of cost from facilities and administrative to direct. Failure to obtain approval may result in cost disallowances.

C. FIXED RATES:
If a fixed rate is in this Agreement, it is based on an estimate of the costs for the period covered by the rate. When the actual costs for this period are determined, an adjustment will be made to a rate of a future year(s) to compensate for the difference between the costs used to establish the fixed rate and actual costs.

D. USE BY OTHER FEDERAL AGENCIES:
The rates in this Agreement were approved in accordance with the authority in Office of Management and Budget Circular A-21 Circular, and should be applied to grants, contracts and other agreements covered by this Circular, subject to any limitations in A above. The organization may provide copies of the Agreement to other Federal Agencies to give them early notification of the Agreement.

E. OTHER:
If any Federal contract, grant or other agreement is reimbursing facilities and administrative costs by a means other than the approved rate(s) in this Agreement, the organization should (1) credit such costs to the affected programs, and (2) apply the approved rate(s) to the appropriate base to identify the proper amount of facilities and administrative costs allocable to these programs.

BY THE INSTITUTION:
Michigan State University
Contract and Grant Administration
(INSTITUTION)

(SIGNATURE)

Daniel T. Evon, Director
Contract & Grant Administration
(NAME)

(TITLE)

March 9, 2007
(DATE)

ON BEHALF OF THE FEDERAL GOVERNMENT:

DEPARTMENT OF HEALTH AND HUMAN SERVICES
(AGENCY)

(SIGNATURE)

Henry Williams
(NAME)

DIRECTOR, DIVISION OF COST ALLOCATION-
(TITLE) CENTRAL STATES FIELD OFFICE

March 8, 2007
(DATE) 5060

HHS REPRESENTATIVE: Peter Nwaogu
Telephone: (214) 767-3764

COMPONENTS OF PUBLISHED F&A COST RATE

INSTITUTION: **Michigan State University**

FY COVERED BY RATE: **JULY 1, 2008 through JUNE 30, 2011**

APPLICABLE TO: **ORGANIZED RESEARCH**

RATE COMPONENT:	ON CAMPUS	OFF CAMPUS
Building Depreciation	3.0	
Equipment Depreciation	2.7	
Interest	3.3	
Operation & Maintenance	16.6	
Library	1.4	
Administration	26.0	26.0
TOTAL	52.0	26.0

CONCURRENCE:

Michigan State University
(Institution)

Daniel T. Evon
(Signature)

Daniel T. Evon, Director
Contract & Grant Administration
(Name)

(Title)

March 12, 2007
(Date)

Applicant Name: Novozymes

Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Total Cumulative Budget

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Budget Period 1	81.087				$43,240	$43,240
2. Budget Period 2	81.087				$82,563	$82,563
3. Budget Period 3	81.087				$17,634	$17,634
4.						$0
5. Totals		$0	$0	$0	$143,437	$143,437

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 1	(2) Budget Period 2	(3) Budget Period 3	(4)	
a. Personnel	$21,800	$38,755	$7,267		$67,822
b. Fringe Benefits	$7,216	$12,828	$2,405		$22,449
c. Travel	$3,533	$3,178			$6,711
d. Equipment					$0
e. Supplies		$8,797	$4,398		$13,195
f. Contractual					$0
g. Construction					$0
h. Other					$0
i. Total Direct Charges (sum of 6a-6h)	$32,549	$63,558	$14,070	$0	$110,177
j. Indirect Charges	$10,691	$19,005	$3,564		$33,260
k. Totals (sum of 6i-6j)	$43,240	$82,563	$17,634	$0	$143,437
7. Program Income					$0

Previous Edition Usable

SF-424A (Rev. 4-92)
Prescribed by OMB Circular A-102

Section C - Non-Federal Resources				
(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 1	$43,240			$43,240
9. Budget Period 2	$82,563			$82,563
10. Budget Period 3	$17,634			$17,634
11.				$0
12. Total (sum of lines 8 - 11)	$143,437	$0	$0	$143,437

Section D - Forecasted Cash Needs					
	Total 1st Year	1st Quarter	2nd Quarter	3th Quarter	4th Quarter
13. Federal	$0				
14. Non-Federal	$44,419	$14,413	$14,413	$14,414	$1,179
15. Total (sum of lines 13 and 14)	$44,419	$14,413	$14,413	$14,414	$1,179

Section E - Budget Estimates of Federal Funds Needed for Balance of the Project				
	Future Funding Periods (Years)			
(a) Grant Program	(b) First	(c) Second	(d) Third	(e) Fourth
16.				
17.				
18.				
19.				
20. Total (sum of lines 16-19)	$0	$0	$0	$0

Section F - Other Budget Information	
21. Direct Charges	22. Indirect Charges 49.00%
23. Remarks	

Applicant Name: Novozymes

Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Budget Period 1

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1. Budget Period 1	81.087				$43,240	$43,240
2.						$0
3.						$0
4.						$0
5. Totals		$0	$0	$0	$43,240	$43,240

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 1	(2)	(3)	(4)	
a. Personnel	$21,800				$21,800
b. Fringe Benefits	$7,216				$7,216
c. Travel	$3,533				$3,533
d. Equipment					$0
e. Supplies					$0
f. Contractual					$0
g. Construction					$0
h. Other					$0
i. Total Direct Charges (sum of 6a-6h)	$32,549	$0	$0	$0	$32,549
j. Indirect Charges	$10,691				$10,691
k. Totals (sum of 6i-6j)	$43,240	$0	$0	$0	$43,240
7. Program Income					$0

Previous Edition Usable

SF-424A (Rev. 4-92)
Prescribed by OMB Circular A-102

Section C - Non-Federal Resources				
(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 1	$43,240			$0
9.				$0
10.				$0
11.				$0
12. Total (sum of lines 8 - 11)	$0	$0	$0	$0

Section D - Forecasted Cash Needs					
	Total	1st Quarter	2nd Quarter	3th Quarter	4th Quarter
13. Federal	$0				
14. Non-Federal	$44,419	$14,413	$14,413	$14,414	$1,179
15. Total (sum of lines 13 and 14)	$44,419	$14,413	$14,413	$14,414	$1,179

Section E - Budget Estimates of Federal Funds Needed for Balance of the Project				
	Future Funding Periods (Years)			
(a) Grant Program	(b) First	(c) Second	(d) Third	(e) Fourth
16.				
17.				
18.				
19.				
20. Total (sum of lines 16-19)	$0	$0	$0	$0

Section F - Other Budget Information	
21. Direct Charges	22. Indirect Charges 49.00%
23. Remarks	

Applicant Name: Novozymes Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Budget Period 2

Section A - Budget Summary						
Grant Program Function or Activity	Catalog of Federal Domestic Assistance Number	Estimated Unobligated Funds		New or Revised Budget		
		Federal	Non-Federal	Federal	Non-Federal	Total
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1. Budget Period 2	81.087				$82,563	$82,563
2.						$0
3.						$0
4.						$0
5. Totals		$0	$0	$0	$82,563	$82,563

Section B - Budget Categories					
6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 2	(2)	(3)	(4)	
a. Personnel	$38,755				$38,755
b. Fringe Benefits	$12,828				$12,828
c. Travel	$3,178				$3,178
d. Equipment					$0
e. Supplies	$8,797				$8,797
f. Contractual					$0
g. Construction					$0
h. Other					$0
i. Total Direct Charges (sum of 6a-6h)	$63,558	$0	$0	$0	$63,558
j. Indirect Charges	$19,005				$19,005
k. Totals (sum of 6i-6j)	$82,563	$0	$0	$0	$82,563
7. Program Income					$0

Previous Edition Usable

SF-424A (Rev. 4-92)
Prescribed by OMB Circular A-102

Section C - Non-Federal Resources				
(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 2	$82,563			$82,563
9.				$0
10.				$0
11.				$0
12. Total (sum of lines 8 - 11)	$82,563	$0	$0	$82,563

Section D - Forecasted Cash Needs					
	Total	1st Quarter	2nd Quarter	3th Quarter	4th Quarter
13. Federal	$0				
14. Non-Federal	$44,419	$14,413	$14,413	$14,414	$1,179
15. Total (sum of lines 13 and 14)	$44,419	$14,413	$14,413	$14,414	$1,179

Section E - Budget Estimates of Federal Funds Needed for Balance of the Project				
	Future Funding Periods (Years)			
(a) Grant Program	(b) First	(c) Second	(d) Third	(e) Fourth
16.				
17.				
18.				
19.				
20. Total (sum of lines 16-19)	$0	$0	$0	$0

Section F - Other Budget Information	
21. Direct Charges	22. Indirect Charges 49.00%
23. Remarks	

Applicant Name: Novozymes Award Number: DE-FOA-0000096

Budget Information - Non Construction Programs

Budget Period 3

Section A - Budget Summary						
Grant Program Function or Activity	Catalog of Federal Domestic Assistance Number	Estimated Unobligated Funds		New or Revised Budget		
		Federal	Non-Federal	Federal	Non-Federal	Total
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1. Budget Period 3	81.087				$17,634	$17,634
2.						$0
3.						$0
4.						$0
5. Totals		$0	$0	$0	$17,634	$17,634

Section B - Budget Categories					
6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1) Budget Period 3	(2)	(3)	(4)	
a. Personnel	$7,267				$7,267
b. Fringe Benefits	$2,405				$2,405
c. Travel					$0
d. Equipment					$0
e. Supplies	$4,398				$4,398
f. Contractual					$0
g. Construction					$0
h. Other					$0
i. Total Direct Charges (sum of 6a-6h)	$14,070	$0	$0	$0	$14,070
j. Indirect Charges	$3,564				$3,564
k. Totals (sum of 6i-6j)	$17,634	$0	$0	$0	$17,634
7. Program Income					$0

Previous Edition Usable

SF-424A (Rev. 4-92)
Prescribed by OMB Circular A-102

Section C - Non-Federal Resources				
(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8. Budget Period 3	$17,634			$17,634
9.				$0
10.				$0
11.				$0
12. Total (sum of lines 8 - 11)	$17,634	$0	$0	$17,634

Section D - Forecasted Cash Needs					
	Total	1st Quarter	2nd Quarter	3th Quarter	4th Quarter
13. Federal	$0				
14. Non-Federal	$44,419	$14,413	$14,413	$14,414	$1,179
15. Total (sum of lines 13 and 14)	$44,419	$14,413	$14,413	$14,414	$1,179

Section E - Budget Estimates of Federal Funds Needed for Balance of the Project				
	Future Funding Periods (Years)			
(a) Grant Program	(b) First	(c) Second	(d) Third	(e) Fourth
16.				
17.				
18.				
19.				
20. Total (sum of lines 16-19)	$0	$0	$0	$0

Section F - Other Budget Information	
21. Direct Charges	22. Indirect Charges 49.00%
23. Remarks	

Instructions and Summary

Award Number: DE-FOA-0000096
Award Recipient: Novozymes (Sub-Award)

Date of Submission: 25-Jun-09
Form submitted by: MBI International
(May be award recipient or sub-recipient)

Please read the instructions on each page before starting.
If you have any questions, please ask your DOE contact. It will save you time!

On this form, provide detailed support for the estimated project costs identified on the SF-424A form (Budget).

- **The dollar amounts on this page must match the amounts on the associated SF-424A.**
- **The award recipient and each sub-recipient with estimated costs of $100,000 or more must complete this form and a SF-424A form.**
- **The total budget presented on this form and on the SF424A must include both Federal (DOE), and Non-Federal (cost share) portions, thereby reflecting TOTAL PROJECT COSTS proposed.**
- **For costs in each Object Class Category on the SF-424A, complete the corresponding worksheet on this form (tab at the bottom of the page).**
- **All costs incurred by the preparer's sub-recipients, vendors, contractors, consultants and Federal Research and Development Centers (FFRDCs), should be entered only in section f. Contractual. All other sections are for the costs of the preparer only.**

SUMMARY OF BUDGET CATEGORY COSTS PROPOSED
(Note: The values in this summary table are from entries made in each budget category sheet.)

CATEGORY	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Total Costs	Project Costs %	Comments (Add comments as needed)
a. Personnel	$21,800	$38,755	$7,266	**$67,822**	**47.3%**	
b. Fringe Benefits	$7,216	$12,828	$2,405	**$22,449**	**15.7%**	
c. Travel	$3,533	$3,178	$0	**$6,711**	**4.7%**	
d. Equipment	$0	$0	$0	**$0**	**0.0%**	
e. Supplies	$0	$8,797	$4,398	**$13,195**	**9.2%**	
f. Contractual						
Sub-recipient	*$0*	*$0*	*$0*	*$0*	*0.0%*	
FFRDC	*$0*	*$0*	*$0*	*$0*	*0.0%*	
Vendor	*$0*	*$0*	*$0*	*$0*	*0.0%*	
Total Contractual	$0	$0	$0	**$0**	**0.0%**	
g. Construction	$0	$0	$0	**$0**	**0.0%**	
h. Other Direct Costs	$0	$0	$0	**$0**	**0.0%**	
i. Indirect Charges	$10,691	$19,005	$3,564	**$33,260**	**23.2%**	
Total Project Costs	**$43,240**	**$82,563**	**$17,634**	**$143,437**	**100.0%**	

Additional Explanations/Comments (as necessary)

a. Personnel

PLEASE READ!!!

List costs solely for employees of the entity completing this form (award recipient or sub-recipient). All other personnel costs (of subrecipients or other contractual efforts of the entity preparing this) must be included under f., Contractual. This includes all consultants and FFRDCs.

Identify positions to be supported. Key personnel should be identified by title. All other personnel should be identified either by title or a group category. State the amounts of time (e.g., hours or % of time) to be expended, the composite base pay rate, total direct personnel compensation and identify the rate basis (e.g., actual salary, labor distribution report, technical estimate, state civil service rates, etc.).

Add rows as needed. Formulas/calculations will need to be entered by the preparer of this form. Please enter formulas as shown in the example.

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
1. Generation 2A Receiver Design		**10000**		**$423,000**	**600**		**$24,000**	**800**		**$31,000**	**11400**	**$478,000**	**Actual Salary**
EXAMPLE	Sr. Engineer	2000	$85.00	$170,000	200	$50.00	$10,000	200	$50.00	$10,000	**2400**	**$190,000**	Actual Salary
ONLY!!!	Electrical engineers	6200	$35.00	$217,000	400	$35.00	$14,000	600	$35.00	$21,000	**7200**	**$252,000**	Actual Salary
	Technician	1800	$20.00	$36,000	0	$0.00	$0	0	$0.00	$0	**1800**	**$36,000**	Actual Salary
1.3.310.1 Hemicellulase Screening on AFEX-treated Corn Stover		**195.29**		**$ 10,936**							**195**	**10936**	**Actual Salary**
	Senior Scientist	195	$56.00	$ 10,936							**195**	**$10,936**	Actual Salary
1.3.3.10.2 Analysis of soluble inhibitors formed during AFEX pretreatm		**162**		**$ 9,072**							**162**	**9072**	Actual Salary
	Senior Scientist	162	$56.00	$ 9,072							**162**	**$9,072**	Actual Salary
1.8 Project Review Meeting		**32**		**$ 1,792**							**32**	**1792**	Actual Salary
	Senior Scientist	32	$56.00	$ 1,792							**32**	**$1,792**	Actual Salary
2.7.4 NREL PDU/IBRF Saccharification and Fermentation Shakedown Trials					**195**		**$11,242**				**195**	**11242**	Actual Salary
	Senior Scientist				195	$57.68	$11,242				**195**	**$11,242**	Actual Salary
2.8.4 NREL PDU/IBRF Saccharification and Fermentation Capstone Runs					**194**		**$11,190**				**194**	**11190**	Actual Salary
	Senior Scientist				194	$57.68	$11,190				**194**	**$11,190**	Actual Salary
2.11 Techno-economic modeling and Life Cycle Analysis					**195**		**$11,248**				**195**	**11248**	Actual Salary
	Senior Scientist				195	$57.68	$11,248				**195**	**$11,248**	Actual Salary
2.16 Project Review Meetings					**88**		**$5,076**				**88**	**5076**	Actual Salary
	Senior Scientist				88	$57.68	$5,076				**88**	**$5,076**	Actual Salary
3.2.1 Techno -economic modeling and Life Cycle Anallysis								**98**		**$5,841**	**98**	**5841**	Actual Salary
	Senior Scientist							98	$59.41	$5,841	**98**	**$5,841**	Actual Salary
3.5 Project Review Meetings								**24**		**$1,426**	**24**	**1426**	Actual Salary
	Senior Scientist							24	$59.41	$1,426	**24**	**$1,426**	Actual Salary

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
	Total Personnel Costs	389		$21,800	672		$ 38,755	122		$7,266	1183	$67,822	

Additional Explanations/Comments (as necessary)

b. Fringe Benefits

	Budget Period 1	Budget Period 2	Budget Period 3	Total
Rate applied:	33.1%	33.1%	33.1%	
Total fringe requested:	$7,216	$12,828	$2,405	**$22,449**

A federally approved fringe benefit rate agreement, or a proposed rate supported and agreed upon by DOE for estimating purposes is required if reimbursement for fringe benefits is requested. Please check (X) one of the options below and provide the requested information, if it has not already been provided to the Contracting Officer, OR if it has changed since it was. Calculate the fringe rate and enter the total amount in Section B, line 6.b. ("Fringe Benefits") of form SF-424A.

_____ **A fringe benefit rate has been negotiated with, or approved by, a federal government agency. A copy of the latest rate agreement is included with this application, and will be provided electronically to the Contracting Officer for this project.**
(When this option is selected, a presentation of the budget that demonstrates the appliction of the approved rate, to arrive at the proposed fringes benefits dollars should also be provided.)

X **There is not a current, federally approved rate agreement negotiated and available.**
(When this option is checked, the entity preparing this form shall submit a rate proposal in the format provided at the following website, or a format that provides the same level of information and which will support the rates being proposed for use in performance of the proposed project. Go to https://www.eere-pmc.energy.gov/forms.aspx and select PMC 400.2 Sample Rate Proposal.)

Additional explanation/comments (as necessary)

This information is considered proprietary and will be submitted directly to DOE upon negotiation of an award.

c. Travel

PLEASE READ!!!

Provide travel detail as requested below, identifying total Foreign and Domestic Travel as separate items. Purpose of travel are items such as professional conference, DOE sponsored meeting, project management meeting, etc. The Basis for Estimating Costs are items such as past trips, current quotations, Federal Travel Regulations, etc.

All listed travel must be necessary for performance of the Statement of Projecct Objectives.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Purpose of travel	No. of Travelers	Depart From (not required for domestic travel)	Destination (not required for domestic travel)	No. of Days	Cost per Traveler	Cost per Trip	Basis for Estimating Costs
Budget Period 1							
Domestic Travel							
EXAMPLE ONLY!!! Visit to PV cell mfr. to set up vendor agreement	2			2	$650	$1,300	Internet prices
Travel to MBI for Colloboration	1			5	$1,600	$1,600	Internet Prices
Travel to MBI for Colloboration	1			2	$967	$967	Internet Prices
Travel to MBI for Colloboration	1			2	$966	$966	Internet Prices
						$0	
						$0	
						$0	
						$0	
Domestic Travel subtotal						$3,533	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 1 Total						**$3,533**	

Purpose of travel	No. of Travelers	Depart From (not required for domestic travel)	Destination (not required for domestic travel)	No. of Days	Cost per Traveler	Cost per Trip	Basis for Estimating Costs
Budget Period 2							
Domestic Travel							
Travel to NREL for Colloboration Work	1			4	$1,589	$1,589	Internet Prices
Travel to NREL for Colloboration Work	1			4	$1,589	$1,589	Internet Prices
						$0	
						$0	
						$0	
						$0	
Domestic Travel subtotal						$3,178	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 2 Total						**$3,178**	
Budget Period 3							
Domestic Travel							
						$0	
						$0	
						$0	
						$0	
						$0	
						$0	
Domestic Travel subtotal						$0	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 3 Total						**$0**	
PROJECT TOTAL						**$6,711**	

Additional Explanations/Comments (as necessary)

d. Equipment

PLEASE READ!!!

Equipment is generally defined as an item with an acquisition cost greater than $5,000 and a useful life expectancy of more than one year. Further definitions can be found at 10 CFR 600 found on the PMC Recipient Resources Forms page at https://www.eere-pmc.energy.gov/Forms.aspx#regs .

List all proposed equipment below, providing a basis of cost such as vendor quotes, catalog prices, prior invoices, etc., and briefly justifying its need as it applies to the Statement of Project Objectives. If it is existing equipment, and the value of its contribution to the project budget is being shown as cost share, provide logical support for the estimated value shown. If it is new equipment which will retain a useful life upon completion of the project, provide logical support for the estimated value shown.

For equipment over $50,000 in price, also include a copy of the associated vendor quote or catalog price list.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 1					
EXAMPLE ONLY!!! Thermal shock chamber	2	$20,000	$40,000	Vendor Quote	Reliability testing of PV modules- Task 4.3
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 1 Total			$0		
Budget Period 2					

Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
			$0		
			$0		
Budget Period 2 Total			$0		
Budget Period 3					
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 3 Total			$0		
PROJECT TOTAL			**$0**		

Additional Explanations/Comments (as necessary)

e. Supplies

PLEASE READ!!!

Supplies are generally defined as an item with an acquisition cost of $5,000 or less and a useful life expectancy of less than one year. Supplies are generally consumed during the project performance. Further definitions can be found at 10 CFR 600 found on the PMC Recipient Resources Forms page at https://www.eere-pmc.energy.gov/Forms.aspx#regs.

List all proposed supplies below, providing a bases of cost such as vendor quotes, catalog prices, prior invoices, etc., and briefly justifying the need for the Supplies as they apply to the Statement of Project Objectives. Note that Supply items must be direct costs to the project at this budget category, and not duplicative of supply costs included in the indirect pool that is the basis of the indirect rate applied for this project.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

General Category of Supplies	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 1					
EXAMPLE ONLY!!! Wireless DAS components	10	$360.00	$3,600	Catalog price	For Alpha prototype - Task 2.4
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 1 Total			**$0**		
Budget Period 2					
Enzymes			$8,797	Vendor Quote	
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 2 Total			$8,797		

General Category of Supplies	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 3					
Enzymes			$4,398	Vendor Quote	
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 3 Total			$4,398		
PROJECT TOTAL			**$13,195**		

Additional Explanations/Comments (as necessary)

f. Contractual

PLEASE READ!!!

The entity completing this form must provide all costs related to sub-recipients, vendors, contractors, consultants and FFRDC partners in the applicable boxes below.

Sub-recipients (partners, sub-awardees):
For each sub-recipient with total project costs of $100,000 or more, a separate SF-424A budget and PMC123.1 budget justification form must be submitted. These sub-recipient forms may be completed by either the sub-recipients themselves or by the preparer of this form. The budget totals on the sub-recipient's forms must match the sub-recipeint entries below.

The preparer of this form need only provide further support of the completed sub-recipient budget forms as they deem necessary. The support to justify the budgets of sub-recipients with estimated costs less than $100,000 may be in any format, and at a minimum should provide what Statement of Project Objectives task(s) are being performed, the purpose/need for the effort, and a basis of the estimated costs that is considered sufficient for DOE evaluation.

Vendors (includes contractors and consultants):
List all vendors, contractors and consultants supplying commercial supplies or services used to support the project. The support to justify vendor costs (in any amount) should provide the purpose for the products or services and a basis of the estimated costs that is considered sufficient for DOE evaluation.

Federal Research and Development Centers (FFRDCs):
For FFRDC partners, award recipient will provide a Field Work Proposal (if not already provided with the original application), along with the FFRDC labor mix and hours, by category and FFRDC major purchases greater than $25,000, including Quantity, Unit Cost, Basis of Cost, and Justification. The award recipient may allow the FFRDC to provide this information directly to DOE.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Sub-Recipient Name/Organization	Purpose/Tasks in SOPO	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
EXAMPLE ONLY!!! XYZ Corp.	Partner to develop optimal fresnel lens for Gen 2 product - Task 2.4	$48,000	$32,000	$16,000	**$96,000**
					$0
					$0
					$0
					$0
					$0

Sub-Recipient Name/Organization	Purpose/Tasks in SOPO	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
					$0
					$0
					$0
	Sub-total	$0	$0	$0	$0

Vendor Name/Organization	Product or Service, Purpose/Need and Basis of Cost (Provide additional support at bottom of page as needed)	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
EXAMPLE ONLY!!! ABC Corp.	Vendor for developing custom robotics to perform lens inspection, alignment, and placement (Task 4). Required for expanding CPV module mfg. capacity. Cost is from competitive quotes.	$32,900	$86,500		**$119,400**
					$0
					$0
					$0
					$0
					$0
					$0
					$0
		$0	$0	$0	$0

FFRDC Name/Organization	Purpose	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
					$0
					$0
					$0
		$0	$0	$0	$0

Total Contractual		$0	$0	$0	$0

AdditionalExplanations/Comments (as necessary)

g. Construction

PLEASE READ!!!

Construction, for the purpose of budgeting, is defined as all types of work done on a particular building, including erecting, altering, or remodeling. Construction conducted by the award recipient is entered on this page. Any construction work that is performed by a vendor or subrecipient to the award recipient should be entered under f. Contractual.

List all proposed construction below, providing a basis of cost such as engineering estimates, prior construction, etc., and briefly justify its need as it applies to the Statement of Project Objectives.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Overall description of construction actiivities:

Example Only!!! - Build wind turbine platform

General Description	Cost	Basis of Cost	Justification of need
Budget Period 1			
Three days of excavation for platform site EXAMPLE ONLY!!!	$28,000	Engineering estimate	Site must be prepared for construction of platform.
Budget Period 1 Total	**$0**		
Budget Period 2			
Budget Period 2 Total	$0		

General Description	Cost	Basis of Cost	Justification of need
Budget Period 3			
Budget Period 3 Total	$0		
PROJECT TOTAL	**$0**		

Additional Explanations/Comments (as necessary)

h. Other Direct Costs

PLEASE READ!!!

Other direct costs are direct cost items required for the project which do not fit clearly into other categories, and are not included in the indirect pool for which the indirect rate is being applied to this project. Examples are meeting costs, postage, couriers or express mail, telephone/fax costs, printing costs, etc.

Basis of cost are items such as vendor quotes, prior purchases of similar or like items, published price list, etc.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

General description	Cost	Basis of Cost	Justification of need
Budget Period 1			
EXAMPLE ONLY!!! Grad student tuition	$16,000	Established UCD costs	Support of graduate students working on project
Budget Period 1 Total	$0		
Budget Period 2			
Budget Period 2 Total	$0		
Budget Period 3			
Budget Period 3 Total	$0		
PROJECT TOTAL	**$0**		

Additional Explanations/Comments (as necessary)

i. Indirect Costs

	Budget Period 1	Budget Period 2	Budget Period 3	Total
Rate applied:	49.0%	49.0%	49.0%	
Total indirect costs requested:	$10,691	$19,005	$3,564	**$33,260**

A federally approved indirect rate agreement, or rate proposed supported and agreed upon by DOE for estimating purposes is required if reimbursement of fringe benfits is requested. Please check (X) one of the options below and provide the requested information if it has not already been provided as requested, or has changed. Calculate the indirect rate dollars and enter the total in the Section B., line 6.j. (Indirect Charges) of form SF 424A.

____ **There is a federally approved indirect rate agreement. A copy is provided with this application and will be provided electronically to the Contracting Officer for this project.**
(When this option is selected, a presentation of the budget that demonstrates the application of the approved rate, to arrive at the proposed indirect charges proposed should also be provided.)

X **There is no current, federally-approved indirect rate agreement.**
(When this option is checked, the entity preparing this form shall submit an indirect cost rate proposal in the format provided at the following website, or in a format that provides the same level of information and which supports the rate(s) being proposed for use in estimating the project. Go to https://www.eere-pmc.energy.gov/forms.aspx and select PMC 400.2 Sample Rate Proposal.)

Additional Explanations/Comments (as necessary)

This information is considered proprietary and will be submitted directly to DOE upon negotiation of an award.

Cost Share

PLEASE READ!!!

A detailed presentation of the cash or cash value of all cost share proposed for the project must be provided in the table below. Identify the source & amount of each item of cost share proposed by the award recipient and each sub-recipient or vendor. Letters of committment must be submitted for all third party cost share (other than award recipient).

Note that "cost-share" is not limited to cash investment. Other items that may be assigned value in a budget as incurred as part of the project budget and necessary to performance of the project, may be considered as cost share, such as: contribution of services or property; donated, purchased or existing equipment; buildings or land; donated, purchased or existing supplies; and/or unrecovered personnel, fringe benefits and indirect costs, etc. For each cost share contribution identified as other than cash, identify the item and describe how the value of the cost share contribution was calculated.

Funds from other Federal sources MAY NOT be counted as cost share. This prohibition includes FFRDC sub-recipients. Non-Federal sources include private, state or local Government, or any source not originally derived from Federal funds. Documentation of cost sharing commitments must be provided, if not already provided with the original application and they have not changed since its submission.

Fee or profit will not be paid to the award recipients or subrecipients of financial assistance awards. Additionally, foregone fee or profit by the applicant shall not be considered cost sharing under any resulting award. Reimbursement of actual costs will only include those costs that are allowable and allocable to the project as determined in accordance with the applicable cost principles prescribed in 10 CFR 600.127, 10 CFR 600.222 or 10 CFR 600.317. Also see 10 CFR 600.318 relative to profit or fee.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Organization/Source	Type (cash or other)	Cost Share Item	Budget Period 1 Cost Share	Budget Period 2 Cost Share	Budget Period 3 Cost Share	Total Project Cost Share
ABC Company **EXAMPLE ONLY!!!**	Cash	Project partner ABC Company will provide 40 PV modules for product development at 50% off the of the retail price of $680	$13,600			**$13,600**
						$0
						$0
						$0
						$0
						$0
						$0

Organization/Source	Type (cash or other)	Cost Share Item	Budget Period 1 Cost Share	Budget Period 2 Cost Share	Budget Period 3 Cost Share	Total Project Cost Share
						$0
						$0
						$0
						$0
		Totals	$0	$0	$0	$0

Total Project Cost: $143,437 **Cost Share Percent of Award: 0.0%**

Additional Explanations/Comments (as necessary)

DOE O 412.1A
4-21-05

U.S. DEPARTMENT OF ENERGY
FY 2009 WORK PROPOSAL

1. Work Proposal Number:	2. Revision Number:	3. Date Prepared:
BMW/541	0	04/29/2009

4. Work Proposal Title: Test Pilot-Scale MBI AFEX Process	5. Budget and Reporting Code: BM01

6. Work Proposal Term: Begin 01/01/2010 End 12/30/2013

7. Name: (Last, First, MI) (Phone Number)	8. DOE Organization:
DOE Program Manager Lightner, Valri Anne (202-586-0937)	Office of the Biomass Program
9. DOE Field Element Work Proposal Reviewer:	**10. DOE Field Element:** GO – Golden Field Office
11. Contractor Work Proposal Manager: John Ashworth	**12. Contractor Name:** Alliance for Sustainable Energy, LLC (NREL)

12. Proposal Description (Approach, Anticipated Benefit in 200 Words or Less):

NREL will work with MBI International as a sub-tier partner under the FOA Recovery Act - Demonstration of Integrated Biorefinery Operations, Number DE-FOA-0000096 to test the pilot-scale MBI AFEX process. NREL will provide a variety of scientific and engineering support for this R&D project, including bench-scale saccharification and fermentation work, review of the MBI pilot-plant design and other new systems at MBI, shakedown and optimization runs of enzymatic hydrolysis and fermentation, and pilot-scale "capstone" runs of enzymatic hydrolysis and fermentation at NREL.

14.		15. DOE Field Element Official:	
John N Ashworth Contractor Work Proposal Manager, John Ashworth	05/27/2009 Date		
Thos D. Foust Laboratory Program Manager, Thomas Foust	05/27/2009 Date		
Joseph M. Cleary Center Director, Joseph M. Cleary	5-29-09 Date	(Signature)	(Date)
Dale Gardner Associate Lab Director, Dale Gardner	5-29-09 Date		

16. Detail Attachments: (See Attachments)

☐ a. Facility Requirements	☐ f. Technical progress	☐ k. Deliverables
☐ b. Publications	☐ g. Future Accomplishments	☐ l. Perform measures/expectations
☐ c. Purpose	☐ h. Relationships to Other Projects	☐ m. ES&H Considerations
☐ d. Background	☐ i. NEPA Requirements	☐ n. Human/Animal Subjects
☐ e. Approach	☐ j. Milestones	☐ o. Other (Specify)

WORK PROPOSAL REQUIREMENTS FOR OPERATING/EQUIPMENT OBLIGATIONS AND COSTS

Contractor Name: National Renewable Energy Laboratory	Work Proposal #: BMW/541	Rev. No.: 0	Date Prepared: 04/29/2009

	FY09 (BY)		FY10	FY11	FY12	FY13	FY14
17. Staffing (staff years):	Request	Authorized					
a. Scientific	0.0	0.0	0.9	0.15	3.6	2.5	0.0
b. Other Direct	0.0	0.0	0.0	0.0	0.0	0.0	0.0
c. Total Direct	0.0	0.0	0.9	0.15	3.6	2.5	0.0
18. Operating Expense:							
a. Total Obligations	$0	$0	$468	$301	$1575	$1130	$0
b. Total Costs	$0	$0	$468	$301	$1575	$1130	$0
19. Equipment:							
a. Equipment Obligations	$0	$0	$0	$0	$0	$0	$0
b. Equipment Costs	$0	$0	$0	$0	$0	$0	$0

20. Milestone Schedule:	Proposed	Authorized
See attachment 16.j.		

21. Reporting Requirements (Description):
See attachment 16.k.

BY = Budget Year

OMB Number: 4040-0004
Expiration Date: 01/31/2009

Application for Federal Assistance SF-424 Version 02

*1. Type of Submission:	*2. Type of Application	* If Revision, select appropriate letter(s)
☐ Preapplication	☒ New	
☒ Application	☐ Continuation	*Other (Specify)
☐ Changed/Corrected Application	☐ Revision	

3. Date Received: 4. Applicant Identifier:

5a. Federal Entity Identifier: *5b. Federal Award Identifier:

State Use Only:

6. Date Received by State: 7. State Application Identifier:

8. APPLICANT INFORMATION:

*a. Legal Name: Alliance for Sustainable Energy LLC

*b. Employer/Taxpayer Identification Number (EIN/TIN):

*c. Organizational DUNS: 805948051

d. Address:

*Street 1: 1617 Cole Boulevard
Street 2:
*City: Golden
County: Jefferson
*State: CO
Province:
*Country: U.S.A.
*Zip / Postal Code 80401

e. Organizational Unit:

Department Name: U.S. Department of Energy

Division Name: Energy Efficiency and Renewable Energy

f. Name and contact information of person to be contacted on matters involving this application:

Prefix: Dr. *First Name: John
Middle Name: Henry
*Last Name: Ashworth
Suffix:

Title: Team Leader, Partnership Development

Organizational Affiliation:
National Biue nergy Center, National Renewable Energy Laboratgory

*Telephone Number: 303-384-6858 Fax Number: 303-384-6877

*Email: john.ashworth@nrel.gov

Application for Federal Assistance SF-424 Version 02

***9. Type of Applicant 1: Select Applicant Type:**

M.Nonprofit w/501C3 IRS Status(Oth Than Higher Edu

Type of Applicant 2: Select Applicant Type:

Type of Applicant 3: Select Applicant Type:

*Other (Specify)

***10 Name of Federal Agency:**

U. S. Department of Energy

11. Catalog of Federal Domestic Assistance Number:

81.087

CFDA Title:

Renewable Energy Research and Development

***12 Funding Opportunity Number:**

DE-FOA-0000096

*Title:

Recovery Act - Demonstration of Integrated Biorefinery Operations

13. Competition Identification Number:

Title:

14. Areas Affected by Project (Cities, Counties, States, etc.):

Jefferson County, Colorado

***15. Descriptive Title of Applicant's Project:**

Team MBI's project will employ an innovative approach to the integrated biorefinery, involving: (a) the use of corn-stover as the cellulosic feedstock; (b) biomass pretreatment/preparation step using Ammonia Fiber Expansion (AFEX) process; (c) enzymatic hydrolysis of AFEX-treated biomass using cellulase and xylanase enzymes; and (d) fermentation of C5 and C6 sugars to ethanol using a strain of Zymomonas mobilis.

OMB Number: 4040-0004
Expiration Date: 01/31/2009

Application for Federal Assistance SF-424 Version 02

16. Congressional Districts Of:

*a. Applicant: *b. Program/Project: MI-008

17. Proposed Project:

*a. Start Date: January 1, 2010 *b. End Date: December 30, 2013

18. Estimated Funding ($):

*a. Federal	3,473,313
*b. Applicant	
*c. State	
*d. Local	
*e. Other	
*f. Program Income	
*g. TOTAL	3,473,313

***19. Is Application Subject to Review By State Under Executive Order 12372 Process?**

☐ a. This application was made available to the State under the Executive Order 12372 Process for review on _____

☐ b. Program is subject to E.O. 12372 but has not been selected by the State for review.

☒ c. Program is not covered by E. O. 12372

***20. Is the Applicant Delinquent On Any Federal Debt? (If "Yes", provide explanation.)**

☐ Yes ☒ No

21. *By signing this application, I certify (1) to the statements contained in the list of certifications** and (2) that the statements herein are true, complete and accurate to the best of my knowledge. I also provide the required assurances** and agree to comply with any resulting terms if I accept an award. I am aware that any false, fictitious, or fraudulent statements or claims may subject me to criminal, civil, or administrative penalties. (U. S. Code, Title 218, Section 1001)

☒ ** I AGREE

** The list of certifications and assurances, or an internet site where you may obtain this list, is contained in the announcement or agency specific instructions

Authorized Representative:

Prefix: _____ *First Name: Dale

Middle Name: A.

*Last Name: Gardner

Suffix: _____

*Title: Associate Lab Director

*Telephone Number: 303-275-3020 | Fax Number: 303-275-3097

* Email: dale.gardner@nrel.gov

*Signature of Authorized Representative: Dale A. Gardner *Date Signed: 5/27/09

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Standard Form 424 (Revised 10/2005)
Prescribed by OMB Circular A-102

Application for Federal Assistance SF-424 Version 02

***Applicant Federal Debt Delinquency Explanation**

The following should contain an explanation if the Applicant organization is delinquent of any Federal Debt.

Applicant Name: MBI

Award Number:

Budget Information - Non Construction Programs

OMB Approval No. 0348-0044

Section A - Budget Summary

Grant Program Function or Activity (a)	Catalog of Federal Domestic Assistance Number (b)	Estimated Unobligated Funds		New or Revised Budget		
		Federal (c)	Non-Federal (d)	Federal (e)	Non-Federal (f)	Total (g)
1.				$3,473,313		$3,473,313
2.						$0
3.						$0
4.						$0
5. Totals		$0	$0	$3,473,313	$0	$3,473,313

Section B - Budget Categories

6. Object Class Categories	Grant Program, Function or Activity				Total (5)
	(1)	(2)	(3)	(4)	
a. Personnel	$650,893				$650,893
b. Fringe Benefits	$335,210				$335,210
c. Travel	$27,600				$27,600
d. Equipment					$0
e. Supplies	$570,000				$570,000
f. Contractual					$0
g. Construction					$0
h. Other	$37,000				$37,000
i. Total Direct Charges (sum of 6a-6h)	$1,620,703	$0	$0	$0	$1,620,703
j. Indirect Charges	$1,852,610				$1,852,610
k. **Totals** (sum of 6i-6j)	$3,473,313	$0	$0	$0	$3,473,313
7. Program Income					$0

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SF-424A (Rev. 4-92)
Prescribed by OMB Circular A-102

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Section C - Non-Federal Resources				
(a) Grant Program	(b) Applicant	(c) State	(d) Other Sources	(e) Totals
8.				$0
9.				$0
10.				$0
11.				$0
12. Total (sum of lines 8 - 11)	$0	$0	$0	$0

Section D - Forecasted Cash Needs					
	Total for 1st Year	1st Quarter	2nd Quarter	3rd Quarter	4th quarter
13. Federal	$467,536				
14. Non-Federal	$0				
15. Total (sum of lines 13 and 14)	$467,536	$0	$0	$0	$0

Section E - Budget Estimates of Federal Funds Needed for Balance of the Project				
	Future Funding Periods (Years)			
(a) Grant Program	(b) First	(c) Second	(d) Third	(e) Fourth
16.	$467,536	$300,876	$1,574,471	$1,130,430
17.				
18.				
19.				
20. Total (sum of lines 16-19)	$467,536	$300,876	$1,574,471	$1,130,430

Section F - Other Budget Information	
21. Direct Charges	22. Indirect Charges

23. Remarks

Instructions and Summary

Award Number: _____ **Date of Submission:** _____

Award Recipient: NREL **Form submitted by:** NREL

(May be award recipient or sub-recipient)

Please read the instructions on each page before starting.
If you have any questions, please ask your DOE contact. It will save you time!

On this form, provide detailed support for the estimated project costs identified on the SF-424A form (Budget). X

- **The dollar amounts on this page must match the amounts on the associated SF-424A.**
- **The award recipient and each sub-recipient with estimated costs of $100,000 or more must complete this form and a SF-424A form.**
- **The total budget presented on this form and on the SF424A must include both Federal (DOE), and Non-Federal (cost share) portions, thereby reflecting TOTAL PROJECT COSTS proposed.**
- **For costs in each Object Class Category on the SF-424A, complete the corresponding worksheet on this form (tab at the bottom of the page).**
- **All costs incurred by the preparer's sub-recipients, vendors, contractors, consultants and Federal Research and Development Centers (FFRDCs), should be entered only in section f. Contractual. All other sections are for the costs of the preparer only.**

SUMMARY OF BUDGET CATEGORY COSTS PROPOSED

(Note: The values in this summary table are from entries made in each budget category sheet.)

CATEGORY	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Total Costs	Project Costs %	Comments (Add comments as needed)
a. Personnel	$0	$0	$0	**$0**	**0.0%**	
b. Fringe Benefits	$0	$0	$0	**$0**	**0.0%**	
c. Travel	$8,400	$9,600	$9,600	**$27,600**	**4.6%**	
d. Equipment	$0	$0	$0	**$0**	**0.0%**	
e. Supplies	$100,000	$250,000	$220,000	**$570,000**	**95.4%**	
f. Contractual						
Sub-recipient	*$0*	*$0*	*$0*	*$0*	*0.0%*	
FFRDC	*$0*	*$0*	*$0*	*$0*	*0.0%*	
Vendor	*$0*	*$0*	*$0*	*$0*	*0.0%*	
Total Contractual	$0	$0	$0	**$0**	**0.0%**	
g. Construction	$0	$0	$0	**$0**	**0.0%**	
h. Other Direct Costs	$0	$0	$0	**$0**	**0.0%**	
i. Indirect Charges	$0	$0	$0	**$0**	**0.0%**	
Total Project Costs	**$108,400**	**$259,600**	**$229,600**	**$597,600**	**100.0%**	

Additional Explanations/Comments (as necessary)

a. Personnel

PLEASE READ!!!

List costs solely for employees of the entity completing this form (award recipient or sub-recipient). All other personnel costs (of subrecipients or other contractual efforts of the entity preparing this) must be included under f., Contractual. This includes all consultants and FFRDCs.

Identify positions to be supported. Key personnel should be identified by title. All other personnel should be identified either by title or a group category. State the amounts of time (e.g., hours or % of time) to be expended, the composite base pay rate, total direct personnel compensation and identify the rate basis (e.g., actual salary, labor distribution report, technical estimate, state civil service rates, etc.).

Add rows as needed. Formulas/calculations will need to be entered by the preparer of this form. Please enter formulas as shown in the example.

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
1. Generation 2A Receiver Design		**10000**		**$423,000**	**600**		**$24,000**	**800**		**$31,000**	**11400**	**$478,000**	**Actual Salary**
EXAMPLE	Sr. Engineer	2000	$85.00	$170,000	200	$50.00	$10,000	200	$50.00	$10,000	**2400**	**$190,000**	Actual Salary
ONLY!!!	Electrical engineers	6200	$35.00	$217,000	400	$35.00	$14,000	600	$35.00	$21,000	**7200**	**$252,000**	Actual Salary
	Technician	1800	$20.00	$36,000	0	$0.00	$0	0	$0.00	$0	**1800**	**$36,000**	Actual Salary
1a & 1b. Bench Scale Enzymatic Saccharification and Fermentation Process Validation, NREL Design Review of Pilot-Scale AFEX Pretreatment Equipment at MBI													
	Team Lead, Partnerships	90	Proprietary			Proprietary			Proprietary		**90**		Actual Salary
	Supervisor, Pretreatment Process	280	Proprietary			Proprietary			Proprietary		**280**		Actual Salary
	Engineer	720	Proprietary			Proprietary			Proprietary		**720**		
	Analytic Chemist	230	Proprietary			Proprietary			Proprietary		**230**		
	Technician	360	Proprietary			Proprietary			Proprietary		**360**		
	Administrative Support	50	Proprietary			Proprietary			Proprietary		**50**		
2a. Pilot Scale Enzymatic Saccharification and Fermentation Equipment Modification at NREL PDU/IBRF											**0**		
	Team Lead, Partnerships		Proprietary		30	Proprietary			Proprietary		**30**		
	Supervisor, Pretreatment Process		Proprietary		60	Proprietary			Proprietary		**60**		
	Engineer		Proprietary		100	Proprietary			Proprietary		**100**		
	Analytic Chemist		Proprietary		10	Proprietary			Proprietary		**10**		
	Master Techician		Proprietary		40	Proprietary			Proprietary		**40**		
	Technician		Proprietary		40	Proprietary			Proprietary		**40**		Actual Salary
	Administrative Support		Proprietary		10	Proprietary			Proprietary		**10**		Actual Salary
2b. Pilot Scale Enzymatic Saccharification and Fermentation Shakedown and Optimization Runs at NREL PDU/IBRF													
etc.	Team Lead, Partnerships		Proprietary		30	Proprietary		30	Proprietary		**60**		
	Supervisor, Pretreatment Process		Proprietary		500	Proprietary		500	Proprietary		**1000**		
	Engineer		Proprietary		620	Proprietary		620	Proprietary		**1240**		
	Analytic Chemist		Proprietary		440	Proprietary		440	Proprietary		**880**		
	Master Techician		Proprietary		720	Proprietary		720	Proprietary		**1440**		
	Technician		Proprietary		980	Proprietary		980	Proprietary		**1960**		

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			
	Administrative Support		Proprietary		70	Proprietary		70	Proprietary		**140**		
	Total Personnel Costs	**1730**		**$0**	**3650**		**$0**	**3360**		**$0**	**0**	**$0**	

Task # and Title	Position Title	Budget Period 1			Budget Period 2			Budget Period 3			Project Total Hours	Project Total Dollars	Rate Basis
		Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 1	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 2	Time (Hours)	Pay Rate ($/Hr)	Total Budget Period 3			

Additional Explanations/Comments (as necessary)

b. Fringe Benefits

	Budget Period 1	Budget Period 2	Budget Period 3	Total
Rate applied:	0.0%	0.0%	0.0%	
Total fringe requested:	$0	$0	$0	**$0**

A federally approved fringe benefit rate agreement, or a proposed rate supported and agreed upon by DOE for estimating purposes is required if reimbursement for fringe benefits is requested. Please check (X) one of the options below and provide the requested information. Calculate the fringe rate and enter the total amount in Section B, line 6.b. ("Fringe Benefits") of form SF-424A.

X **A fringe benefit rate has been negotiated with, or approved by, a federal government agency. A copy of the latest rate agreement is included with this application, and will be provided electronically to the Contracting Officer for this project.**
**In the area designated below, identify the full calculations used to derive the total fringe costs. See further information below.*

____ **There is not a current, federally approved rate agreement negotiated and available.**
*When this option is checked, the entity preparing this form shall submit a rate proposal in the format provided at the following website, or a format that provides the same level of information and which will support the rates being proposed for use in performance of the proposed project. Go to https://www.eere-pmc.energy.gov/forms.aspx and select PMC 400.2 Sample Rate Proposal. * In the area designated below, identify the full calculations used to derive the total fringe costs. See further information below.*

Additional explanation/comments (as necessary)

*IMPORTANT: In the space provided below (or as an attachment) provide a complete explanation and the full calculations used to derive the total fringe costs. If the total fringe costs are a cumulative amount of more than one calculation or rate application, the explanation and calculations should identify all rates used, along with the base they were applied to (and how the base was derived), and a total for each (along with grand total). The rates and how they are applied should not be averaged to get one fringe cost percentage. NOTE: The fringe benefit rate should be applied to both the Federal Share and Recipient Cost Share.

NREL fringe rate is on file with the DOE Golden Field Office and has been negotiated with that office and approved. .

***

c. Travel

PLEASE READ!!!

Provide travel detail as requested below, identifying total Foreign and Domestic Travel as separate items. Purpose of travel are items such as professional conference, DOE sponsored meeting, project management meeting, etc. The Basis for Estimating Costs are items such as past trips, current quotations, Federal Travel Regulations, etc.

All listed travel must be necessary for performance of the Statement of Projecct Objectives.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Purpose of travel	No. of Travelers	Depart From (not required for domestic travel)	Destination (not required for domestic travel)	No. of Days	Cost per Traveler	Cost per Trip	Basis for Estimating Costs
Budget Period 1							
Domestic Travel							
EXAMPLE ONLY!!! Visit to PV cell mfr. to set up vendor agreement	2			2	$650	$1,300	Internet prices
Internal review meeting	4			2	$900	$3,600	Internet pricing
DOE review meeting	2			2	$1,050	$2,100	Internet pricing
Visit to AFEX facility for consultation	3			2	$900	$2,700	
						$0	
						$0	
						$0	
						$0	
						$0	
Domestic Travel subtotal						$8,400	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 1 Total						**$8,400**	

Purpose of travel	No. of Travelers	Depart From (not required for domestic travel)	Destination (not required for domestic travel)	No. of Days	Cost per Traveler	Cost per Trip	Basis for Estimating Costs
Budget Period 2							
Domestic Travel							
Internal review meeting	4			2	$1,000	$4,000	Internet pricing
DOE review meeting	4			2	$1,000	$4,000	Internet pricing
Pilot Plant Collaboration	1			4	$1,600	$1,600	Internet pricing
						$0	
						$0	
						$0	
						$0	
Domestic Travel subtotal						$9,600	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 2 Total						**$9,600**	
Budget Period 3							
Domestic Travel							
Internal review meeting	3			2	$1,000	$3,000	Internet pricing
DOE review meeting	2			2	$1,050	$2,100	Internet pricing
Pilot Plant Collaboration	3			4	$1,500	$4,500	
						$0	
						$0	
						$0	
						$0	
Domestic Travel subtotal						$9,600	
International Travel							
						$0	
						$0	
						$0	
						$0	
International Travel subtotal						$0	
Budget Period 3 Total						**$9,600**	
PROJECT TOTAL						**$27,600**	

Additional Explanations/Comments (as necessary)

d. Equipment

PLEASE READ!!!

Equipment is generally defined as an item with an acquisition cost greater than $5,000 and a useful life expectancy of more than one year. Further definitions can be found at 10 CFR 600 found on the PMC Recipient Resources Forms page at https://www.eere-pmc.energy.gov/Forms.aspx#regs .

List all proposed equipment below, providing a basis of cost such as vendor quotes, catalog prices, prior invoices, etc., and briefly justifying its need as it applies to the Statement of Project Objectives. If it is existing equipment, and the value of its contribution to the project budget is being shown as cost share, provide logical support for the estimated value shown. If it is new equipment which will retain a useful life upon completion of the project, provide logical support for the estimated value shown.

For equipment over $50,000 in price, also include a copy of the associated vendor quote or catalog price list.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 1					
EXAMPLE ONLY!!! Thermal shock chamber	2	$20,000	$40,000	Vendor Quote	Reliability testing of PV modules- Task 4.3
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 1 Total			$0		
Budget Period 2					
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 2 Total			$0		

General Category of Supplies	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 2 Total			$250,000		
Budget Period 3					
Pilot Scale Saccharification Supplies			$100,000		
Pilot Scale Fermentation Supplies and Nutrients			$120,000		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 3 Total			$220,000		
PROJECT TOTAL			**$570,000**		

Additional Explanations/Comments (as necessary)

e. Supplies

PLEASE READ!!!

Supplies are generally defined as an item with an acquisition cost of $5,000 or less and a useful life expectancy of less than one year. Supplies are generally consumed during the project performance. Further definitions can be found at 10 CFR 600 found on the PMC Recipient Resources Forms page at https://www.eere-pmc.energy.gov/Forms.aspx#regs.

List all proposed supplies below, providing a bases of cost such as vendor quotes, catalog prices, prior invoices, etc., and briefly justifying the need for the Supplies as they apply to the Statement of Project Objectives. Note that Supply items must be direct costs to the project at this budget category, and not duplicative of supply costs included in the indirect pool that is the basis of the indirect rate applied for this project.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

General Category of Supplies	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 1					
EXAMPLE ONLY!!! Wireless DAS components	10	$360.00	$3,600	Catalog price	For Alpha prototype - Task 2.4
compositional analysis supplies			$8,000		
saccharification and fermentation supplies			$92,000		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 1 Total			**$100,000**		
Budget Period 2					
Pilot Scale Saccharification Supplies			$150,000		
Pilot Scale Fermentation Supplies and Nutrients			$100,000		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		

Equipment Item	Qty	Unit Cost	Total Cost	Basis of Cost	Justification of need
Budget Period 3					
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
			$0		
Budget Period 3 Total			$0		
PROJECT TOTAL			**$0**		

Additional Explanations/Comments (as necessary)

f. Contractual

PLEASE READ!!!

The entity completing this form must provide all costs related to sub-recipients, vendors, contractors, consultants and FFRDC partners in the applicable boxes below.

Sub-recipients (partners, sub-awardees):
For each sub-recipient with total project costs of $100,000 or more, a separate SF-424A budget and PMC123.1 budget justification form must be submitted. These sub-recipient forms may be completed by either the sub-recipients themselves or by the preparer of this form. The budget totals on the sub-recipient's forms must match the sub-recipeint entries below.

The preparer of this form need only provide further support of the completed sub-recipient budget forms as they deem necessary. The support to justify the budgets of sub-recipients with estimated costs less than $100,000 may be in any format, and at a minimum should provide what Statement of Project Objectives task(s) are being performed, the purpose/need for the effort, and a basis of the estimated costs that is considered sufficient for DOE evaluation.

Vendors (includes contractors and consultants):
List all vendors, contractors and consultants supplying commercial supplies or services used to support the project. The support to justify vendor costs (in any amount) should provide the purpose for the products or services and a basis of the estimated costs that is considered sufficient for DOE evaluation.

Federal Research and Development Centers (FFRDCs):
For FFRDC partners, award recipient will provide a Field Work Proposal (if not already provided with the original application), along with the FFRDC labor mix and hours, by category and FFRDC major purchases greater than $25,000, including Quantity, Unit Cost, Basis of Cost, and Justification. The award recipient may allow the FFRDC to provide this information directly to DOE.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Sub-Recipient Name/Organization	Purpose/Tasks in SOPO	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
EXAMPLE ONLY!!! XYZ Corp.	Partner to develop optimal fresnel lens for Gen 2 product - Task 2.4	$48,000	$32,000	$16,000	**$96,000**
	N/A	N/A			**$0**
					$0
					$0
					$0
					$0

Sub-Recipient Name/Organization	Purpose/Tasks in SOPO	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
					$0
					$0
					$0
	Sub-total	$0	$0	$0	$0

Vendor Name/Organization	Product or Service, Purpose/Need and Basis of Cost (Provide additional support at bottom of page as needed)	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
EXAMPLE ONLY!!! ABC Corp.	Vendor for developing custom robotics to perform lens inspection, alignment, and placement (Task 4). Required for expanding CPV module mfg. capacity. Cost is from competitive quotes.	$32,900	$86,500		**$119,400**
					$0
					$0
					$0
					$0
					$0
					$0
					$0
		$0	$0	$0	$0

FFRDC Name/Organization	Purpose	Budget Period 1 Costs	Budget Period 2 Costs	Budget Period 3 Costs	Project Total
					$0
					$0
					$0
		$0	$0	$0	$0

Total Contractual		$0	$0	$0	$0

AdditionalExplanations/Comments (as necessary)

g. Construction

PLEASE READ!!!

Construction, for the purpose of budgeting, is defined as all types of work done on a particular building, including erecting, altering, or remodeling. Construction conducted by the award recipient is entered on this page. Any construction work that is performed by a vendor or subrecipient to the award recipient should be entered under f. Contractual.

List all proposed construction below, providing a basis of cost such as engineering estimates, prior construction, etc., and briefly justify its need as it applies to the Statement of Project Objectives.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Overall description of construction actiivities:

Example Only!!! - Build wind turbine platform

General Description	Cost	Basis of Cost	Justification of need
Budget Period 1			
Three days of excavation for platform site EXAMPLE ONLY!!!	$28,000	Engineering estimate	Site must be prepared for construction of platform.
N/A			
Budget Period 1 Total	**$0**		
Budget Period 2			
Budget Period 2 Total	$0		

General Description	Cost	Basis of Cost	Justification of need
Budget Period 3			
Budget Period 3 Total	$0		
PROJECT TOTAL	**$0**		

Additional Explanations/Comments (as necessary)

h. Other Direct Costs

PLEASE READ!!!

Other direct costs are direct cost items required for the project which do not fit clearly into other categories, and are not included in the indirect pool for which the indirect rate is being applied to this project. Examples are meeting costs, postage, couriers or express mail, telephone/fax costs, printing costs, etc.

Basis of cost are items such as vendor quotes, prior purchases of similar or like items, published price list, etc.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

General description	Cost	Basis of Cost	Justification of need
Budget Period 1			
EXAMPLE ONLY!!! Grad student tuition	$16,000	Established UCD costs	Support of graduate students working on project
N/A			
Budget Period 1 Total	$0		
Budget Period 2			
Budget Period 2 Total	$0		
Budget Period 3			
Budget Period 3 Total	$0		
PROJECT TOTAL	**$0**		

Additional Explanations/Comments (as necessary)

i. Indirect Costs

	Budget Period 1	Budget Period 2	Budget Period 3	Total
Rate applied:	0.0%	0.0%	0.0%	
Total indirect costs requested:				**$0**

A federally approved indirect rate agreement, or rate proposed supported and agreed upon by DOE for estimating purposes is required if reimbursement of fringe benfits is requested. Please check (X) one of the options below and provide the requested information if it has not already been provided as requested, or has changed. Calculate the indirect rate dollars and enter the total in the Section B., line 6.j. (Indirect Charges) of form SF 424A.

_____ **There is a federally approved indirect rate agreement. A copy is provided with this application and will be provided electronically to the Contracting Officer for this project.**
**In the area designated below, identify the full calculations used to derive the total indirect costs. See further information below.*

_____ **There is no current, federally-approved indirect rate agreement.**
*When this option is checked, the entity preparing this form shall submit an indirect cost rate proposal in the format provided at the following website, or in a format that provides the same level of information and which supports the rate(s) being proposed for use in estimating the project. Go to https://www.eere-pmc.energy.gov/forms.aspx and select PMC 400.2 Sample Rate Proposal. *In the area designated below, identify the full calculations used to derive the total indirect costs. See further information below.*

Additional Explanations/Comments (as necessary)

*IMPORTANT: In the space provided below (or as an attachment) provide a complete explanation and the full calculations used to derive the total indirect costs. If the total indirect costs are a cumulative amount of more than one calculation or rate application, the explanation and calculations should identify all rates used, along with the base they were applied to (and how the base was derived), and a total for each (along with grand total). The rates and how they are applied should not be averaged to get one indirect cost percentage. NOTE: The indirect rate should be applied to both the Federal Share and Recipient Cost Share.

NREL indirect rate is on file with the DOE Golden Field Office and has been negotiated with that office and approved. .

Cost Share

PLEASE READ!!!

A detailed presentation of the cash or cash value of all cost share proposed for the project must be provided in the table below. Identify the source & amount of each item of cost share proposed by the award recipient and each sub-recipient or vendor. Letters of committment must be submitted for all third party cost share (other than award recipient).

Note that "cost-share" is not limited to cash investment. Other items that may be assigned value in a budget as incurred as part of the project budget and necessary to performance of the project, may be considered as cost share, such as: contribution of services or property; donated, purchased or existing equipment; buildings or land; donated, purchased or existing supplies; and/or unrecovered personnel, fringe benefits and indirect costs, etc. For each cost share contribution identified as other than cash, identify the item and describe how the value of the cost share contribution was calculated.

Funds from other Federal sources MAY NOT be counted as cost share. This prohibition includes FFRDC sub-recipients. Non-Federal sources include private, state or local Government, or any source not originally derived from Federal funds. Documentation of cost sharing commitments must be provided, if not already provided with the original application and they have not changed since its submission.

Fee or profit will not be paid to the award recipients or subrecipients of financial assistance awards. Additionally, foregone fee or profit by the applicant shall not be considered cost sharing under any resulting award. Reimbursement of actual costs will only include those costs that are allowable and allocable to the project as determined in accordance with the applicable cost principles prescribed in 10 CFR 600.127, 10 CFR 600.222 or 10 CFR 600.317. Also see 10 CFR 600.318 relative to profit or fee.

Add rows as needed. If rows are added, formulas/calculations may need to be adjusted by the preparer.

Organization/Source	Type (cash or other)	Cost Share Item	Budget Period 1 Cost Share	Budget Period 2 Cost Share	Budget Period 3 Cost Share	Total Project Cost Share
ABC Company **EXAMPLE ONLY!!!**	Cash	Project partner ABC Company will provide 40 PV modules for product development at 50% off the of the retail price of $680	$13,600			**$13,600**
N/A.						**$0**
						$0
						$0
						$0
						$0
						$0

Organization/Source	Type (cash or other)	Cost Share Item	Budget Period 1 Cost Share	Budget Period 2 Cost Share	Budget Period 3 Cost Share	Total Project Cost Share
						$0
						$0
						$0
						$0
		Totals	$0	$0	$0	$0

Total Project Cost: $597,600 **Cost Share Percent of Award: 0.0%**

Additional Explanations/Comments (as necessary)

Department of Energy
Golden Field Office
1617 Cole Boulevard
Golden, Colorado 80401-3393

May 26, 2009

Mr. Hank Eggink
Contracting Officer
U.S. Department of Energy
Golden Field Office
Mail Stop 1501
1617 Cole Boulevard
Golden, Colorado 80401
Phone: 303-275-4825
Fax: 303-275-4858

Re: DOE Funding Opportunity Announcement, Recovery Act – Demonstration of Integrated Biorefinery Operations, No. DE-FOA-0000096

Dear Mr. Eggink:

Authorization is granted for the National Bioenergy Center of the National Renewable Energy Laboratory to assist MBI International with validation of its bench-scale enzymatic saccharification and fermentation process; NREL design review of MBI pilot-scale AFEX pretreatment equipment; pilot-scale enzymatic saccharification and fermentation equipment modification at the NREL PDU/IBRF; and pilot-scale enzymatic saccharification and fermentation demonstration runs at the NREL PDU for the above-cited solicitation. The proposed work is consistent with, or complementary to, the missions of the laboratory and will not adversely impact execution of the laboratory's DOE-assigned programs.

Sincerely yours,

Jean M. Siekerka
Contracting Officer

Cc:
Rick Elander, NREL

Federal Recycling Program Printed on Recycled Paper

Environmental Questionnaire for FOA Applicants

PART I: General Information

Applicant Name:	**MBI International**
Proposed Project Title:	**Demonstration of an AFEX Integrated Biorefinery at Pilot Scale**
Solicitation Number:	**DE-FOA-0000096**
Applicant Preparer:	**Bernie Steele**
Applicant Phone:	**517-336-4642**
Applicant Email:	**steele@mbi.org**

1. Please describe the intended use of DOE funding in your proposed project. For example, would the funding be applied to the entire project or only support a phase of the project? Describe the activity as specifically as possible, i.e. planning, feasibility study, design, data analysis, education or outreach activities, construction, capital purchase and/or equipment installation or modification.

MBI International, with the assistance of a strong team of collaborators from industry, academia and federal laboratories (Team MBI), will design, construct, and operate an innovative integrated biorefinery at pilot scale. The biorefinery will be capable of processing lignocellulosic biomass, at the rate of one ton per day, into ethanol to meet the biorefinery objectives of the U.S. Department of Energy under solicitation number DE-FOA-0000096.

The complete proposed field-to-fuel AFEX Integrated Biorefinery pilot process is described below. The process is divided into four steps at three locations: corn stover collection and pre-processing by Vermeer Corporation in Ames, Iowa; AFEX treatment and densification by MBI International in Lansing, Michigan; saccharification and fermentation by NREL in Golden, Colorado; and ethanol recovery also by NREL.

During Budget Period 1 (approximately 9 months) a limited amount of research and development will be performed to support final design of the AFEX Integrated Biorefinery. This will include bench scale research and development related to ammonia recovery, enzyme selection, enzymatic saccharification, organism selection and fermentation to ethanol. During the entire project techno-economic models and the Life Cycle Analysis will be updated. The research and development activities will take place at the MBI facility in Lansing, Michigan; the NREL facility in Golden, Colorado; and the Novozymes facility in Franklinton, North Carolina. During Budget Period 2 (approximately 27 months) equipment procurement, construction and installation of equipment, equipment shakedown, and demonstration runs will take place. During Budget Period 3 MBI and NREL will continue to operate the AFEX Integrated Biorefinery for approximately 8 months. MBI does not anticipate decommissioning the pilot plant following the project but will continue to use the facility for continued work in biomass processing to fuels and chemicals.

<u>Corn Stover collection and preprocessing (Vermeer)</u> - The corn stover will be supplied from land in either Mahaska or Marion County of Iowa. The current agricultural practices in these counties typically include frequent crop rotation between corn and soybeans with minimum or no-till practices. Fertilization and pest management is traditional, and depends on individual field characteristics. The stover will be harvested from crop lands up to a maximum of 9% slopes. The fields will be selected to provide typical crop properties, as possible. The specific hybrids, fertilization rates, and pest management tools utilized can be noted at the time of harvest, if so desired. The stover will be processed by grinding equipment located in Ames, Iowa, including a Vermeer BP-8000 bale processor, and a Vermeer HG-200 horizontal grinder. The process and equipment settings will be modified as required to produce material size of

approximately ¼-inch particles.

Ammonia Fiber Expansion Process (MBI)- In the AFEX process moist cellulosic biomass is treated with ammonia at moderate pressure (<300 psi) and temperature (90-100C). After a few minutes under these conditions, the pressure is released, causing some of the ammonia to flash to vapor, which may be recovered and re-used. The ammonia and water remaining with the biomass after flashing can be removed in subsequent steps, and re-used. For continuous treatment of corn stover at pilot-scale processing rates (≥ one ton per day), we propose to use a horizontal, Pandia-type digestor reactor vessel with plug screw feed and discharge devices. Horizontal Pandia-type reactor designs are commonly used for treatment of wood chips in pilot-scale pulping operations. Materials of construction for all wetted parts of the continuous AFEX reactor system can be 300-series or DIN 1.4571 stainless steel, or equivalent. Double mechanical seals with water flush will be used for all of the transport screws in the reactor system. After moisture adjustment, the biomass will be loaded into a feed weighing conveyor. The feed weighing conveyor will transport the stover at a set mass flow rate into a feeder hopper. The feeder hopper uses twin feeder screws to force the moist stover particles into a plug screw feeder. The plug screw feeder is designed to form a compressed plug by forcing biomass against a choke cone. The compressed plug seals and segregates the pressurized sections of the reactor system from the hopper, which is at atmospheric pressure. The plug screw feeder will partially de-water the stover, and the water drained from the feeder will be returned to the pre-mixing vessel. The plug of biomass exiting the plug screw feeder will crumble as it falls into a mixing tee, where ammonia and steam will be added to achieve target composition and temperature of the slurry entering the reactor. The pneumatically- or hydraulically-activated choke cone positioned in the top of the mixing tee is used to prevent blowback of pressurized vapor from the mixing tee through the plug screw feeder in the event of imperfect plug formation in the feeder. Absorption of ammonia and steam will be enhanced by the expansion of the biomass fibers as the plug decompresses and crumbles into the vertical mixing tee. Complete mixing of ammonia and steam with the stover can be achieved by means of agitators within the mixing tee. The well-mixed slurry will fall from the outlet of the mixing tee into the first flight of the reactor screw. The reactor volumetric fill factor will be only about 35%, to allow for precise retention time control by preventing spillover from flight to flight along the reactor screw. Residence time of the stover slurry in the reactor will be controlled by the transport screw rotation rate, which will be adjusted by a VFD controller. Residence time will be variable from 10 to 30 minutes. As the stover slurry reaches the end of the reactor vessel it will fall into a discharge plug screw, which will operate similar to the plug screw feeder, forming a seal to hold pressure in the reactor while allowing the slurry to discharge continuously from the reactor.

Flash cyclone - As the stover/ammonia/water slurry is discharged out of the reactor by the discharge screw, the pressure will rapidly drop from the reactor operating pressure to near atmospheric pressure, allowing for rapid expansion of ammonia vapor. This rapid expansion will drive flow through a transfer pipe to a flash cyclone, where separation of ammonia-rich vapor from wet solids will occur. The ammonia vapor from the flash cyclone will be transported to the ammonia handling section, while the wet solids will be discharged from the bottom of the cyclone by means of a discharge screw into the continuous ammonia recovery section.

Ammonia recovery dryer – Several possible approaches exist for recovery of ammonia from the biomass as it is discharged from the continuous AFEX reactor system. However, at present these approaches are only conceptual; none have been tested at any scale. Three general approaches to ammonia recovery that are worth considering are vacuum drying, steam stripping, and superheated ammonia stripping. Figure 1 shows flow sketches illustrating how each of these three approaches might work in practice. In a vacuum drying approach (Figure 1-a), an indirectly-heated (e.g. steam-jacketed) dryer is evacuated to

a slightly sub-atmospheric pressure using a vacuum blower. The vapor from the dryer is a mixture of water and ammonia, which is condensed and mixed with the condensed vapor from the flash cyclone. The condensed mixture is stored in a pressurized tank for recycle to the AFEX reactor. In a steam stripping approach (Figure 1-b), ammonia is stripped from the biomass in a contacting column using superheated steam.

The vapor from the top of the column may then be quenched by mixing with cold water in the ammonia handling operations, and the ammonia/water mixture is condensed and pumped back into the AFEX reactor. In a superheated ammonia stripping approach (Figure 1-c), water and ammonia vapor are stripped from the biomass in a directly heated dryer. Vapor is drawn from the dryer using a blower, and mixed with vapor from the flash cyclone in the ammonia handling operations, where water is separated out with a condenser or distillation column, and the ammonia-rich stream is split into two streams, one of which is recycled to the AFEX reactor, while the other is superheated and recirculated to the dryer. Each of these conceptual approaches could be practiced in a variety of different specific configurations, using different hardware. The primary performance requirement for any ammonia recovery approach is that the total ammonia recovery must meet the minimum for economic operation of the process, which we anticipate will be at least 95 wt%, and probably greater than 98 wt% recovery. A secondary performance requirement is that the approach should minimize the energy input for recovering the ammonia.

Ammonia handling – Any vapor or liquid streams arising from the Ammonia Recovery section of the continuous AFEX process will have to be consolidated and, if necessary, separated and purified to allow for recycle back to the AFEX reactor. Water recycle to the pre-mixing vessel for stover moisture adjustment must be low in ammonia concentration, because the pre-mixing vessel and live-bottom feeder will both be open to the atmosphere. Depending on the ammonia recovery approach used, the separation techniques used in the ammonia handling section may be simple condensers, or more complex distillation columns may be required. Design and operation of distillation columns for separation of ammonia/water mixtures have been studied and modeled, and the relevant thermodynamic and transport properties of these mixtures have been measured (Figueiredo, 2006; Chua, 2002). The design of an effective ammonia handling system integrated with an ammonia recovery approach will require a research effort to acquire design data during the first budgetary period of the project. The research effort needed to obtain ammonia recovery and handling data is outlined in the task descriptions below.

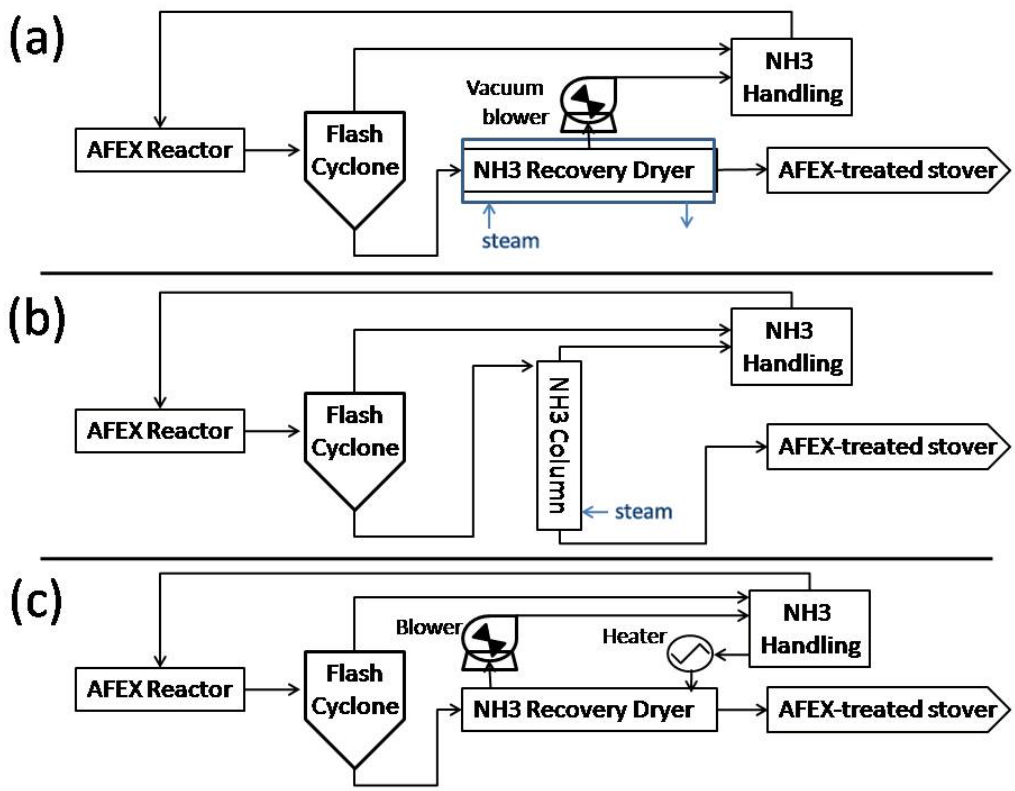

Figure 1. Three concepts for ammonia recovery from AFEX-treated corn stover. (a) Vacuum drying approach; (b) Steam stripping NH3 Column approach; (c) Superheated ammonia stripping approach.

Densification Of AFEX-Treated Corn Stover– Treated corn stover will be densified for storage and transport to hydrolysis facilities. A number of options exist for densification equipment, including pellet presses, gear mesh particle compactors, etc. It is anticipated that the treated stover will need to be dried to less than 15 wt% moisture in the ammonia recovery section to allow for effective densification and storage without excessive spoilage. The detailed specification of the densification equipment to be used in this project will be made based on the results of an ongoing research effort at MSU, which will study densification of corn stover, switchgrass, and prairie cordgrass, with the intention of optimizing densification conditions. ComPaker densification equipment, manufactured by Federal Machine Co. of Fargo, ND, is an example of an efficient mechanical design that has proven in preliminary testing to be effective for densification of AFEX-treated corn stover.

Expansion of Existing Pilot Plant at MBI - The continuous AFEX pilot process equipment described above will be installed and operated in a new facility to be constructed as an addition to the existed MBI Building in Lansing, Michigan. The existing structure is a 120,000 square feet facility.

44' X 110' Building addition with full brick veneer

This facility is a full sized extension that will expand the building on the southern end between column lines 17 and 12 44' south (Figure 1). A supply of masonry bricks matching those used for the original construction has been located and a brick veneer will be applied to the building to match the appearance of the existing building. Interior architectural details will match MBI's existing building including the masonry walls and design of the staircase. The west side of the building will have a large

receiving and storage area for biomass feedstock with direct access to the processing equipment. The building will also feature an electrical/utilities room, control/lab room, and a large lab area. Excavation of approximately 5,000 square feet will be necessary for building additions at the MBI location in Lansing, Michigan. The proposed excavation will be in an existing parking lot and open field. No clearing will be needed. For more detailed information on the construction activities please see Section 4.7 of the Project Execution Plan.

Capital Equipment will be purchased and installed in this facility including the AFEX Reactor System, the Ammonia Recovery System, materials handling equipment, and laboratory equipment (feedstock and product analysis).

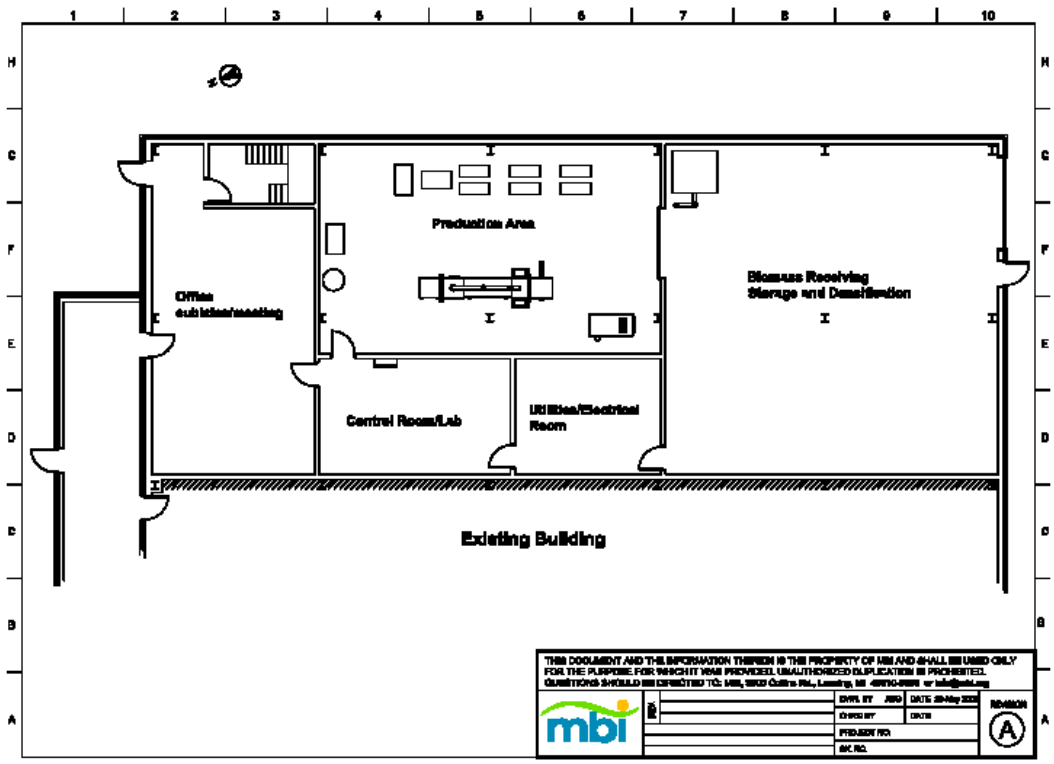

Figure 1. Proposed facility expansion at MBI, Lansing, Michigan

<u>Saccharification and Fermentation (NREL)</u> - The AFEX-treated and densified corn stover will be hydrolyzed enzymatically in modified ribbon blender-type reactors sized for approximately 24 hours of residence time at solids loadings of 20 wt% or greater. The details of the process for high solids enzymatic hydrolysis at pilot scale are unknown at this time. A research effort to determine the equipment and methods required for high solids hydrolysis of AFEX-treated corn stover is planned. It is anticipated that the treated stover at 20 wt% solids will be a highly viscous slurry that will initially be difficult to mix with enzyme solutions. At least 24 hours of residence time in the hydrolyzers at 50°C minimum will be needed to break down the solids to the point at which the slurry viscosity will permit transfer by pump to the ethanol fermentors.

The partially hydrolyzed stover slurry from the enzyme hydrolysis reactors will be transferred by

pump to large fermentation vessels for further hydrolysis and ethanol fermentation. Fermentation equipment at NREL's Integrated Biorefinery Research Facility (IBRF) includes four 9000-liter, two 1450-liter, and two 160-liter fermentors. After appropriate residence time in the fermentors, it is expected that the alcohol titer in the beer will reach at least 5 wt%. At this point the beer can be transferred to the beer distillation column.

Distillation equipment at NREL's PDU includes a ten meter beer stripping column. This column will be used to remove dissolved carbon dioxide and concentrate the beer from an ethanol content of about 5% to approximately 40%.

To minimize both fresh makeup water and wastewater treatment requirements of saccharification and fermentation operations, it is important that backset water from ethanol recovery be recycled to the biomass hydrolysis reactors. Backset water includes thin stillage and other aqueous streams recovered from the beer distillation column by centrifugation. NREL's PDU is equipped to recycle backset water between distillation and hydrolysis processes.

2. Does any part of your project require review and/or permitting by any other federal, state, regional, local, environmental, or regulatory agency? If yes, please describe.

Vermeer's new facility in Ames is currently under construction, but is scheduled to receive all necessary permits for biomass processing before the scheduled start of this proposed project. MBI currently has permits in place for anhydrous ammonia storage and handling at their facility in Lansing. No new environmental permitting requirements for ammonia handling or any other materials are anticipated for the new pilot plant. MBI anticipates permitting to be required for new construction of the proposed pilot plant annex and will work with local and state regulators to acquire the appropriate permitting. NREL's PDU in Golden is already permitted for biomass handling at the proposed scale (1 tonne/ day). No new permit requirements are anticipated.

3. Has any review (e.g., NEPA documentation, permits, agency consultations) been completed? If yes, is a finding or report available and how can a copy be obtained?

No review has been completed to date.

4. Is the proposed project part of a larger scope of work? If yes, please describe.
   No
   a. Do you anticipate requesting additional federal funding for subsequent phases of this project? If yes, please describe.
      Not at this time

5. Does the scope of your project **only** involve one or more of the following:
   - Information gathering such as literature surveys, inventories, audits,
   - Data analysis including computer modeling,
   - Document preparation such as design, feasibility studies, analytical energy supply and demand studies, or
   - Information dissemination, including document mailings, publication, distribution, training, conferences, and informational programs.

No

PART II: Environmental Considerations

Section A. Please indicate if any of the following conditions or special areas is present, required, or could be affected by your project. For each item listed below please indicate:

- Yes or No,
- The specific nature or type of activity or condition,
- Whether a consultation, approval, or permit applies and a description and status of the permitting/approval/documentation process.
- Where appropriate, please indicate if additional documentation is available.

1. Clearing or Excavation (indicate if greater than 1 acre)
   Yes, excavation of approximately 5000 square feet will be necessary for building additions at the MBI location in Lansing, Michigan. The proposed excavation will be in an existing parking lot and open field. No clearing will be needed.

2. Dredge and/or Fill. Specify the number of acres.
   No dredge or fill activities will occur. The location of the proposed building addition at MBI will be an existing parking lot and grassy field. Neither location is near water.

3. New or Modified Federal/State Permits and/or Requests for Exemptions
   Not expected

4. Pre-Existing Contamination
   No pre-existing contamination was discovered with a Phase I Environmental Assessment conducted in 2003 at the MBI location in Lansing, MI.

5. Asbestos
   No known asbestos is at the current sites, and no asbestos will be used in the proposed addition. The buildings at MBI were built between 1985 and 1987, so it is highly unlikely that asbestos-containing materials would be encountered in any of the building materials.

6. Criteria Pollutants
   No criteria pollutants will be emitted with this proposed process.

7. Non-Attainment Areas
   No, the proposed building renovation location is not in a non-attainment area.

8. Class I Air Quality Control Region
   No, the proposed building addition is not located in a Class I Air Quality Control Region.

9. Navigable Air Space
   No, the height of the proposed building addition would not impact navigable air space.

10. Areas with Special Designation (e.g., National Forests, Parks, Trails)
    No, there are no areas of special designation near the proposed building addition.

11. Prime, Unique or Important Farmland
    No, the proposed building addition would not be near any prime, unique or important farmland. Proposed addition would be on existing parking lot and open field.

12. Archeological/Cultural Resources
    No, the proposed building addition would not be near any archeological or cultural resources. Proposed addition would be on existing parking lot and open field (previously used as farmland).

13. Threatened/Endangered Species and/or Critical Habitat
    No, the proposed building addition would not be near any critical habitat or any threatened or endangered species.

14. Other Protected Species (Wild Burros, Migratory Birds)
    No, the proposed building addition would not impact any other protected species.

15. Floodplains
    No, based on the topography of the area, the facility is not in a floodplain.

16. Special Sources of Groundwater (e.g., Sole Source Aquifer)
    No, the facility is not located near any special sources of groundwater. The county where the facility is located is served by the Saginaw aquifer.

17. Underground Extraction/Injection (non-hazardous substances)
    No, the proposed project would not involve underground extraction or injection of any substances.

18. Wetlands
    No, the proposed project area is not in a wetland area as defined by Michigan Department of Environmental Quality.

19. Coastal Zones
    No, the proposed project area is not near any coastal zones.

20. Public Issues or Concerns
    No, there are no existing public issues or concerns. The proposed process will be conducted within the building, and no additional public concern is expected.

21. Noise
    No additional noise issues are expected as the proposed project will be conducted indoors. Noise levels at the facility are within city ordinance levels.

22. Depletion of a Non-Renewable Resource
    No, the proposed project will not involve the depletion of any non-renewable resources.

23. Aesthetics

No, the planned construction of the building addition will conform to existing site specifications to match the current façade and will not pose an aesthetic concern.

24. Odor

No, the proposed project will not cause any odor concerns. All work will be contained indoors.

Section B. Would your project use, disturb, or produce any chemicals or biological substances? (i.e., pesticides, industrial process, fuels, lubricants, bacteria) For each materials or processes listed below please indicate:

- Yes or No,
- Quantity,
- Whether a permit is required and if so what type of permit,
- Specific type, use, or condition,
- Where appropriate, please indicate if additional documentation is available.

1. Polychlorinated Biphenyls (PCBs)

No, the proposed project would not use, disturb or produce any PCBs.

2. Import, Manufacture, or Processing of Toxic Substances

The proposed project would not involve import, manufacture or processing of toxic substances.

3. Chemical Storage, Use, and Disposal

Yes, the proposed project would require storage of a 1000 gallon tank of ammonia.

4. Pesticide Use

No, the proposed project would not require any pesticide use.

5. Hazardous, Toxic, or Criteria Pollutant Air Emissions

No, the proposed project involves no air emissions as it is a contained system.

6. Liquid Effluent

MBI location: As a maximum, the proposed project may discharge up to 120 gallons per day of water with residual biomass or ammonia to the East Lansing Public Owned Treatment Works.

NREL location: The broth stillage (or its centrate/filtrate if we do any subsequent solid-liquid separation) would be discharged under our standard PDU discharge procedures. Any fermentation beer (including accidental spills) that contain live recombinant cells that is being disposed must be killed (with kill verification) prior to disposal or discharge. NREL has a Biosafety Authorization Program that specifies such disposal procedures on an individual project basis before authorization to operate is granted. The killed broth is then sent to the PDU neutralization Tank (as are all liquid effluent that are being discharged from our pilot plant) for pH adjustment prior to discharge, per agreements with the local wastewater utility district.

7. Underground Extraction/Injection (hazardous substances)
   No, the proposed project involves no underground extraction or injection of any substances.

8. Hazardous Waste
   No, the proposed project would involve no hazardous waste being produced, used or disturbed.

9. Underground Storage Tanks
   No, there are no underground storage tanks at either of the facility locations.

10. Biological Materials. Indicate if genetically altered materials are involved.
    Yes, genetically modified organisms will be used during this project. All of the microorganisms to be used are considered Biosafety Level -1 strains, and are not classified as potential threats to either human or animal health. All use of these organisms in the proposed project meet current federal, state, and local guidelines and regulations. Both MBI and NREL operate under NIH guidelines for handling of genetically modified organisms.

Section C. Would your project require or produce any radiological materials? For each item below, please indicate:

- Yes or No,
- Quantity,
- Whether a permit is required and if so what type,
- Specific nature of use,
- Where appropriate, please indicate if additional documentation is available.

1. Radioactive Mixed Waste
   No, the proposed project would not require or produce any radioactive mixed waste.

2. Radioactive Waste
   No, the proposed project would not require or produce any radioactive waste.

3. Radiation Exposures
   No, the proposed project would not produce any radiation exposure.

Section D. The following questions are designed specifically to guide applicants who are doing laboratory/bench-scale projects or who will have laboratory work associated with their projects.

NEPA R&D Laboratory Questions

In order for a recipient to receive financial assistance, their project must be reviewed under the National Environmental Policy Act (NEPA) for potential environmental impacts. For research and development laboratory activities, the following questions must be sufficiently answered before the review can be

completed. Please add as much detail as possible.

1. Please provide and describe the location of the facility or facilities where lab work will take place.
MBI – The existing MBI pilot plant is a 20,000 square foot space located within a 120,000 square foot facility at 3800 Collins Road in Lansing, Michigan. During this project we propose to add an additional 44 x 110 foot extension to house the AFEX pilot system. This will house a small laboratory for chemical analysis specifically for this project. MBI has an additional square foot of existing laboratory space containing fume hoods, biological safety cabinets, bench space for microbiology and chemistry experiments as well as analytical equipment such as UV spectrophotometers, HPLC, an gas chromatography.

NREL-The National Renewable Energy Laboratory (NREL) is owned by the U.S. Department of Energy (DOE) and is the nation's only laboratory dedicated to the applied research and development of renewable energy. NREL is primarily funded by the DOE's Office of Energy Efficiency and Renewable Energy and is overseen by the DOE Golden Field Office (GO). NREL is managed and operated by Midwest Research Institute and Battelle.

All work will be completed at NREL's South Table Mountain (STM) complex located in Golden, Colorado. The 327-acre STM complex currently comprises six laboratory facilities, a few small test facilities, and several support buildings. http://www.eere.energy.gov/golden/NREL_STM.aspx. Work efforts associated with this Statement of Work will be conducted in the PDU of the AFUF.

Novozymes-Novozymes will conduct bench scale enzyme hydrolysis screening at their facility in Franklinton, North Carolina. Existing laboratory space contains fume hoods, biological safety cabinets, bench space for microbiology and chemistry experiments.

2. What type of safety protocols are in place in the areas where work will take place? Who monitors these? Internally and externally? OSHA standards?
MBI – MBI has an established health and safety program and an excellent safety record. The safety program includes chemical hygiene, hazard communication, biosafety, personal protective equipment, laboratory safety and is compliant with OSHA standards. The program is administered and monitored by an internal safety committee, an Institutional Biosafety Committee (registered with NIH). This program is in compliance with, and subject to, monitoring by local and State agencies.

NREL- DOE's Golden Field Office has approved NREL's ISMS Description as of May 1, 2007. This approval states that NREL's ISMS Description adequately describes the environment, safety, health and quality management systems at NREL and complies with the requirements of 10CFR 851 to have an approved Worker Safety and Health Program.

All work is to be conducted in accordance with established written procedures or authorized in a Safe Work Permit. New activities and processes are required to undergo a preliminary safety (and environmental) assessment to address hazard identification, and a subsequent readiness verification to ensure all necessary controls are in place prior to work starting.

Novozymes- Novozymes has an established health and safety program that includes chemical hygiene, hazard communication, biosafety, personal protective equipment, laboratory safety and is compliant with OSHA standards. The program is administered and monitored by an internal safety committee, and is in compliance with, and subject to, monitoring by local and State agencies.

3. How are the gases, chemicals, heavy metals, etc...? handled, stored and disposed?

All chemicals used and produced will be handled, stored, and disposed in accordance with MBI and NREL's written lab-level procedures. Procedures vary depending upon the type, form, and quantity of material. All workers receive annual and biennial training regarding chemical use and disposal.

4. What type of safety equipment is in place for the facilities (i.e. fume hoods, alarms, scrubbers, etc...)?

MBI, Novozymes and NREL maintain state-of-the-art research facilities. Safety controls and equipment vary depending upon the area of activities. These include: 1)fume hoods with occupancy sensors, low-flow alarms, and variable speed drives; 2) digital controls and automatic shut-down features; 3) temperature monitoring; 4) fire suppression systems; 5) eyewash and safety shower stations; 6) rupture disks; 7) secondary containment; 8) hazardous materials enclosures.

5. What permits are in place for the facility for this type of work? Please list.

MBI- MBI's parent company maintains registrations and notifications for operations and building support systems applicable to this work including boiler registration, EPA hazardous waste generator I.D., permit for wastewater discharge, storage and use of anhydrous ammonia, etc.
No additional permits are required for the proposed work.

NREL- NREL/DOE maintain numerous registrations and notifications for operations and building support systems applicable to this work effort (e.g. boiler registration, XRD registration, EPA hazardous waste generator I.D., hazardous materials use and storage permits, etc.). No additional permits are required for the proposed work. NREL/DOE maintain permits as necessary for other operations and activities as necessary (e.g. stationary source air permits, fugitive dust permit, APHIS permits, etc.). Work associated with this project will be conducted in the PDU at the AFUF.

Novozymes- Novozymes maintains registrations and notifications for operations and building support systems applicable to this work including, EPA hazardous waste generator I.D., permit for wastewater discharge, storage and use of laboratory chemicals, etc.
No additional permits are required for the proposed work.

6. What permits are needed or will be acquired for this type of work? Please list.
MBI and NREL

It is anticipated there will be no need for additional permits for this work. During both MBI and NREL's internal risk assessment process, permitting requirements are addressed and no work can be initiated until the proper permits are in place if required.

7. How is liquid effluent handled and discharged?

MBI – All discharges from MBI's facility are in accordance with an agreement with the City of Lansing. MBI workers are provided training addressing discharges. No hazardous waste is discharged.

NREL- NREL prohibits the discharge of chemicals from research laboratories and facility operations. All discharges from NREL's ethanol pilot plant are in accordance with NREL's agreement with the Pleasant View Water and Sanitation District and the Metro Wastewater Reclamation District. NREL workers are provided annual training addressing discharges. No hazardous waste is discharged.

Novozymes- All discharges from Novozyme's facility are in accordance with Novozyme's agreement with their local wastewater treatment facility.

8. How is toxic waste handled, stored, disposed?

MBI and Novozymes- The handling, storage and disposal of hazardous and non-hazardous wastes is addressed in the laboratory safety program and communicated to workers during safety training. Proper container selection, storage practices (labeling, segregation, area inspections, accumulation, etc.) are incorporated. Wastes are disposed off-site at properly permitted facilities.

NREL- The handling, storage, and disposal of hazardous and non-hazardous wastes is addressed in NREL's Waste Management and Minimization Program, and communicated to workers during biennial training. Proper container selection, storage practices (labeling, segregation, area inspections, accumulation, etc.) are incorporated. Wastes are disposed off-site at properly permitted facilities.

9. Will the work being done create any air pollutants? If so please explain how these are handled/disposed/mitigated.

Air pollutants will be limited to fugitive emissions from bench-scale laboratory research activities and are likely to include very small quantities of organic solvents, dilute acids and bases, and dusts from biomass processing. Research staff are provided training regarding the minimizing the use of hazardous materials and keeping containers closed when not in use. Pilot-plant activities incorporate the use of a baghouse and scrubbers, depending on the processes for the specific activity.

10. Are Genetically Modified Organisms (GMOs) being used? If so please describe how these will be transported, stored, handled and disposed. How are these classified by APHIS? By TSCA? By state and local agencies?

A previously developed recombinant *Zymomonas mobilis* strain capable on co-fermenting glucose and xylose sugars to ethanol will be used. Pilot plant-scale operations involving this strain are categorized as Biosafety Level 1-Large Scale (BL1-LS). NREL has conducted several projects involving this strain or closely related strains in pilot-scale fermentations in a manner similar to what will be done in this project.

Typically, fermentation broth containing this strain would be further processed in the NREL PDU distillation column, which will heat-kill the strain. Complete kill verification on distillation column stillage streams would be performed prior to discharge. Any fermentation broth (including accidental spills) that contain live recombinant cells that is being disposed must be killed (with kill verification) prior to disposal or discharge. Both MBI and NREL have a Biosafety Authorization Program that specifies such disposal procedures on an individual project basis before authorization to operate is granted. The Biosafety Authorization Program also specifically identifies all required methods of handling of such strains, including identification of all required personnel protective equipment and containment procedures.

11. Will prototypes be tested in a separate location, if so, please describe the location and answer questions #1-9?

No prototypes will be tested in other locations.

12. Are subcontractors being used for some of the work? If so please answer Questions #1-10 for work being completed by subcontractors.

Yes, subcontractors will be used for construction of the addition to MBI's pilot plant in Lansing, Michigan. Specific contractors have not been chosen as this will happen during the course of the project. MBI's acquisition plan specifies that all subcontractors must adhere to local, State and Federal regulations in the performance of any work at MBI. There are not expected to be any discharges or handling of materials outside of the scope of questions 1-10 as answered for MBI and NREL above. Novozymes will be the only subcontractor to perform work at a facility other than MBI or NREL. Responses to questions 1-10 have been answered for Novozymes above.

Demonstration of an AFEX Integrated Biorefinery at Pilot Scale

Submitted by MBI International

DE-FOA-0000096

Project Management Plan

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1.0 Work Plan and Schedule Summary

The Work Breakdown Structure, with resource loaded schedule is shown at the end of this document (Figure 3). The cost column indicates the direct cost for MBI labor for each task. Other costs associated with Budget Period 1 include materials and supplies, travel, materials handling and capital equipment, and indirect costs, as well as subcontracts for MSU(design, R&D, LCA, modeling, business and commercialization planning, and project reviews), Novozymes (R&D, modeling, LCA, and project reviews), Vermeer (feedstock procurement and pre-processing) and an Engineering Contractor (design, bid and permitting). Complete details of these categories can be seen in the proposal budget SF 424A and the associated budget justification. Costs associated with Budget Period 2 include MBI labor, materials and supplies, travel, materials handling and capital equipment, as well as subcontracts for MSU (design, LCA, modeling, business and commercialization planning, and project reviews), Novozymes (modeling, LCA, shakedown and operations, materials and project reviews) and an Engineering Contractor (design, procurement, construction and equipment installation). Complete details of these categories can be seen in the proposal budget SF 424A and the associated budget justification. Costs associated with Budget Period 3 includes MBI labor, materials, travel and subcontracts with MSU (modeling, LCA, business and commercialization planning, and project reviews), Vermeer and Novozymes (operations, materials, modeling, LCA, and project reviews).

Throughout the project NREL will participate in design, R&D, modeling, LCA, shakedown and operations, project reviews and reporting through a Cooperative Research and Development Agreement with DOE. Details can be seen in the proposal budget SF 424A and the associated budget justification.

The project is scheduled for 44 months at a total cost of $23.5 MM. Budget Period 1 is estimated at 9.25 months and a cost of $3 MM. Budget Period 2 is estimated at 27 months and a cost of $18.8 MM. Budget Period 3 is estimated at 8 months and $1.7 MM.

2.0 Project Organization and Communication

The Project Organizational Chart is shown in Figure 1. MBI currently uses Microsoft SharePoint, and MS Project Server as day-to-day communication tools for ongoing projects. These will be used during the proposed project for real time distribution of project plans, modifications, data, and documentation. All Project Teams (see below) will communicate at least biweekly with the Project Manager with regard to Task progress, status and plans to proceed. This information will be communicated to the Project Management Team on a regular basis for decisions requiring PMT approval. All project teams will participate in quarterly project reviews of project progress, status, and plans to proceed with regard to both technical and budget activities.

2.1 Key Functions

MBI has assembled a strong team with the knowledge and background to successfully execute and manage the proposed project. Team MBI personnel bring years of experience in design, engineering and construction, biomass processing, enzymatic hydrolysis, strain development and fermentation. Team MBI brings a significant portfolio of intellectual property to support the technology to be demonstrated and the inventors of the technology are integral members of the team.

MBI – MBI will lead the project and will design, construct and operate a pilot facility (1 dry tonne/day) for producing a stable intermediate feedstock (AFEX-treated corn stover). This material will be compacted/densified and shipped to NREL for conversion to ethanol in an existing pilot facility. A limited amount of R&D will be conducted at MBI, NREL and Novozymes (primarily related to ammonia recovery and enzyme hydrolysis).

MBI International has a successful 27-year history of bringing renewable products from academic research to the commercial market. One example is polylactic acid (PLA). Engineering, scale-up and applications research for production of lactic acid and PLA biodegradable plastics technology

were conducted at MBI and MSU with collaboration and support of Cargill Inc., one of the world's largest agribusinesses. Today, this biodegradable polymer is broadly in use around the world in both plastics and fibers in clothing and carpets, containers for food and garbage bags, car parts, etc. Another example, Evercorn, Inc., was a successful joint venture between an MBI subsidiary and Japan Corn Starch (one of Japan's leading starch-based industrial products companies) to develop a family of polymer resins that are processed into films and moldable products for disposable use applications. These polymers are strong, water-resistant thermoplastics and are used in disposable cutlery, plastic containers, and paper coatings. Evercorn's biodegradable products were featured at the Nagano Olympic Games (1998).

MSU – MSU personnel will assist with feedstock logistics, design, life cycle analysis, modeling and updating of the Business and Commercialization Plan. MSU personnel will participate in quarterly meetings and Stage-Gate reviews.

Michigan State University pioneered the concept of the Land Grant University and has the fundamental infrastructure necessary to establish the foundation for bioeconomy development in Michigan. This includes laboratories and core facilities for instrumentation, computation and modeling; field research facilities across the state; funding for creative new research projects; and pilot and scale-up facilities for unique commercialization expertise through MBI International, a firm with proven success in bringing biotechnology ideas to the market. MSU also has strongly developed links with other research universities and private sector partners, including established relationships with all major agricultural input providers, select biotechnology firms and key manufacturing industries

NREL – NREL will perform a limited amount of R&D directed at high solids enzyme hydrolysis and fermentation. They will also be involved in overall design, modeling, and life cycle analysis. NREL will process AFEX-treated corn stover (supplied by MBI) by high solids enzyme hydrolysis and fermentation (1 tonne/day scale) to produce ethanol. NREL personnel will participate in quarterly meetings and Stage-Gate reviews.

The National Bioenergy Center (NBC) of the National Renewable Energy Laboratory (NREL) has led the nation's efforts in the R&D of bioprocess conversion technology for lignocellulosic ethanol and other fuels and chemicals from biomass for over 30 years. In addition to its world-class bioprocessing laboratories and pilot plant facilities, the NBC is home to over 100 technical and support staff who are focused on R&D of biochemical and thermochemical conversion processes for lignocellulosic biomass. Many researchers in the NBC have over 15 years of experience in the development of such processes, including key personnel who will be leading and contributing to the MBI-led project team. Personnel in the NBC lead and conduct core research tasks for DOE's Office of the Biomass Program (OBP), including several activities with multi-million dollar annual budgets that span the entire range of biochemical conversion technologies, including biomass pretreatment, enzymatic hydrolysis, fermentation, bioprocess integration and scale-up, chemical analysis, and techno-economic analysis. The activities represent the core R&D of DOE's OBP, and NBC researchers are renowned world-wide as experts in all conversion technology aspects, with an extensive patent and publications portfolio.

Additionally, NBC staff members have extensive experience in leading and conducting R&D programs in collaboration with numerous industrial partners to further the deployment of biomass conversion bioprocesses. In recent years, key industrial collaboration projects that the NBC has provided a major technical role included those with DuPont, Abengoa, POET, ADM, NatureWorks/Cargill-Dow, New Energy Company of Indiana, and Amoco, among others. The NBC staff is proficient in all aspects of managing and conducting such collaborations and has extensively utilized the NBC laboratory and pilot plant facilities in these projects.

Novozymes –Novozymes will perform limited R&D to select enzymes that are most efficient in converting AFEX-treated corn stover to monomeric sugars. Novozymes personnel will also be involved in techno-economic modeling, life cycle analysis, and shakedown and capstone runs to demonstrate the

proposed technology. They will also participate in quarterly meetings and Stage-Gate reviews. Novozymes will provide all enzymes required for the project

Novozymes is a world leader in enzyme development, production and sales and has lead the way in development of next generation enzymes for conversion of cellulosic feedstocks to biofuels and chemicals. Through prior work with DOE they have dramatically increased the efficiency and lowered the cost of these enzymes. Novozymes is currently investing $160-200 million in new facilities in Blair, NE to meet demand for enzymes for the production of first and second generation bioethanol. The new facility will be fully operational in approximately 2010 and will bring 100 new green jobs to the area.

Vermeer – Vermeer will procure, harvest and pre-process corn stover for the project. Vermeer personnel will also participate in quarterly meetings and Stage-Gate reviews.

Vermeer Corporation manufactures agricultural, construction, environmental, and industrial equipment in Pella, Iowa. From modest beginnings, quality product innovations and demand has allowed the company to expand its offerings to more than 60 countries. Today Vermeer consists of eight manufacturing plants spanning some 110 acres that occupy more than 1.5 million square feet of manufacturing space in Pella, Iowa. Vermeer is recognized as a global leader in forage, tree care, wood-waste processing, composting, compact and underground installation equipment. Currently, Vermeer employs over 2000 people.

ICM - ICM will be a critical business and commercialization partner for the proposed technology. During this project ICM personnel will participate in quarterly meetings and Stage-Gate meetings were they will review progress in design, modeling, life cycle analysis, and facility shakedown. They will participate in quarterly meetings and Stage-Gate reviews, and assist in updating the Business and Commercialization Plan throughout the project.

ICM is the nation‘s leading provider of ethanol process design and engineering, with 78 dry-mill fuel ethanol plants operating in the United States and Canada that use ICM ethanol process technology. ICM-designed plants consistently perform 24 hours per day, at least 353 days per year for a 96% runtime – the highest performance measure in the industry. ICM‘s market success, an approximate 50% market share in current ethanol production, results from the fact that ICM process technology simply runs better, faster, cheaper and with less downtime than competing technologies. ICM employs 30 full-time engineers in its various departments, including process chemical engineers, mechanical engineers, electrical engineers, and civil engineers. ICM also designs, engineers, and installs a proprietary distributive control system (DCS) for ethanol plants that use ICM process technology.

The Andersons - The Andersons will be a critical business and commercialization partner for the proposed technology. During this project Andersons’ personnel will participate in quarterly meetings and Stage-Gate meetings where they will review progress in design, modeling, life cycle analysis, and facility shakedown. They will participate in quarterly meetings and Stage-Gate reviews, and assist in updating the Business and Commercialization Plan throughout the project.

The Andersons is a publicly traded company with diverse interests that include agribusinesses such as grain and plant nutrients as well as railcar leasing and repair, industrial products formulation, turf products, retailing and most recently, ethanol operations. The Grain Division operates grain terminals in Ohio, Michigan, Indiana, and Illinois with storage capacity of nearly 90 million bushels. The division trades and merchandises more than 250 million bushels of grain in the Eastern Corn Belt and Canada. The Ethanol Division operates three plants; a 55 million gallon/yr plant in Albion, Michigan and two 110 million gallon/yr plants with partner Marathon Petroleum Company. Throughout all of The Andersons' business endeavors, the company and its nearly 3,000 employees are committed to providing extraordinary service with the utmost integrity.

Airgas - Airgas will participate in design, risk mitigation and safety during the project related to ammonia storage, use and recycle. They will participate in quarterly meetings.

Airgas, Inc. (NYSE: ARG), Radnor, PA through its subsidiaries, is the largest U.S. distributor of industrial, medical, and specialty gases. Airgas Specialty Products, formerly the Atlanta-based Industrial Products Division of LaRoche Industries, is a leading distributor of anhydrous ammonia and related services in the United States. Airgas Specialty Products' network of 24 ammonia distribution, field service and office locations, focuses exclusively on industrial applications and serves over 3,000 customers. The company is a primary supplier of ammonia to the fast-growing market segment of power plants, oil refineries and other manufacturing facilities nationwide who require ammonia for nitrogen oxide removal. ASP also serves the metal treating, heat treating, chemical processing, industrial refrigeration and water treatment industries. Ammonia is one of the most highly used inorganic chemicals in the world today. Worldwide ammonia production in 2004 was 109 million metric tons according to the United States Geological Survey.

Please see Section 9 of the Business and Commercialization Plan (BCP) for more details on Team MBI experience and capabilities.

2.2 Roles & Responsibilities

Prior to the start of the proposed project MBI will establish teaming agreements with all of the project partners. These agreements, or cooperative research and development agreements (CRADA), will document scope of work (including key decision points and milestones), schedules, budgets, communication plans with reporting structure and schedules, and descriptions of intellectual property agreements. Once these agreements have been established partners will function as part of specific teams as outlined below for project implementation.

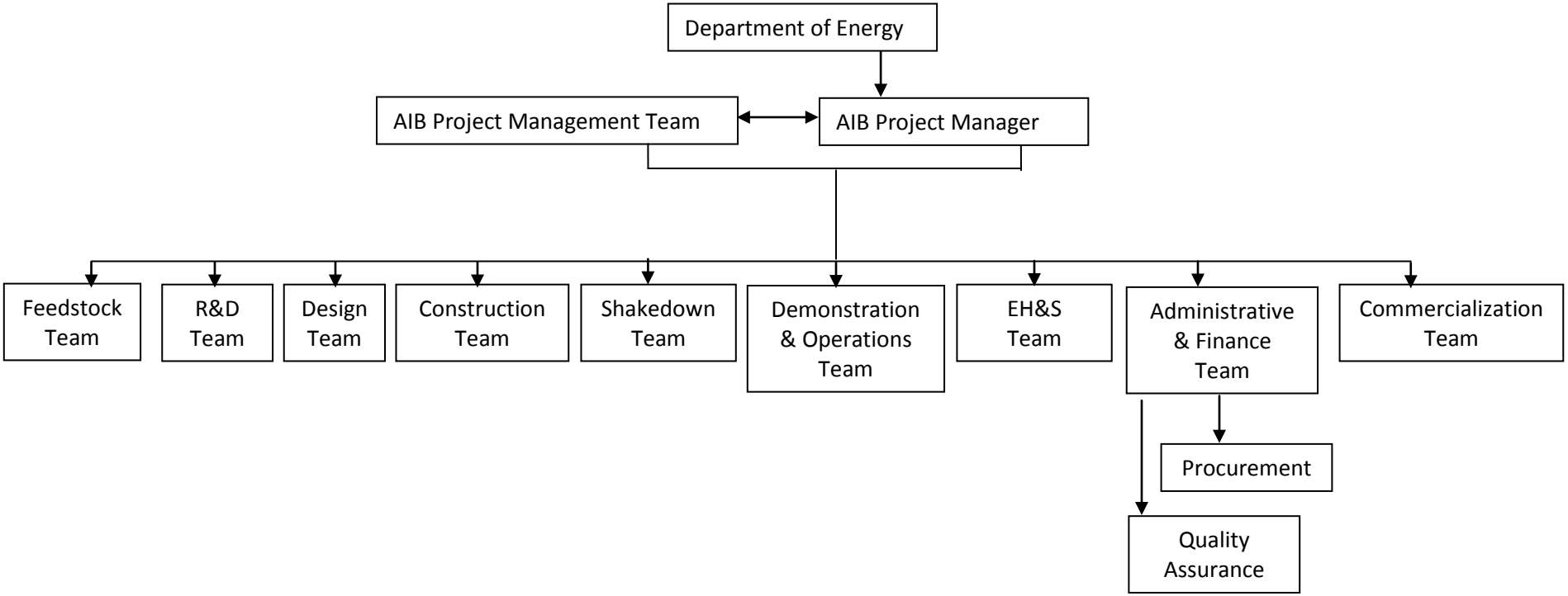
Project Management Team: The project will be led by a Project Management Team that has oversight and decision-making authority over all project aspects, including technical, administrative, and financial. This team has ultimate responsibility for meeting the project goals and objectives and will consist of senior level engineers, scientists, and administrative personnel. The Project Manager is a member of this Team.

Project Manager: The Project Manager over sees the research agenda, prepares reports for DOE, and is the primary contact with DOE staff. Other duties include:

- Manage issues that will arise with funding partners and collaborators
- Organize and direct both internal and external reviews of the project
- Manage resources to meet schedule and technical milestones
- Manage the project budget to meet project targets

Feedstock Team: The Feedstock Team will be lead by Vermeer and has oversight for all activities regarding feedstock growth, harvesting, pre-processing, storage and transportation to the primary work site at MBI/MSU. This team is responsible for on-time delivery of required feedstock to meet project specifications. They are also responsible for monitoring and managing all environmental issues with regard to farming, harvest, and processing of the biomass. Key MSU personnel will also be a part of this team.

Figure 1. Project Organization Chart
Demonstration of an AFEX Integrated Biorefinery (AIB) at Pilot-Scale



Research & Development Team: The R&D Team has oversight for all research and development activities aimed at enabling a robust final design of the proposed facilities. MBI, MSU, Novozymes and NREL will all be represented on this team and have responsibility for design of experiments, execution of R&D activities, data analysis, and recommendations for moving forward. They will interact closely with the Design Team, as well as the Construction and Operations Teams. This Team is also responsible for updating process and economic models as well as Life Cycle Analyses.

Design Team: The Design Team has oversight on finalizing the design of the proposed integrated biorefinery facilities. They are responsible for selection of a design engineering firm to assist with final design. This firm will become a member of the Design Team. This Team is responsible for incorporating results from the R&D Team into the final design, and working with vendors to ensure specifications are documented. They will work closely with the Environmental Health and Safety Team for design of all safety systems for the proposed facilities. This team will consist of MBI, MSU, and NREL team members as well as the selected engineering and construction firm (to be determined).

Construction Team: The Construction Team will oversee modifications to existing facilities at MBI as detailed in Section 3.2.7 of the Project Execution Plan (PEP). The Project Management Team will select an engineering, procurement and construction (EPC) firm early in the project according to the criteria described in Section 5 of this document. This firm will become part of the Construction Team and will interact with the Design Team and equipment vendors to ensure construction efforts remain on schedule, on budget and adhere to all EH&S guidelines.

Shakedown Team: This Team will consist of senior MBI, MSU, Novozymes and NREL team members as well as representatives of the EPC firm, the equipment vendors, and appropriate safety managers. They are responsible for testing and troubleshooting of installed equipment to ensure that all equipment meets operational and safety specifications.

Demonstration & Operations Team: This Team will consist of MBI, MSU, Novozymes, Vermeer and NREL team members well experienced in the processes being demonstrated, including feedstock procurement and preprocessing, AFEX treatment, enzyme hydrolysis and fermentation for production of ethanol. They are responsible for meeting the project objectives and requirements for demonstration of the proposed technology.

Environmental Health & Safety Team: This team will consist of MBI, NREL, MSU, and Airgas personnel trained in all aspects of environmental health and safety required for this project. This would include, but is not limited to, personal protective equipment, electrical and mechanical safety systems and procedures, hazardous chemical safety, emergency response for both personal injury and environmental issues. Airgas is also collaborating with Team MBI on hazard and safety issues with regard to ammonia handling.

Administrative & Finance Team: This team will consist of MBI, NREL, and MSU personnel and oversee documentation of all project related activities. They will assist in contract negotiation, report and presentation preparation, and budget monitoring and management, including oversight of budget cost share activities. They will also oversee all procurement activities and coordinate strongly with the EPC firm during construction. This team will also oversee all quality assurance activities during the project.

Business & Commercialization Team: This Team will consist of senior business development personnel at MBI and MSU, as well as our commercialization partners The Andersons and ICM. They will monitor

technical progress, market conditions, and other issues that could influence business decisions. They are responsible for updating the business and commercialization plan and maintaining strong communications with our potential commercial partners.

2.3 Facilities

MBI International and Michigan State University

Activities related to this project will be performed primarily in the laboratories and pilot plant of MBI which is located in Lansing, Michigan adjacent to Michigan State University. This facility houses numerous laboratories and equipment for biochemical conversion of biomass to fuels, chemicals and materials. This proposed project would expand our existing pilot plant to accommodate the pilot scale AFEX equipment with associated ammonia recovery system. Current facilities and capabilities include:

Biomass Conversion Lab - MBI has custom-made 1-gallon and 5-gallon pressure reactors equipped with electric heaters and heavy duty magnetic stirrers for batch treatment of lignocellulosic biomass with the Ammonia Fiber Expansion (AFEX) process. These 1- and 5-gallon batch reactors are capable of treating up to 500 and 2,500 g of biomass, respectively. We also have a 316L stainless steel flash tank to capture the released ammonia. The batch reactors and ancillary equipment are located in a walk-in ventilation area. The lab also contains a Class A Batch Oven (Blue M) for drying biomass and a Fitzpatrick JT6 Homoloid Mill for grinding biomass to specified particle sizes. This laboratory also includes equipment for metered ammonia pumping, as well as ammonia scrubbing and neutralization equipment. MBI utilizes ASPEN Plus software for modeling of process systems and has a highly trained staff of Chemical Engineers focused on this type of activity.

Chemistry lab - Chemistry laboratories contain chemical fume hoods, laboratory-size solvent storage cabinets, and refrigerator/freezer storage space. As with the microbiology laboratories, the chemistry labs contain numerous outlets for all house utilities except steam. These labs are also equipped with medium and high-temperature ovens and bench-top analytical equipment such as pH meters, spectrophotometers, and centrifuges. Laboratory-scale gel-chromatography and purification, solvent extraction, distillation, crystallization, evaporation, and chemical isolation work is typically conducted in the chemistry laboratories. MBI routinely conducts analyses of biomass, including composition of feedstocks, process intermediates, and final products. Components typically monitored include polymeric and monomeric sugars, organic acids, protein, sugar degradation products, ash and moisture.

Instrumentation - MBI International has a broad range of contemporary analytical instrumentation to fully support pilot plant and research activities in microbiology, molecular biology, chemistry, and polymer science. For chromatographic analysis MBI International has multiple High Pressure Liquid Chromatographs (HPLC) and Gas Chromatographs (GC) systems capable of analyzing a variety of material from sugars and organic acids, to proteins, to specialty chemicals. These chromatographic systems include isocratic, gradient, affinity, and gel permeation HPLC systems; and GCs with FID, EC, or TC detectors and a GC with a mass selective detector (GC/MS). For spectroscopic analysis MBI is equipped with two UV-Vis spectrophotometers; a Cary BIO 50 and a Hitachi U-2010. Infra-red analysis is performed on BioRad FTS-40 FT-IR. MBI International also has specialized analytical equipment such as YSI glucose analyzers for real time monitoring of glucose levels, a state of the art imaging system for use with DNA analyses and cloning experiments, and a differential scanning calorimeter (DSC) and a thermal gravimetric analyzer (TGA) for thermal analysis.

Pilot plant - MBI's 20,000 square-foot pilot facility serves the company's bioprocess scale-up needs for fermentation, separation, and purification. The three-level pilot facility, with a cargo elevator connecting the levels, is equipped with modern equipment, instrumentation, and computer-control systems. A five-ton capacity ceiling crane is available for movement of heavy processing equipment. The lower level contains much of the separation and purification equipment, including several

evaporators, micro- and ultrafiltration systems, and three 3700 L fermentors. The main floor houses 80L and 100L fermentors as well as industrial chromatography systems and evaporators. The top level houses 10L, 150L and 500 L fermentation systems, molecular distillation, a centrifuge and both micro- and ultrafiltration systems. A 900 square-foot cold room is also available in this area. Complete process utilities are available throughout the pilot plant, including pressurized air, clean steam (500 lbs/hr at 1575 psig and 603°F), water, purified water, gas, vacuum, and adequate drainage. Most of the downstream processing equipment is on wheels and are thus completely mobile for relocation throughout the pilot facility. This allows great flexibility when designing and conducting bioprocess development, scale-up, and production in MBI's pilot plant. MBI intends to expand this pilot plant facility to house the new AFEX pilot system as described in this proposal.

Equipment Design & Fabrication - MBI also has its own machine and fabrication shop staffed by experienced crafts people, where specialized equipment and fittings can be manufactured from plastic, iron, aluminum, carbon steel, stainless steel, and various other materials.

MSU - Due to its proximity and close working relationship with Michigan State University, MBI International has convenient access to the world class research tools of MSU, such as the Max T. Rogers NMR Facility, MSU Center for Advanced Microscopy, Genomics Technology Support Facility, and the MSU Mass Spectrometry Facility. Located in the MBI facility is the laboratory of Dr. Bruce Dale, furnished with similar equipment for biomass processing and analysis to MBI. MSU also has appropriate facilities and equipment for biomass feedstock storage and handling.

National Renewable Energy Laboratory

NREL's activities will primarily be performed in the laboratories and pilot-scale facilities within the Alternative Fuels User Facility (AFUF), located on the South Table Mountain site in Golden, CO. The AFUF houses numerous pretreatment, enzymatic hydrolysis, fermentation, analytical chemistry, and support laboratories, where process development R&D activities to develop and improve technologies for biochemical conversion of biomass to fuels, chemicals, and materials are conducted. Additionally, a 1 tonne/day (TPD) integrated biochemical biomass conversion Process Development Unit (PDU) is located in the AFUF, which will be augmented by the Integrated Biorefinery Research Facility (IBRF) pilot-scale high-bay expansion, which is slated for completion in 2010 and will be available for pilot-scale operations during later years of this project.

The AFUF's bench scale pretreatment capabilities include the following equipment:

- Stirred tank batch Parr reactors with optional hot separation and washing
- A batch steam-explosion reactor system and flash tank
- A high-solids stirred-tank Zipperclave reactor
- Various percolation and shrinking-bed flow-through systems

All of these systems are constructed of appropriate materials and are rated for high pressure conditions to allow for operations under a wide range of acidic, neutral, or alkaline pretreatment temperatures and reaction conditions.

AFUF laboratories for shake flask enzymatic hydrolysis and fermentation, stirred-vessel enzymatic hydrolysis and fermentation (from 1 L to 100 L working volume), and bench-scale, high-solids enzymatic hydrolysis are available. These capabilities will be employed for the bench-scale enzymatic saccharification and fermentation process validation activities and the bench-scale enzymatic saccharification and fermentation control runs that will be conducted In parallel with each pilot-scale enzymatic saccharification and fermentation run.

The AFUF also houses the NREL Process Development Unit (PDU), an integrated pilot-scale demonstration facility with capabilities to convert various types of lignocellulosic

biomass to ethanol at a rate of 900 kg (1 TPD). Existing unit operations include feedstock washing and milling, pretreatment in continuous high-solids reactor systems, enzymatic hydrolysis, fermentation, distillation, and solid-liquid separation. For specific use in this project, the four existing 9000 L enzymatic hydrolysis and fermentation vessels and supporting seed vessels (two vessels of 1450 L capacity) and pre-seed vessels (two vessels of 160 L capacity) will be used to conduct the pilot-scale enzymatic saccharification and fermentation runs in both the shakedown/optimization and demonstration phases of this project.

Additionally, new pilot-scale capabilities that are currently being specified for the Integrated Biorefinery Research Facility (IBRF) expansion of the NREL PDU are anticipated to be employed in this project. The IBRF will accommodate a broader and more flexible range of equipment and processing options and configurations in a manner that effectively leverages the existing infrastructure in the AFUF and PDU. Key design criteria for the IBRF include:

- Provisions to more effectively handle high solids concentrations throughout the entire biochemical biomass conversion process.
- Achieve front-end flexibility to feed/mill/test a wide variety of feedstocks.
- Provide enhanced and flexible continuous pilot-scale pretreatment capabilities (broad range of operating conditions and chemical catalysts).
- Provide a suitable enzymatic hydrolysis reactor configuration for high solids saccharification operations;
- Integrate fully with existing fermentation and distillation testing equipment.
- Enable alternate treatment process configurations to be evaluated more easily by skid-mounting of equipment.
- Provisions to test internal water recycle and process wastewater treatment options.

It is anticipated that the pilot-scale high solids enzymatic saccharification capabilities that will be installed in the IBRF will extensively be utilized in both the shakedown/optimization and demonstration phases of this project. While this capability will not be installed and become operational until 2010, it is anticipated that two horizontally-oriented mixing vessels with axially-mounted high-solids mixing arms/paddles will be available for this project. The vessels will have a working volume of 4000-6000 L each, with large manways/ports to accept “off-line” pretreated solids. These vessels will be of stainless steel construction and can be chemically and/or steam-sanitized. The vessels will be temperature controlled via a tempered water jacket and will be equipped with multiple spray bars for acid/base pH adjustment and control and for evenly distributing liquid saccharification enzyme preparations. It is anticipated that the initial phase of enzymatic saccharification of AFEX-pretreated (by MBI) feedstocks will be conducted in one or both of these vessels, with transfer of the liquefied, partially-saccharified slurry to one or more of the existing 9000 L stirred tank fermentors in the PDU to complete saccharification and then conduct fermentation of available sugars using a recombinant, co-fermenting ethanologen.

Existing AFUF analytical chemistry laboratories will be used to conduct a portfolio of analytical methods to determine the composition of feedstocks and process intermediates. Components typically monitored include polymeric and monomeric sugars, lignin, organic acids, protein, sugar degradation products, extractives, ash and moisture. Available instrumentation includes a range of spectrometers (infrared, visible, ultraviolet), automated extraction units, moisture measurement systems, and high performance liquid chromatographs equipped with a variety of columns and detector systems. “Rapid analysis” methods that use multivariate techniques to extract compositional information directly from complex sample spectra can also be used for feedstocks and process intermediates where existing wet chemistry-derived calibration data is available. Such methods enable accurate and low cost determination of multiple components in solid, liquid and slurry samples. The PDU, IBRF, and larger

laboratory-scale enzymatic saccharification and fermentor systems have sophisticated data acquisition and control systems that permit effective real-time process control and monitoring. Dedicated mass spectrometers are available and permit on-line monitoring of fermentor exhaust gas compositions.

2.4 Communications Plan

Communication is critical to project success. Project management must equip project teams with communication processes that facilitate coordination of efforts to enable efficient planning and systematic decisions in a timely manner. MBI's business model is built on the concept of "De-Risking" early stage innovations and moving them through scale-up to commercialization. MBI has been doing this successfully for over 27 years. This type of endeavor most often requires a strong partnership between MBI, academia, and industrial firms. Communication is essential to success and MBI has a proven track record of work with multiple entities and cross-functional teams to accomplish project goals and objectives. Project Teams will meet weekly, at a minimum, to discuss project status. This will include progress tracking, variances, and key decisions. All Project Teams (see below) will communicate at least biweekly with the Project Manager with regard to Task progress, status and plans to proceed. This information will be communicated to the Project Management Team (PMT) on a regular basis for decisions requiring PMT approval. All project teams will participate in quarterly project reviews of project progress, status, and plans to proceed with regard to both technical and budget activities. It is anticipated that quarterly reports will be prepared and disseminated to DOE and all project partners. These reports will include project progress and status, EVMS reports, explanations of variances, and plans for proceeding. Team MBI anticipates participating in annual DOE Peer Review Programs as well as annual Program Stage-Gate meetings with DOE staff. Results of project efforts will be communicated through professional conferences and meetings during the course of the project.

MBI currently uses Microsoft SharePoint, and MS Project Server as day-to-day communication tools for ongoing projects. These will be used during the proposed project for real time distribution of project plans, modifications, data, reports and documentation. See Section 3.2, Project Management Tools for further details.

3.0 Operational Project Management Plan

3.1 Plans for Staffing

All project collaborators currently have adequate staff to man the proposed project with the exception of final design and construction; however, if needed, all collaborators have administrative and human resource capability to respond quickly to personnel needs, both internal and external. An EPC firm will be contracted to assist with final design and construction (see Section 5: Acquisition Plan & Procurement Strategy).

The staffing needs of the biorefinery are modeled on a starch-to-ethanol plant. Many of the functions of unit operations will be similar. Staffing will include operators, laboratory technicians and support staff focused on developing the targeted information required by the project.

Significant amounts of information will come from experience and troubleshooting the process as the new technology is tested. The team assigned to this task will need to ensure information is analyzed and documented in a timely manner. Although much smaller in capacity than a larger ethanol plant the number of operators required to monitor, sample and keep the process running smoothly will be similar to larger operations. This is due, in part, to the experimental nature of the proposed pilot plant and the need to test and troubleshoot issues that arise during the shakedown phase.

The AFEX treatment facility will operate with three shifts. Each shift will have two operators, one supervisor, one lab technician and one material handling technician. It is anticipated that there may be operational problems with the new technology and this type of situation will require more resources to continually solve problems on a daily basis. Experienced process engineers will be utilized as shift

supervisors to help facilitate troubleshooting and development of operational changes in a timely manner. These process engineers will be supervised by the Plant Manager. The supervisory team, led by the Plant Manager will meet daily to review plant performance and coordinate activities to ensure the pilot plant is developing the targeted information on schedule.

The PDU/IBRF pilot plant facilities at NREL which will be employed for pilot-scale demonstration of enzymatic hydrolysis and fermentation of AFEX-pretreated feedstocks are capable of around-the-clock operations for extended periods. In this project, numerous enzymatic hydrolysis and fermentation runs for up to 10 days at a time are anticipated. In conjunction with the IBRF expansion scheduled to be completed in 2010, NREL will be expanding its existing pilot plant operations technician team extensively. This will provide much greater scheduling flexibility for staffing extended campaigns that require around-the-clock operations.

Typically, pilot plant operations shifts include a lead operator (either a Master Technician or staff Engineer/Scientist) along with one or more additional technicians, depending on operation workloads. NREL safety policies require a minimum of two NREL staff assigned to the pilot plant during such operations on all shifts. Additional technical and management staff assigned to this project will be on site during regular business hours to conduct various technical and project management functions. Analytical chemists will be dedicated to this project in order to analyze process samples in a timely manner to enable routine monitoring of process performance and operations. Depending on sample loads and timing requirements, it is anticipated that most, if not all sample analysis activities can be conducted during normal business hours, although some coverage during evening shifts and weekends may be periodically required.

Project collaborators from MBI and/or other participating organizations will have access to appropriate NREL facilities (subject to standard NREL visitor access procedures) during these operations, although they must be accompanied by regular NREL staff members. Collaborators will be allowed to observe all operations and will be permitted to be involved in conducting and/or assisting in some operations, pending appropriate training and authorization from NREL Environment Health and Safety representatives.

3.2 Project Management Tools

MBI's current project management practice is consistent with DOE O 413.3A and addresses such elements as strategic planning, roles and responsibilities, work planning and control, fact-based decision making, Stage-Gate reviews, financial planning and control, and reporting.

3.2.1 Software

MBI employs Microsoft Project as its primary project management tool. MS Project is integrated with MS SharePoint, a collaboration tool that enables real time communication between all team members and stakeholders. MS SharePoint enables all team members to view the status of the project WBS, budgets, resources, modifications and any related documents. It incorporates task assignment, monitoring and management as well as calendar events related to the project.

All senior technical, business and administrative personnel are trained in the use of MS Project and all personnel are trained in the use of MS SharePoint.

3.2.2 Stage-Gated Work Process

MBI uses a Stage-Gate approach (Figure 2) to project and portfolio management. The Stage-Gate process is an approach for making disciplined decisions about research and development that lead to focused process and/or product development efforts. We use it to:

- Guide decisions on which projects to include in our portfolio of projects, and

- Manage projects effectively once they have been selected.

One of the advantages of this process is that it focuses efforts on the most critical and uncertain elements early in the life of a project and thereby minimizes spending to cover only the most important tasks and activities. By focusing on critical success factors and best practices the system heightens the effectiveness. These success factors include sharper focus, better prioritization, true cross-functional team approach and better planning up front. As a project passes from one stage to the next, it moves to a higher level of effort and spending. Typical criteria for evaluation during Stage-Gate reviews include:

- Strategic Fit
- Market/Customer
- Technical Feasibility and Risks
- Competitive Advantage
- Legal/Regulatory Compliance
- Critical Success Factors and Show Stoppers
- Plan to Proceed

During the proposed project reviews will be conducted in which critical Go/No Go Decisions are addressed as identified in the PEP (Section 4.3). Project Teams along with appropriate stakeholders will review project progress, critical success factors, risks, budgets and updated business/commercialization information to formulate a plan to proceed to the next stage of the project. It is anticipated that Stage-Gate reviews will be held with DOE at the end of each major project phase to assess progress and make recommendations for moving to the next phase. The proposed project is in the Development Phase.

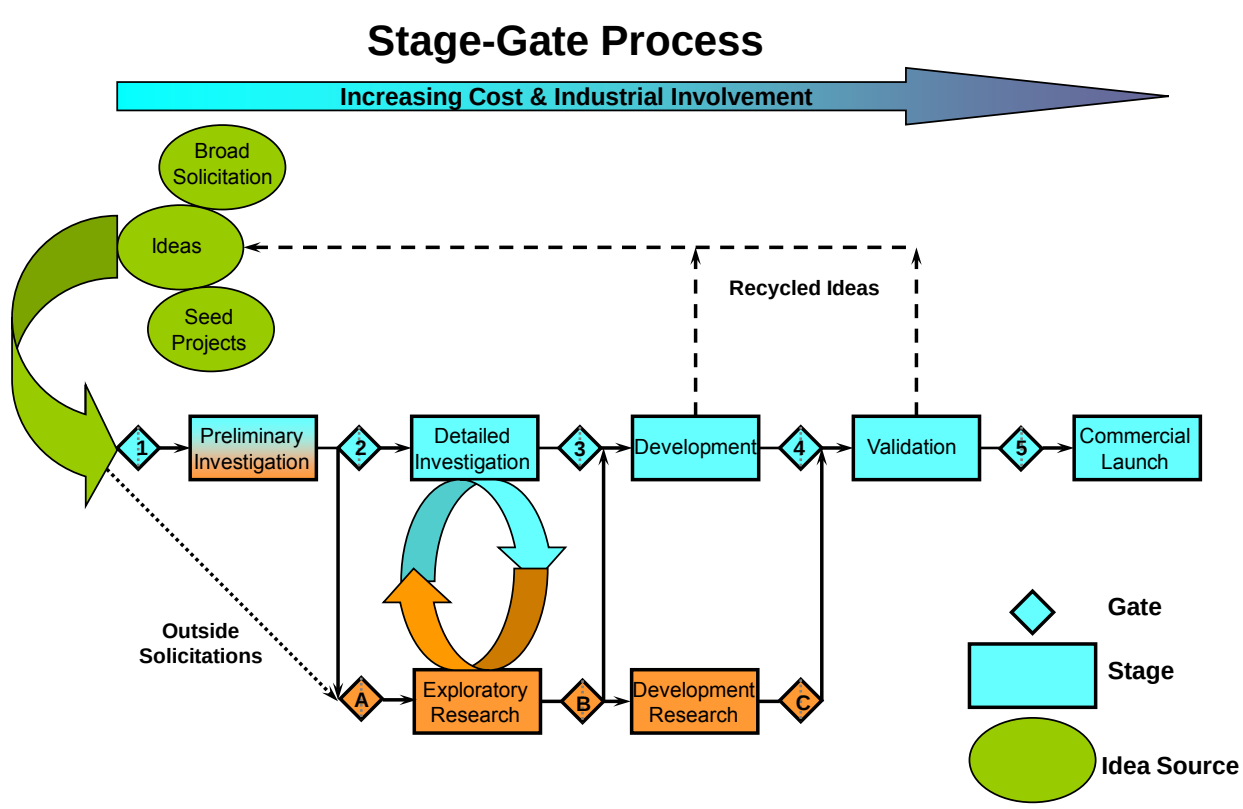


Figure 2. Schematic of Stage-Gate Process

3.2.3 Code of Accounts, EVMS and Invoicing

MBI's accounting system is run on Deltek Costpoint software, which utilizes a project job costing method. This allows MBI to track expenses and invoice in detail on a project basis and to the appropriate WBS level. The Earned Value Management System (EVMS) software MBI uses is an integrated Microsoft Project/ Web Access/ SharePoint system. This software allows MBI to manage using the basic principles of EVMS.

MBI breaks down the scope of work into finite pieces (WBS) that can be assigned to a person or organization for control of technical, schedule and cost objectives. MBI then integrates that scope of work, schedule, and cost objectives into a performance measurement baseline plan against which accomplishments may be measured including the control of changes to the baseline.

During regular reviews MBI analyzes significant variances from the plan, forecast impacts, and prepares an estimate of completion based on performance to date and work to be performed.

MBI will administer subcontracts. It is expected that an EPC firm will be contracted to complete construction activities within the project. A designated Construction Team, comprised of engineers and stakeholders will inspect construction work in progress to ensure compliance with the design drawings and specifications and that all proposed changes are reviewed and approved according to the Configuration Management and Change Control Plan. The Construction Team will also manage the site contractor for the interface tie-ins (electrical, communication, safety, equipment vendors, etc.). The site contractor will adhere to all requirements with regard to project management and the EVMS.

4.0 Risk Management Plan Summary

Risk identification, analysis and management are an important aspect of project management at MBI. Risk Management practices are consistent with guidelines described in DOE G 413.3-7. Risks are identified and prioritized through brainstorming, as well as focused risk assessment work sessions. Risks are analyzed and estimates are made with regard to probability of occurrence and potential impact on the project on a scale of 1-5, low to high. The probability estimate is multiplied by the impact estimate to generate an overall risk score. Risk management encompasses all aspects of the project including technical, financial, and environmental.

A preliminary technical risk assessment for this project has identified eight major technical risk areas as shown in Table 1. The first year's work plan addresses mitigation of these risks through final research and development work and final design efforts (see Section 4.6 of the PEP). Business and Financial risks are discussed in the BCP (Section 5.0). A preliminary environmental risk assessment has not identified any significant environmental risks associated with this project; however, environmental issues will be addressed through the final NEPA evaluation and environmental risks assessment will be an ongoing part of this project.

The Project Management Team will be responsible for risk management throughout the project. The Project Manager and other members of the Project Management Team shall meet biweekly to review the status of all risk mitigation efforts, review the exposure assessments for any new risk items, and redefine the project's priority risk list.

The Project Management Team has the responsibility of coordinating risk identification and analysis activities, maintaining the project's risk list, notifying project management of new risk items, and reporting risk resolution status to management. They will assign each newly identified risk to a project member or team, who will assess the exposure and probability for the risk factor and report the results of that analysis back to the Project Management Team. Assigned project members or teams are also responsible for performing the steps of the mitigation plan and reporting progress to the Project Management Team biweekly.

The risk factors identified and managed for this project will be accumulated in a risk list document. The following information will be stored for each project risk: Risk identification,

classification and description; probability, impact and risk exposure; mitigation approaches; owner; date due; and contingency plan. A risk item can be considered closed when the planned mitigation actions have been completed and the estimated risk exposure of probability multiplied by the impact is less than 3.

5.0 Acquisition Plan & Procurement Strategy

MBI has assembled a team of collaborators with a broad range of experience and capabilities to meet the specific requirements of the proposed project. This includes feedstock procurement and preprocessing (Vermeer), AFEX treatment processing (MBI and MSU), enzyme hydrolysis (Novozymes, MBI, MSU and NREL), fermentation of feedstock to ethanol (MBI and NREL) and construction/start up of both pilot and commercial biorefineries (ICM and The Andersons). Our acquisition strategy is consistent with DOE O 413.3A and is based on a business and management approach designed to achieve project objectives within our specific resource constraints.

The total cost of the proposed project is $23.5 MM over a 44 month schedule. Major aspects of the Acquisition Plan include environmental and regulatory sensitivities, logistics and location of new construction/modifications to existing structures, technical and business risk analysis, funding and budget management, interface and integration requirements, and procurement strategy for vendors and outsourced services. The proposed project will entail construction of an addition to MBI's existing pilot plant.

While no environmental issues are expected, the proposed project will be reviewed and updated under the National Environmental Policy Act (NEPA). Location and design of the addition will be determined through a rigorous selection process that engages all applicable stakeholders, and addresses technical, logistical, safety, and cost constraints.

MBI's procurement strategy is aimed at meeting key acquisition objectives such as 1) clear specifications that include standards and quality; 2) full and open competition; 3) communication between and coordination of all acquisition personnel, including vendors; 4) careful planning; 5) identification and prioritizing of issues that could delay procurement or result in increased cost or technical risk.

Vendors for specialized equipment required for the proposed pilot plant have already been contacted by MBI and furnished design and cost information quotations. Site visits and meetings/interviews with vendors are expected prior to final procurement selections. MBI has an established procurement process that meets all federally mandated guidelines, and is administered by an in-house purchasing agent. Typically, clear specifications are determined for the needed service/products and proposals are collected from available vendors. The proposals are evaluated on requirements satisfaction (specifications, cost and schedule), contract type, and contractor/vendor capability.

All possible efforts will be made to ensure that iron, steel and manufactured goods are produced in the United States, in compliance with the American Recovery and Reinvestment Act (Recovery Act) of 2009.

Table 1. Preliminary Technical Risk Assessment

Risk	Consequence	Probability	Impact	Score	Risk Response
Inability to maintain steady state operating conditions	Negative impact on process performance	3	4	12	Institute performance guarantee terms for key equipment vendors; Root cause analysis; reevaluate process control scheme (consult with vendors and experts); modify or replace equipment/procedures;
Inability to manage contaminant load in fermentation	Negative impact on fermentation performance	3	4	12	Address in early R&D plan for design and process development; root cause analysis; reevaluate process scheme (consult with vendors and experts); modify or replace equipment/procedures;
Insufficient NH_3 recovery	Negative impact on process economics and fermentation productivity	2	4	8	Address in early R&D plan for design and process development; Root cause analysis; reevaluate ammonia recovery scheme (consult with vendors and experts); modify or replace equipment/procedures;
Inability to reach targeted reaction conditions	Negative impact on process performance	2	4	8	Institute performance guarantee terms for key equipment vendors; Root cause analysis; reevaluate process control scheme (consult with vendors and experts); modify or replace equipment/procedures;
Cost of enzymes remains prohibitive	Negative impact on process economics	2	4	8	Evaluate use of CBP organisms and/or enzyme recycle
Recycle streams build up inhibitors/toxins	Negative impact on process performance and economics	2	3	6	Root cause analysis; consult with vendors/experts on work around (i.e. clean up of streams)
Inability to hydrolyze and ferment AFEX-treated feedstock at pilot scale	Negative impact on process performance and economics	1	5	5	Address in early R&D plan for design and process development; root cause analysis; reevaluate process scheme (consult with vendors and experts); modify or replace equipment/procedures;
Safety systems failure	Increase probability of personnel injury and environmental release	1	4	4	Root cause analysis; modify or replace equipment/procedures; receive approval from appropriate agencies for mitigation plan

5.1 Contracting Strategy (EPC selection)

Design and construction of the proposed pilot plant will be outsourced to an engineering, procurement and construction (EPC) firm. This firm will interface with key project teams to facilitate a design and construct effort that meets the project objectives aimed at successful demonstration of the technology in a timely manner and within budget. The contract(s) for design and construction will be competitively solicited and awarded. Awards will not be made on cost alone, but rather a combination of cost, experience and capability.

With regard to external contractors an award is made employing a formally documented decision analysis and resolution process. The MBI Contracts & Grants office administers the contract. The Project Manager is responsible for monitoring and tracking the contractor performance, including measurement collection, correspondence, funding and deliverables. The PM delegates contractor monitoring on a technical basis to the technical managers/leads, and on a financial basis to MBI's Financial Officer. Issues raised at contractor reviews are resolved during the review, assigned to a technical manager, or escalated up the chain-of-command.

6.0 Schedule Justification for Completing Proposed Pilot Plant

Team MBI members are experienced in design and engineering of facilities, scale-up of processes, forecasting, purchasing, tracking, expediting, transportation, contracting, and management of materials. MBI's Facilities Director was directly involved in the original design and construction of the 120,000 sq. ft. facility in Lansing and has a thorough knowledge of facility structure, utilities and equipment. Our commercialization partners are adept in efficient construction and startup of ethanol plants throughout the U.S. This combination of expertise, as well as contracted engineering consultants was used to estimate the schedule and budget for the proposed project.

It is anticipated that the final research and development required to support a final design will take approximately 9 months to complete. This R&D effort is aimed at mitigating specific risks as detailed in the Risk Management Plan Summary (Section 4.0), and includes work focused on ammonia recovery and recycle, enzyme selection and loading, and the challenges of pilot scale high solids loading of AFEX-treated corn stover into the hydrolysis fermentation modules. The information from this work will be integrated into a final design for the integrated biorefinery. This design phase is expected to take 4-6 months. It is expected that initial procurement of primary equipment for the AFEX reactor can begin within ten months of the project start and will continue through most of the construction phase. It is necessary to begin procurement as early as possible due to the long lead times (estimates supplied by vendors) of the customized equipment required for the pilot plant. The rest of the process design is dependent on the specific equipment selected for the AFEX reactor. The construction phase of the project is expected to take approximately 12 months and will commence when sufficient areas of design are completed for that portion of the project and DOE has approved start on Budget Period 2.

Time schedule and cost are based on estimates from several experienced engineering firms, including MBI's business and commercialization partners, and is consistent with similar efforts already in progress on other DOE supported projects. We have previously commissioned a preliminary design study for a pilot AFEX system. This study was recently updated to current costs and scale appropriate to this proposed project. Quotations have been solicited directly from primary vendors for specialized equipment to establish current cost and delivery schedules.

Due to the uniqueness of the AFEX process, in particular the use of ammonia recovery and recycle, it is expected that the shakedown phase of the project will require 6-9 months. All reasonable efforts will be made to keep this phase to a minimum while maintaining appropriate quality assurance and safety standards. Approximately twelve months have been allocated for the validation runs to demonstrate the functionality and performance of the AFEX Integrated Biorefinery. This is based on the

concept of three campaigns (see Section 6.1 below) similar to industry standards for scale up of commercial fermentations.

6.1 Planned Period of Operation of the Pilot Plant

Following shakedown of the completed pilot plant Team MBI will operate the plant by processing a minimum of one dry tonne/day of biomass in at least three campaigns of 10 – 14 days duration each to satisfy the FOA demonstration requirements. To demonstrate the de-centralized concept of operation as described in Section 5 of the BCP, the AFEX treatment will be conducted at MBI and the hydrolysis and fermentation at NREL. AFEX-treated biomass will need to be produced at MBI prior to NREL conducting high solids enzyme hydrolysis and fermentation to ethanol. Therefore the total time for demonstration/capstone runs is estimated at twelve months. AFEX treatment will be run in three shifts to process a minimum of one tonne of corn stover/day. This may include occasional shutdown and startup phases to evaluate the robustness of the process; however, no less than one tonne of corn stover will be processed each day. By running campaigns in this fashion the Team will be able to analyze data and make adjustments as necessary to achieve the desired production and efficiency targets. This type of validation is consistent with industrial scale up of fermentation processes for commercial applications. Following the successful demonstration of the pilot plant Team MBI will continue to operate the plant for approximately eight months during the fourth year to gather data on the processing of alternative high impact feedstock's and to evaluate alternative processing equipment to improve efficiency. However, MBI's primary objective is to get enough data to move quickly to a demonstration/commercial scale plant as described in Section 5.0 of the BCP.

7.0 Contingency Planning & Management

MBI uses a robust project management system that includes strong fiscal management of all projects (see Section 3.2 above) that includes tracking and forecasting of project budgets integrated with technical progress. MBI has developed the proposed budget and schedule using a systematic approach that includes vendor and potential contractor quotations and schedule input. MBI will make all efforts to adhere to the proposed budget and schedule during the project; however, cost overruns and schedule slippage can still be caused by unforeseen circumstances. Therefore a contingency budget of approximately $925,000 has been included during Budget Period 2 for cost overruns associated with construction and shakedown. The contingency was estimated by standard practices as a percent of capital construction cost. As can be seen in the WBS and schedule, we have proposed to utilize approximately 7% of the budget to the continued operation of the integrated biorefinery to develop further data on processing during the fourth year of the project (Budget Period 3). If problems occur that require funds greater than the allotted contingency during the course of the project, Team MBI will request a budget modification and, upon approval, will utilize a portion of the Budget Period 3 funding to cover the cost overruns and reduce Budget Period 3 appropriately.

8.0 Safety Plan During Project Execution and Operation

8.1 Preliminary Process Hazard Analysis (PHA)

MBI has been working with early prototype AFEX reactors in our existing facility during the past year. During this time we have installed equipment and safety systems at pilot scale for handling ammonia in a high pressure system. We are already fully permitted for operations involving ammonia at the scale required for this proposed project. We have also conducted a preliminary process hazard analysis (PHA) with regard to the existing systems that is largely applicable to the proposed system. A brief summary of this PHA is shown below (Tables 2-6). During the first year of the proposed project Team MBI will update the PHA and continue to monitor process hazards as the final design and testing

are implemented. This information will be used to develop and implement safety protocols and training, as well as equipment fail safes.

8.2 Safety Oversight

MBI adheres to all applicable environmental health & safety guidelines. MBI facility safety is overseen by MBI's internal Safety Officer. MBI internal laboratory safety is governed by MBI safety policy as outlined in our Laboratory Safety Manual, Biosafety Manual, and Hazards Communication Manual. MSU internal laboratory safety is overseen by the Office of Radiation, Chemical and Biological Safety (ORCBS). Both the MSU ORCBS and MBI Safety Office are charged with providing leadership and resources for the coordination and delivery of comprehensive health, safety and risk management programs. Safety department staff will provide consultation, oversight and training to help with managing risks. Areas of expertise include biological safety, occupational health, industrial hygiene, general safety, fire prevention/life safety, environmental affairs, accident/injury prevention, chemical safety, radiation safety, hazardous waste management, research compliance, laboratory design and laboratory security, emergency response, and ergonomics.

All work with biohazardous materials during this project is subject to the same procedures and federal standard requirements for biological safety oversight as outlined in both the MSU and MBI Biosafety Manuals. Research activities involving biohazardous materials are registered with the Biosafety Officer and reviewed by the Institutional Biosafety Committee for compliance with NIH r-DNA Guidelines and experimental protocol safety prior to approval. Routine facility inspections are conducted by MSU/ MBI Safety Officers. The NREL facility operates under an established safety plan and as a DOE facility meets all safety requirements of the Department of Energy. Additionally, Airgas will assist in safety planning, training and operations with regard to ammonia storage and handling during this project. MBI will make all efforts to ensure all subcontractors adhere to safety operations to meet the guidelines as stated above.

9.0 Quality Assurance

The MBI management of quality control/assurance is consistent with DOE policy DOE O 414.1C, Quality Assurance, and with any applicable elements of ANSI/ISO/ASQ Q 9001-2000, the international consensus standard for quality assurance. MBI currently operates under a Quality Assurance Management Plan (MBI QAMP 1.03). Essential elements of Quality Assurance governed by this plan include roles and responsibilities, systematic planning, quality assurance project plans, standard operating procedures, document control, data quality assessment, corrective action, peer review, and personnel training.

NREL operates under a similar Quality Assurance Plan and is consistent with DOE policy DOE O 414.1C, Quality Assurance.

9.1 Configuration Management and Change Control Plan Summary

The purpose of our Configuration Management and Change Control Plan is to establish and maintain the integrity of work products using configuration identification, control, status accounting and auditing.

Managing change is an important factor for success and requires planning, discipline, and communication among the project teams' customers, and stakeholders. MBI has Standard Operating Procedures for change control that will be the basis for change control management during this project. Types of changes that might occur on this project are:

- Scope creep
- Schedule changes
- Technical changes

- Budget changes
- Design changes
- Resource and material changes

Components of MBI change control include:

- A quality assurance management plan and system
- A written change control procedure
- A change request form
- Change review teams

Team leaders are responsible for recognizing the need to modify the project. Proposed modifications are documented as to scope and justification and submitted to the Project Manager as a Change Request. If necessary the Change Request is submitted to the Project Management Team or other appropriate Change Review Team for review and approval. Approved changes are documented and incorporated into the project plans and communicated to all project teams.

Configuration management is developed by mapping of system and developmental baselines (product component requirements) including architecture design, module design, and integration and test baselines. Change and configuration status accounting is supported by a documentation trail showing the history of configuration items and changes to them. This includes dates, component identification, versions, baseline descriptions, change details, and information regarding personnel involved in the change. Baseline auditing addresses:

- Integrity of the baselines
- Completeness and correctness of baseline documentation
    - Based on the requirements as stated in the plan and the approved requirements change requests
- Overall functionality and performance of the technical process compared to the requirements
- Documentation for maintenance activities and operational use compared to the requirements

Design and other possible SOW issues may occur, and the Team MBI Project Manager will inform the DOE Program Manager through regular progress reports of items that may affect the SOW. If the MBI Project Manager and the DOE Program Manager determine that a contract modification is necessary, the MBI Project Manager and Contracts Administrator will draft a justification for contract modification to be submitted to the DOE Program Manager and Contracts Officer for formal approval and issuance of the contract modification.

MBI does not anticipate a walk away situation; however, MBI's walk away criteria include items such as:

- Unfavorable economic conditions
- Safety factors not easily resolved
- Unfavorable environmental conditions
- Any issue that results in uneconomical process operations

10.0 Financial Management

Overall financial management will be the responsibility of the Administrative and Finance Team. This team includes MBI's Vice-President of Finance, Kevin Fitzgerald and MBI's Director of Operations, Bernie Steele (Project Manager). See Section 3.2.3 for details on MBI's accounting system and methods for budget control. The Administrative and Finance Team will also include a senior manager from NREL to ensure close integration of budget management between the two facilities.

10.1 Spend Plan

The overall spend plan is illustrated in Table 7. The Total Project Cost (TPC) is $23.5 MM over 44 months. The first year will include final R&D work, final design work and initial procurement activities at a cost of $3 MM for Budget Period 1. Budget Period 2 includes the second and third year of work. During the first 15 months of Budget Period 2 procurement is completed, as well as construction and equipment installation for a cost of $11.3 MM. During year three facilities shakedown is completed and capstone (demonstration) runs of continuous operation are completed at a cost of $6.7 MM for the year. During the fourth year (Budget Period 3) Team MBI will continue to operate the integrated biorefinery for approximately eight months to generate data to be used for evaluating potential for other feedstock and alternative processes that could potentially lower operating cost. The fourth year costs are estimated at $1.7 MM. More detailed information can be found in the proposed budget Form SF 424.

There is approximately $925,000 of contingency built into the construction and installation budget to address potential cost overruns. If problems occur that require funds greater than the allotted contingency during the course of the project, Team MBI will request a budget modification and, upon approval, will utilize a portion of the Budget Period 3 funding to cover the cost overruns and reduce Budget Period 3: Continued Operation, appropriately.

In order to house the AFEX pretreatment and ammonia recovery equipment MBI will need to make an addition to its facility. The addition will be built adjacent to the existing facility and in order to use the existing infrastructure. Steam, water, waste disposal, and electrical power distribution capacity already exists that is sufficient to supply the AFEX treatment pilot plant.

The addition will match the original construction and appearance of the existing building. Interior architectural details will match MBI's existing building including the masonry walls. The west side of the building will have a large receiving and storage area for biomass feedstock with direct access to the processing equipment. The building will also feature an electrical/utilities room, control room, and a laboratory area. Workstations for staff are also included.

The building cost estimate was prepared by EPS, an engineering design firm with 14 years experience in the biotech and energy industries. The cost estimate was based on the development of detailed drawings, vendor quotations on major components, and several site visits to determine the scope of the effort. Other costs were based on EPS' past experience and industry standards.

Process equipment, piping and electrical costs were prepared by Dick Engineering, a full service design firm serving the process industries for 40 years. The cost estimate is an order-of-magnitude estimate with an accuracy of +/-30%. The methodology used was based on PFDs created from an Aspen simulation model of the AFEX process. Preliminary P&IDs and layouts were then made. Budget quotations for major equipment were obtained. Piping, electrical, and instrumentation costs were based on the preliminary P&IDs and layouts. Other costs are based on Dick Engineering's opinions and are made on the basis of Dick Engineering's experience.

Table 2. Process Hazard Analysis NODE: 2.0 Pilot Plant – Ammonia Pump

NO.	DEVATION GUIDE WORD	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	RESPONSIBLE PERSON
2.1	High Pressure	2.1.1 Ammonia flashing in tank due to higher than normal temperatures.	2.1.1 Pump pressurizes and ruptures.	2.1.1 Pressure relief on ammonia line ball valves.	2.1.1 Pressure relief valve on pump discharge line set to 450 psig.	2.1.1 Pilot Plant Specialist
		2.1.2 Heat exchanger not cooling ammonia to a lower vapor pressure.	2.1.2 Ammonia line pressurizes and ruptures.	2.1.2 Pressure relief valve.	2.1.2 Pressure monitoring of line.	2.1.2 Opta Programmer
			2.1.3 Ammonia line pressurizes and ruptures.	2.1.3 Pressure switch.	2.1.3 Pressure switch on pump discharge line set to 450 psig.	2.1.3 Opta Programmer
2.2	High Flow	2.2.1 Control signal malfunction.	2.2.1 Ammonia line pressurizes and ruptures.	2.2.1 Flow meter.	2.2.1 Flow rate alarm setpoints.	2.2.1 Opta Programmer
		2.2.2 Control signal malfunction.	2.2.2 Pump overheats and motor is damaged.	2.2.2 Pressure relief on pump discharge line and ball valves.	2.2.2 Flow rate alarm setpoints.	2.2.2 Opta Programmer
2.3	No Flow	2.3.1 Electrical failure.	2.3.1 Pump overheats and motor	2.3.1 Surge protector on electrical circuit.	2.3.1 Install surge protector for pump.	2.3.1 Pilot Plant Specialist

					is damaged						
		2.3.2	Control signal malfunction.	2.3.2	Ammonia system is shutdown.	2.3.2	Training/SOP.	2.3.2	Training of operators. Flow rate alarm setpoints.	2.3.2	Opta Programmer
		2.3.3	Human error, closed valve.	2.3.3	Ammonia system does not flow.	2.3.3	Training/SOP.	2.3.3	Training of operators.	2.3.3	Pilot Plant Operator
2.4	Reverse Flow	2.4.1	Check valve failure.	2.4.1	Ammonia system does not flow.	2.4.1	Pressure switch.	2.4.1	Flowrate monitoring.	2.4.1	Pilot Plant Specialist
		2.4.2	High pressure downstream.	2.4.2	High pressure from Seepex pump.	2.4.2	Pressure relief valve.	2.4.2	Pressure alarm setpoints.	2.4.2	Opta Programmer
		2.4.3	High pressure downstream.	2.4.3	Ammonia line pressurizes and ruptures.	2.4.3	Pressure relief valve.	2.4.3	Pressure alarm setpoints.	2.4.3	Opta Programmer
2.5	Corrosion	2.5.1	Incompatible construction materials.	2.5.1	Leakage of ammonia.	2.5.1	Corrosion resistant materials.	2.5.1	Steel or stainless steel materials; no copper, brass, or zinc alloys.	2.5.1	Engineering

Table 3. Process Hazard Analysis NODE: 3.0 Pilot Plant – Biomass Feed

NO.	DEVATION GUIDE WORD	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	RESPONSIBLE PERSON
3.1	High Pressure	3.1.1 Downstream plugging of process line. 3.1.2 Control signal malfunction.	3.1.1 Process line pressurizes. 3.1.2 Process line pressurizes.	3.1.1 Pressure gauge. 3.1.2 Pressure switch.	3.1.1 Pressure monitoring of line. 3.1.2 Interlocking of pressure switch with pump motor.	3.1.1 Pilot Plant Operator 3.1.2 Opta Programmer
3.2	High Flow	3.2.1 Control signal malfunction. 3.2.2 Control signal malfunction. 3.2.3 Incorrect setpoint for biomass flow.	3.2.1 Process line pressurizes. 3.2.2 Pump overheats and motor is damaged. 3.2.3 Process line pressurizes.	3.2.1 Pressure gauge. 3.2.2 Pressure switch. 3.2.3 Pressure switch.	3.2.1 Pressure monitoring of line. 3.2.2 Interlocking of pressure switch with pump motor. 3.2.3 Operator training.	3.2.1 Opta Programmer 3.2.2 Opta Programmer 3.2.3 Pilot Plant Operator
3.3	No Flow	3.3.1 Electrical failure. 3.3.2 Control signal malfunction. 3.3.3 No feed available.	3.3.1 Pump overheats and motor is damaged 3.3.2 System is shutdown. 3.3.3 Pump operates without feed.	3.3.1 Surge protector on electrical circuit. 3.3.2 Training/SOP. 3.3.3 Pump has dry running protection.	3.3.1 Install surge protector for pump. 3.3.2 Training of operators. 3.3.3 Frequent inspection while operating.	3.3.1 Electrician 3.3.2 Opta Programmer 3.3.3 Pilot Plant Operator

		3.3.4	Downstream plugging of process line.	3.3.4	Process line pressurizes.	3.3.4	Pressure gauge.	3.3.4	Pressure monitoring of line.	3.3.4	Production operator
3.4	Corrosion	3.4.1	Incompatible construction materials.	3.4.1	Leakage of ammonia.	3.4.1	Corrosion resistant materials.	3.4.1	Steel or stainless steel materials; no copper, brass, or zinc alloys.	3.4.1	Engineering

Table 4. Process Hazard Analysis NODE: 4.0 Pilot Plant – AFEX Reactor

NO.	DEVATION GUIDE WORD	CAUSES		CONSEQUENCES		SAFEGUARDS		RECOMMENDATIONS		RESPONSIBLE PERSON	
4.1	High Pressure	4.1.1	Steam pressure reducing valve failure.	4.1.1	Pump and reactor over pressurize.	4.1.1	Pressure relief valve on steam inlet.	4.1.1	Pressure switch alarm and interlock with steam flow control valve.	4.1.1	Opta Programmer
		4.1.2	Boiler pressure controller fails.	4.1.2	Pump and reactor over pressurize.	4.1.2	Pressure relief valve on steam inlet.	4.1.2	Pressure switch alarm and interlock with steam flow control valve.	4.1.2	Opta Programmer
		4.1.3	Biomass pump overfeeds.	4.1.3	Pump and reactor over pressurize.	4.1.3	Dual rupture discs downstream of pump.	4.1.3	Pressure relief device on reactor set to 250 and downstream to 200 psig.	4.1.3	Pilot Plant Specialist
		4.1.4	Ammonia pump overfeeds.	4.1.4	Pump and reactor over pressurize.	4.1.4	Pressure switch.	4.1.4	Pressure monitoring of reactor. Pressure switch	4.1.4	Opta Programmer

									alarm.		
4.2	High Flow	4.2.1	Steam flow control valve failure.	4.2.1	Reactor experiences high flow rates.	4.2.1	Pressure switch.	4.2.1	Pressure switch alarm and interlock with steam flow control valve.	4.2.1	Opta Programmer
		4.2.2	Biomass pump failure.	4.2.2	Pump overheats and motor is damaged.	4.2.2	Dual rupture discs downstream of pump.	4.2.2	Pressure monitoring of reactor.	4.2.2	Opta Programmer
		4.2.3	Ammonia pump overfeeds.	4.2.3	Reactor experiences high flow rates.	4.2.3	Training/SOP.	4.2.3	Training of operators. Flow rate alarm setpoints.	4.2.3	Pilot Plant Operator
4.3	No Flow	4.3.1	Electrical failure.	4.3.1	Reactor pressurizes from steam and ammonia.	4.3.1	Pressure switch.	4.3.1	Pressure relief device on reactor set to 250 and 200 psig.	4.3.1	Electrician
		4.3.2	Control signal malfunction.	4.3.2	Pump overheats and motor is damaged.	4.3.2	Dual rupture discs downstream of pump.	4.3.2	Pressure monitoring of reactor.	4.3.2	Opta Programmer
		4.3.3	Human error, closed valve.	4.3.3	Pump and reactor over pressurize.	4.3.3	Training/SOP.	4.3.3	Training of operators. Flow rate alarm setpoints.	4.3.3	Pilot Plant Operator
		4.3.4	Larox valve closed (manually actuation).	4.3.4	Pump and reactor over pressurize.	4.3.4	Dual rupture discs upstream of Larox valve.	4.3.4	Training of operators.	4.3.4	Pilot Plant Operator
4.4	High Temperature	4.4.1	Steam pressure	4.4.1	Pump and reactor	4.4.1	Temperature alarm and	4.4.1	Temperature monitoring and	4.4.1	Opta Programmer

			reducing valve failure.		temperature goes above setpoint.		control.		alarm of reactor.		
		4.4.2	Steam flow control valve failure.	4.4.2	Pump and reactor temperature goes above setpoint.	4.4.2	Temperature alarm and control.	4.4.2	Temperature monitoring and alarm of reactor.	4.4.2	Opta Programmer
4.5	Corrosion	4.5.1	Incompatible construction materials.	4.5.1	Leakage of steam.	4.5.1	Corrosion resistant materials.	4.5.1	Steel or stainless steel materials; no copper, brass, or zinc alloys.	4.5.1	Engineering
4.6	Sampling	4.6.1	Opening of sample ports.	4.6.1	Discharge of material.	4.6.1	Stainless steel sample containers.	4.6.1	Training of operators.	4.6.1	Pilot Plant Operator

Table 5. Process Hazard Analysis NODE: 5.0 Pilot Plant – Flash Tank

NO.	DEVATION GUIDE WORD	CAUSES		CONSEQUENCES		SAFEGUARDS		RECOMMENDATIONS		RESPONSIBLE PERSON	
5.1	High Pressure	5.1.1	Tank not venting to scrubber.	5.1.1	Tank pressurizes.	5.1.1	Pressure relief valve.	5.1.1	Pressure relief valve on tank set to 10 psig.	5.1.1	Pilot Plant Specialist
		5.1.2	Acid flow control malfunction.	5.1.2	Water pH increases.	5.1.2	Rupture disk.	5.1.2	Rupture disc on tank set to 15 psig.	5.1.2	Pilot Plant Specialist
		5.1.3	Quench water flow control malfunction	5.1.3	Tank pressurizes.	5.1.3	Rupture disk.	5.1.3	Rupture disc on tank set to 15 psig.	5.1.3	Pilot Plant Specialist
5.2	High Level	5.2.1	Acid flow control	5.2.1	Tank liquid level	5.2.1	Level switch.	5.2.1	Level monitoring and	5.2.1	Opta Programmer

			malfunction.		increases.				alarm.		
		5.2.2	Reactor flow malfunction.	5.2.2	Reactor system is shutdown.	5.2.2	Level switch.	5.2.2	Level monitoring and alarm.	5.2.2	Opta Programmer
		5.2.3	Quench water flow control malfunction	5.2.3	Tank liquid level increases.	5.2.3	Level switch.	5.2.3	Level monitoring and alarm.	5.2.3	Opta Programmer
5.3	High Temperature	5.3.1	Chilled water malfunction.	5.3.1	Increased pressure due to ammonia vaporization.	5.3.1	Temperature switch on steam.	5.3.1	Temperature monitoring.	5.3.1	Opta Programmer
		5.3.2	Steam regulation malfunction.	5.3.2	Increased product temperature.	5.3.2	Pressure switch alarm and interlock with steam flow control valve.	5.3.2	Pressure switch alarm and interlock with steam flow control valve.	5.3.2	Opta Programmer
5.4	High pH	5.4.1	Acid flow control malfunction.	5.4.1	Water pH increases.	5.4.1	pH control loop.	5.4.1	pH monitoring.	5.4.1	Opta Programmer
5.5	Corrosion	5.5.1	Incompatible construction materials.	5.5.1	Leakage of product.	5.5.1	Corrosion resistant materials.	5.5.1	Steel or stainless steel materials; no copper, brass, or zinc alloys.	5.5.1	Engineering

Table 6. Process Hazard Analysis NODE: 6.0 Pilot Plant Scrubber

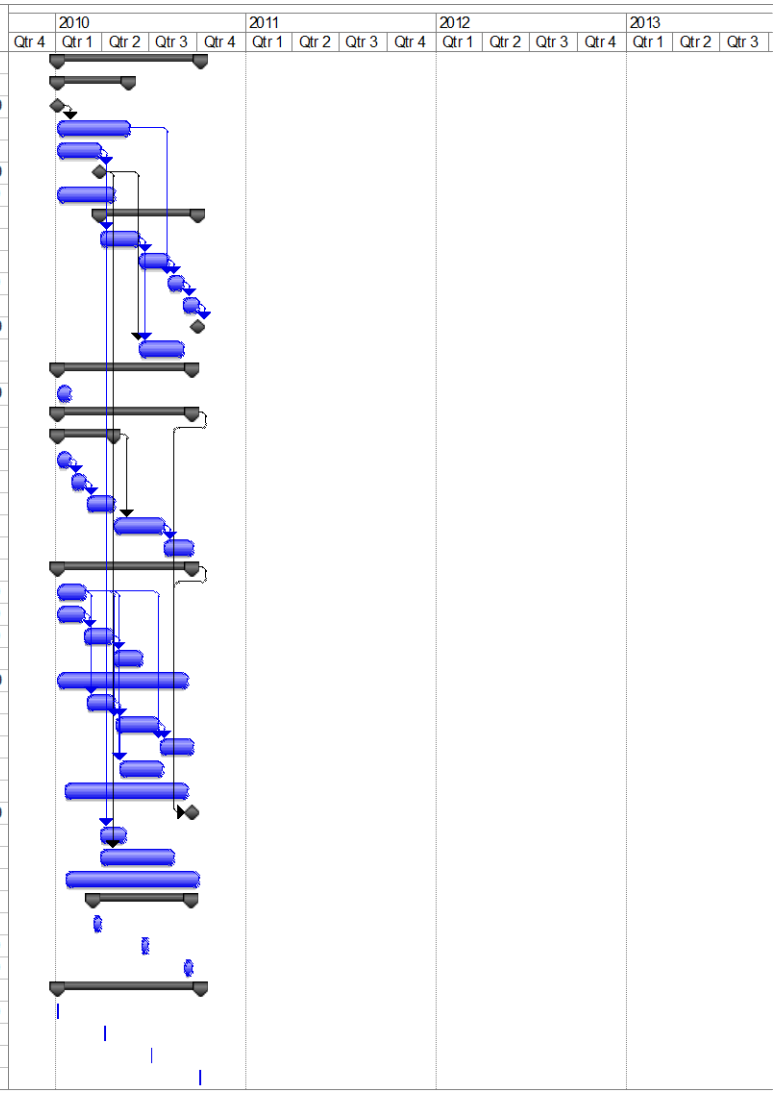
NO.	DEVATION GUIDE WORD	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	RESPONSIBLE PERSON
6.1	High Pressure	6.1.1 Scrubber is plugged.	6.1.1 Scrubber pressurizes and ruptures. 6.1.2 Ammonia vapor leaks.	6.1.1 Pressure relief valve. 6.1.2 Pressure differential instrument across scrubber packing.	6.1.1 Pressure relief device on tank set to 1/2 psig. 6.1.2 Pressure differential monitoring and alarm across scrubber packing.	6.1.1 Pilot Plant Specialist 6.1.2 Opta Programmer
6.2	High Level	6.2.1 Water supply flow malfunction. Acid flow control malfunction.	6.2.1 Scrubber pressurizes and ruptures. 6.1.2 Ammonia vapor leaks.	6.2.1 Biowaste drain. 6.2.2 Pressure relief device.	6.2.1 Monitor water supply flow. 6.2.2 Monitor scrubber pH levels.	6.2.1 Pilot Plant Operator 6.2.2 Opta Programmer
6.3	No Flow	6.3.1 Scrubber packing is plugged. 6.3.2 Scrubber packing is plugged.	6.3.1 Scrubber vessel pressurizes. 6.3.2 Ammonia vapor leaks.	6.3.1 Pressure relief device. 6.3.2 Pressure differential monitoring across scrubber packing.	6.3.1 Pressure relief device on tank set to 1/2 psig. 6.3.2 Pressure differential alarm across scrubber packing.	6.3.1 Pilot Plant Specialist 6.3.2 Opta Programmer
6.4	Corrosion	6.4.1 Incompatible construction materials.	6.4.1 Leakage of ammonia vapors.	6.4.1 Corrosion resistant materials.	6.4.1 Steel or stainless steel materials; no copper, brass, or zinc alloys.	6.4.1 Engineering.

Table 7. Spend Plan

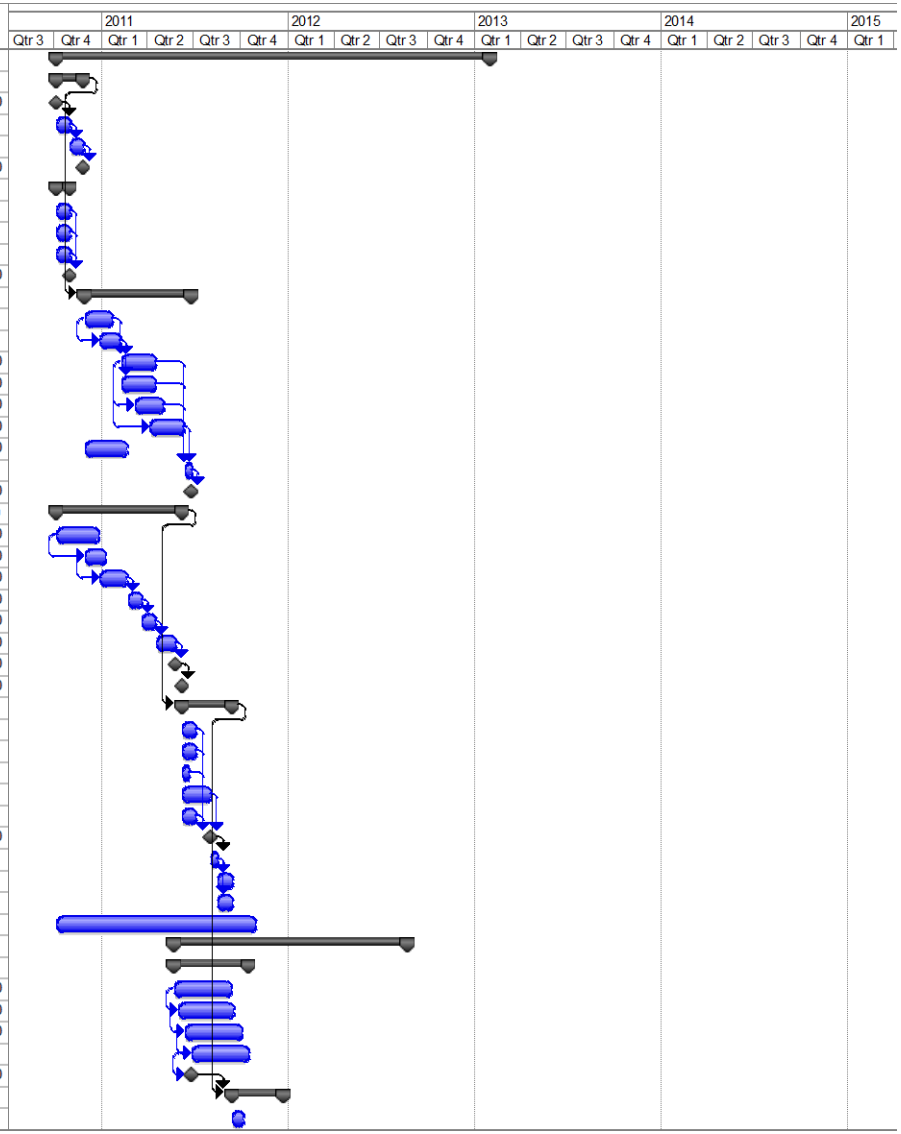
Budget Period	Category	2010	2011	2012	2013	Totals
1	R&D	$1.5				$1.5
	Design, Bid, Procure	$0.9				$0.9
	Lab Equipment	$0.2				$0.2
	Model & LCA	$0.1				$0.1
	Proj. Mgmt, Risk Mitigation, NEPA, Reporting	$0.3				$0.3
Total		**$3.0**				**$3.0**
2	Equipment	$1.6	$3.9			$5.5
	Design, Construction & Installation	$0.6	$5.2			$5.8
	Shakedown Capstone Runs			$5.7		$5.7
	Model & LCA			$0.5		$0.5
	Proj. Mgmt, Risk Mitigation, Reporting	$0.2	$0.6	$0.5		$1.3
Total		**$2.4**	**$9.7**	**$6.7**		**$18.8**
3	Operation				$1.5	$1.5
	Proj. Mgmt., LCA, Modeling, Reporting				$0.2	$0.2
Total					**$1.7**	**$1.7**
Total Budget		**$5.4**	**$9.7**	**$6.7**	**$1.7**	**$23.5**

Figure 3. Work Breakdown Structure with Direct Labor Cost*

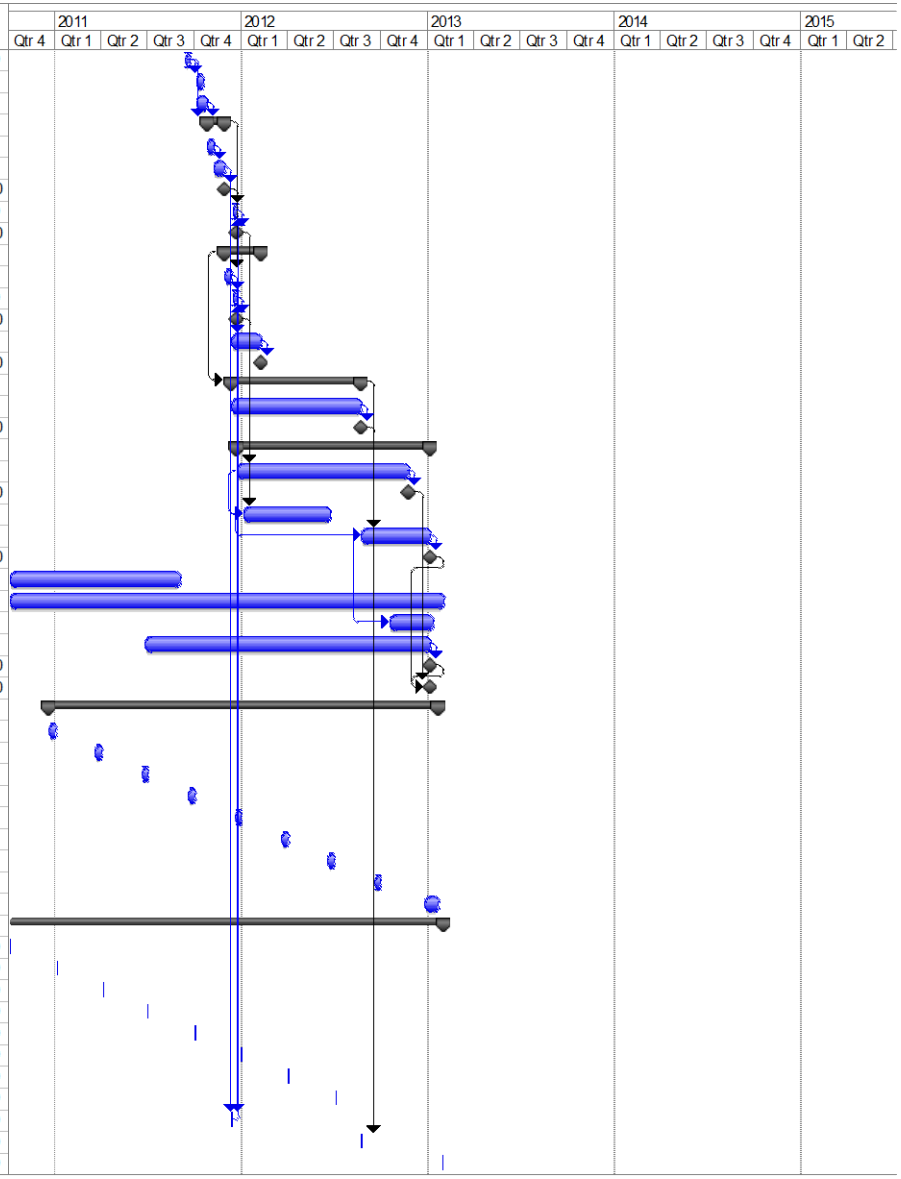
ID	WBS	Task Name	Cost
1	**1**	**Budget Period 1: Design and Supporting R&D**	**$ 591,922.00**
2	**1.1**	**Design**	**$ 105,913.00**
3	1.1.1	Full notice to proceed	$ 0.00
4	1.1.2	Select Engineering, Procurement, and Construction firm	$ 38,979.00
5	1.1.3	Preliminary process design	$ 59,766.00
6	1.1.4	Complete preliminary process design	$ 0.00
7	1.1.5	NREL design review of pilot-scale AFEX equipment and other systems	$ 7,168.00
8	**1.2**	**AFEX Pilot plant new construction - bids and permits**	**$ 84,907.00**
9	1.2.1	Complete final site plan	$ 24,958.00
10	1.2.2	Complete final construction plan	$ 14,289.00
11	1.2.3	Bid preparation and responses	$ 8,033.00
12	1.2.4	Building permit applications	$ 14,174.00
13	1.2.5	Obtain building permits	$ 0.00
14	1.2.6	Complete NEPA determination	$ 23,453.00
15	**1.3**	**R&D**	**$ 233,188.00**
16	1.3.1	Produce stover feedstock material	$ 0.00
17	**1.3.2**	**NH3 recovery design**	**$ 115,376.00**
18	**1.3.2.1**	**Measure heat and mass transfer coefficients in AFEX-treated stover**	**$ 73,409.00**
19	1.3.2.1.1	Design bench scale NH3 recovery experiments.	$ 21,108.00
20	1.3.2.1.2	Set up experiments in lab.	$ 14,505.00
21	1.3.2.1.3	Conduct experiments and calculate coefficients.	$ 37,796.00
22	1.3.2.2	Aspen model of NH3 recovery process using coefficients	$ 17,288.00
23	1.3.2.3	Design or specify NH3 recovery equipment using Aspen model	$ 24,679.00
24	**1.3.3**	**AFEX Integration with Saccharification and Fermentation**	**$ 117,812.00**
25	1.3.3.1	Prepare AFEX-treated stover in batch reactor	$ 8,996.00
26	1.3.3.2	Design high-solids enzyme hydrolysis reactor	$ 8,369.00
27	1.3.3.3	Fabricate high-solids enzyme hydrolysis reactor	$ 9,526.00
28	1.3.3.4	Shakedown high solids enzyme hydrolysis reactor	$ 14,833.00
29	1.3.3.5	NREL Bench scale enzymatic saccharification and fermentation process validation	$ 0.00
30	1.3.3.6	SSF trials using NREL's organism with AFEX-treated stover at MBI	$ 11,838.00
31	1.3.3.7	SSF trials using other organisms with AFEX-treated stover at MBI	$ 18,643.00
32	1.3.3.8	SSF trials using improved enzymes with AFEX-treated stover at MBI	$ 17,861.00
33	1.3.3.9	SSF trials using EtOH anitbiotics	$ 15,905.00
34	1.3.3.10	Novozymes enzyme screening, loading, inhibitors study	$ 11,841.00
35	1.3.4	Complete R&D Efforts	$ 0.00
36	1.4	Complete Risk Mitigation Plan	$ 30,402.00
37	1.5	Business and Commercialization Plan update	$ 43,684.00
38	1.6	Project Management Support	$ 27,692.00
39	**1.7**	**Reporting**	**$ 29,557.00**
40	1.7.1	Reporting - Q1	$ 15,159.00
41	1.7.2	Reporting - Q2	$ 7,195.00
42	1.7.3	Reporting - Ph1 Final	$ 7,203.00
43	**1.8**	**Meetings / Communications**	**$ 36,579.00**
44	1.8.1	Meeting - Budget Period 1 Kickoff	$ 5,835.00
45	1.8.2	Meeting - Quarterly Review	$ 10,274.00
46	1.8.3	Meeting - Quarterly Review	$ 10,235.00
47	1.8.4	Meeting - Budget Period 1 StageGate Review	$ 10,235.00



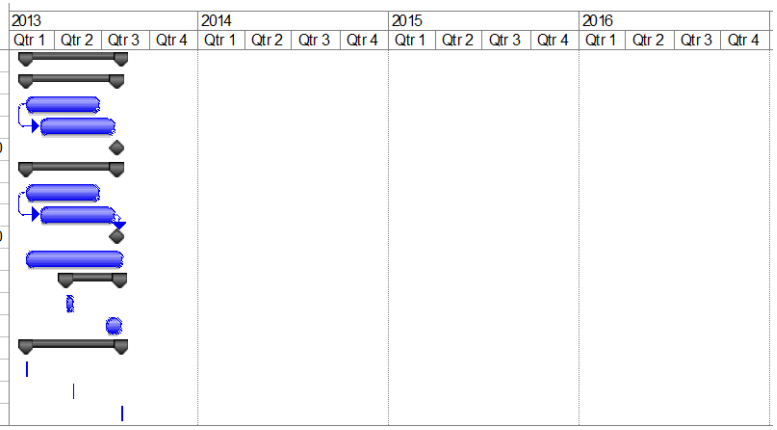
ID	WBS	Task Name	Cost
2	**2**	**Budget Period 2 - Construction, shakedown, and operation**	**$ 1,548,491.89**
3	**2.1**	**Project Start**	**$ 9,681.00**
4	2.1.1	Completion of preliminary engineering	$ 0.00
5	2.1.2	Management review	$ 5,500.00
6	2.1.3	Contract negotiation	$ 4,181.00
7	2.1.4	Full notice to proceed	$ 0.00
8	**2.2**	**Procurement - Major Equipment**	**$ 10,583.00**
9	2.2.1	Finalize spec and order feeder/reactor/discharge equipment	$ 2,291.00
10	2.2.2	Finalize spec and order NH3 recovery equipment	$ 4,739.00
11	2.2.3	Finalize spec and order densification equipment	$ 3,553.00
12	2.2.4	Complete major equipment orders	$ 0.00
13	**2.3**	**Engineering**	**$ 10,666.00**
14	2.3.1	Finalize P&IDs	$ 4,340.00
15	2.3.2	Finalize equipment layouts	$ 3,255.00
16	2.3.3	Mechanical	$ 0.00
17	2.3.4	Civil, structural, architecture	$ 0.00
18	2.3.5	Electrical	$ 0.00
19	2.3.6	Instrumentation	$ 0.00
20	2.3.7	Site specific design	$ 0.00
21	2.3.8	Final engineering review	$ 3,071.00
22	2.3.9	Completion of detailed engineering	$ 0.00
23	**2.4**	**AFEX plant building construction**	**$ 0.00**
24	2.4.1	Site prep	$ 0.00
25	2.4.2	Concrete	$ 0.00
26	2.4.3	Structural	$ 0.00
27	2.4.4	Masonry	$ 0.00
28	2.4.5	Thermal & moisture	$ 0.00
29	2.4.6	Mechanical	$ 0.00
30	2.4.7	Complete buliding construction	$ 0.00
31	2.4.8	Construction inspection	$ 0.00
32	**2.5**	**AFEX pilot plant equipment installation**	**$ 43,241.00**
33	2.5.1	Install feeder/reactor/discharge equipment	$ 4,152.00
34	2.5.2	Install NH3 recovery equipment	$ 4,152.00
35	2.5.3	Install densification equipment	$ 2,679.00
36	2.5.4	Piping & electrical	$ 9,314.00
37	2.5.5	Install instrumentation	$ 3,595.00
38	2.5.6	Attain mechanical completion	$ 0.00
39	2.5.7	Commissioning and startup	$ 6,997.00
40	2.5.8	Write and issue SOPs for all new equipment	$ 10,397.00
41	2.5.9	Operator safety training for all new equipment	$ 1,955.00
42	2.6	NREL PDU/IBRF saccharification and fermentation equipment modification	$ 36,067.00
43	**2.7**	**Equipment shakedown trials**	**$ 187,490.84**
44	**2.7.1**	**Produce stover for shakedown trials**	**$ 8,537.00**
45	2.7.1.1	Acquire raw corn stover	$ 0.00
46	2.7.1.2	Stover milling and other preparation	$ 0.00
47	2.7.1.3	Prepared stover shipping to MBI	$ 0.00
48	2.7.1.4	Stover receiving and storage at MBI	$ 8,537.00
49	2.7.1.5	Initial stover received at MBI	$ 0.00
50	**2.7.2**	**AFEX plant equipment shakedown trials**	**$ 85,957.00**
51	2.7.2.1	Stover throughput trial, atmos P	$ 16,911.00



ID	WBS	Task Name	Cost
52	2.7.2.2	Reactor P test (air or N2)	$ 6,561.00
53	2.7.2.3	Stover throughput trial, design P (air or N2)	$ 11,509.00
54	2.7.2.4	Stover mixing trial	$ 14,007.00
55	**2.7.2.5**	**Stover NH3 trials with NH3 recovery**	**$ 28,037.00**
56	2.7.2.5.1	Stover NH3 trial - no steam	$ 11,232.00
57	2.7.2.5.2	Stover NH3 trial - live steam	$ 16,805.00
58	2.7.2.5.3	AFEX equipment shakedown complete	$ 0.00
59	2.7.2.6	AFEX Independent Engineer performance test	$ 8,932.00
60	2.7.2.7	AFEX equipment Independent Engineer approval	$ 0.00
61	**2.7.3**	**Densification equipment shakedown**	**$ 46,859.00**
62	2.7.3.1	Densification equipment shakedown	$ 10,809.00
63	2.7.3.2	Densification equipment Independent Engineer test	$ 6,255.00
64	2.7.3.3	Densification Equipment Independent Engineer approval	$ 0.00
65	2.7.3.4	Monitor hydrolysis and fermentation yields of densified AFEX-treated sto	$ 29,795.00
66	2.7.3.5	Demonstrate < 10% yield loss over 6 weeks storage of AFEX-treated sto	$ 0.00
67	**2.7.4**	**NREL saccharification and fermentation equipment shakedown trials**	**$ 46,137.84**
68	2.7.4.1	NREL saccharification and fermentation equipment shakedown	$ 46,137.84
69	2.7.4.2	NREL saccharification and fermentation equipment Independent Enginee	$ 0.00
70	**2.8**	**Capstone Runs**	**$ 684,431.49**
71	2.8.1	AFEX equipment capstone runs	$ 583,954.89
72	2.8.2	Demonstrate continuous operation of AFEX reactor with NH3 recovery	$ 0.00
73	2.8.3	Densification capstone runs	$ 62,326.61
74	2.8.4	NREL saccharification and fermentation capstone runs	$ 38,150.00
75	2.8.5	Demonstrate integrated high-solids enzyme hydrolysis and mixed-sugar co-fe	$ 0.00
76	2.9	AFEX shakedown and capstone run support	$ 51,400.55
77	2.10	Project Management Support	$ 93,385.00
78	2.11	Update techno-economic model using data from demonstration runs	$ 10,723.00
79	2.12	Business and Commercialization Plan Update	$ 209,657.00
80	2.13	Complete techno-economic model using capstone data	$ 0.00
81	2.14	All CSFs completed within scope, schedule, and budget	$ 0.00
82	**2.15**	**Reporting**	**$ 142,194.00**
83	2.15.1	Reporting - Budget Period 2 Q1	$ 14,129.00
84	2.15.2	Reporting - Budget Period 2 Q2	$ 14,129.00
85	2.15.3	Reporting - Budget Period 2 Q3	$ 14,166.00
86	2.15.4	Reporting - Budget Period 2 Q4	$ 14,504.00
87	2.15.5	Reporting - Budget Period 2 Q5	$ 12,070.00
88	2.15.6	Reporting - Budget Period 2 Q6	$ 12,070.00
89	2.15.7	Reporting - Budget Period 2 Q7	$ 14,504.00
90	2.15.8	Reporting - Budget Period 2 Q8	$ 14,842.00
91	2.15.9	Reporting - Final Budget Period 2 report	$ 31,780.00
92	**2.16**	**Meetings / Communications**	**$ 58,972.00**
93	2.16.1	Meeting - Budget Period 2 Kickoff	$ 4,444.00
94	2.16.2	Meeting - Quarterly review	$ 5,734.00
95	2.16.3	Meeting - Quarterly review	$ 5,734.00
96	2.16.4	Meeting - Quarterly review	$ 5,419.00
97	2.16.5	Meeting - Quarterly review	$ 5,419.00
98	2.16.6	Meeting - Budget Period 2 stage gate review	$ 4,888.00
99	2.16.7	Meeting - Quarterly review	$ 5,419.00
100	2.16.8	Meeting - Quarterly review	$ 5,562.00
101	2.16.9	Meeting - Independent Engineer review at MBI	$ 4,888.00
102	2.16.10	Meeting - Independent Engineer review at NREL	$ 3,098.00
103	2.16.11	Meeting - Budget Period 2 Final Review	$ 8,367.00



ID	WBS	Task Name	Cost
3	**3**	**Budget Period 3: Operation**	**$ 278,655.00**
4	**3.1**	**Extended Operation of Pilot Plant**	**$ 141,522.00**
5	3.1.1	MBI pilot scale AFEX and densification extended operations	$ 128,934.00
6	3.1.2	NREL PDU/IBRF pilot scale saccharification and fermentation extended operations	$ 12,588.00
7	3.1.3	Extended operations complete	$ 0.00
8	**3.2**	**Modelling and BCP Development**	**$ 89,223.00**
9	3.2.1	Economic modelling	$ 48,226.00
10	3.2.2	Business & Commercialization Plan Development	$ 40,997.00
11	3.2.3	Business & Commercialization Plan Complete	$ 0.00
12	3.3	Project Management Support	$ 20,308.00
13	**3.4**	**Reporting**	**$ 12,677.00**
14	3.4.1	Reporting - Budget Period 3 Q1	$ 2,282.00
15	3.4.2	Reporting - Budget Period 3 Final report	$ 10,395.00
16	**3.5**	**Meetings / Communications**	**$ 14,925.00**
17	3.5.1	Meeting - Budget Period 3 Kickoff	$ 5,278.00
18	3.5.2	Meeting - Quarterly Review	$ 4,230.00
19	3.5.3	Meeting - Budget Period 3 StageGate Review	$ 5,417.00



*Costs shown are for MBI direct labor costs. Please see the Budget Justification File for a complete breakdown of all costs by Budget Period and task.

Technical and Financial Data | Existing Facility | AFEX Integrated Biorefinery Pilot Plant

Existing Bench, Pilot, or Demonstration Facility Applicant is currently operating as the basis for the Proposed Facility

General Plant Information

Name	**MBI International**
Facility Location	**Lansing , Michigan 48910**
Total Operating Hours as of 12/31/2008	**Work related to this project has been performed in bench scale batch reactor**
Operating Days per Year	**MBI International works on a 283 days per year calendar**
Conversion Technology Type	☑ Biochemical ☐ Thermochemical ☐ Hybrid
Short Technology Description	**Conversion of corn stover to ethanol utilizing Ammonia Fiber Expansion (AFEX) biomass treatment process in combination with bioconversion process**
Scale up Size from Previous Facility	**Scaled up for 300ml rector to 5 gallon reactor**
Requested Dollars from DOE	**Not applicable**
Total Facility Capital Cost	**Not applicable**
Cost Share Percent	**Not applicable**
Industrial Project Partners)	**None**
National Lab Project Partners)	**None**
Academic Project Partners)	**Michigan State University**
Other Project Partners)	

Products (denote Primary Product in Bold) — **Existing facility is a R&D facility and does not produce any product for sale.**

All Tonnes per year are on a dry basis in the "Product" category — **No products produced**

	Units	
Gross Production Rate	Gal/year	**Not applicable**
	Tonnes/year	**Not applicable**
Net Production Rate	Gal/year	**Not applicable**
	Tonnes/year	**Not applicable**
Energy Value	Btu/Gal	**84,500**
	Btu/Ton	**Not applicable**
Break Even Sales Price	$/Gal	**Not applicable**
	$/Tonne	**Not applicable**
Yield	Gal/Tonne	**Not applicable**
	Tonnes Product/Tonne Feedstock	**Not applicable**

Waste Streams — **Work related to this project has been carried out at bench scale and has only generated small waste streams..**

Production Rate	**kgs/hour**	**500**
Cost of Disposal	**$/Tonne**	**no cost**

Feedstock — **Work related to this project has been carried out at bench scale and has not required large quantity of biomass. However we have worked with variety of biomass**

	Units	
Consumption Rate (dry basis)	Tonnes/Year	**No Information**
	Gal/Year	**Not applicable**
Moisture Content - Delivered	Percent	**15%**
Percent Foreign Material - Delivered	Percent	**Very little**
High Heating Value (dry basis)	Btu/lb	**7487**
Transportation Method	Truck	**All by truck**
Transportation Charge	Truck ($/Tonne)	**Not applicable**
Storage Charge		**Not applicable**
Expected cost of feedstock at process throat		**Not applicable**

Consumables

	Consumption Rate	Process Chemicals
	Primary Product	**Work related to this project has been carried out at bench**
	$/MMBtu of Product	**Not applicable**
	kWh/MMBtu of Product	**Not applicable**
	Gal/MMBtu of Product	**Not applicable**

Proforma Information — **No Proforma for existing facility**

$/kWh	**Not applicable**
$/MMBtu Consumed	**Not applicable**
$/MMBtu Produced	**Not applicable**
Max Utilization (availability, days and %)	**Not applicable**
Operational Uptime (capacity factor)	**Not applicable**
Ramp-up percent during 1st 12 months	**Not applicable**
Land Acquisition Costs	**Not applicable**

Cost and Schedule Information applicable

Budget Information	**Existing facility is at lab scale**
Administrative	**Not applicable**
Land, Structures, rights-of-way, appraisals	**Not applicable**
Relocation expenses and payments	**Not applicable**
Architectural and engineering fees (EPC)	**Not applicable**
Other Architectural and engineering fees	**Not applicable**
Project inspection fees	**Not applicable**
Site Work	**Not applicable**
Demolition and removal	**Not applicable**
Construction (EPC)	**Not applicable**
Equipment	**Not applicable**
Miscellaneous	**Not applicable**
Startup	**Not applicable**
Operation	**Not applicable**
SUBTOTAL	**Not applicable**
Contingency ($)	**Not applicable**
Contingency (%)	**Not applicable**
Project Income	**Not applicable**
Capital Costs	**Existing facility is at lab scale**
Construction (EPC)	**Not applicable**
Equipment	**Not applicable**
Miscellaneous (explain)	**Not applicable**
Capital Costs per Gallon Primary Product	**Not applicable**
Capital Costs per Ton Primary Product	**Not applicable**
Estimated Post completion capital costs	**Not applicable**
Operational Costs	
Feedstock costs per year	**Not applicable**
Transportation Charges per year	**Not applicable**
Chemical Cost per year	**Not applicable**
Utility Costs per year	**Not applicable**
Maintenance Costs per year	**Not applicable**
Insurance Costs per year	**Not applicable**
Labor Costs per Year	**Not applicable**
Other Costs per Year	**Not applicable**
Operational Cost per Gallon Primary Product	**Not applicable**
Operational Cost per Ton Primary Product	**Not applicable**
Expected duration of operation (months)	**Not applicable**
Expected cost per month of operation	**Not applicable**
Startup costs	**Existing facility is at lab scale**
Costs	**Not applicable**
Other costs (explain)	**Not applicable**
Subtotal	**Not applicable**
Other Income (explain)	**Not applicable**
Total	**Not applicable**
Schedule (days)	**Existing facility is at lab scale**
Contingency	**Not applicable**
Award	**Not applicable**
Total Project duration (inception of project team to completion of independent engineer performance test)	**Not applicable to existing facility**
Procurement	**Not applicable to existing facility**
Engineering	**Not applicable to existing facility**
Construction	**Not applicable to existing facility**
Commissioning	**Not applicable to existing facility**
Startup	**Not applicable to existing facility**
Shakeout	**Not applicable to existing facility**
Operations - Piloting	**Not applicable to existing facility**
Total Project duration	**Not applicable to existing facility**

Technical and Financial Data | **Proposed Facility** | **AFEX Integrated Biorefinery Pilot Plant**

General Plant Information

Name	AFEX Integrated Biorefinery Pilot Plant
Facility Location	Biomass treatment at MBI in Lansing Michigan/Fermentation at NREL in Golden Colorado
Operating Days per Year	This is not a year around operation; It will be operated to derisk the technology for commercial scale up
Conversion Technology Type	☑ Biochemical
Short Technology Description	Conversion of corn stover to ethanol using AFEX treatment process and Zymomonas mobilis for ethanol fermentation
Scale up Size from Previous Facility	From bench scaled batch reactor to continuous process capable of handling 1 ton per day
Requested Dollars from DOE	$23,527,272.00
Total Proposed Facility Capital Cost	$11,277,174.00 AFEX Pilot Plant
Cost Share Percent	20%
Industrial Project Partners	Vermeer, Novozyme, ICM, Airgas
National Lab Project Partner(s)	National Renewable Energy Laboratory (NREL)
Academic Project Partner(s)	Michigan State University
Other Project Partner(s)	Airgas

Products (denote Primary Product in Bold) **Ethanol**

This facility will not produce salable product. The purpose of this facility is to derisk the AFEX treatment, hydrolysis and fermentation process, beer column operation, and handling fermentation residues. This work will not include ethanol distillation and recovery.

All Tonnes per year are on a dry basis in the "Product" category

Gross Production Rate	**Units = Gals/yr**	-0-
	Tonnes Product/Tonne Feedstock	Not applicable

Waste Streams: This is not a year around operation; It will be operated long enough to derisk the technology for commercial scale up. Therefore will not generate large quantity of waste

Production Rate	Tonne/year	unknown
Cost of Disposal	$/Tonne	unknown

Feedstock — Corn stover

This is not a year around operation; It will be operated to derisk the technology for commercial scale up. It is projected that overall about 60 tones of corn stover will be used for project life

	Units		
Consumption Rate (dry basis)			
Moisture Content - Delivered	Percent	15%	
Percent Foreign Material - Delivered	Percent	1%	
High Heating Value (dry basis)	Btu/lb	7487	
Transportation Method (% of feedstock per method)			
	Truck	100%	
Transportation Charge	Truck ($/Tonne)	$0.00	Delivered by Vermeer
Storage Charge		Stored on site	
Expected cost of feedstock at process throat		No charge to project	

Consumables	**Consumption Rate**	**Process Chemicals**
	Primary Product	
	$/MMBtu of Product	To be determined
	kWh/MMBtu of Product	To be determined
	Gal/MMBtu of Product	To be determined

Proforma Information

$/kWh	To be determined
$/MMBtu Consumed	To be determined
$/MMBtu Produced	To be determined
Max Utilization (availability, days and %)	Not applicable
Operational Uptime (capacity factor)	Not applicable
Ramp-up percent during 1st 12 months	Not applicable
Land Acquisition Costs	No land acquired

Cost and Schedule Information

Budget Information

R & D	$423,000
Administrative	$242,306
Indirect costs	$4,511,016
Travel	$95,200
Supplies	$80,240
Other Direct Coast	$36,800
Land, Structures, rights-of-way, appraisals	$0
Relocation expenses and payments	$0
Architectural and engineering fees (EPC)	$400,000
Other Architectural and engineering fees	$25,000
Project inspection fees	$25,000
Site Work	$350,000
Demolition and removal	$0
Construction (EPC)	$4,795,000
Equipment	$4,932,174
Miscellaneous	$350,000
Startup	$1,200,000
Operation	$1,525,000
Sub Recipient	$594,523
FFRDC	$3,473,313
Other Vendors	$68,700
Contingency ($)	$400,000
SUBTOTAL	$23,527,272
Contingency (%)	1.70%
Project Income	0

Capital Costs

Construction (EPC)	$5,795,000
Equipment	$5,482,174
Capital Costs per Gallon Primary Product	To be determined
Capital Costs per Ton Primary Product	To be determined
Estimated Post completion capital costs	unknown
	This is not a year around operation; It will be operated long enough to derisk the technology for commercial scale up.

Operational Costs

Feedstock costs per year	none
Transportation Charges per year	none
Chemical Cost per year	To be determined
Utility Costs per year	To be determined
Maintenance Costs per year	To be determined
Insurance Costs per year	To be determined
Labor Costs per Year	To be determined
Other Costs per Year	To be determined
Operational Cost per Gallon Primary Product	To be determined
Operational Cost per Ton Primary Product	To be determined
Expected duration of operation (months)	43
Expected cost per month of operation	$547,145.86

Startup costs

Costs	$1,200,000
Other costs (explain)	$0
Subtotal	$1,200,000
Other Income (explain)	$0
Total	$1,200,000
Contingency	
Award	$18,821,818

Schedule (days)	Start Day	End Day	Total Days
Total Project duration (inception of project team to completion of independent engineer performance test)		959	959
Procurement	**273**	519	246
Engineering	**329**	536	207
Construction & Equipment Installation	**273**	616	343
Commissioning	**710**	959	249
Startup	**617**	716	99
Shakeout	**617**	959	342
Operations	**959**	1,301	342
Total Project duration	**1**	1,301	

Technical and Financial Data — Future Commercial Facility

Facility that will be constructed following successful operation of the Proposed Facility or Demonstration Facility

General Plant Information

Name	AFEX Integrated Biorefinery
Facility Location	To Be Determined
Operating Days per Year	350
Conversion Technology Type	☑ Biochemical ☐ Thermochemical ☐ Hybrid ☐ Other
Short Technology Description	Coproduction of ethanol, steam and power from corn stover utilizing Ammonia Fiber Expansion (AFEX) biomass treatment process in combination with bioconversion processes
Scale up Size from Previous Facility	From 1 ton per day to 3800 ton/day
Total Proposed Facility Capital Cost	$378,896,163
Cost Share Percent	Unknown
Industrial Project Partners)	Anderson, Vermeer, Novozyme, ICM
National Lab Project Partners)	NERL
Academic Project Partners)	Michigan State University
Other Project Partners)	Airgas

Products (denote Primary Product in Bold)

All Tonnes per year are on a dry basis in the "Product" category

	Units	Ethanol	
Gross Production Rate	Gal/year	120,000,000	
Net Production Rate	Gal/year	120,000,000	
Energy Value	Btu/Gal	84,530	10,143,600 MMBtu/year
	Btu/Ton	25,664,000	
Break Even Sales Price (without interest, taxes and ROI)	$/Gal	$1.195	
Break Even Sales Price (without interest and with taxes and a 9.02% ROI)	$/Gal	$1.586	
Yield	Gal/Tonne	90	
	Tonnes Product/Tonne Feedstock	0	
Waste Streams			
Production Rate - Ash	Tonne/year	59,769	
Production Rate - Residue for boiler	Tonne/year	378,865	
Cost of Disposal - Ash	$/Tonne	$26.24	

Feedstock

	Units	Corn stover	
Consumption Rate (dry basis)	Tonnes/Year	1,328,205	
Moisture Content - Delivered	Percent	15%	
Percent Foreign Material - Delivered	Percent	1%	
High Heating Value (dry basis)	Btu/lb	7487	21,875,536 MMBtu/year
Transportation Method (% per method)	Truck	100%	
Transportation Charge	Truck ($/Tonne)		Feedstock is quoted preprocessed and delivered
Storage Charge			
Expected cost of feedstock at process throat	Cost per tonne	$49.39	

Consumables

	Consumption Rate	Process Chemicals (ammonia , Nutrient, other raw material, enzyme)	Utilities	Other Process Consumables
	Primary Product			
	$/MMBtu of Product	$5.03		
	kWh/MMBtu of Product		14.20	
	Gallons of water /MMBtu of Product			35.35

Proforma Information

$/kWh	$0.05855	
$/MMBtu Consumed	$3.00	(biomass cost/mmbtu available in biomass)
$/MMBtu Produced	-$7.71	Net revenues from Pro forma/(mmbtu from ethanol+mmbtu from generated electricity)
Max Utilization (availability, days and %)	350 days	95.9%
Operational Uptime (capacity factor)	350	Days
Ramp-up percent during 1st 12 months	100%	
Land Acquisition Costs	Unknown	

Cost and Schedule Information

Budget Information

Administrative	$535,000
Land, Structures, rights-of-way, appraisals	$450,000
Relocation expenses and payments	$0

Architectural and engineering fees (EPC)	$9,605,000	
Other Architectural and engineering fees	$3,450,000	
Project inspection fees	$1,275,000	
Site Work	$2,140,000	
Demolition and removal	$0	
Construction (EPC)	$150,831,295	
Equipment	$200,109,868	
Miscellaneous		
Startup	$3,000,000	
Operation	$0	
SUBTOTAL	$371,396,163	
Contingency ($)	$7,500,000	
Contingency (%)	2.14%	of EPC + Equipment Cost
Project Income	$82,048,349	
Capital Costs		
Construction (EPC)	$150,831,295	
Equipment	$200,109,868	
Miscellaneous (explain)	$27,955,000	Contingency, start up cost, engineering, ADM Fees, land and site work, inspection fees
Capital Costs per Gallon Primary Product	$3.16	
Capital Costs per Ton Primary Product		
Estimated Post completion capital costs	-0-	
Operational Costs		
Feedstock costs per year	$65,600,045	
Transportation Charges per year		
Chemical Cost per year	$50,994,477	
Utility Costs per year	-$7,731,913	
Maintenance Costs per year	$3,483,004	
Insurance Costs per year	$1,741,502	
Labor Costs per Year	$3,416,400	
Other Costs per Year	$40,511,792	Other fixed costs, depreciation, taxes, royalty, marketing expenses, emissions costs
Operational Cost per Gallon Primary Product	$1.317	

Expected duration of operation (months)	480
Expected cost per month of operation	$13,167,942
Startup costs	$3,000,000
Other costs (explain)	$0
Subtotal	$3,000,000
Other Income (explain)	$0
Total	$3,000,000
Contingency	$7,500,000

Schedule (days)	Start	End	Total Days
Total Project duration (inception of project team to completion of independent engineer performance test)	Day 1	(Commissioning) Day 395	399
Procurement	Day 35	Day 371	336
Engineering	Day 1	Day 252	251
Construction	Day 139	Day 343	204
Commissioning	Day 385	Day 405	20
Startup	Day 385	Day 399	14
Shakeout	Day 399	Day 455	56
Operations	Day 455	Day 8618	8163
Total Project duration (includes 20 yrs operations)	Day 1	Day 8618	8618

Demonstrations of an AFEX Integrated Biorefinery at Pilot Scale
Submitted by MBI International
DOE-FOA-0000096

PROJECT BUSINESS AND COMMERCIALIZATION PLAN

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1.0 INTRODUCTION

This proposal for a pilot scale AFEX Integrated Biorefinery has novel features that provide flexible options that will facilitate commercializing the technology. As explained in the Narrative, the Ammonia Fiber Expansion (AFEX) treatment produces a stable intermediate that can be stored, densified and can be hydrolyzed and fermented at high solids loading to produce ethanol. The stable intermediate allows us to envision two options for commercialization: 1) a centralized option for commercialization wherein the AFEX treatment facility is co-located at the bioconversion facility (saccharification and fermentation); and 2) a de-centralized option for commercialization wherein biomass processing and AFEX treatment are located separate from the bioconversion facility. These options will be further investigated during the course of the project as commercial techno-economic models are developed.

MBI International has a successful history of bringing products based on renewable resources to the commercial market. MBI is leading a world-class team of industry, university, and federal laboratory partners to design, construct, and operate an innovative AFEX Integrated Biorefinery to produce ethanol from corn stover at pilot scale and to develop the data and plans necessary for commercialization.

2.0 INVESTMENT JUSTFICATION

Our envisioned commercial AFEX Integrated Biorefinery is projected to produce a return on investment that is much greater than the cost of capital (see Pro formas). This will attract significant commercial interest from parties interested in building the biofuels industry. In order to achieve commercial success, the next enabling step is to demonstrate an AFEX Integrated Biorefinery at 1 dry tonne/day (TPD) pilot-scale.

As explained in more detail in Section 2 of the Project Execution Plan (PEP), bench-scale batch experiments have demonstrated: 1) 94% of theoretical yield of fermentable sugars from AFEX-treated corn stover; 2) 98% recovery of ammonia from AFEX-treated corn stover; and 3) 5% ethanol titer in high-solids hydrolysis and fermentation from AFEX-treated corn stover. These data demonstrate that our AFEX Integrated Biorefinery has significant commercial potential and is ready for validation at pilot scale. The successful completion of this project will result in a package of techno-economic data necessary to demonstrate the commercial viability of the AFEX Integrated Biorefinery. This in turn will attract the capital investment necessary for widespread adoption of cellulosic ethanol.

The Department of Energy (DOE) investment of $18.8 million in the proposed pilot plant and the successful commercial adoption of the AFEX Integrated Biorefinery will lead to: (i) reduced dependence on imported oil; (ii) creation of a domestic bio-industry; and (iii) creation and retention of jobs and promotion of economic recovery.

The investment of $4.7 million cost share, by MBI and its partners, in the proposed pilot plant will lead to opportunities for financial returns via licensing revenues upon successful commercial adoption of the AFEX Integrated Biorefinery.

3.0 PROPOSED WORK AND ALIGNMENT WITH BUDGET

The proposed pilot-scale biorefinery will allow MBI and its partners to evaluate the integration of the AFEX treatment process in a novel integrated biorefinery system. The major objectives of the pilot-scale AFEX Integrated Biorefinery are:

1) Operate a continuous AFEX treatment process with ammonia recovery and reuse at 1 TPD.
2) Integrate the AFEX treated material with high-solids enzyme hydrolysis and mixed sugar co-fermentation steps to demonstrate ethanol production from corn stover at the 1 TPD scale.
3) Evaluate the fermentation residues and determine their value.

4) Collect performance data and mass and energy balances from these operations and incorporate them into techno-economic models for a commercial AFEX Integrated Biorefinery.

The proposed work plan calls for: 1) limited R&D to support the final AFEX Integrated Biorefinery design; 2) partner Vermeer to source and prepare the corn stover; 3) AFEX treatment in a new 1 TPD processing plant at MBI; 4) ethanol production at the newly-expanded National Renewable Energy Laboratory (NREL) pilot plant in Golden, Colorado; and 5) composite analysis by MBI and NREL to determine the value of the fermentation residue.

The detailed Work Breakdown Structure (WBS) is detailed in Section 1 of the Project Management Plan (PMP). There are three Budget Periods of activity throughout the pilot-scale project; Budget Period 1 includes the design, equipment selection, R&D, NEPA determination, Risk Mitigation Plan, final site and construction plan, and construction permits; Budget Period 2 includes the AFEX building construction, equipment installation, shakedown trials, and capstone runs; Budget Period 3 includes on-going pilot-scale operations of the AFEX Integrated Biorefinery, data reporting, and economic modeling.

This creative work plan is well aligned with the proposed budget and the accelerated timeline. It makes maximum use of each partners' existing infrastructure and reduces costs by not duplicating infrastructure. The facilities for pilot scale high-solids enzymatic hydrolysis are under construction at NREL (to be completed prior to proposed project start), and a preliminary design for an AFEX treatment plant is already in hand. As a result, we have been able to compress the work plan into an accelerated time frame. Specifically, Budget Period 1 is completed within 9.25 months. We expect the new AFEX treatment plant to be operational within the first 13 months of Budget Period 2. We expect the Independent Engineers Performance Test to be completed within 8 months following completion of construction and equipment installation. The entire project is to be completed within 44 months. Each part of the plan is within the guidelines and meets the objectives of FOA DE-FOA-0000096.

4.0 VALUE PROPOSITION AND ALIGNMENT WITH FOA GOALS AND OBJECTIVES

MBI is an experienced leader in delivering commercially-viable product and process solutions to address the emerging need for new bio-based products that combine environmentally friendly attributes, sustainable production processes, and renewable raw-material sources. MBI applies multidisciplinary expertise, modern lab and pilot facilities and a robust flexible de-risking approach to accelerate the development and scale-up of bio-based technologies. MBI partners with both universities and end-user companies to bridge the gap between early innovations and commercial applications. For example, MBI developed the technology package for the production of the first biodegradable polymer, polylactic acid (PLA) in collaboration with Cargill, which formed the technological basis for the NatureWorks commercial venture. MBI is currently collaborating with DuPont on the de-risking and scale up of a novel and proprietary DuPont bio-product.

Our team proposes an innovative approach to the integrated biorefinery that is enabled by the AFEX treatment process. This approach addresses technical barriers to cost effective production of ethanol from lignocellulosic biomass including: 1) recalcitrance of lignocellulosic biomass to enzymatic hydrolysis; 2) catalyst recovery and recycle; 3) high solids loading of treated materials for enzyme hydrolysis and fermentation; 4) enzyme cost; and 5) compatibility of biomass sugar stream with fermentation. The stable intermediate from the AFEX treatment process allows for flexibility in designing a commercial operation wherein AFEX treatment could be practiced separate from the bioconversion facility or AFEX treatment could be co-located at the bioconversion facility.

We have a unique framework of collaborators that have the experience and full spectrum of capabilities for successful project implementation. MBI and its technology partners have the necessary

technical and economic performance data that validates readiness for the next level of scale up to pilot scale (see Section 2.0 of the PEP).

To support the DOE's goals, our team will have the capability to proceed rapidly through to demonstration-scale and commercialization. We have a sound business and technology strategy to deploy and/or license and market the technology commercially. The goals of this project align with the goals and objectives of the DOE published in May of 2008 (Aden, 2008) in the following ways:

1) Reduce dependence on imported oil
2) Spur the creation of the domestic biofuels industry
3) Meet the 2007 targeted price of ethanol from corn stover of $2.43 per gallon
4) Meet the 2012 targeted price of ethanol from corn stover of $1.49 per gallon (Humbird et al., 2009)
5) Reduce greenhouse gas (GHG) emissions

We have developed a Pro forma projection for an envisioned commercial AFEX Integrated Biorefinery to become operational in 2015 (Proforma.xls). This analysis has been performed for a centralized option wherein the AFEX treatment facility is co-located at the bioconversion facility. The corresponding analysis for the decentralized option (wherein biomass processing and AFEX treatment are located separate from the bioconversion facility) will require information from the proposed project and will be developed as part of the project.

Our Pro forma analysis shows that the AFEX Integrated Biorefinery is a cost-effective way to produce cellulosic ethanol. Using the value of fuel, the financing terms, and the inflation factor provided in the Pro forma forms, the envisioned commercial plant in 2015 produces ethanol for $2.19 per gallon with a 21.6% return on Total Project Investment (TPI).

The envisioned commercial AFEX Integrated Biorefinery expects to produce ethanol from a sustainable commercial platform that reduces GHG emissions by 65% compared to current petrochemical fuel emissions (see Life Cycle GHG Reduction Data).

MBI has a history of working with the U.S. Department of Energy (DOE) under several grants and contracts over the past ten years. We have a successful track record of meeting the proposed milestones within the framework of the budgets and management plans proposed. In previous contracts with the DOE, we established a working group that included NREL, the National Corn Growers Association, DeltaT and other ethanol industry participants to provide models for grain ethanol plants. Under DOE Contract DE-FC36-02GO12001, we provided a model for converting the current Heartland Grainfuels Ethanol plant, in Aberdeen, South Dakota, to a biorefinery utilizing dry corn fractionation and processing the corn fiber cellulose to ethanol with AFEX treatment. We are experienced in using Aspen modeling programs and believe the proposed pilot plant will provide the necessary technical and economic data to create a convincing model for a commercial plant.

5.0 VISION FOR COMMERCIALIZATION OF PROPOSED TECHNOLOGY

Our strategy for commercialization of the AFEX Integrated Biorefinery is to:

1) Operate the AFEX Integrated Biorefinery at 1 TPD pilot scale
2) Generate techno-economic models of commercial plants using data from the pilot plant
3) Partner with a commercial grain-ethanol plant operator to add an AFEX treatment unit.
4) Proceed with a non-exclusive licensing plan for implementation in multiple commercial plants in various geographies

Funding pilot plant development is often the most difficult step in the de-risking process. Bench-scale data is not necessarily sufficient to convince commercial partners that the technology or the process is sufficiently de-risked for commercial investment. With pilot plant data, we are aligned with commercial partners for a demonstration-scale plant or, with sufficient validation, directly to

commercialization. MBI's pathway to commercialization will be operated in a Stage-Gate format with clear milestones and critical success factors (see Figure 3 in the Narrative). This project offers an outstanding opportunity to fund the scale-up to pilot-scale of a very promising and innovative technology for ethanol production from cellulosic materials.

This proposal for a pilot scale AFEX Integrated Biorefinery has novel features that provide flexible options that will facilitate commercializing the technology. The AFEX treatment process produces a stable intermediate (Section 2 of the PEP). This stable intermediate gives us two options in planning a commercial biorefinery;

Option 1: AFEX Treatment Collocated with Bioconversion Facility. Research indicates that large biorefineries, capable of handling 5,000-10,000 MT of biomass/day, are preferable from an economic standpoint (Carolan, Joshi, and Dale, 2007). The technology proposed herein would support this type of sustained operations with the AFEX treatment collocated with bioconversion. Large biorefineries, however, have to incur increased costs for transportation and storage of low bulk density biomass.

The envisioned commercial AFEX Integrated Biorefinery is based on a centralized concept wherein all the feedstock is dedicated to ethanol production. The envisioned commercial plant produces 120 million gallons of ethanol/yr beginning in 2015 (see Pro forma). A significant component of the projection is a residue-combustion plant that produces all power for the facility and sells excess electrical power to the grid, generating $8.2 million of income per year. The projections of capital and operating costs for the power plant come from NREL/TP-510-43205 (Aden, 2008), with noted modifications to the budget with AFEX treatment assumptions based on bench scale data. The balance of the design and capital cost for the commercial bioconversion plant also come from NREL/TP-510-43205 (Commercial Pro forma assumptions).

Option 2: AFEX Treatment Located Separate from Bioconversion Facility. Our second option is for a network of Regional Biomass Processing Centers (RBPCs) that form an extended supply chain for the bioconversion facility. Biomass would be collected and processed at these centers using the AFEX treatment process. The AFEX treatment process makes a stable intermediate material that can be stored four weeks or longer with no deterioration of available sugars (see Section 2.1, Table 5 of the PEP). Because lignin is moved to the particle surface in the AFEX process (Balan et. al., 2006), the biomass is easily densified. The AFEX-treated biomass would be densified on site for storage and transportation cost advantage and shipped to a central bioconversion facility. With such a system, storage and transportation of biomass to the RBPC could be left in the hands of the feedstock producer. It is likely the RBPC could be cooperatively owned by feedstock producers, much like the current economic system and infrastructure that is in place in rural areas for grain storage and delivery. Such a system addresses the supply chain complexities with most current commercialization plans.

The above options will be further investigated during the course of the project as commercial techno-economic models are developed.

The inherent flexibility of the AFEX Integrated Biorefinery offers additional novel concepts that will be explored during implementation of the commercialization plan:

The first novel concept is to explore the options for mechanically densifying the AFEX treated material so that it can be stored and handled similar to the current processes utilized for grain handling and storage. Such a system would allow a more conventional delivery and receiving system at the bioconversion plant: reducing truck traffic, elimination of dust and simplifying the storage needs. Because lignin is moved to the particle surface in the AFEX process (Balan et al. 2006), the biomass is easy to densify (unpublished data, Dr. Bruce Dale, Michigan State University) without the use of steam or binders normally required for agricultural products. This concept will be further investigated and demonstrated in the proposed project.

The second novel concept is to explore options for on-site ammonia production as a way to reduce costs, simplify the supply chain and reduce the environmental footprint associated with

ammonia production and distribution. Such technologies are already being developed by the DOE/EERE Industrial Technologies Program (for example, ammonia production using pressure swing adsorption; DOE, 2009). We will follow these developments and determine their applicability for our commercial plan, but these activities will not be funded by this project.

The third novel concept is the opportunity to produce animal energy feed at the RBPCs as well as feedstock for ethanol production. Testing of bench-scale AFEX-treated materials has proven that the ruminant digestibility is directly correlated to the availability of monomeric sugars after enzyme hydrolysis. This ruminant animal feed has a digestibility equivalent to corn grain (Bals et al., 2009). We are developing a plan, not funded by this project, to determine through feeding trials the ability of various classes of ruminants to convert AFEX-treated corn stover to energy. With an operating pilot plant, we will be able to process the quantities of biomass necessary to provide the material needed for these feeding trials. Use of AFEX-treated biomass as animal feed could allow for an alternative product opportunity at the RBPCs. Use of AFEX-treated biomass could help resolve the "food vs. fuel tradeoff" because cellulosic residues are upgraded to provide an energy source for food animals in place of grain. Land used to grow crops can simultaneously support both animal feed and bio-based products; this concept helps address the perceived land use competition issue.

The above three concepts are novel in our business and commercialization plans and are unique to the AFEX Integrated Biorefinery.

MBI is a collaborative partner of Michigan State University (MSU) and follows the MSU "Land Grant" philosophy of developing technologies that can benefit the world and then disseminating them as widely as possible. With this objective, our primary path to market is to offer non-exclusive licenses to commercial entities. An additional method for commercializing the AFEX Integrated Biorefinery could be to join a Technology Integrator Alliance. This method has proven to be a successful model for the corn ethanol industry. ICM has provided integrated engineering and technologies for multiple grain ethanol facilities and has provided MBI a letter of support showing interest in such a marketing approach.

Financial Assurances

MBI is a wholly owned subsidiary of the Michigan State University Foundation (MSUF), a Michigan not-for-profit organization with over $300 million in assets. MSUF invests over $15 million annually in the Michigan State University enterprise, in areas including basic research, intellectual property development and technology commercialization. MSUF has agreed to invest the required operating capital in MBI, which will enable MBI to provide the majority of the cost share for the project. In addition, MBI has Letters of Commitment for cost share contributions from MSU, Novozymes, and Vermeer.

As to be expected for a technology at this stage of development, there are currently no financial assurances for building the envisioned commercial facility. Letters are included from The Andersons and ICM indicating their interest in participating in commercialization based on successful completion of the proposed project and the generation of favorable techno-economic data.

Continuity and Continuous Improvement

MBI and MSU have a major commitment to the bioeconomy through MSU's Office of Bio-based Technologies (OBT), the Great Lakes Bioenergy Research Center (GLBRC) and through MBI's development, scale up and de-risking approach to commercialization of bio-based technologies. MSU is the primary provider of biomass processing research to the GLBRC. The addition of an AFEX treatment pilot plant to the MBI facilities will allow for continued processing development work as new energy crops are developed and new processes are invented to enhance biorefinery performance. A continuous program for process improvements will follow the proposed project. Other researchers at MSU are

currently planting trial acreages (100 or more acres) of biomass crops for energy use. This data will be valuable to convince growers of the anticipated cost for growing and harvesting these crops as well as provide a source of alternative biomass feedstocks for the pilot biorefinery. MBI effectively uses research and development to further improve its technology with the goal of minimizing costs. MBI's biorefinery pilot plant facility proposed in this FOA will allow for continuous improvement to the forecasted commercial facility. Examples of areas for advancement are:

1. Feedstock and Materials Management:
   a. Integration of transportation and storage logistics for biomass
   b. Optimization of material handling and biomass processing
   c. Development and testing of new energy crops
2. Conversion Technologies:
   a. Improvement in enzyme robustness to reduce operational costs
   b. Improvement in fermentation organisms to increase yields
3. Systems integration
   a. New concepts for bioprocessing and second generation treatment processes
   b. Reduction in energy demand
4. Reduction of capital and maintenance costs of new facilities through review of pilot plant demonstration.

We do not foresee decommissioning the pilot plant. We see an ongoing need for continued process development improvements as commercial cellulosic plants begin to operate. We also see a need for such a plant to process newly developing energy crops and as a place for active technology transfer and training.

We envision an emerging need for AFEX-treated biomass as a feedstock for bio-based chemicals and products other than ethanol. We foresee that an investment in the proposed AFEX Integrated Biorefinery would allow us to provide feedstocks to researchers and pilot facilities developing such bio-based chemicals and products.

Outputs and Business Strategies

The AFEX Integrated Biorefinery Pilot Plant proposal is consistent with MBI's business plan. Providing de-risked technologies and developing Commercially Viable Technology Packages to encourage commercial partners to participate in the commercialization of biofuels is a strategic interest of MBI.

In addition, Table 1 shows that all of the partners involved with MBI in this project have a strategic interest in seeing the commercialization of this technology package.

Business Risks

Market dynamics and business risks are standard in the startup and development of new businesses. Survival and success are a function of proactive planning, adherence to best business practices (systematic process), performance measures, and control disciplines. Changing market dynamics, particularly the pricing policies for hydrocarbon fuels from oil producing countries, will have the highest degree of risk associated with determining the selling price of cellulosic ethanol. Policies of the U.S. government relative to the continued support for renewable fuels, particularly in the face of falling prices for hydrocarbon fuels, will greatly influence the success of renewable fuels industry. MBI has identified five categories that represent potential business risks associated with producing ethanol as shown in the table 2 below.

Table 1: Outputs Matched with Partner Business Strategy

Partners	Business Strategy	Strategy Alignment	Comments
MBI/MSUF	Broad deployment of technology	Positive	Not for profit mission emphasizes broadest deployment
MSU	Broad deployment of technology	Positive	Land grant mission emphasizes broadest deployment
NREL	Meet national goals	Positive	Meets national goals of DOE
Vermeer	Sell agricultural equipment	Positive	All producers need harvesting equipment
Novozymes	Sell enzymes	Positive	All users need enzymes
Airgas	Distribute and sell ammonia	Positive	Ammonia distributor to the industry
ICM	Design and build plants	Positive	Complements current business
The Andersons	Make and sell ethanol	Positive	Complements current business

Table 2: Business Risk Scenarios, Sensitivities, and MBI Influence

Risk Category	Risk Scenario	Scenario Sensitivity	MBI Influence
Supply	Shortages of feedstocks due to drought	Medium	Medium
	Cost/price pressures of biomass due to harvest, transport or production cost	High	Low
	Technology is focused or relies on a single feedstock	Low	High
Demand	Pressures from lower crude oil prices	High	Low
	Demand for ethanol remains static due to infrastructure	Medium	Low
Environmental			
	Environmental regulations become more restrictive	High	High
Operations	Plant operations costs increase	High	Low
	Capacity or throughput of the plant is constrained due to biomass feedstock	Medium	Medium
	Capabilities (knowledge/skill sets) of personnel are diluted due to continued rapid growth in the industry	High	High
	Competency or the ability to perform well will be subject to a learning curve	Medium	Medium
	Cost of enzymes is prohibitive	High	Medium
Technology	Incompatibility of biomass technology with the existing starch-to-ethanol process	Medium	High

MBI expects to utilize internal resources, as well as leading industrial firms, in its commercialization efforts to mitigate the major operational risks of:

- Safety & Insurance Risk Management
- Environmental Application, Permitting, and Compliance Systems
- Plant Operations Training & Start-up
- Plant Asset Preservation & Predictive Maintenance Systems
- Routine Plant Shutdown & Preventative Maintenance Program
- Technology Retrofit, Upgrade, Modification, and Expansion Services

We manage risk through a disciplined Stage-Gate process. This process involves a multi-step approach of logical thought and decision-making for conceptualizing and developing new processes and products. Each stage is defined by a set of specific research activities and outcomes, and each gate is a checkpoint where decisions are made based on overall program scope, quality, and performance. It is a phased project management approach that will:

- Provide consistent program integration and project management guidelines.
- Monitor project progress against milestones.
- Help assess viability of technology commercialization.
- Guide decisions to enable that our AFEX Integrated Biorefinery pilot plant has the greatest probability for success.

In summary, MBI recognizes and responds to business risk and market dynamics through systematic processes with corresponding feedback and control systems.

Legal and Regulatory

MBI retains the services of outside legal firms on an as-needed basis. Our legal team has extensive experience with the legal and regulatory issues impacting the development of technologies, protecting intellectual property and marketing intellectual property through non-exclusive licensing arrangements. Other skills available in this group include contracting for construction services, insurance and regulatory environmental issues.

MBI intends to employ an Engineering, Procurement and Construction (EPC) firm to design and manage the construction of the AFEX treatment plant. This firm, along with MBI and MSU personnel, will be responsible for the permitting and construction management. In the development of a demonstration plant or commercial plants, we would augment our internal capabilities with firms experienced in environmental affairs and emission compliance. These consultants would be responsible for permits, plans and approvals necessary to construct, start-up, and operate plants and equipment.

Liability Insurance

MBI currently has umbrella liability insurance coverage through Chubb Insurance for $5,000,000. We have had continuous coverage and have never had coverage declined or had coverage lapse. Liability insurance would be the responsibility of the commercial producer in a biorefinery licensed to use the proposed technology.

Product Marketing and Deployment Plan

The planned schedule calls for the construction of the first commercial operation to be completed by 2015 per the Pro forma. The primary product, ethanol, is a well established biofuel, which will be distributed through normal blending and distribution channels.

Likely customers for cellulosic ethanol technologies are investment groups or commercial operators currently in the ethanol production. Many of the potential customers currently own grain ethanol facilities. These facilities supply ethanol to transportation fuel blenders, who in turn supply the

market place. The ultimate end-users are the consumers who desire to use ethanol and ethanol blends as an alternative to conventional fuels.

Once commercialized, we assume that the deployment of additional operations will proceed rapidly. Over the period from 2015 to 2030, we anticipate that ethanol produced using AFEX Integrated Biorefinery technology will increase to account for about 33% of total domestic ethanol production. We estimate 33% market penetration for our technology by assuming that about one-third of ethanol in 2030 will be produced from corn and other grains, one-third from woody biomass, and one-third from non-woody biomass, including agricultural residues and purpose-grown energy crops such as switch grass and energy cane. Based on the considerable benefits of the AFEX Integrated Biorefinery, as outlined in the Project Narrative, it is reasonable to expect that AFEX Integrated Biorefinery plants will lead the market for conversion of non-woody biomass to ethanol. A total of 68 commercial AFEX Integrated biorefineries, each converting 1.33 million ton/annum of non-woody biomass feedstock to ethanol product at a yield of 90 gallons/ton, will produce a combined total of 30.8 billion L/annum, or 530,000 barrels/ day in 2030. The petroleum displaced by these 68 AIB plants in 2030 will equal 120 million barrels per annum. Further discussion is available in the Petroleum Displacement Analysis included in this submission.

Production Costs, Economic Analysis, Life Cycle Analysis

We have determined the alignment of our bench scale results with the estimates provided by Technical Report: NRELTP-510-43205 (Aden, 2008). Assumptions used in the commercial facility Pro forma are also consistent with published technical reports from CAFI (Eggeman and Elander, 2005), MBI (Campbell et al., 2008; Campbell et al., 2009), and MSU (Laureano-Perez et al., 2005; Teymouri et al., 2004; Teymouri et al., 2005a; Teymouri et al., 2005b). Please see the Pro forma (Proforma.xls) for more detail on these assumptions. We find that our data aligns well with NREL estimates and in fact certain aspects of the AFEX treatment have demonstrated advantages over proposed acid pre-treatment in the NREL plan. These advantages are:

1) AFEX treatment results in high rates of hydrolysis and high sugar yields without appreciable sugar degradation.
2) There is no need for a neutralization step in the process.
3) Waste streams are very small with the AFEX process.
4) Process conditions are mild and expensive alloys are not required in the capital cost estimates.
5) The ammonia catalyst is recycled and reused in the pilot plant.
6) 65% ethanol yields from theoretically available sugars are expected.
7) No significant inhibitors to fermentation of biomass sugar streams are produced in the AFEX treatment process.

These particular advantages of AFEX treatment rank it high among the treatment processes as studied by CAFI. This project will support work necessary to provide data on the AFEX process from a continuously operating pilot plant that recovers and reuses the ammonia catalyst. To establish a base case for the proposed Integrated Biorefinery at pilot-scale, we have made the following modifications to the proposed NREL Reference Model: A0802A (Aden, 2008).

1) With the AFEX treatment, there is no need for a neutralization/conditioning process. We have eliminated this cost item.
2) We have changed the estimate for current yield from 64% to 65% based on bench-scale data.

All other capital cost and operating cost estimates remain similar to those estimated in NREL Reference Model A0802A.

Using the value of fuel, the financing terms, and the inflation factor provided in the Pro forma forms, the envisioned commercial plant in 2015 produces ethanol for $2.19/ gallon with a 21.6% return on Total Project Investment (TPI). The minimum ethanol selling price (MESP) to meet a 9.02% return on

TPI is $1.58/gallon without financing. This MESP is equivalent to the $1.49/gallon projection (for 2012, also without financing) made by NREL at the 2009 Symposium for Biotechnology for Fuels and Chemicals (Humbird et al., 2009) for the dilute acid process when adjusted for inflation at 2.4%/yr to the year 2015. The AFEX Integrated Biorefinery thus provides a cost effective way to produce cellulosic ethanol.

A Life Cycle Analysis (LCA) of the proposed AFEX Integrated Biorefinery process has been conducted by MBI and MSU for a conceptual commercial AFEX Integrated Biorefinery to determine net GHG emission reductions for our primary product, ethanol, compared to petroleum-derived gasoline. Details of the LCA are found in the LCA_GHG.xls document. LCA results show that cellulosic ethanol derived from corn stover via the AFEX Biorefinery reduces fossil energy by about 73% and greenhouse gas emissions by about 65%. The mass and energy balance data collected from this project will allow the LCA to be refined, by using actual measured values from pilot operations in the model calculations.

Configuration and Control Management Plan Summary

The configuration and control management plan is only for projects that intend to produce a product for sale during the award period, and as such, is not applicable to MBI's submittal.

6.0 TECHNOLOGY AND MARKET CONDITIONS

Status of the Technology: Proposed AFEX Integrated Biorefinery

Both a conventional and the proposed AFEX Integrated Biorefinery are shown in Figure 1 below. The first step in both processes is to grow, harvest, and preprocess the biomass into a stable intermediate – harvested biomass – that can be stored and transported as needed for subsequent steps. Next, in a conventional model, the biomass is pretreated, conditioned, enzymatically hydrolyzed, and fermented, after which ethanol is recovered. Note that no stable intermediate is produced between pretreatment and the subsequent steps. This means that pre-treatment must occur at the same location as all subsequent steps, and processing must be followed through to the final product, ethanol.

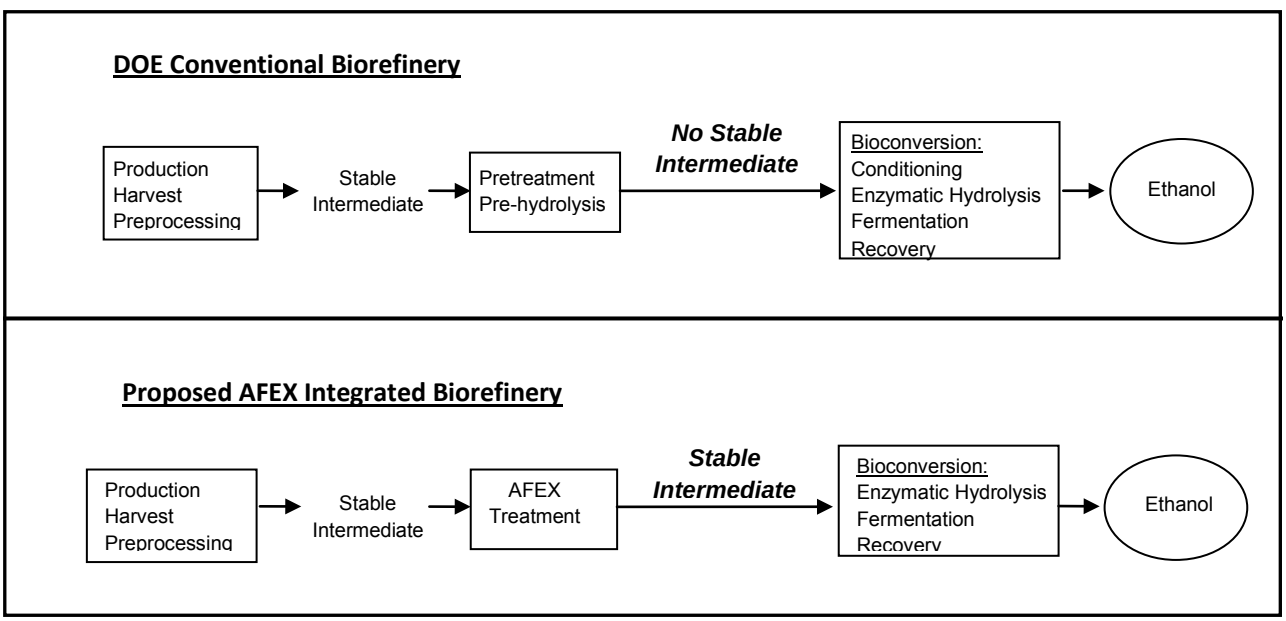


Figure 1. Integrated Biorefinery Concepts

For the AFEX Integrated Biorefinery, the preprocessed biomass is subjected to AFEX treatment, which prepares the biomass for bioconversion. Since AFEX is a "dry biomass in - dry biomass out" process, no initial pre-hydrolysis occurs and the resulting AFEX-treated biomass is in a stable

intermediate form that can be stored and transported. AFEX-treated biomass does not require subsequent conditioning; therefore final bioconversion steps are simply enzymatic hydrolysis, fermentation, and recovery. Our AFEX Integrated Biorefinery has inherent flexibility with respect to where the various processes can be located. For example: 1) in a centralized option, AFEX treatment is co-located with the Bioconversion Facility; and 2) in a de-centralized option, AFEX treatment would be located separately from the Bioconversion Facility, with multiple AFEX treatment centers serving a given Bioconversion Facility. We plan to capitalize on this flexibility during the pilot plant and subsequent commercial phases. For the proposed pilot plant, we will de-centralize the stages and capitalize on our partners' existing infrastructure.

We achieve process integration in three key ways:

1) Producing ethanol as the primary product from 1 TPD of biomass through the entire process
2) Linking each stage to the next by the flow of a stable intermediate
3) Maintaining integrity by restricting energy and recycle streams within a given stage unless two stages are co-located (The only material transferred from one stage to the next is a stable intermediate)

Table 3 below summarizes the underlying technical features, the systems benefit arising from these features, and overall outcomes for our proposed AFEX Integrated Biorefinery. The table illustrates how the successful development of our proposed biorefinery will address rapid commercialization and the national goal of producing 16 billion gallons of cellulosic fuels by year 2022.

Table 3: Advantages of an AFEX Integrated Biorefinery

Feature	Systems Benefit	Overall Outcomes
AFEX can be linked with upstream and downstream steps via stable intermediates	High level of overall process integration from biomass to ethanol	Performs favorably in terms of cost and reduced greenhouse gas emissions
AFEX-treated biomass can be stored and transported	Centralized and decentralized options for integrated biorefinery operation	Flexible deployment of commercial biorefineries in varied geographical areas
Properties of AFEX-treated biomass facilitate densification	Efficient storage and transportation between stages utilizing existing infrastructure	Improves supply-chain logistics
AFEX is effective on multiple agricultural feedstocks	Multiple feedstocks can be processed in a given integrated biorefinery	Mitigates vulnerability to supply chain disruption and facilitates year-round operation
AFEX treatment does not produce high levels of metabolic inhibitors	AFEX treated biomass is compatible with fermentation using diverse organisms	Speeds acceptance of next generation organisms
AFEX treated biomass does not require neutralization, washing or conditioning	AFEX treated biomass can be used as feedstock for a variety of bio-based products	AFEX infrastructure can support both fuels and bio-based chemicals
AFEX-treated biomass can be digested by ruminants	AFEX-treated biomass can be used as animal feed	Addresses food versus fuel tradeoff and land use issues; Reduces market vulnerability

The benefits summarized above are important from a commercial perspective since they address three key criteria for sustainable biofuels -- cost effectiveness, scalability, and reduction in greenhouse gas emissions. The AFEX stable intermediate can be used as a feedstock for other bio-based

products as well as animal feed. A product that can be sold into several markets is less vulnerable to the volatility of a single market. This feature reduces risk and could enhance the prospects for rapid and broad commercial deployment.

The competitive advantage of the MBI approach is chiefly in the AFEX treatment step. We propose a continuous AFEX process in which ammonia is recovered and reused. Below is a summary (Table 4) of AFEX treatment contrasted with competing forms of pre-treatment:

Table 4: AFEX Treatment Contrasted with Selected Pretreatments

	AFEX Treatment	Selected Pretreatments		
		Dilute Acid	**Steam**	**Dilute Ammonia**
Capital Cost	Medium	High	High	Medium
Fermentation Compatibility	High	Low	Medium	High
Waste Streams	Low	High	Medium	Medium
Water Usage	Low	High	Medium	High
Expected Scalability	Good/Fair	Difficult	Fair	Good
C5 Hydrolytic Enzyme Usage	High	Low	Medium	High
Hazard/Toxicity	Ammonia Containment	Acidic Streams	Acidic Streams	Ammonia Containment
Animal Feed Value	Yes	No	Maybe	No
Ability to De-Centralize from Biorefinery	Yes	No	Maybe	No

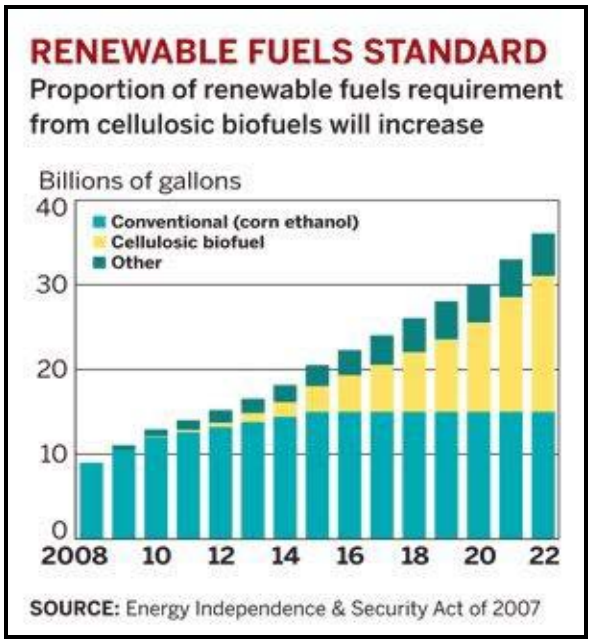
Prior work at MBI and MSU has addressed several technical barriers through bench-scale experiments. As explained in more detail in Section 2 of the PEP, bench-scale batch experiments have demonstrated: 1) 94% of theoretical yield of fermentable sugars from AFEX-treated corn stover; 2) 98% recovery of ammonia from AFEX-treated corn stover is achievable; and 3) 5% ethanol titer in high-solids hydrolysis and fermentation from AFEX-treated corn stover. This data demonstrates that our AFEX Integrated Biorefinery has significant commercial potential and is ready for validation at pilot scale.

We have confidence that the AFEX process can be transitioned rapidly from pilot to commercialization. AFEX equipment can be based on modifications to equipment currently used in alkaline pulping processes. Such processes are routinely operated at > 1000 TPD scale. Companies that manufacture large-scale alkaline pulping equipment include Andritz Ltd. and Metso Paper, both of whom have provided budgetary quotes to MBI for AFEX pilot-scale equipment.

Market Conditions

The Energy Independence and Security Act (EISA) of 2007 targeted 30% of the U.S. transportation fuels to come from renewable fuel sources by 2022. It also targeted 16 billion gallons to come from cellulosic biofuels in 2022. (Figure 2)

Corn ethanol currently makes up nearly 100% of the renewable fuels in our domestic fuel supply. Corn ethanol is expected to grow from its current base of 9 billion gallons/yr to 15 or more



billion gallons by 2022. Cellulosic fuels are considered to be more sustainable than corn ethanol because of larger supplies of feedstock available, lower greenhouse gas emissions and the lack of competition with food and feed grains. To be commercially viable, cellulosic ethanol must be produced cost-competitively with petroleum fuels and other alternative fuels. With efficient and economically viable technologies to convert biomass to fuels, there is ample reason to believe that biomass has potential to compete with petrochemical fuels.

Figure 2. Renewable Fuels Standard

Biofuel solutions must offer significant levels of GHG reduction to meet DOE/FOE requirements and targets. Our Life Cycle Analysis (LCA_GHG.xls) projects the proposed AFEX Integrated Biorefinery will reduce GHG by 65% when compared to petroleum fuels. Ethanol from corn stover can be a serious contributor to GHG reduction.

Supply chain issues have challenged many commercialization plans for cellulosic bio fuels. The low bulk density of biomass has presented challenges in the collection, preprocessing, transportation and storage of biomass. The AFEX Integrated Biorefinery commercialization plan offers an effective option for storage and transportation of densified AFEX-treated feedstock. This is possible because AFEX treated materials can be densified and stored, much like grains, making transportation and storage more compatible with currently available systems and machinery.

Infrastructure systems for the movement, blending and distribution of ethanol and ethanol-blended products need to be continuously improved as the renewable fuel standards are met. Government policies for blending ethanol in fuels for current vehicles need to be aliened with the renewable fuel standards. Current grain ethanol production capacity can meet the current 10% standard in gasoline. Research indicates that current vehicles in the domestic fleet can use ethanol blends up to 20% without engine modifications (Shockey et al., 2007; Knoll et al., 2009). The State of Minnesota has moved forward with a mandate to add 15% ethanol to gasoline and the Renewable Fuels Association is highly supportive of higher requirements for ethanol blended with gasoline.

Consumer behavior will play an important role in determining the success for biofuels. Consumers must believe in the price and demonstrated performance of biomass-derived products. Their attitude toward biofuel vehicles and the environment will affect ultimate success. In order for biofuels to meet DOE standards and succeed in the U.S. and worldwide, they must be both cost competitive and sustainable alternative sources of energy.

7.0 FEEDSTOCKS FOR A COMMERCIAL SCALE FACILITY

Feedstock Availability

The selected feedstock for the proposed pilot plant is corn stover, which based on the FOA definition, is a high impact feedstock (a feedstock that is domestically available and has the agronomical and ecologically sustainable ultimate availability potential of at least 100 million dry metric tons of biomass/ yr). As a by-product of grain production, corn stover is a readily available feedstock physically present within the current ethanol production infrastructure. Corn is the most widely planted crop and

corn stover is the most abundant agriculture residue. Corn stover is a clear choice for large scale cellulosic ethanol production in U.S. as it represents about 80% of the total agricultural residue.

Currently annual production of corn grain in U.S. is about 196 million tons/yr and using the assumption of corn-to-stover ratio of 1:1, the average corn stover production can be estimated to be 196 million tons per year (Graham et. al., 2007). Under current rotation and tillage practices roughly 30% of this stover (about 60 million dry tons/annum) can be sustainably collected. Changing agricultural practices with reduced tillage, improved hybrids, and higher-efficiency harvesting techniques is expected to raise the sustainable corn stover harvest significantly. For example, if all U.S. corn producers adopt mulch till practice, the total collectible stover supply would increase to 70 million tons/yr and if no-till practices were universally adopted, the total collectible corn stover supply would increase to 101 million ton/year (Graham et. al., 2007).

Feedstock cost to the plant gate consists of four operations: production, collection, return to producer, and transport to the plant. Production costs for corn stover are negligible because costs associated with growing the stover are incurred by conventional corn grain production. Collection costs are associated with the flail mowing, baling, and moving the bale to the field edge. These costs are seen to be comparable with other biomass feedstocks such as switchgrass and forage sorghum. Other costs associated with production are fertilizer replacement costs, producer incentive, costs associated with transport to the plant and biomass preprocessing. Although feedstock volumes and their delivered plant gate costs vary by growing region, as production economics depend on climate, soil conditions, transportation costs, and other factors, we are using the biomass cost projection in NREL Technical Report: NREL/TP-510-4305 (Aden, 2008), published May of 2008 at $60/ton (2007 basis) for preprocessed corn stover delivered to the plant.

Feedstock Interface with Plant and Source Management

For the proposed pilot-scale AFEX Integrated Biorefinery, our partner Vermeer will harvest, preprocess, and store feedstock for delivery to MBI. Vermeer's practices are directly adaptable to the needs of providing lignocellulosic feedstocks for industrial processing, and no novel equipment or changes to existing agricultural practices are required. AFEX-treated biomass will be densified and transported to the NREL bioconversion facility for conversion to ethanol.

Established harvesting practices would also be used to collect, store, and transport feedstocks at larger scale. The commercialization plan envisioned in this proposal calls for producers to transport the stover to either the centralized biorefinery or the decentralized regional center where it is preprocessed and subjected to AFEX treatment. In the decentralized option, the AFEX-treated biomass could be densified for ease of handling, storage and transportation. Densified AFEX treated corn stover could be stored and delivered with much the same equipment as corn grain, eliminating the need to develop a new biomass transportation infrastructure. The commercialization option chosen would dictate where the AFEX treated corn stover could be stored; in the centralized option, the feedstock would be stored at the bioconversion facility and in the decentralized option, the material would be stored at the regional centers, obviating the need for storage and biomass processing at the bioconversion facility.

Feedstock Practices

There are some constraints to stover collection. One is that collection operations leave some stover in the field, and the amount left is a function of the equipment and method used to collect the stover, the condition of the stover and the requirements of the soil type. Reduced tillage practices and higher-efficiency harvesting and collection techniques should allow for improved stover supplies. In some regions of the country where an area is moisture deficient, all stover is usually left behind to maintain the soil moisture for the next crop. Graham et al (2007) report that the areas affected by soil moisture constraints are predominantly in the western half of the U.S. Our proposal is to harvest,

collect, and transport corn stover predominantly from mid-west states not in the region of soil moisture constraints. Another constraint is water and wind erosion, wherein the stover needs to remain in the field to assure that erosion does not exceed tolerable soil loss. Our proposal is to obtain feedstocks from states that are not affected by water and wind erosion. Life Cycle Analysis dictates that containment of nitrous oxide release from corn fields is an issue to be managed in a sustainable model. We believe that planting a cover crop can not only be an additional source of biomass feedstock, but it can also utilize the nitrogen in the soil that is escaping as nitrous oxide. Cover crop harvest in the spring could reduce the need for year around storage of a one-time-available corn stover feedstock.

We envision the future commercialization to occur initially as additions to current grain-ethanol plants. These plants currently have supply management systems for their feedstock and often have some level of producer ownership. The current supplies of corn stover are in the hands of these same producers, all of which are prospective suppliers of feedstock for commercial cellulosic biorefineries. A long term contract from the commercial biorefinery that incentivizes growers is essential to establish a dependable supply of feedstock.

8.0 NEPA AND OTHER ENVIRONMENTAL COMPLIANCE FOR A FORECASTED COMMERCIAL FACILITY

The majority of grain ethanol plants (20-110 MMGY) operate as "minor" sources of air contaminants. The environmental and emission technology being used qualifies as the Best Available Control Technology. While these plants typically discharge non-contact water to a flowing water body (e.g., creek, stream, or river), they do not discharge any contact process water. It is assumed that commercial plants designed for cellulosic ethanol will follow these same patterns for operations and waste water usage.

MBI currently operates a fermentation pilot plant used in de-risking of fermentation processes as well as production runs for certain small batch customers. We have installed equipment and safety systems for handling ammonia in a high pressure system and are permitted for operations involving ammonia at the scale required for this project. All systems are in compliance with national, state and city regulations for air and water emissions. The MBI facility is equipped to manage hazards' materials and follows a comprehensive safety and compliance program. To make changes to our facilities, introduce new processes with new wastes, or to introduce new hazardous or potentially hazardous materials, we have used internal and external expertise to help meet the compliance requirements for local, state and national regulations.

The purpose of the proposed AFEX Integrated Biorefinery is to provide the data necessary to complete the design and the techno-economic models for a commercial plant. Part of this project work will be to determine the waste streams and provide for their regulatory compliance in the scale-up plan. All mass balances for energy, feedstocks, emissions and waste streams will be a part of the techno-economic model for the commercial plant. Potential streams and emissions of concern to our process are:

1) Dust - Full dust control equipment and procedures are an expected necessity for both a demonstration scale and commercial facilities. Dust control may not be an issue at a bioconversion facility receiving densified feedstock from a RBPC.
2) Ammonia (NH_3) – Ammonia is the catalyst for the AFEX process; it is expected that ammonia will be contained, and reused. All plants, pilot, demonstration and commercial, will be required to have an approved ammonia containment plan.
3) Water – low amounts of water will be discharged in accordance with existing federal, state, and local regulatory permits.
4) Carbon Dioxide – some amount of carbon dioxide will be released, as is expected for ethanol fermentations.

MBI and its team will utilize the best available control technology for its environmental and emission assessment. An assessment of the waste streams and emissions for the proposed AFEX Integrated Biorefinery pilot plant project is evaluated in the NEPA Questionnaire (Enviro.pdf). Plans for the forecasted commercial and demonstration scale facilities will be designed for full NEPA as well as state and local compliance. No decisions have been made as to location or most efficient size for the RBPC of the bioconversion facility. MBI and its partners in the development of a demonstration scale or a commercial plant would expect to employ both internal and external expertise in regulatory affairs and compliance issues and would incorporate proposed practices in the design for these facilities.

9.0 APPLICANT CORE COMPETENCIES AND EXPERIENCE

MBI has a talented R&D team at its Lansing, Michigan headquarters, with 7 Ph.D. scientists in microbiology, biochemistry, chemical engineering, and analytical chemistry, along with 33 additional degreed and non-degreed technical support personnel. Joining the MBI scientists and engineers on the AFEX Integrated Biorefinery project is a strong team of collaborators from industry, academia and federal laboratories. MBI and its three main technology partners, Michigan State University (MSU), Novozymes and The National Energy Research Laboratories (NREL) at Golden, Colorado, have been leading innovators of cellulosic biofuels technologies. Our team brings together the required knowledge, experience, and facilities to meet the broad range of requirements set forth in the DOE FOA to successfully demonstrate the AFEX Integrated Biorefinery Pilot Plant and subsequent commercial plants on a timely basis.

The leadership, organization, and experience that are a part of MBI will be instrumental in effectively managing the activities of our team. MBI's President and Chief Executive Officer co-founded a biotechnology company with US and German R&D and manufacturing operations. This company pioneered, scaled up and formed a technology alliance with a major pharmaceutical company to commercialize a breakthrough technology for plant cell fermentation to produce an anti-cancer treatment. MBI's Senior Vice President of Business Development and Commercialization has had over 25 years of experience in the chemical industry commercializing technologies via alliance mechanisms including licensing and joint ventures. MBI's Director of Operations has over 29 years in biotechnology product development from specialty chemicals and enzymes to fuels and commodity chemicals. He has extensive experience in project management of multiple collaborations in the U.S., Central and South America, Europe, and Asia involving, government, industry, and academia. MBI's VP of Engineering has over 20 years in all facets of biotech manufacturing, including process and project engineering, operations, process development, facility maintenance, and quality control. He has expert level knowledge in fermentation manufacturing and enzyme technology and associate applications. MBI's Facilities Director has over 25 years of experience in biotechnology laboratory, pilot plant and greenhouse management.

Roles of Organizations Involved

The MBI team includes collaborators from the following organizations specializing in cellulose conversion:

- **MBI :** a leader in developing and commercializing bio-based technologies
  Role: Lead Applicant; AFEX Treatment; Enzyme Hydrolysis; Fermentation Scale-Up; Plant Design and Engineering; Plant Operations and Maintenance; NEPA and Environmental Permitting; Techno-Economic Analysis; Commercialization Plan Development
- **MSU:** a nationally recognized leader in academia and biomass technology
  Role: Feedstock Procurement, Processing and Handling; AFEX Treatment; Technology Scale-Up; NEPA and Environmental Permitting; Techno-Economic Analysis; Commercialization Plan

Development

- **NREL:** a world leader in renewable energy technology development
  Role: Pretreatment; Enzyme Hydrolysis; Fermentation; Ethanol Recovery; Techno-Economic Analysis
- **Vermeer:** a premier agricultural and construction, equipment manufacturing
  Role: Feedstock Procurement, Processing, and Handling; Commercialization Plan Development
- **Novozymes:** a biotech world leader in industrial enzyme development
  Role: Enzyme development, enzyme cocktails for AFEX treated materials
- **Airgas Specialty Products:** a nationwide supplier of ammonia and ammonia services
  Role: Ammonia installation, safety permits and safety training; Commercialization Plan
- **ICM Inc.:** a world leader in design, construction, and support of ethanol plants
  Role: NEPA and Environmental Permitting, equipment design, technology distribution; Commercialization Plan Development
- **The Andersons:** Make and Sell Ethanol and Ethanol Fermentation Byproducts
  Role: NEPA and Environmental Permitting; Commercialization Plan Development

By combining the capabilities of the entire team, we have a wealth of in-depth experience in feedstock collection and preprocessing, AFEX treatment, enzymatic hydrolysis, fermentation conversion, downstream recovery of ethanol and residue analysis. As we add new pilot plant facilities, our ability to refine our process design, incorporate continuous improvements, reduce raw material usage, and increase yield will demonstrate that we have the commitment to excellence in our mission to promote cellulosic biofuels as a viable alternative to petroleum energy sources. Our partners have committed their resources to this project. Letters of Commitment, both providing cost share as well other support integral to the success of this project, are submitted in a separate file with this proposal.

Facilities

The facilities at MBI and its partners are more than adequate to meet the needs of the project, except for the continuous AFEX-Treatment Pilot Plant to be constructed in new facilities at MBI. All laboratory, fermentation and administration facilities are in place or under construction at NREL. For a completed description of facilities available to this project please see Section 2.3 of the PMP.

Experience

Feedstock and Feedstock Source Management

Partner Vermeer is an experienced agricultural machinery manufacturer and biomass processer. Vermeer will be the biomass provider for the proposed AFEX Integrated Biorefinery. In addition, key personnel at MSU have years of experience in research regarding growth, collection and processing of biomass.

Designing, Engineering, and Constructing Similarly Sized Operations

MBI has the advantage of previously commissioning an engineering firm to design a continuous AFEX treatment system similar, but larger in scale, to the one proposed for this pilot plant. The same firm has provided estimates for the currently proposed AFEX system. MBI built and has maintained its own 120,000 sq. ft. facility. MBI will select the parties for the design and construction work for commercial plants with input from ICM, Andersons, Airgas, and MSU. These parties all have experience in design and construction of similar sized facilities.

Operating Similarly Sized Facilities

MBI currently operates a pilot scale fermentation facility that conducts work for MBI projects as well as scale up, demonstration work and contract production for customers. Partners NREL, Vermeer and Novozymes all have experience in pilot scale and operations of this magnitude and larger. Novozymes and Andersons have experience operating commercial fermentation plants. Airgas has experience with commercial scale ammonia handling.

Team Alignment and Communications

MBI's business model is built on the concept of "de-risking" early stage innovations and moving them through scale-up to commercialization. We have been doing this successfully for over 27 years. MBI uses a Stage-Gate approach to project and portfolio management. Our approach allows for the making of disciplined decisions about research and development that lead to focused process and/or product development efforts. Microsoft SharePoint and MS Project Server will be used as day-to-day communication tools for real time distribution of project plans, modifications, data, and documentation. See Section 2.4 and 3.2 of the PMP for further details.

Communication Pathways Within and Between Team Members

Communication is critical to project success. MBI project management will equip our project teams with processes that facilitate coordination of efforts to enable efficient planning and systematic decisions in a timely manner. MBI will coordinate regularly scheduled review meetings to evaluate progress on activities defined for this project. We will provide structure and consistent communication to our team. MBI has strategies in place to allow for seamless communication and coordination with expert companies that are spread throughout the country involved with cellulosic biomass to ethanol conversion. Further details of our Communication Plan can be seen in Section 2.4 of the PMP.

10.0 SENIOR MANAGEMENT BUY-IN

The MBI management team is motivated, highly experienced, and well qualified. MBI is wholly owned subsidiary of the Michigan State University Foundation and as such is part of the Michigan State University Enterprise. MBI's Senior Management Commitment to this proposal is demonstrated by letters of support from MBI President and CEO, Bobby Bringi and from MSU Vice President for Research and Graduate Studies, J. Ian Gray and from MBI Board members, George Benson (Executive Director of MSU Foundation) and Ronald Goldsberry (Chairman of the MBI Board of Directors and Member of the MSU Foundation Board and Executive Committee).

11.0 CONCLUSION

Our envisioned commercial AFEX Integrated Biorefinery is projected to produce a return on investment that is much greater than the cost of capital (see Pro formas). This will attract significant commercial interest from parties interested in building the biofuels industry. The successful completion of this project will result in a package of techno-economic data necessary to demonstrate the commercial viability of the AFEX Integrated Biorefinery. This, in turn, will attract the capital investment necessary for widespread adoption of cellulosic ethanol.

The AFEX Integrated Biorefinery is a breakthrough technology comprising multiple innovations for improved biomass processing, supply chain logistics, and bioconversion efficiency. The underlying technologies have been thoroughly demonstrated at the bench-scale and the process is shovel ready for pilot-scale demonstration. The successful demonstration of these innovations will enable the proposed biorefinery technology to proceed rapidly and cost effectively to commercialization.

MBI International has a successful track record of leading technology development collaborations and accelerating the commercialization of bio-based products. MBI will lead a strong team of collaborators from industry, academia and federal laboratories to design, construct, and operate an innovative, integrated biorefinery at pilot scale. The collective knowhow and experience of the team gives the project and future commercialization a high probability of success.

This proposal warrants the support of the DOE because our scalable AFEX Integrated Biorefinery will address three critical issues that face sustained biomass-to-ethanol production: cost effectiveness, scalability, and greenhouse gas emissions reduction.

U.S. Department of Energy	Name of Applicant:	MBI International Lansing, MI
Generic Pro-Forma	Name of Facility:	AFEX Integrated Biorefinery, Pilot Scale
Form Revision 1	Engineer Performance Test:	12-2011 to 08-2012
	Facility Capitalized Const Cost:	$11,277,174

Year Ending December 31,			2010-2011	2011-2012	2012-2013	2013-2014	Total
PERFORMANCE	**Pilot Scale Plant will be operated intermittently**						
Plant Operating Days			350	350	350	350	
Plant Availability Factor			95.9%	95.9%	95.9%	95.9%	
Plant Operating Days			350	350	350	350	
No of Days per Batch			7	7	7	7	
Batches per year			0	50	50	50	
Production		*Units* (1)					
Ethanol (FOB)		gallons/year	0	0	0		
Performance							
Ethanol per ton of stover		gallons/ton					
Current yield		Actual/Theoretical	65%	65%	65%	85%	
Feedstock Consumption							
Corn stover		ton/year				35	
Utility Consumption							
Natural Gas Consumed		None	0	0	0	0	
Net Electricity Consumed		MWh	0	0	0	0	
Water Consumed		kGal	0	0	0	0	
Other Consumed residue		ton/year	0	0	0	0	
Facility Emissions & Wastes							
Ash Wastes		tons/yr	0	0	0	0	
COMMODITY PRICES							
General Inflation	2.40%						
Product Pricing		*Units* (1)					
Ethanol	**No Ethanol will be sold from pilot plant**						
Feedstock Pricing		*Units* (1)					
Corn stover (preprocessed and delivered)		$/ton					
Utility Consumption							
Natural Gas Consumed	$/MMBTU	$10.49					
Net Electricity Consumed	$/MWh	$54.5300					
Water Consumed	$/kGal	$1.25					
Other Consumed (residues)	$/ton	$3.00					
Emissions & Waste Allowances							
SO_2	$/ton	$0.00		$0.00	$0.00	$0.00	
NO_x	$/ton	$0.00		$0.00	$0.00	$0.00	
Other Wastes	$/ton	$22.00					
REVENUES							
Revenues							
DOE Contribution			4,331,212	7,776,849	5,371,638	1,342,118	
Cost Share contribution			1,082,803	1,944,212	1,342,910	335,530	
Ethanol			$0	$0	$0	$0	
TOTAL OPERATING REVENUES			**$5,414,015**	**$9,721,061**	**$6,714,548**	**$1,677,648**	**$23,527,272**
EXPENSES							
Variable Operating Costs							
Feedstock Costs							
Corn stover	(Provided by Vermeer)		$0	$0	$0	$0	
Total Feedstock Costs			$0	$0	$0	$0	
Utility Costs							

Natural Gas Consumed		$0	$0	$0	$0	
Net Electricity Consumed	/ton residue					
Water Consumed		$0	$0	$0	$0	
Other Consumed		$0	$0	$0	$0	
Total Utility Costs		$0	$0	$0	$0	
Emissions & Waste Allowance Costs						
Residue waste		$0	$0	$0	$0	
Other Wastes		$0	$0	$0	$0	
Total Emissions Allowance Costs		$0	$0	$0	$0	
Product Marketing Cost						
Ethanol	% of Revenue	$0	$0	$0	$0	
Total Product Marketing Cost		$0	$0	$0	$0	
Process Supplies						
Materials and Supplies		$24,911	$20,659	$14,270	$20,400	
Enzyme	(provided by Novozymes)					
Total Supplies Cost		$24,911	$20,659	$14,270	$20,400	
Total Variable Operating Costs		**$24,911**	**$20,659**	**$14,270**	**$20,400**	**$80,240**
Fixed Operating Costs						
Construction		$0	$0	$0		**$0**
Equipment		$841,715	$2,744,661	$1,895,797	$0	**$5,482,174**
Contractual						
Sub-recipient		$166,064	$173,082	$119,552	$135,825	**$594,523**
FFRDC		$775,770	$1,245,781	$860,488	$591,274	**$3,473,313**
Vendors		$989,120	$2,870,271	$1,982,559	$21,750	**$5,863,700**
Total Contractual		$1,930,955	$4,289,134	$2,962,598	$748,849	**$9,931,536**
Payroll		$790,515	$802,628	$554,392	$265,151	**$2,412,686**
Payroll Benefits	40.52% of Payroll	$320,317	$325,224	$224,640	$107,439	**$977,620**
Travel		$23,026	$29,203	$20,171	$22,800	**$95,200**
Indirect Charges		$1,476,239	$1,492,835	$1,031,133	$510,809	**$4,511,016**
Other Direct Costs		$6,336	$16,717	$11,547	$2,200	**$36,800**
Total Fixed Operating Costs		**$5,389,104**	**$9,700,402**	**$6,700,278**	**$1,657,248**	**$23,527,272**
Royalty Expense		$0	$0	$0	$0	
TOTAL OPERATING EXPENSES		**$5,414,015**	**$9,721,061**	**$6,714,548**	**$1,677,648**	**$23,527,272**
Financing cost	(No financing projected)					
NET OPERATING REVENUES		**$0**	**$0**	**$0**	**$0**	**$0**

Notes:	2010-2011	2011-2012	2012-2013	2013-2014
1.0 Expected award date Sept 2009				
2.0 Expected start date Jan 2010 to Sept 2010				
3.0 Budget Period One: Jan 2010 to March 2012	100.00%			
Limited R&D, Design Period, NEPA Determination				
4.0 Budget Period Two: March 2012 to September 2014	12.7660%	51.5957%	35.6383%	
Construction Period: 13 months, March 2012 to April 2013				
Shakedown Operations: 13 months				
Independent Engineers Performance Test: MBI June 2013, NREL November 2013				
Capstone Runs: November 2013 to September 2014				
5.0 Budget Period Three: September 2014 to February 2015				100.00%
Extended Runs, Modeling work, Reporting				

U.S. Department of Energy	Name of Applicant	MBI International
Pro-Forma	Name of Facility	AFEX Integrated Biorefinery
Division 1	Commercial Operation Date	10/1/2015
	Facility Capitalized Const Cost (Total Project Investment)	$ 378,896,163 Note (1)

Projected Operating Results

Y 0.		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
PERFORMANCE											
Plant Operating Days		350	350	350	350	350	350	350	350	350	350
Plant Availability Factor		95.9%	95.9%	95.9%	95.9%	95.9%	95.9%	95.9%	95.9%	95.9%	95.9%
Production	*Units (1)*										
#1 Ethanol	Gallons/yr	119,538,462	119,538,462	119,538,462	119,538,462	119,538,462	119,538,462	119,538,462	119,538,462	119,538,462	119,538,462
Feedstock Consumption	*Units (1)*										
A Corn stover	ton/year	1,328,205	1,328,205	1,328,205	1,328,205	1,328,205	1,328,205	1,328,205	1,328,205	1,328,205	1,328,205
Utility Consumption											
Natural Gas Consumed	MMBTU	0	0	0	0	0	0	0	0	0	0
Net Electricity Consumed	MWh	(140,264)	(140,264)	(140,264)	(140,264)	(140,264)	(140,264)	(140,264)	(140,264)	(140,264)	(140,264)
Water Consumed	kGal	358,615	358,615	358,615	358,615	358,615	358,615	358,615	358,615	358,615	358,615
Other Consumed (Residue)	ton/yr	420,962	420,962	420,962	420,962	420,962	420,962	420,962	420,962	420,962	527,962
Facility Emissions & Wastes											
SO_2	tons/yr	0	0	0	0	0	0	0	0	0	0
NO_x	tons/yr	0	0	0	0	0	0	0	0	0	0
Other Wastes (Ash)	tons/yr	66,410	66,410	66,410	66,410	66,410	66,410	66,410	66,410	66,410	66,410
COMMODITY PRICES											
General Inflation		2.40%	2.40%	2.40%	2.40%	2.40%	2.40%	2.40%	2.40%	2.40%	2.40%
Product Pricing	*Units (1)*										
#1 Ethanol Note (2)	$/gallon	$2.190	$2.243	$2.296	$2.351	$2.408	$2.466	$2.525	$2.585	$2.648	$2.711
Feedstock Pricing	*Units (1)*										
Corn stover (delivered and preprocessed)	$/ton	$49.39	$50.58	$51.79	$53.03	$54.30	$55.61	$56.94	$58.31	$59.71	$61.14
Utility Consumption											
Natural Gas Consumed	$/MMBTU										
Net Electricity Consumed	$/MWh	$58.55	$59.96	$61.39	$62.87	$64.38	$65.92	$67.50	$69.12	$70.78	$72.48
Water Consumed	$/kGal	$1.34	$1.37	$1.41	$1.44	$1.47	$1.51	$1.54	$1.58	$1.62	$1.66
Other Consumed	$/ton	$23.07	$23.62	$24.19	$24.77	$25.37	$25.97	$26.60	$27.24	$27.89	$28.56
Emissions & Waste Allowances											
SO_2	$/ton	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
NO_x	$/ton	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Other Wastes Ash	$/ton	$23.07	$23.62	$24.19	$24.77	$25.37	$25.97	$26.60	$27.24	$27.89	$28.56
OPERATING REVENUES											
Product Revenues											
#1 Ethanol		$261,789,231	$268,072,172	$274,505,904	$281,094,046	$287,840,303	$294,748,471	$301,822,434	$309,066,172	$316,483,760	$324,079,371
TOTAL OPERATING REVENUES		**$261,789,231**	**$268,072,172**	**$274,505,904**	**$281,094,046**	**$287,840,303**	**$294,748,471**	**$301,822,434**	**$309,066,172**	**$316,483,760**	**$324,079,371**
OPERATING EXPENSES											
Variable Operating Costs											
Feedstock Costs											
Corn stover		$65,600,045	$67,174,446	$68,786,633	$70,437,512	$72,128,012	$73,859,084	$75,631,703	$77,446,863	$79,305,588	$81,208,922
Total Feedstock Costs		$65,600,045	$67,174,446	$68,786,633	$70,437,512	$72,128,012	$73,859,084	$75,631,703	$77,446,863	$79,305,588	$81,208,922
Utility Costs											
Natural Gas Consumed		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Net Electricity Consumed		-$8,212,457	-$8,409,556	-$8,611,386	-$8,818,059	-$9,029,692	-$9,246,405	-$9,468,319	-$9,695,558	-$9,928,252	-$10,166,530
Water Consumed		$480,544	$492,077	$503,887	$515,980	$528,364	$541,045	$554,030	$567,326	$580,942	$594,885
Other Consumed		$9,711,593	$9,944,672	$10,183,344	$10,427,744	$10,678,010	$10,934,282	$11,196,705	$11,465,426	$11,740,596	$15,078,213
Total Utility Costs		$1,979,680	$2,027,193	$2,075,845	$2,125,665	$2,176,681	$2,228,922	$2,282,416	$2,337,194	$2,393,287	$5,506,568
Emissions & Waste Allowance Costs											
SO_2		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Residue waste	(credit for using in boiler)	-$9,711,593	-$9,944,672	-$10,183,344	-$10,427,744	-$10,678,010	-$10,934,282	-$11,196,705	-$11,465,426	-$11,740,596	-$15,078,213
Other Wastes	(ash)	$1,532,079	$1,568,849	$1,606,501	$1,645,057	$1,684,538	$1,724,967	$1,766,366	$1,808,759	$1,852,169	$1,896,622
Total Emissions Allowance Costs		-$8,179,515	-$8,375,823	-$8,576,843	-$8,782,687	-$8,993,471	-$9,209,315	-$9,430,338	-$9,656,666	-$9,888,426	-$13,181,591
Product Transportation Pricing											
Ethanol (sold FOB)	$/gallon	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000	$0.0000
Product Transportation Cost											
		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Product Transportation Cost		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Feedstock Transportation Pricing											
(Purchased Delivered)	$/Ton	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Feedstock Transportation Cost											
		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Total Feedstock Transportation Cost		$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Product Marketing Pricing											
Ethanol	% of Revenue	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
Product Marketing Cost											
Ethanol		$2,617,892	$2,680,722	$2,745,059	$2,810,940	$2,878,403	$2,947,485	$3,018,224	$3,090,662	$3,164,838	$3,240,794
Total Product Marketing Cost		$2,617,892	$2,680,722	$2,745,059	$2,810,940	$2,878,403	$2,947,485	$3,018,224	$3,090,662	$3,164,838	$3,240,794
Miscellaneous Process Supplies											

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Projected Operating Results

Y	0.		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Ammonia			$17,113,793	$17,524,524	$17,945,113	$18,375,795	$18,816,814	$19,268,418	$19,730,860	$20,204,401	$20,689,306	$21,185,850
Nutrients			$2,818,572	$2,886,218	$2,955,487	$3,026,419	$3,099,053	$3,173,430	$3,249,592	$3,327,582	$3,407,444	$3,489,223
Other raw materials			$18,226,767	$18,664,209	$19,112,150	$19,570,842	$20,040,542	$20,521,515	$21,014,032	$21,518,368	$22,034,809	$22,563,645
Enzymes			$12,835,345	$13,143,393	$13,458,835	$13,781,847	$14,112,611	$14,451,314	$14,798,145	$15,153,301	$15,516,980	$15,889,387
Total Miscellaneous Supplies Cost			$50,994,477	$52,218,344	$53,471,585	$54,754,903	$56,069,020	$57,414,677	$58,792,629	$60,203,652	$61,648,540	$63,128,105
Total Variable Operating Costs			**$113,012,580**	**$115,724,882**	**$118,502,279**	**$121,346,334**	**$124,258,646**	**$127,240,853**	**$130,294,634**	**$133,421,705**	**$136,623,826**	**$139,902,798**
Fixed Operating Costs												
Payroll & Benefits		% of Revenue	1.30%	1.30%	1.30%	1.30%	1.30%	1.30%	1.30%	1.30%	1.30%	1.30%
			$3,403,260	$3,484,938	$3,568,577	$3,654,223	$3,741,924	$3,831,730	$3,923,692	$4,017,860	$4,114,289	$4,213,032
Fixed Operating Expenses		% of Revenue	3.64%	3.64%	3.64%	3.64%	3.64%	3.64%	3.64%	3.64%	3.64%	3.64%
			$9,529,128	$9,757,827	$9,992,015	$10,231,823	$10,477,387	$10,728,844	$10,986,337	$11,250,009	$11,520,009	$11,796,489
Annual Maintenance		% of Capex	1.00%	1.02%	1.05%	1.07%	1.10%	1.13%	1.15%	1.18%	1.21%	1.24%
			$3,788,962	$3,879,897	$3,973,014	$4,068,367	$4,166,007	$4,265,992	$4,368,375	$4,473,216	$4,580,574	$4,690,507
Total Fixed Operating Costs			**$16,721,350**	**$17,122,662**	**$17,533,606**	**$17,954,412**	**$18,385,318**	**$18,826,566**	**$19,278,404**	**$19,741,085**	**$20,214,871**	**$20,700,028**
General & Administrative												
Corporate Overhead		% of Revenue	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%	2.00%
			$1,312,001	$1,343,489	$1,375,733	$1,408,750	$1,442,560	$1,477,182	$1,512,634	$1,548,937	$1,586,112	$1,624,178
Insurance		% of Capex	0.50%	0.51%	0.52%	0.54%	0.55%	0.56%	0.58%	0.59%	0.60%	0.62%
			$1,894,481	$1,939,948	$1,986,507	$2,034,183	$2,083,004	$2,132,996	$2,184,188	$2,236,608	$2,290,287	$2,345,254
Property Tax		% of Capex	1.00%	1.02%	1.05%	1.07%	1.10%	1.13%	1.15%	1.18%	1.21%	1.24%
			$3,788,962	$3,879,897	$3,973,014	$4,068,367	$4,166,007	$4,265,992	$4,368,375	$4,473,216	$4,580,574	$4,690,507
Management Fees		% of Revenue	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Depreciation	Note (3)		20 yr									
			$18,944,808	$18,944,808	$18,944,808	$18,944,808	$18,944,808	$18,944,808	$18,944,808	$18,944,808	$18,944,808	$18,944,808
IP Fees		0.4750%	0.4750%	0.4750%	0.4750%	0.4750%	0.4750%	0.4750%	0.4750%	0.4750%	0.4750%	0.4750%
			$1,243,499	$1,273,343	$1,303,903	$1,335,197	$1,367,241	$1,400,055	$1,433,657	$1,468,064	$1,503,298	$1,539,377
Total G&A Expenses			**$27,183,750**	**$27,381,485**	**$27,583,965**	**$27,791,305**	**$28,003,621**	**$28,221,032**	**$28,443,662**	**$28,671,634**	**$28,905,078**	$29,144,125
Contingency												
Contingency		% of O&M, G&A	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%	2.50%
			$1,097,627	$1,112,604	$1,127,939	$1,143,643	$1,159,723	$1,176,190	$1,193,052	$1,210,318	$1,227,999	$1,246,104
Total Contingency			**$1,097,627**	**$1,112,604**	**$1,127,939**	**$1,143,643**	**$1,159,723**	**$1,176,190**	**$1,193,052**	**$1,210,318**	**$1,227,999**	**$1,246,104**
TOTAL OPERATING EXPENSES			**$158,015,307**	**$161,341,632**	**$164,747,789**	**$168,235,694**	**$171,807,308**	**$175,464,641**	**$179,209,751**	**$183,044,742**	**$186,971,774**	**$190,993,054**
NET OPERATING REVENUES			**$103,773,923**	**$106,730,540**	**$109,758,115**	**$112,858,352**	**$116,032,995**	**$119,283,829**	**$122,612,683**	**$126,021,430**	**$129,511,987**	**$133,086,316**
Internal Rate of return, Net Operating Revenues/TPI			**27.39%**	**28.17%**	**28.97%**	**29.79%**	**30.62%**	**31.48%**	**32.36%**	**33.26%**	**34.18%**	**35.12%**
DEBT SERVICE												
Capitalized Construction Cost (from top of sheet)			**$378,896,163**									
Equity Contribution			**$189,448,082**									
Total Debt Financing			**$189,448,082**									
Interest Rate on Debt		**Annual %**	**8.0%**									
Term of Loan		**Years**	**15**									
Monthly Payment on Loan			**($1,810,465)**									
ANNUAL DEBT SERVICE			**($21,725,574)**	**($21,725,574)**	**($21,725,574)**	**($21,725,574)**	**($21,725,574)**	**($21,725,574)**	**($21,725,574)**	**($21,725,574)**	**($21,725,574)**	**($21,725,574)**
NET REVENUES			**$82,048,349**	**$85,004,965**	**$88,032,541**	**$91,132,778**	**$94,307,420**	**$97,558,255**	**$100,887,109**	**$104,295,855**	**$107,786,412**	**$111,360,742**
% return, Net Revenues/TPI			**21.65%**									

Notes:

(1) For Total Project Investment, we have calculated 2005 cost, increased it using the Chemical Engineering Plant Cost Index (CEPCI) to 2009 and then applied the 2.4% inflation factor for subsequent years.

(2) For this proforma, we have taken the kBTU per gallon of Ethanol times $0.025/kBTU to get $1.90 per gallon for a 2009 price. We then inflated this price by 2.4% per year to give us a price of $2.19 per gallon in 2015.

(3) We have added expected depreciation the Estimated G & A costs.

U.S. Department of Energy	Name of Applicant	MBI International	
Pro-Forma	Name of Facility	AFEX Integrated Biorefinery	
Division 1	Commercial Operation Date	10/1/2015	
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Projected Operating Results

Y	0.	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024

Assumptions for Future Commercial Proforma

Projection used to grow from current vision(2007) to 2015 (point of commercial plant vision)

							Expected Year of Commercialization
Total Project Investment:	**$205,276,317**	**$231,700,000**		**$352,874,550**	**$361,343,539**	**$370,015,784**	**$378,896,163**
	Calculated from 2007	**Current Estimate**	**Technology**	**Proforma Period**			
				Commercial Plants			
Year Ending December 31,	**2005**	**2007**	**Improvements**	**2012**	**2013**	**2014**	**2015**
PERFORMANCE							
Plant Operating Days		350		350	350	350	350
Plant Availability Factor		95.9%		95.9%	95.9%	95.9%	95.9%
Plant Operating Days		350		350	350	350	350
Saccharification and fermentation time (days)		7		4	4	4	4
Fermentation batches per year		50		88	88	88	88
Production	*Units* [1]						
Ethanol (FOB)	gallons/year	55,500,000	175.00%	119,538,462	119,538,462	119,538,462	119,538,462
Performance							
Ethanol per ton of stover	gallons/ton	73.125	90	90	90	90	90
Current yield	Actual/Theoretical	65%	85%	85%	85%	85%	85%
Feedstock Consumption							
Corn stover	ton/year	758,974		1,328,205	1,328,205	1,328,205	1,328,205
Utility Consumption							
Natural Gas Consumed	None	0		0	0	0	0
Net Electricity Consumed	MWh	(106,363)		(140,264)	(140,264)	(140,264)	(140,264)
Water Consumed	kGal	166,500		358,615	358,615	358,615	358,615
Other Consumed residue	ton/year	400,359		420,962	420,962	420,962	527,962
Facility Emissions & Wastes							
Ash Wastes	tons/yr	37,949		66,410	66,410	66,410	66,410
COMMODITY PRICES							
General Inflation 2.40%					2.40%	2.40%	2.40%
Product Pricing	*Units* [1]						
Ethanol	**$/gal**	**$2.34**		**$1.49**	**$1.53**	**$1.56**	**$1.586**
Feedstock Pricing	*Units* [1]						
Corn stover (preprocessed and delivered)	$/ton	$60.00		$46.00	$47.10	$48.23	$49.39
Utility Consumption							
Natural Gas Consumed	$/MMBTU	$10.49					
Net Electricity Consumed	$/MWh	$54.5300		$54.5300	$55.8387	$57.1788	$58.5511
Water Consumed	$/kGal	$1.25		$1.25	$1.28	$1.31	$1.34
Other Consumed (residues)	$/ton	$22.00		$22.00	$22.53	$23.07	$23.62
Emissions & Waste Allowances							
SO_2	$/ton	$0.00		$0.00	$0.00	$0.00	$0.00
NO_x	$/ton	$0.00		$0.00	$0.00	$0.00	$0.00
Other Wastes	$/ton	$22.00		$22.00	$22.53	$23.07	$23.62
OPERATING REVENUES							
Product Revenues							
Ethanol		$129,870,000		$178,112,308	$182,387,004	$186,764,292	$189,588,001
TOTAL OPERATING REVENUES		**$129,870,000**		**$178,112,308**	**$182,387,004**	**$186,764,292**	**$189,588,001**
OPERATING EXPENSES							
Variable Operating Costs							
Feedstock Costs							
Corn stover		$45,538,462		$61,097,436	$62,563,775	$64,065,305	$65,602,873
Total Feedstock Costs		$45,538,462		$61,097,436	$62,563,775	$64,065,305	$65,602,873
Utility Costs							
Natural Gas Consumed							
Net Electricity Consumed		-$5,800,000		-$6,098,476	-$6,244,839	-$6,394,715	-$6,548,189
Water Consumed		$208,125		$448,269	$459,028	$470,044	$481,325
Other Consumed		$8,807,898		$9,261,164	$9,483,432	$9,711,034	$12,471,687
Total Utility Costs		$3,216,023		$3,610,958	$3,697,621	$3,786,363	$6,404,824

Emissions & Waste Allowance Costs								
Residue waste	(credit for using in boiler)		-$8,807,898		-$9,261,164	-$9,483,432	-$9,711,034	-$12,471,687
Other Wastes			$834,878		$1,461,020	$1,496,084	$1,531,991	$1,568,758
Total Emissions Allowance Costs			-$7,973,020		-$7,800,144	-$7,987,347	-$8,179,044	-$10,902,929
Product Marketing Cost								
Ethanol	0.12%	% of Revenue	$155,844		$213,735	$218,864	$224,117	$227,506
Total Product Marketing Cost			$155,844		$213,735	$218,864	$224,117	$227,506
Process Supplies								
NH3	2%	$600/ton	$9,107,692	175.00%	$15,938,462	$16,320,985	$16,712,688	$17,113,793
Nutrients			$1,500,000	175.00%	$2,625,000	$2,688,000	$2,752,512	$2,818,572
Other Raw Materials			$9,700,000	175.00%	$16,975,000	$17,382,400	$17,799,578	$18,226,767
Enzyme	$0.32	per gal ETOH	$17,200,000	175.00%	$11,953,846	$12,240,738	$12,534,516	$12,835,345
Total Supplies Cost			$37,507,692		$47,492,308	$48,632,123	$49,799,294	$50,994,477
Total Variable Operating Costs			**$78,445,001**		**$104,614,292**	**$107,125,035**	**$109,696,036**	**$112,326,750**
Fixed Operating Costs								
Payroll & Benefits	1.30%	% of Revenue	$1,684,102	125.00%	$1,793,718	$1,836,767	$1,836,767	$1,836,767
Fixed Operating Expenses (includes G&A)	3.64%	% of Revenue	$4,727,268	125.00%	$5,034,960	$5,155,799	$5,155,799	$5,155,799
Annual Maintenance	1.00%	% of Capex	$2,317,000	125.00%	$2,896,250	$2,965,760	$3,036,938	$3,109,825
Capital Depreciation	20 yr amort		$11,600,000		$17,643,728	$18,067,177	$18,500,789	$18,944,808
Total Fixed Operating Costs			**$20,328,370**		**$27,368,656**	**$28,025,503**	**$28,530,294**	**$29,047,199**
Royalty Expense	$0.01	per gallon	$555,000		$1,195,385	$1,224,074	$1,224,074	$1,224,074
TOTAL OPERATING EXPENSES			**$99,328,371**		**$133,178,333**	**$136,374,612**	**$139,450,404**	**$142,598,023**
Financing cost	(No financing projected)							
NET OPERATING REVENUES			**$30,541,629**		**$44,933,975**	**$46,012,391**	**$47,313,888**	**$46,989,978**
Income taxes			**$8,857,072**	**29.00%**	**$13,030,853**	**$13,343,594**	**$13,721,028**	**$13,627,094**
NET REVENUES			**$21,684,557**		**$31,903,123**	**$32,668,798**	**$33,592,861**	**$33,362,884**
		Return	**9.36%**		**9.04%**	**9.04%**	**9.08%**	**9.02%**

ASSUMPTIONS

This projection was used to create the vision of a commercial plant in 2015.

The current vision for a commercial plant operating at 55.5 million gallons per year is patterned after work presented by NREL and reported in Technical Report NREL/TP-510-43205 published 5-08
We have made two changes from the assumptions made in the NREL report (Aden 2008):
a. We have increased the ethanol production from 64% of theoretical to 65% of theoretical. As reported in the background section of the PEP, we have already attained this result in bench scale work. The effect of this is change is an increase in ethanol production from 71.9 gallons per ton of stover to 73.125 gallons per ton of stover.
b. The second change is to reduce the variable operating expenses by $1.8 million. We have added the cost of ammonia, reduced the amount of CSL nutrient, based on bench scale fermentation results, and reduced the amount of other raw materials because neither acid or neutralization materials are necessary in the AFEX Integrated Biorefinery.
c. Ethanol selling price is calculated to produce a return of 9%(+/-) of net revenue/TPI after tax.

For Total Project Investment (TPI), we took NREL'S cost at 2007 of $231,700,000 (Alden 2008) and calculated 2009 cost using the Chemical Engineering Plant Cost Index (CEPCI)
We then applied an annual inflation rate of 2.4% to TPI numbers from 2009 forward. 2005 cost was calculated using 2007 cost and the related CEPCI

The fermentation cycle is reduced from 7 days to 4 days in 2012. Ths results in a capacity increase to 119 million gallons per year. TPI is increased in 2012 by a factor of 1.4 to account for needed capacity in all areas of the plant, except for fermentation. This causes TPI to go to **$352,874,550** in 2012

Agricultural Ammonia, current cost, FOB Lima, Ohio, is $520 per ton, delivery at $80/ton: Total $600 per ton

We have projected the improvements made in the process between 2007 and 2012. The proposed performance improvements are the same as those proposed in NREL/TP-510-43205; ethanol yield goes to 85%; ethanol per ton of stover goes to 90 gallons, delivered and preprocessed corn stover goes to $46 per ton and enzyme cost goes from $.10 per gallon of ethanol

NREL/TP-510-43205 proposes that scarification & fermentation time will be reduced by 2012 from 7 days to 3 days. Our proforma proposes a reduction to 4 days. This cycle reduction to 4 days results in a 175% increase in the performance of the fermentation plant. The variable expenses have been increased by 175% and the fixed operating expense have been adjusted by 125% to reflect the increased production.

In the Proforma for the future commercial plant, we have taken the kBTU per gallon of Ethanol times $0.025/kBTU to get $1.90 per gallon for a 2009 price. We then inflated this price by 2.4% per year to give $2.19 per gallon in 2015. This price is then inflated by the 2.4% inflation factor for subsequent years.

IP Statement – Pilot Plant Proposal

Michigan Biotechnology Institute d/b/a MBI International (MBI/MBI International), in combination with its partners named in this proposal owns or has licensed all of the intellectual property necessary to carry out the proposed project.

MBI owns the intellectual property related to its biomass processing technology, shown in Table 1. None of the intellectual property is licensed to any other party.

Table 1. MBI International Intellectual Property

ID/Application/Patent No.	Filing Country	Title	Filing Date
60/627,259	US PRO	Process for Treatment of Biomass Feedstocks	11/12/2004
11/719,158	US	Process for Treatment of Biomass Feedstocks	5/11/2007
PCT/US2005/040540	PCT	Process for Treatment of Biomass Feedstocks	5/26/2006
2005306812	Australia	Process for Treatment of Biomass Feedstocks	11/9/2005
PI0517337-0	Brazil	Process for Treatment of Biomass Feedstocks	11/9/2005
2,588,116	Canada	Process for Treatment of Biomass Feedstocks	11/9/2005
200580046177.4	China	Process for Treatment of Biomass Feedstocks	11/9/2005
05818812.9	European	Process for Treatment of Biomass Feedstocks	6/11/2007
2521/CHENP/2007	India	Process for Treatment of Biomass Feedstocks	6/12/2007
MX/a/2007/005744	Mexico	Process for Treatment of Biomass Feedstocks	5/11/2007
60/895,673	US PRO	System and Method for Continuous Biomass Processing	3/19/2007
12/050,496	US UTL	System and Methods for Continuous Biomass Processing	3/18/2008
PCT/IB2008/000714	PCT	System and Methods for Continuous Biomass Processing	3/19/2008

MBI has licensed the intellectual property related to the AFEX process shown in Table 2 from Michigan State University (MSU), owner of the intellectual property. MBI holds an exclusive worldwide license with rights to sublicense, to make, have made, use, sell and lease Products developed from the Licensed Rights. The license agreement became effective November 20, 1998 and terminates at the expiration of the last to expire patents based upon the MSU Invention Disclosure under the Licensed Rights.

Table 2. Intellectual Property Licensed from Michigan State University

ID/Application/Patent No.	Filing Country	Title	Filing (F)/Issue (I) Date
Invention Disclosure 96-067 - An extrusion-based process for treating plant materials with volatile liquids			
6,176,176	US	Process and Apparatus for Treating Cellulosic Materials	1/23/2001 (I)
6,106,980	US - DIV	Process and Apparatus for Treating Cellulosic Materials	8/22/2000 (I)
PCT/US1999/003624	PCT	Process and Apparatus for Treating Cellulosic Materials	Expired
P000105718	Argentina	Process and Apparatus for Treating Cellulosic Materials	2/19/1999 (F)
739929	Australia	Process and Apparatus for Treating Cellulosic Materials	Issued
PI9910017-7	Brazil	Process and Apparatus for Treating Cellulosic Materials	2/19/1999 (F)
2,330,489	Canada	Process and Apparatus for Treating Cellulosic Materials	9/7/2004 (I)
ZL99807580.9	China	Process and Apparatus for Treating Cellulosic Materials	11/10/2004 (I)
1076488	Europe	Process and Apparatus for Treating Cellulosic Materials Patents issued in Germany, Denmark, Spain, Finland, France, United Kingdom, Netherlands, Sweden	10/30/2000 (F) Validated (see individual countries)
215452	India	Process and Apparatus for Explosively Expanding Lignocellulosic Material	2/26/2008 (I)
3725423	Japan	Process and Apparatus for Treating Cellulosic Materials	9/30/2005 (I)
2005-033757	Japan - DIV	Process and Apparatus for Treating Cellulosic Materials	Filed
230923	Mexico	Process and Apparatus for Treating Cellulosic Materials	9/29/2005 (I)
507,774	New Zealand	Process and Apparatus for Treating Cellulosic Materials	6/9/2003 (I)
2239329	Russia	Process and Apparatus for Treating Cellulosic Materials	11/10/2004 (I)
PI20005071	Malaysia	Process and Apparatus for Treating Cellulosic Materials	Filed
Invention Disclosure 05-004F – Maintaining Effective Ammonia Liquid/Vapor Ratios for Lignocellulosic Pretreatment			
60/796,375	US PRO	Process for Treatment of Lignocellulosic Biomass	Expired
PCT/US2007/010415	PCT	Process for Treatment of Lignocellulosic Biomass	Expired
11/901,336	US	Process for Treatment of Lignocellulosic	9/1/2007 (F)

		Biomass	
2007248736	Australia	Process for Treatment of Lignocellulosic Biomass	Filed
TBD	Brazil	Process for Treatment of Lignocellulosic Biomass	4/30/2007 (F)
TBD	Canada	Process for Treatment of Lignocellulosic Biomass	4/30/2007 (F)
07776479.3	Europe	Process for Treatment of Lignocellulosic Biomass	4/30/2007 (F)
MX/a/2008/013981	Mexico	Process for Treatment of Lignocellulosic Biomass	Filed
12/226/763	US	Process for Treatment of Lignocellulosic Biomass	10/27/2008
Invention Disclosure 05-003 – Optimal Treatment of Lignocellulosic Biomass with Anhydrous Ammonia and Ammonium Hydroxide to Enhance Enzymatic Conversion to Sugars			
Invention Disclosure 05-005 – Complete Conversion of Mixed Starchy and Cellulosic Biomass to More Digestible Products			
Invention Disclosure 05-031 – Biomass Refining Using Ammonia			

The Alliance for Sustainable Energy, LLC, Management and Operating Contractor for the National Renewable Energy Laboratory (NREL), acting under U.S. Department of Energy Contract No. DE-AC36-08GO28308, holds title to Patent No. 7,223,575 , "*Zymomonas* Pentose-Sugar Fermenting Strains and Uses Thereof". This patent covers the use of the microbial strains to be used in the proposed project as is available for license on a non-exclusive basis (see NREL letter below).

National Renewable Energy Laboratory
Innovation for Our Energy Future

June 18, 2009

Dr. Bobby Bringi, CEO
MBI International
3900 Collins Road
Lansing, MI 48910-8396

Re: DOE Funding Opportunity Announcement No. DE-FOA-0000096
"Recovery Act – Demonstration of Integrated Biorefinery Operations"

Dear Dr. Bringi:

This letter is confirmation that the Alliance for Sustainable Energy, LLC, Management and Operating Contractor for The NATIONAL RENEWABLE ENERGY LABORATORY (NREL), acting under U.S. Department of Energy Contract No. DE-AC36-08GO28308 holds title to U.S. Patent 7,223,575 "Zymomonas Pentose-Sugar Fermenting Strains and Uses Thereof." The intellectual property in the aforementioned patent is available for licensing on a non-exclusive basis.

Sincerely,

Joseph M. Cleary

Joseph Michael Cleary, Ph.D.
Center Director
National Bioenergy Center

JMC:ldp

Instructions and Overview:

The purpose of this section is to assess the merits of the selected technology and the status of the process technology in order to gain an understanding of project risks and the potential viability of the proposed project. Please answers all questions as thoroughly as possible based on current knowledge.

It is expected that applicants have collected data from some **(a) existing facility** that is used to design the **(b) proposed facility** which in turn will be used to gain process information to build a **(c) commercial facility** in the future. Please pay particular attention to the proposed pilot or demonstration scale facility when reading and answering the questions. The attached PFD should relate to the proposed project.

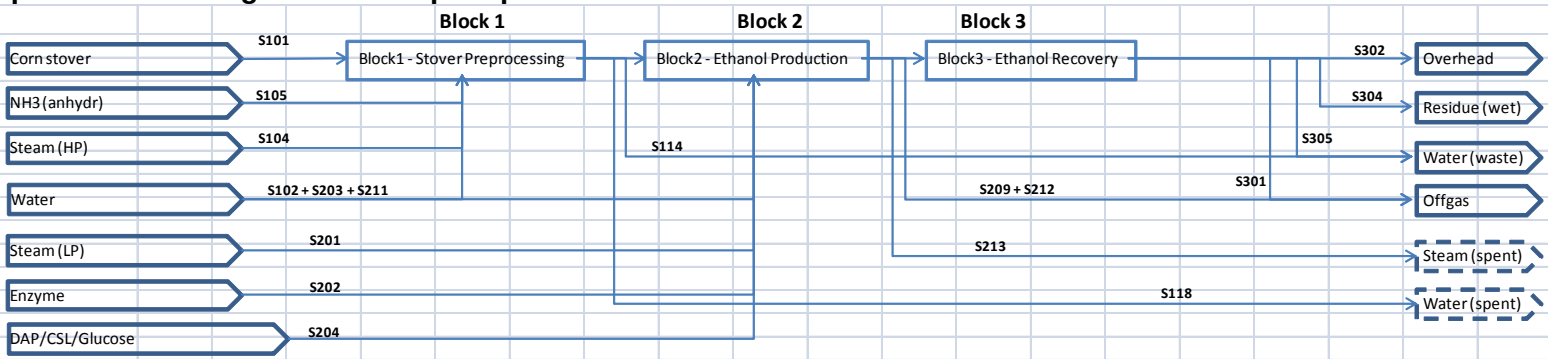
Unit Operation Step: Unit operation steps are defined as the areas in the plant where a change occurs, such as reactions, physical changes to materials including materials handling, or chemical conversions. (A physical step physically alters material, and a chemical conversion step involves changes in the molecular form of a material.) Some examples of items to be included as unit operation steps appear below.

Examples of block steps:

Reactors	Shredder
Distillation	Mixers
Drying	Aerators
Separations	Filters
Ion exchange	Gas absorption

Use a unique number for each unit operation in the PFD. Show recycle loops and waste streams as well. The characteristics of each output should directly tie to input of the respective unit operation in the process. If additional processing is required before the output of one unit can be used as the input to another, an additional unit operation should be included to describe how the stream is altered. It is particularly important to focus on the heat and material balance of each block step.

Overall process flow diagram for MBI pilot plant



	stream	S101	S102	S104	S105	S201	S202	S203	S204	S211	S114	S118	S209	S212	S213	S301	S302	S304	S305	O/A
Component	Unit																			Mass Bal
Cellulose group	kg/hr	15															0	0.9		14.1
Hemicellulose group	kg/hr	11															0	0.66		10.34
Ash + Lignin	kg/hr	7.5															0	7.5		0
Crude protein	kg/hr	1.2															0	1.2		0
Acetate	kg/hr	1.2															0	1.1		0.1
Oils	kg/hr	3.6															0	3.6		0
Contaminants	kg/hr	1										1								0
Ammonia (NH3)	kg/hr				0.7															0.7
Water/steam	kg/hr	7	40	20		45	0.6	160	2	20	34.8	27.7			45	0.010	18.5	8.4295	160.1605	0
Sugars (C6)	kg/hr								2.8								0	0.0705	1.3395	1.39
Sugars (C5)	kg/hr																0	0.0517	0.9823	-1.034
Ethanol	kg/hr															0.027	12.40886	0.004727	0.089818	-12.53
Cellulase	kg/hr						0.1										0	0.005	0.095	0
CO2	kg/hr												11.97	1.23		0.012	0	0	0	-13.22
Others	kg/hr								0.3								0.05	0.0049	0.0931	0.152
Total mass flow	kg/hr	47.5	40	20	0.7	45	0.7	160	5.1	20.0	34.80	28.70	11.97	1.23	45.00	0.05	30.96	23.53	162.76	0.0
Pressure	psig	0	0	300	109	125	0	0	0	0	0	0	0	0	0	12	12	15	15	
Temperature	°C	20	20	217	20	179	20	20	20	20	20	20	41	41	100	60	113	92	121	
Moisture	wt%	15	100	100	0	100	86	100	39	100	100	97	0	0	100	20	60	36	98	
Vapor fraction		0	0	1	0	1	0	0	0	0	0	0	1	1	0	1	1	0	0	
Ethanol concentration	wt%	0	0	0	0	0	0	0	0	0	0	0.00	0	0	0	55.1	40.1	0.020	0.055	
NH3/(NH3+H2O)		0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			0.00	0.00	0.00	0.00	0.00	

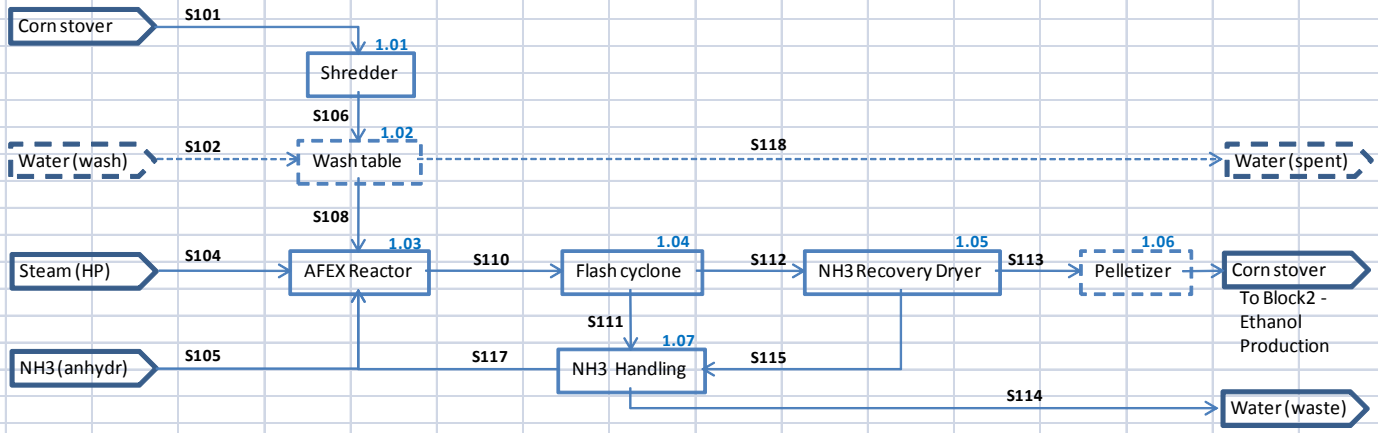
Stover biomass feed rate = 1.04 ton (dry contaminant-free) /day

Ethanol yield = 86 gal/ton (dry)

MBI Proposed Pilot Plant - Unit Ops, Streams, and Mass Balances for Process Flow Diagram
Block 1. Stover Preparation and AFEX treatment

MBI Proposed Pilot Plant - Unit Ops, Streams, and Mass Balances for Process Flow Diagram

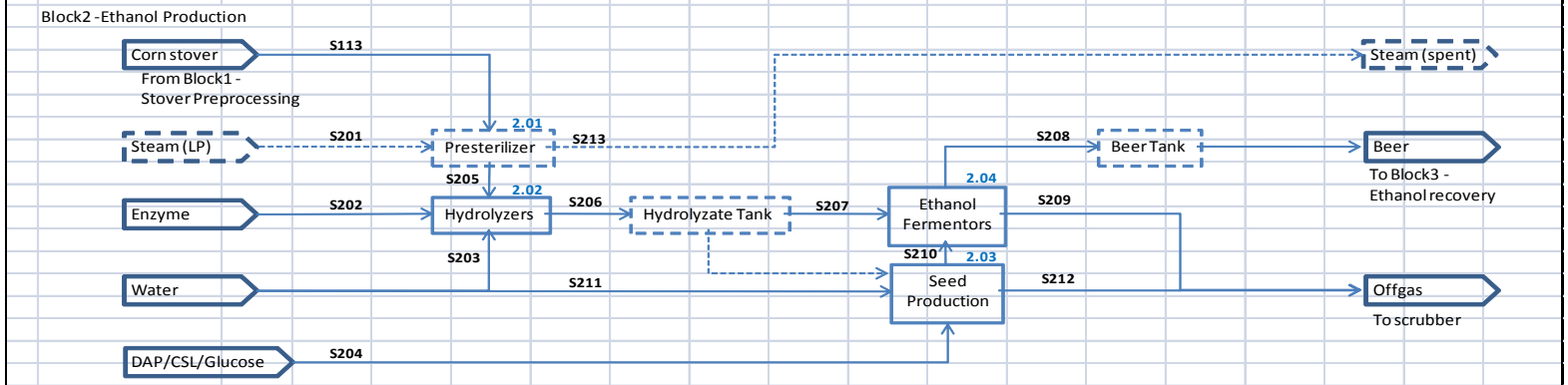
Block1 - Stover Preprocessing



	stream	S101	S102	S104	S105	S106	S108	S110	S111	S112	S113	S114	S115	S117	S118	Block1
Component	Unit															MBal
Cellulose group	kg/hr	15				15	15	15		15	15					0
Hemicellulose group	kg/hr	11				11	11	11		11	11					0
Ash + Lignin	kg/hr	7.5				7.5	7.5	7.5		7.5	7.5					0
Crude protein	kg/hr	1.2				1.2	1.2	1.2		1.2	1.2					0
Acetate	kg/hr	1.2				1.2	1.2	1.2		1.2	1.2					0
Oils	kg/hr	3.6				3.6	3.6	3.6		3.6	3.6					0
Contaminants	kg/hr	1				1									1	0
Ammonia (NH3)	kg/hr				0.7			50	23	27	0.7		26.3	49.3		0
Water/steam	kg/hr	7	40	20		7	19.3	73.6	1	72.6	4.5	34.8	68.1	34.3	27.7	0
Total mass flow	kg/hr	47.5	40	20	0.7	47.5	58.8	163.1	24	139.1	44.7	34.8	94.4	83.6	28.7	0.0
Pressure	psig	0	0	300	109	0	0	152	7	7	0	0	0	0	0	
Temperature	°C	20	20	217	20	20	20	90	26	26	80	20	80	20	20	
Moisture (wt%)		15	100	100	0	15	33	45	4	52	10	100	72	41	97	
Vapor fraction		0	0	1	0	0	0	0	1	0	0	0	1	0	0	
NH3/(NH3+H2O)		0.00	0.00	0.00	1.00	0.00	0.00	0.40	0.96	0.27	0.13	0.00	0.28	0.59	0.00	

Block 2. Ethanol Production

MBI Proposed Pilot Plant - Unit Ops, Streams, and Mass Balances for Process Flow Diagram

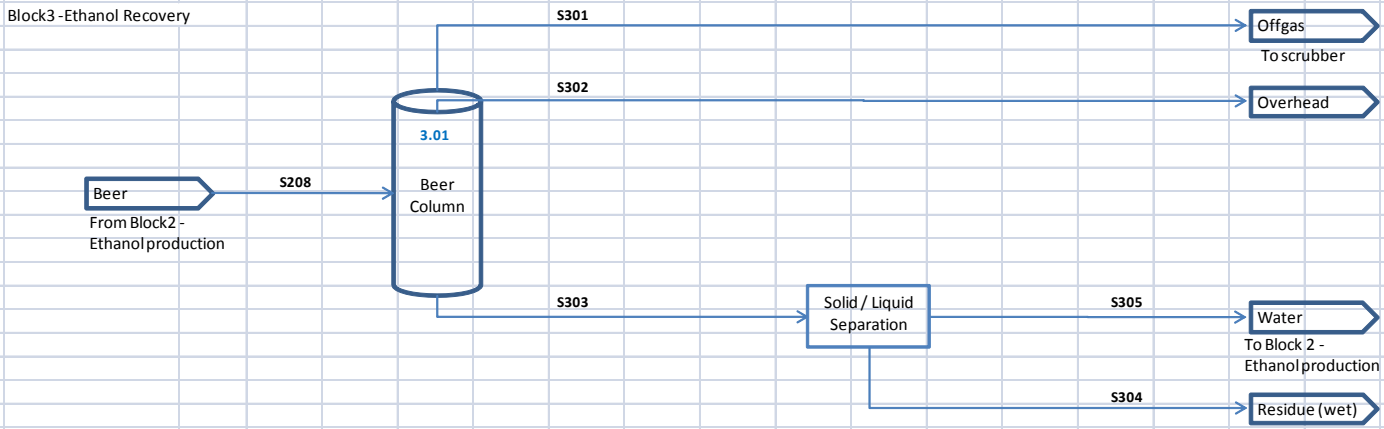


	stream	S113	S201	S202	S203	S204	S205	S206	S207	S208	S209	S210	S211	S212	S213	Block2
Component	Unit															MBal
Cellulose group	kg/hr	15					15	0.9	0.9	0.9						
Hemicellulose group	kg/hr	11					11	0.66	0.66	0.66						
Ash + Lignin	kg/hr	7.5					7.5	7.5	7.5	7.5						
Crude protein	kg/hr	1.2					1.2	1.2	1.2	1.2						
Acetate	kg/hr	1.2					1.2	1.2	1.2	1.1						
Oils	kg/hr	3.6					3.6	3.6	3.6	3.6						
Ammonia (NH3)	kg/hr	0.7					0.7	0.7	0.7	0						
Water/steam	kg/hr	4.5	45	0.6	160	2	4.5	165.1	165.1	187.1		22	20		45	0.0
Sugars (C6)	kg/hr					2.8		14.1	14.1	1.41		0.28				
Sugars (C5)	kg/hr							10.34	10.34	1.034						
Ethanol	kg/hr									12.5		1.29				
Cellulase	kg/hr			0.1				0.1	0.1	0.1						
CO2	kg/hr									0.01	12.0			1.23		
Others	kg/hr					0.3				0.148		0.3				
Total mass flow	kg/hr	44.7	45	0.7	160	5.1	44.7	205.4	205.4	217.3	11.97	23.87	20	1.23	45	0.0
Pressure	psig	0	125	0	0	0	0	0	0	0	0	0	0	0	0	
Temperature	°C	20	179	20	20	20	90	65	41	41	41	41	20	41	100	
Moisture (wt%)		10	100	86	100	39	10	80	80	86	0	92	100	0	100	
Vapor fraction		0	1	0	0	0	0	0	0	0	1	0	0	1	0	
Ethanol concentration	wt%	0	0	0	0	0	0	0	0	5.77	0	5.40	0	0	0	
NH3/(NH3+H2O)		0.13	0.00	0.00	0.00		0.13	0.00	0.00	0.00		0.00	0.00			

cellulose/hemicellulose conversion to sugars =	94	wt%
sugar conversion to ethanol =	90	% of theoretical
Overall Cellulose to Ethanol =	85	% of theoretical

Block 3. Ethanol Recovery

MBI Proposed Pilot Plant - Unit Ops, Streams, and Mass Balances for Process Flow Diagram



	stream	S208	S301	S302	S303	S304	S305	Block3
Component	Unit							MBal
Cellulose group	kg/hr	0.9			0.9	0.9		0
Hemicellulose group	kg/hr	0.66			0.66	0.66		0
Ash + Lignin	kg/hr	7.5			7.5	7.5		0
Crude protein	kg/hr	1.2			1.2	1.2		0
Acetate	kg/hr	1.1			1.1	1.1		0
Oils	kg/hr	3.6			3.6	3.6		0
Water/steam	kg/hr	187.1	0.010	18.5	168.59	8.4295	160.1605	0
Sugars (C6)	kg/hr	1.41			1.41	0.0705	1.3395	0
Sugars (C5)	kg/hr	1.034			1.034	0.0517	0.9823	0
Ethanol	kg/hr	12.530	0.027	12.4	0.095	0.004727	0.089818	0
Cellulase		0.100			0.1	0.005	0.095	0
CO2		0.012	0.012		0	0	0	0
Others	kg/hr	0.148		0.05	0.098	0.0049	0.0931	0
Total mass flow	kg/hr	217.3	0.049	31.0	186.3	23.53	162.76	0
Pressure	psig	0	12	12	12	15	15	
Temperature	°C	41	60	113	123	92	121	
Moisture (wt%)		86	20.41	59.76	90.50	36	98	
Vapor fraction		0	1	1	0	0	0	
Ethanol concentration	wt%	5.8	55.1	40.1	0.05	0.0	0.1	

Ethanol recovery in beer column overhead = 99.03 wt%

Liquid recovery in S/L Sep = 95 wt%

Provide the following information for the process shown in the PFD

1. How and why was the proposed process chosen? Discuss technical and business risks, benefits and opportunities associated with the process.

The proposed AFEX Integrated Biorefinery will address the three key criteria for sustainable biofuels: (i) **cost effectiveness** of production (ii) **scalability** to meet the petroleum displacement objectives in the renewable fuels standards and (iii) **reduction in greenhouse gas emissions** relative to fossil fuels. The bench scale data indicates high sugar yields, high fermentability of sugar streams and minimal waste streams of concern. As explained in greater detail in Section 2.0 of the Project Execution Plan (PEP), the technology is mature and ready for pilot plant stage. The technical risks are understood and are discussed in more detail in Section 4.1.2 of the PEP. The business risks are known and are discussed in Section 5 of the Business and Commercialization Plan. Operating a one ton per day integrated pilot plant will allow us to determine the cost of all processes as well as catalyst recovery and reuse. The lack of data on the cost of catalyst recovery and AFEX treatment processes is a barrier to convince commercial partners to invest in a demonstration plant. In this project we will collect the data necessary to create the techno-economic models needed to interest commercial partners in a demonstration plant and commercialization.

2. Describe the history of research and development performed by the applicant for the proposed process including scale, duration of runs, type of data collected, etc.

The ammonia fiber expansion (AFEX) process developed by Prof. Bruce Dale (Michigan State University) has been exclusively licensed by MBI. AFEX treats cellulosic biomass with ammonia under moderate pressure and temperatures. After a few minutes under these conditions, the pressure is released. The ammonia evaporates and is recovered. The treated biomass is now much more easily converted by acid or enzymes to fermentable sugars, and thence to ethanol. The combination of mild processing conditions, fast conversion rates, low operating costs, and no waste streams makes AFEX highly competitive with other proposed pretreatment schemes. In a 2005 comparative economic evaluation of advanced pretreatments by the National Renewable Energy Laboratory, AFEX performed much better than all other pretreatments studied except for the dilute acid process (Eggeman and Elander, 2005).

AFEX works on corn stover in batch mode. The AFEX process has been studied at bench scale for decades. In detailed studies using small batch reactors, AFEX has been shown to be an effective treatment method for a number of lignocellulosic feedstock materials. Batch AFEX treatment of corn stover at scales from a few grams to several hundred grams per batch, followed by enzymatic hydrolysis under standard conditions, have consistently demonstrated that hydrolysis yields improve significantly compared to untreated stover. In one published study (Wyman et al., 2005b), combined yields of glucose and xylose from corn stover were shown to exceed 94% of theoretical yield after AFEX treatment followed by enzyme hydrolysis. An economic analysis of various corn stover pretreatment methods was conducted by the Biomass Refining Consortium for Applied Fundamentals and Innovation (CAFI, Eggeman and Elander 2005), and found that the Minimum Ethanol Selling Price (MESP) for ethanol produced using AFEX treatment was lower than for any pretreatment other than dilute acid.

AFEX batch reaction conditions that are effective for corn stover are known. In batch studies of AFEX treatment (Teymouri et al., 2005a), the key independent variables were found to be

ammonia loading, feedstock moisture level, temperature, and reaction time. Effective conditions for AFEX batch treatment of corn stover were found to be ammonia mass loading of 1 kg per kg of dry stover, 60 to 80 wt% feedstock moisture (dry weight basis), 90 to 110°C temperature, and 5 minutes reaction time. Pressure in a closed batch AFEX reactor is not an independent variable, but is determined by temperature and ammonia concentration. The effect of residence time on fermentable sugar yield is fundamentally different with alkaline treatments such as AFEX, compared to acid pretreatments. Under acidic conditions, five-carbon monomeric sugars are unstable intermediates between the hemicellulose from which they are formed by hydrolysis and the furfural degradation products into which they are rapidly converted. As a consequence, biomass residence times in acidic pretreatment processes must be precisely controlled. In contrast, five-carbon monomeric sugars are not formed under alkaline conditions. This should simplify the design of continuous AFEX reactors compared to dilute acid pretreatment reactors. In principle, as long as the moist biomass feedstock is well mixed with an adequate concentration of ammonia, and held at an adequate temperature for a sufficiently long residence time, the AFEX treatment effect should be achieved, regardless of whether the reactor is batch or continuous. However, the scalability of the batch AFEX conditions above in a continuous process remains unclear. It is reasonable to assume that the conditions that are effective in a batch AFEX reactor should be scale independent, and conditions that work in a bench scale batch should work in a large scale continuous flow-through reactor. This assumption has not yet been validated for continuous AFEX treatment of corn stover at any scale.

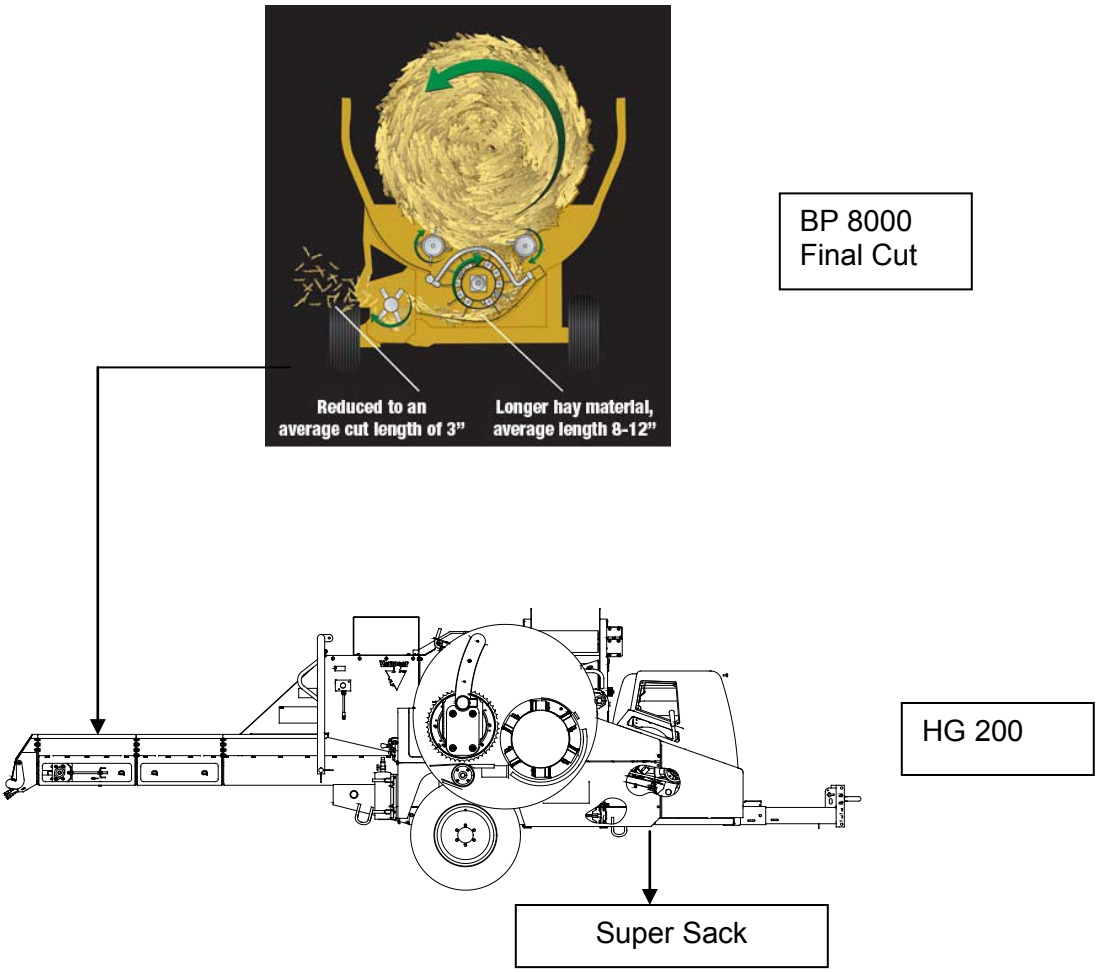
AFEX integrates well with high-solids hydrolysis and fermentation at bench scale for conversion of corn stover to ethanol. In any process that involves fermentation of hydrolyzed biomass to produce ethanol, a significant concern is achieving a high enough ethanol concentration in the fermented beer to allow for cost-effective recovery of the ethanol product by distillation. Distillation energy cost per gallon of ethanol product increases as the beer concentration decreases, becoming prohibitive for ethanol concentrations below about 5 % (50 g/L). Stoichiometric conversion of sugars yields 51 wt% ethanol and 49 wt% carbon dioxide. Corn stover composition varies, but typically is composed of less than 60 wt% combined glucan and xylan (Aden et al., 2002), and actual conversions of glucan and xylan to ethanol are normally less than 85% of stoichiometric conversion. As a result, to achieve 5% ethanol concentration in the fermented beer requires at least 20 wt% loading of corn stover solids in the hydrolysis and fermentation process. AFEX is a “dry in, dry out” process, meaning that the treated biomass can be completely recovered as a dry solid, without any dilute liquid sugar product streams. AFEX-treated stover can be loaded into hydrolysis and fermentation processes at concentrations of 20 wt% or higher, without any requirement for pre-concentration of dilute aqueous sugar streams. AFEX treatment of corn stover is therefore suitable for integration with hydrolysis and fermentation processes for ethanol production.

A more detailed discussion of the bench-scale background data is available in Section 2.0 of the PEP.

Equipment used for biomass preprocessing

The proposed process includes the use of a Vermeer BP8000 Final Cut Bale Processor that will be used for an initial size reduction process, sometime known as de-baling. The material will then be fed to a Vermeer HG200 for final size reduction. This process allows the use of existing equipment, with that ability to be operated in a variety of ways to experiment with different size reduction characteristics. This experimental combination of machines will allow us to identify operating characteristics of the grinding equipment that may affect final properties of the processed biomass. It also provides economic advantages by utilizing existing equipment.

Vermeer has been working with Idaho National Labs, associated with their use of a Vermeer HG 200, to process a variety of Ag residues, including corn stover. The testing has been completed using various scales of operation. INL has collected extensive data to evaluate/document performance of the grinder.



Complete the following questionnaire for each Unit Operation shown in the PFD

Unit Operation {BP8000 Final Cut}

1. Name or title (It is not shown in the PFD. This equipment will be used in the field).

Vermeer BP 8000 Final Cut Bale Processor

2. Description of the unit operation.

1) Capacity and throughput.

Estimated capacity of 15 to 20 tons per hour

2) Provide the heat and material balance (H&MB).

The work load will be determined during this project.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

Operation is at room or ambient temperature and pressure. Residence time is negligible, estimated to be less than 1 second.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

This machine has been developed as an agricultural machine, designed to process baled material, which it converts from being wrapped and bound together into loose material, with some size reduction. It can convert materials similar to corn stover into particle sizes of 3 to 4 inches.
There are no by-products, but it will produce dust. Some dirt or other loose contaminants that were attached to the biomass will be dislodged and become airborne. A percentage of the material, about 5 to 15 wt%, will also be converted to small particles and be lost as airborne dust. The fraction lost as dust is an estimate that has not been verified.

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

Carbon steel

6) Provide the expected service life.

3000 hrs

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

No major system upsets are anticipated.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Operates at ambient temperature, input and output stream are solid

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

Batch, machine will operate bale - by - bale

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

No waste stream is generated in this unit operation.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Based on the information provided by the vendor the estimated cost for this unit is $28,561

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

None

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

Yes, but as noted, this equipment is designed for agricultural use, and not specifically for this application, although it will work well for this experimental process.

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

The equipment will be used at the same scale at which it is currently used in industry.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

Bale processors are widely used agricultural equipment that have been in service for many years.

4) If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

This is a well developed technology and it is not based on R&D

Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

No further R&D needed.

Complete the following questionnaire for each Unit Operation shown in the PFD

Unit Operation 1.01 – {Shredder HG 200}

1. Name or title (Shredder 1.01).

Vermeer HG 200 horizontal grinder

2. Description of the unit operation.

1) Capacity and throughput.

Estimated capacity of 2 to 5 tons per hour

2) Provide the heat and material balance (H&MB).

Mass balance: Provided in PFD (Block 1)

Energy balance*:

	PFD Unit #		In	Out	Rel. diff.%
Shredder	**1.01**	kg/hr	47.5	47.5	0
		kJ/hr	-420310	-420310	0

*Energy In and Out (kJ/hr) includes enthalpies of all material streams, as well as energy streams, as calculated using ASPEN PLUS. Relative difference indicates the convergence of the balance.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

Operation is at room or ambient temperature and pressure. Residence time is negligible, estimated to be less than 1 second.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

This machine has been developed to process woody materials, with size reduction determined by a screen. It can convert materials similar to corn stover into particle sizes down to less than 1", depending on the screen.
There are no by-products, but it will produce dust. Some dirt or other loose contaminants that were attached to the biomass will be dislodged and become airborne. A percentage of the material, about 5 to 15 wt%, will also be converted to small particles and be lost as airborne dust. The fraction lost as dust is an estimate that has not been verified.

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

Carbon steel

6) Provide the expected service life.

3000 hr

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

No major system upsets are anticipated.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Input (S101) and output (S106) streams are solid and at ambient temperature. Information on the physical and chemical composition of the process streams for this unit is provided in the PFD (Block 1) stream table.

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

Continuous flow, as long as material is fed to the unit continuously.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

No waste is generated in this unit operation.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Based on the information provided by the vendor the estimated cost for this unit is $55,000.

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

Particle size is controlled manually by changing out the discharge screen hole size.

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

Yes, but as noted, this equipment is designed for a different use, grinding woody materials, and not specifically for this application, although it will work well for this experimental process.

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up =

proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

The equipment will be used at the same scale at which it is currently used in industry.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

Grinders are widely used agricultural equipment that have been in service for many years.

4) If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

This technology is well developed and this is not based on R&D.

Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

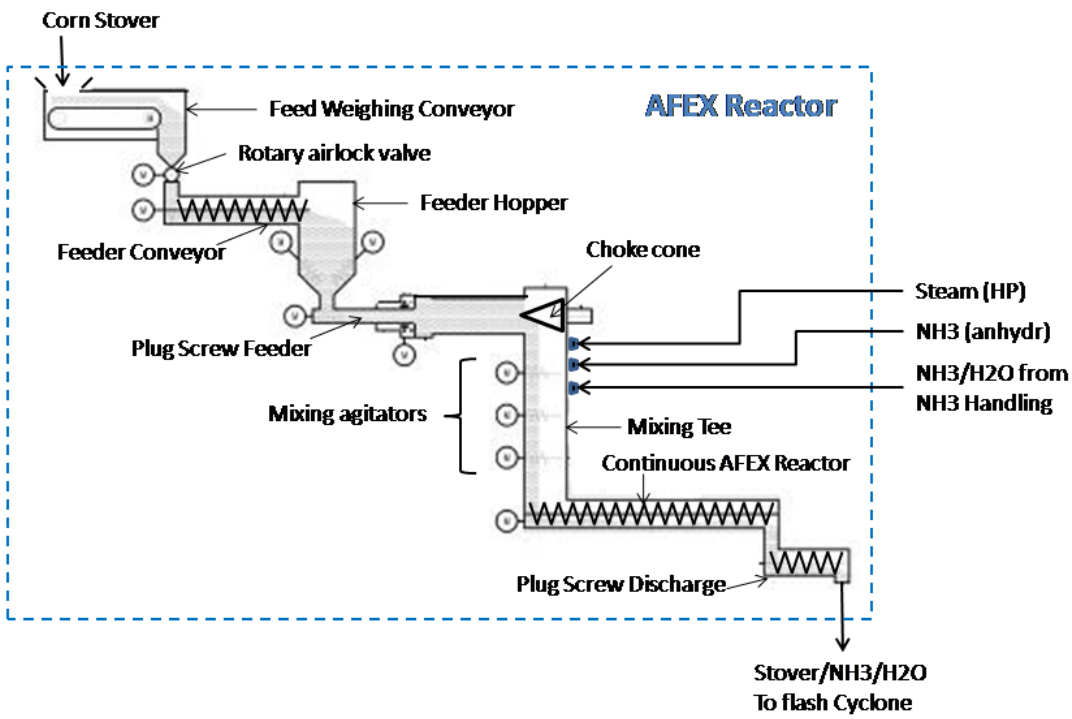
No further R&D is needed.

Complete the following questionnaire for each Unit Operation shown in the PFD

Unit Operation 1.03 – {AFEX reactor}

1. Name or title (AFEX reactor 1.03).

The major components in the AFEX reactor are the feeder conveyor and hopper, the plug screw feeder, the choke cone, the reactor, the discharge screw, and the blow valve.



2. Description of the unit operation.

1) Capacity and throughput.

The capacity of the AFEX reactor will be 100 kg/hr OD (oven dried) biomass. Typical expected throughput will be 40 kg/hr OD biomass.

2) Provide the heat and material balance (H&MB).

Material balance: Provided in PFD (Block 1)

Energy balance*:

	PFD Unit #		In	Out	Rel. diff. %
AFEX reactor	**1.03**	kg/hr	163.1465	163.1465	0
		kJ/hr	-1582324	-1660697	4.72

*Energy In and Out (kJ/hr) includes enthalpies of all material streams, as well as energy streams, as calculated using ASPEN PLUS. Relative difference indicates the convergence of the balance.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

Reactor temperature will be controlled between 70-90°C.
Reactor pressure will be controlled between 200-350psig.
Reactor residence time will be controlled between 5-30min.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

The product of the AFEX reactor is AFEX-treated biomass. Actual conversion and mass yield data is available only from bench-scale batch reactor studies. No byproducts or waste streams will be generated in this unit operation. The mass recovery is 100% and net yield is 1 kg OD AFEX treated biomass/kg of feedstock. The designed operating conditions for the pilot-scale AFEX reactor will be based on the bench-scale data.

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

All steel components of the AFEX reactor are constructed of 316SS. All elastomers and other components are compatible with ammonia and are based on the manufacturer's (SunOpta) recommendation.

6) Provide the expected service life.

The expected service life is variable and depends on many factors such as the abrasive nature of the feedstock, operational and maintenance practices. It could range between one year and 25 years. For this application we would expect several years of service life.

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

Periodically the integrity of the plug in the reactor feeder deteriorates to the point that it cannot retain the pressure in the reactor and a blow back occurs. When this happens, a large vent line on the feeder hopper vents the pressure to the blow cyclone. With the pressure reduction in the reactor, some liquid in the reactor is flashed to vapor and the solid-vapor mixture is transported through the vent line to the flash cyclone where the solids and vapor are separated and recovered. The reactor and flash cyclone also have pressure relief valves to protect the integrity of each vessel. In the event vessel pressure exceeds its designed capacity the pressure relief valve will open and vapor stream will be vented to a safety flare or some other ammonia control device.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Information on the physical and chemical composition of the process streams in the AFEX reactor is provided in the PFD (Block 1) stream table.

Input streams: S104, S105, S108, and S117
Output stream: S110

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

The AFEX reactor operates in a continuous mode.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

No waste stream is generated in this unit operation.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Capital cost for this unit operation including the plug screw feeder, reactor, discharge device and the flash cyclone is $3.4 million based on a 2009 SunOpta quote.

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

The AFEX reactor system and flash cyclone will be controlled by a PLC. The PLC will start /stop the reactor system, control the key reactor operating parameters, and monitor the safe operation of the reactor system. Equipment will be interlocked so that equipment is started in reverse order of product flow (last to first to see feed/product) and in upset conditions all equipment upstream will stop. Each conveyor will have a motion sensor to confirm travel; rotary valves and remotely activated valves will have proximity switches to confirm their position; and motor loads will be monitored to detect overload conditions through the PLC. The PLC will control feed stream flow rates, which will determine biomass moisture content and reactor ammonia concentration, which will be monitored by offline measurements. Reactor temperature and residence time will be measured and controlled by the PLC.

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

A horizontal, Pandia-type reactor vessel (referred to in the figure above as the continuous AFEX reactor) with plug screw feeder and discharge devices will be used for continuous AFEX treatment of corn stover. Horizontal Pandia-type reactor designs are commonly used for treatment of wood chips in the pulp and paper industry. This type of reactor has been used at commercial scale for steam explosion treatment and

autohydrolysis of biomass. This unit will be modified to handle ammonia. Double mechanical seals with water flush will be used for all dynamic seals (transport screws, mixer shafts, etc.). The operating temperature and pressure for the proposed process are within the manufacturers' normal operating parameters.

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

The Pandia-type reactor has been used in pulp and paper, and biomass pretreatment industries at 25-1000 ton per day scale. For this case the AFEX reactor unit will actually be a scaled down version of commercially available units. Based on our discussion with equipment manufacturers like SunOpta BioProcess Inc., Metso Paper Inc., and Andritz Ltd., who are leaders in this type of reactor, scaling down the reactor size, should not be an issue. Also the National Renewable Energy Laboratory (NREL) currently is using a similar reactor design with 1 tonne/day capacity for their continuous dilute acid pretreatment.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

As mentioned above this type of reactor has not been extensively used with ammonia. Biomass is processed and treated in this type of reactor at commercial scale and at pilot scale as low as 1 ton/day in the pulp and paper industry and in biomass treatment.

4) If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

The continuous AFEX reactor design will be based on extensive AFEX batch work at bench scale. The objectives of the bench scale R&D were to determine the operating conditions that provide optimal enzyme hydrolysis yields for corn stover. The operating conditions for the pilot scale AFEX reactor unit will be based on our AFEX batch research. A more detailed discussion of the background data is available in Section 2.0 of the PEP.

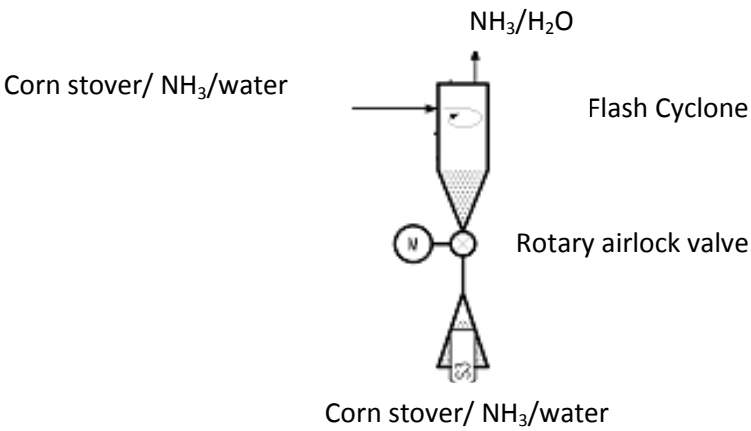
Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

No further R&D is needed.

Complete the following questionnaire for each Unit Operation shown in the PFD

Unit Operation 1.04 – {Flash cyclone}

1. Name or title (Flash cyclone 1.04).



2. Description of the unit operation.

1) Capacity and throughput.

The capacity of the flash cyclone will be 100kg/hr OD treated biomass. Typical expected throughput will be 40 kg/hr OD biomass.

2) Provide the heat and material balance (H&MB).

Mass balance: provided in PFD (Block 1)

Energy balance*:

	PFD Unit#		In	Out	Rel. diff. %
Flash Cyclone	**1.04**	kg/hr	163.1465	163.1465	0
		kJ/hr	-1660697	-1648415	0.75

*Energy In and Out (kJ/hr) includes enthalpies of all material streams, as well as energy streams, as calculated using ASPEN PLUS. Relative difference indicates the convergence of the balance.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

Flash cyclone operating temperature: 26°C
Flash cyclone operating pressure: 7 psig
Flash cyclone residence time: Vapor phase < 1 minute; solid phase < 10 minutes.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

This unit is used for separation of AFEX-treated biomass from ammonia vapor. The cyclone can be designed for high separation efficiency. Products from this unit are ammonia/water vapor stream (S111) and AFEX-treated biomass (S112). No waste streams or byproducts are generated.

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

All steel components of the flash cyclone are constructed of 316SS. All elastomers and other components are compatible with ammonia based on the manufacturer's (SunOpta) recommendation.

6) Provide the expected service life.

The expected service life is variable and depends on many factors such as the abrasive nature of the feedstock, operational and maintenance practices. It could range between one year and 25 years. For this application we would expect several years of service life.

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

Any upset in the upstream equipment may affect the cyclone operation. Periodically the integrity of the plug in the AFEX reactor feeder deteriorates to the point that it cannot retain the pressure in the reactor and a blow back occurs. When this happens, a vent line on the feeder hopper vents the pressure to the flash cyclone. With the pressure reduction, some liquid is flashed to vapor and the solid-vapor mixture is transported through the vent line to the flash cyclone where the solids and vapor are separated and recovered. The reactor and flash cyclone also have pressure relief valves to protect the integrity of each vessel. In the event vessel pressure exceeds its designed capacity the pressure relief valve will open and vapor stream will be vented to a safety flare or some other ammonia control device.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Information on the physical and chemical composition of the process streams in the flash cyclone is provided in the PFD (Block1) stream table.
Input stream: S110
Output stream: S111 and S112

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

The flash cyclone operates in a continuous mode.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

No waste stream is generated in this unit.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Capital cost for this unit operation including the plug screw feeder, reactor, discharge device and cyclone is $3.4 million based on a 2009 SunOpta quote

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

The AFEX reactor system and flash cyclone will be controlled by a PLC (see AFEX reactor instrumentation and controls). The speed of the rotary valve at the bottom of the flash cyclone will be controlled by the PLC and adjusted to maintain the proper solids level.

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

Use of a cyclone for separating solid and gas mixtures is a very common industrial practice. In our process this unit will be used for the same propose and will operate within the manufacture's normal operating parameters (design pressure: 30psig, target working pressure: 7 psig).

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

Cyclones are commonly used in industry at various scales for separating solid and gas streams.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

See Item 2 above.

4) If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not

met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

The state of technology for this unit is based on common and standard operation not R&D.

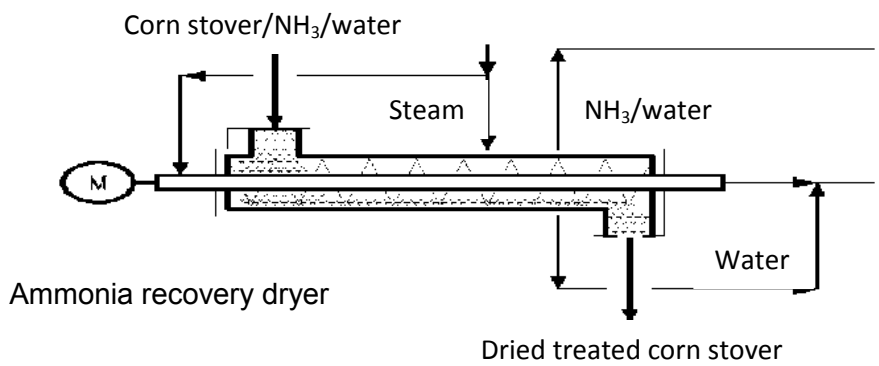
Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

No further R&D is needed.

Complete the following questionnaire for each Unit Operation shown in the PFD

Unit Operation 1.05 – {NH3 recovery dryer}

1. Name or title (Ammonia recovery dryer 1.05)



2. Description of the unit operation.

1) Capacity and throughput.

The capacity of the NH_3 recovery dryer will be 100kg/hr OD treated biomass. Typical expected throughput will be 40 kg/hr OD biomass.

2) Provide the heat and material balance (H&MB).

Material balance: Provided in PFD (Block 1)

Energy balance*:

	PFD unit #		In	Out	Rel. diff.%
NH_3 recovery dryer	**1.05**	kg/hr	135.5445	135.5445	0
		kJ/hr	-1561024	-1557418	0.23

*Energy In and Out (kJ/hr) includes enthalpies of all material streams, as well as energy streams, as calculated using ASPEN PLUS. Relative difference indicates the convergence of the balance.

The estimated steam flow for indirect heating of the dryer will be 115 kg/hr of saturated steam at 100 psig. The estimated heat duty for the dryer will be 66 kW at the typical throughput of 40 kg/hr OD biomass.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

The design of the NH_3 recovery dryer is conceptual at this point. Calculated conditions and energy requirements for this unit are based on an indirectly-heated rotary dryer. This type of dryer is available in the size range required for the proposed pilot plant from various manufacturers, including Bepex International LLC and GEA Barr-Rosin.
Temperature: 80°C

Pressure: -3 psig
Residence time: 10-30 min
Heat medium:
Fluid: steam (saturated)
Nominal operating pressure: 100 psig
Inlet temperature: 25°C
Outlet temperature: 80°C

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

As the treated biomass is conveyed through the NH_3 recovery dryer, it will be indirectly heated to vaporize NH_3 and H_2O. The design parameters for this unit operation will be selected to exploit the high volatility of NH_3 relative to H_2O such that nearly all of the NH_3 will be extracted as vapor without removing all of the H_2O. Under the design conditions more than 98% of ammonia used in the process will be recovered. It is anticipated that H_2O will be removed from the biomass (stream S113) to a moisture level of about 10 wt%, to facilitate subsequent densification and storage of the treated biomass. The saturated vapor extracted from the biomass in the dryer (stream S115) will contain about 28 wt% NH_3. This vapor will be directed to the NH_3 handling unit for condensation and NH_3/H_2O separation. No waste stream or byproduct stream is generated in this unit. The design of the NH_3 recovery dryer will be based on supporting R&D conducted during Budget Period 1 (task 1.3). Some approaches to be considered for the design are shown in Figure 22 of the Project Execution Plan. Actual yield, conversion, and efficiency data for the dryer will be collected during capstone runs during Budget Period 2.

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

All wetted parts will be compatible with ammonia and based on vendor recommendation, using materials such as ANSI 316L, 304 or DIN 1.4571 stainless steel.

6) Provide the expected service life.

The expected service life is variable and depends on many factors such as the abrasive nature of the feedstock, operational and maintenance practices. It could range between one year and 25 years. For this application we would expect several years of service life.

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

Material flow rate through the unit must be uniform and continuous, which may be controlled with a variable speed drive. NH_3 vapor flow may be driven by a vacuum blower or an inert sweep gas. Blockage or interruption of any of these flows would cause system upset. An overpressure condition in the dryer would activate a pressure relief valve, allowing vapor to vent to the safety flare or other control device. Contamination of the vapor stream with ambient air could occur if leaks develop; this would lead to a hazardous condition, as NH_3 can form explosive mixtures with air.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Detailed information is provided in the PFD stream table. Stream S112 flowing from the flash cyclone into the dryer is AFEX-treated corn stover solids with absorbed saturated NH_3/H_2O liquid mixture. Stream S113 exiting the dryer is treated solids with 10 wt% moisture and residual NH_3. The vapor stream S115 exiting the dryer contains about 28 wt% NH_3, balance H_2O. Both output streams are at near-ambient pressure.

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

This unit is operated in a continuous mode.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

No waste stream is generated in this unit.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Estimated capital cost for this unit based on a vendor (Bepex International LLC) budgetary quote is $297,975.

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

The key parameters for this unit are the moisture and NH_3 content in AFEX-treated biomass; the operator will set these operating conditions in the control system based on the designed parameters for the AFEX reactor. Moisture in the treated biomass (stream S113) will be measured off-line using a moisture balance. Based on the product moisture the operator will manually adjust the dryer temperature by controlling steam flow. Detailed specifications of instruments and control procedures will be based on the final design of the dryer, which will be determined by an R&D effort in Budget Period 1.

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

The use of indirect dryers for drying fibrous solid materials such as biomass is a standard industrial practice that is well developed. A variety of dryer designs are commercially available from various manufacturers with throughput and drying capacities within the range necessary for the proposed pilot plant. However, conditions and specifications for NH_3 recovery are not within the manufacturers' normal operating parameters. It is unclear at this point whether a commercial dryer unit can be modified to meet the

requirements for the ammonia recovery unit operation, or whether a custom-built dryer will be necessary. We have discussed this application with two commercial dryer manufacturers, and both have expressed confidence that standard drying equipment can be modified for NH_3 recovery at the proposed pilot scale. Vaporization of volatile, flammable solvents from wet biomass is commercially practiced for desolventizing of soybean and corn after oil extraction. Project partner ICM has considerable expertise in commercial biomass drying operations, and will be a resource in development of the NH_3 recovery dryer.

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

Recovery of NH_3 from AFEX-treated biomass has only been investigated at bench scale (see Section 2.2 of the PEP for more background information). However, biomass drying and desolventizing is widely practiced from pilot scale up to large commercial scale. Bepex International LLC is one of the premier companies that manufacture this type of dryer. They have manufactured rotary dryers in a size range between 10' and 60' length, which is the appropriate scale for our proposed process. Project partner ICM is also very experienced in the development of dryers.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

Drying equipment for continuous NH_3 recovery from AFEX-treated biomass has not been run at any scale for any length of time. Development and demonstration of this equipment is one of the primary goals of this project. However, as explained above, biomass dryers in general are standard industrial practice.

4) If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

Bench-scale R&D, described in more detail in Section 2.2 of the Project Execution Plan, is the basis for the current state of NH_3 recovery technology.

Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

Further R&D is needed. Task number 1.3.2 in the WBS (see Section 4.5 of the PEP) will provide the R&D effort needed to support design of the NH_3 recovery dryer. This task is broken down into subtasks for measurement of heat and mass transfer coefficients in ammonia recovery processes, incorporation of the coefficients into analytical models of various drying operations, and detailed design of a custom dryer or specification of a commercial dryer based on model results.

Unit Operation 1.06 – {Pelletizer}

1. Name or title (Pelletizer 1.06).

ComPAKer (By ComPAKco LLC – Fargo ND)

2. Description of the unit operation.

1) Capacity and throughput.

Wheel ComPAKer. 5 different units – optimum is 10 tons per hour

2) Provide the heat and material balance (H&MB).

Mass balance is provided in PFD (Block 1)
Energy balance: Work load will be determined during pilot plant operation.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

The machine works in a wide range of conditions.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

There are no byproducts or waste streams. Design and actual mass yield is 100%.

12) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

Hardened steel product contact surfaces.

13) Provide the expected service life.

The wear parts are steel teeth designed to be replaced. Service life will be determined as part of this project.

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

We don't envision any upset for the system itself; however the moisture content of the biomass might affect the stability of the generated pack.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Input and output streams are solid and at ambient temperature. Information on the physical and chemical composition of the process streams are provided in the PFD (Block 1) stream table. The compaction factor for this unit is about 10 to 1.

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

The mode of operation is continuous.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

No waste streams are generated in this unit operation.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Capital cost estimate is $60,000, including time and materials.

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

Pellet dimensions are controlled manually by changing out compression gears.

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

The COMPaker machine is a unique and proprietary technology. It is not manufactured commercially. The equipment to be used will be a prototype.

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

The COMPaker has been designed and tested at 10 ton/hour scale. The design can be modified for more throughput.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

Hundreds of runs have been made over the past 2 years. The machines are run daily.

4) If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

The COMPaker machine is currently operating at pilot scale.

Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

Further R&D is needed, and will be provided by a parallel MSU effort that is not part of this project (Dale, 2009).

Complete the following questionnaire for each Unit Operation shown in the PFD

Unit Operation 1.07 – {NH3 handling}

1. Name or title (NH_3 handling 1.07)

Recovered NH_3 and H_2O vapor from the flash cyclone and NH_3 recovery dryer will be directed to the NH_3 handling operation for condensation and separation. The detailed specifications of the actual unit operations, such as compressors, condensers, pumps, and storage tanks, that will make up the NH_3 handling operation will be determined during preliminary process design (see task 1.1.3 in the WBS).

2. Description of the unit operation

1) Capacity and throughput.

The NH_3 handling operation capacity will be determined during preliminary process design (see task 1.1.3 in the WBS). Total capacity will be compatible with the flash cyclone, NH_3 recovery dryer, and AFEX reactor.

2) Provide the heat and material balance (H&MB).

Mass flows of streams S111, S114, S115, and S117 are given in the PFD (Block 1) stream table above.

Overall energy balance* for the ammonia handling system:

	PFD Unit #		In	Out	Rel. diff.%
NH_3 handling	**1.07**	kg/hr	118.4	118.4	0
		kJ/hr	-265,440	-265,440	0

*Energy In and Out (kJ/hr) includes enthalpies of all material streams, as well as energy streams, as calculated using ASPEN PLUS. Relative difference indicates the convergence of the balance.

The heat duty for the ammonia handling operation is estimated to be -72 kW (72 kW of heat rejected). Compressor electric power and other shaft work requirements are not included in this duty, and will be determined during preliminary process design.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

Processing conditions will be determined during preliminary process design. Maximum stream temperature entering NH_3 handling will be 80°C, and streams exiting will be about 20°C. Operating pressure will be low, < 10 psig.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

Design efficiency will be determined during preliminary process design, and measured during capstone runs. Product streams are condensed ammonia and water streams.

Stream S114 is shown on the PFD as a waste stream. It is unclear whether this stream will be a waste stream, or can be recycled for biomass washing or moisture adjustment (stream S102).

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

The materials of construction must be compatible with NH_3/H_2O mixtures, such as 316 SS for wetted parts.

6) Provide the expected service life.

The expected service life for condensers, compressors, and other relevant equipment are variable and depend on many factors. It could range between one year and 25 years. For this application we would expect several years of service life.

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

Ammonia leaks could cause an upset in operating this system. A safety discharge flare as well as a leak detection system will be provided. Volatile compounds may arise from AFEX-treated biomass and accumulate in the ammonia handling system. These contaminants could eventually lead to system upsets.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Detailed information is provided in the PFD (Block 1) stream table.
Input streams: S111, S115
Output streams: S114, S117

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

The mode of operation is continuous.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

No waste stream is generated in this unit operation, assuming that stream S114 is recycled to stream S102 for biomass washing or moisture adjustment.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

The capital cost is estimated at $1.6 million based on a quote received from Rowald Refrigeration Systems for a commercial ammonia handling system of similar size.

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

Required instrumentation and controls will be determined during preliminary process design.

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

Compressors, condensers, and other equipment for NH_3 handling are commercially available for refrigeration systems. Rowald Refrigeration Systems is an example of a vendor who has many systems installed in commercial and industrial applications where ammonia refrigeration is required. Project partner Airgas also has expertise in NH_3 handling systems, and will be a resource during preliminary design of the NH_3 handling operation.

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

The NH_3 handling operation has not been tested for use with AFEX biomass treatment in continuous operation at any scale. However, the specific equipment that is anticipated to make up the NH_3 handling operation has been tested over a wide range of scales including the proposed pilot scale.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

As discussed in Items 1 and 2 above, this operation has not been run for continuous AFEX NH_3 handling at any scale for any duration; however, the specific equipment anticipated to make up the NH_3 handling operation have been tested over a wide range of scales including the proposed pilot scale.

4) If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

R&D will not be required for preliminary design of the NH_3 handling operation. The properties of NH_3/H_2O mixtures have been thoroughly investigated and are available in

the literature (Alamdari, 2007; Tillner-Roth and Friend, 1998; Smolen et al. 1991). The data quality for these mixtures is very good, as reviewed by Tillner-Roth and Friend (Tillner-Roth and Friend, 1998). These properties will be used to design the NH_3 handling operation.

Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

No further R&D is needed, as explained above.

Unit Operation 2.02 – {Hydrolyzer}

1. Name or title (Hydrolyzer)

High Solids Enzymatic Hydrolysis Reactors (Unit Operation 2.02)

2. Description of the unit operation.

1) Capacity and throughput.

Two 5,000 L capacity high-solids enzymatic hydrolysis reactors are currently being purchased by NREL and will be installed in the NREL IBRF pilot plant expansion in 2010. They have a nominal capacity of 24-36 hours of enzymatic hydrolysis time per vessel at an initial solids loading of 20-35% insoluble solids. They are intended to be operated until the yield stress of the slurry is reduced to 10 Pa via liquefaction by the enzymes. At this point, partially hydrolyzed slurry will then be quickly pumped to the first 9000 L fermentation vessel for the end of enzymatic hydrolysis and fermentation. One of the high-solids enzymatic hydrolysis reactors can be charged with treated solids while the other is reacting/discharging.

2) Provide the heat and material balance (H&MB).

Material balance: Provided in PFD (Block 2)

Energy balance*:

	PFD Unit #		In	Out	Rel. diff.%
Hydrolyzer	**2.02**	kg/hr	205.40	205.40	0
		kJ/hr	-2.30E+06	-2.30E+06	0

*Energy In and Out (kJ/hr) includes enthalpies of all material streams, as well as energy streams, as calculated using ASPEN PLUS. Relative difference indicates the convergence of the balance.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

Enzymatic hydrolysis is typically operated at 40-60 ^{o}C. Vessels are operated at atmospheric pressure Residence time options are as stated in item 1.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

About 40-60% conversion of cellulose and xylan is anticipated to occur in the high-solids enzymatic hydrolysis reactor, at which point the slurry has liquefied enough to be pumpable and can be further reacted in the 9000 L stirred tank fermentors. No waste streams are envisioned.

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

High solids enzymatic hydrolysis reactors are SS304, per recommendation of NREL IBRF I&EC contractor (Merrick & Co.).

6) Provide the expected service life.

25 years (purchased in 2009, being installed in 2010).

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

Microbial contamination in enzymatic hydrolysis is a potential issue. Good cleaning protocols and equipment sanitization techniques and sterile operating practices will limit the risk of such process upsets. The high-solids enzymatic hydrolysis reactors can be chemically sanitized and steam sanitized with live steam contacting of all process surfaces (at atmospheric pressure) prior to each run.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Input streams: S202, S203 and S205
Output streams: S206
Information on the physical and chemical composition of the process streams are provided in the PFD (Block 2) stream table.

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

High-solids enzymatic hydrolysis reactors are operated in a batch mode. The second reactor can be charged with treated solids while the first reactor is reacting/discharging.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

There are no anticipated waste streams from this unit operation, as the partially hydrolyzed slurry is transferred to the 9000 L NREL PDU fermentors once sufficient liquefaction of the slurry has occurred. In the event of a severe microbial contamination, the slurry would be diluted (if necessary) and transferred to one of the PDU fermentation vessels or the PDU broth kill tank for sterilization prior to being neutralized and discharged per standard NREL PDU procedures.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Each 5000 L high solids enzymatic hydrolysis reactor is being purchased in 2009 at a budgetary cost of $180,000 each.

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

Each high solids enzymatic hydrolysis reactor is outfitted with temperature measurement and control, pH measurement and control, adjustable agitation rate (with a high solids mixing arm and paddles), and pressure measurement and control.

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

Yes.

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

High solids enzymatic hydrolysis in bench scale devices of up to 5 L (including a horizontal shaft paddle reactor and a rotating roller bottle reactor) have been operated to perform high solids enzymatic hydrolysis of treated biomass on a routine basis over the past 5 years. This reactor concept has been proven successful at that scale.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

The bench scale high solids enzymatic hydrolysis reactors are currently being operated on a routine basis in support of several process development projects.

If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

Original goals were to demonstrate the concept in high solids enzymatic hydrolysis using scalable reactor designs. There is sufficient available data to demonstrate that reproducible results can be achieved and that good enzymatic hydrolysis performance can be achieved.

Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

Bench scale high solids enzymatic hydrolysis runs using AFEX-treated feedstocks are planned to be conducted over a 9 month period in Phase 1 of this project. Additionally, bench-scale control high solids enzymatic hydrolysis runs are planned to be conducted in parallel with each pilot scale high solids enzymatic hydrolysis run for this project.

Unit Operation 2.03 – {Seed Production}

1. Name or title (Seed production).

Ethanologen Seed Production for Pilot Plant Fermentors (Unit Operation 2.03)

2. Description of the unit operation.

1) Capacity and throughput.

Two 160 L capacity pre-seed vessels and two 1,450 L capacity seed vessels are installed in the NREL PDU. These vessels can produce appropriate quantities of recombinant co-fermenting ethanologen inoculum to support operation of fermentation in the 9,000 L fermentation train in the NREL PDU.

2) Provide the heat and material balance (H&MB).

Material balance: Provided in PFD (Block 2)

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

Seed production (in both the pre-seed and seed stages) typically occurs at 30-38 ^{o}C Vessels are generally operated at very slight overpressurization above atmospheric pressure to minimize contamination risk. Vessels are rated for 50 psig to accommodate steam sterilization. Pre-seed and seed residence times generally range from 12-36 hours each, depending upon specific growth characteristics, media formulation, and desired cell mass concentrations.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

Seed growth is monitored by measuring optical density and residual sugar concentration. Typically, a residual level of sugars remains when transfer to the next stage occurs in order to ensure that the culture is in an active growth phase. Consumed carbon is transferred primarily to cell mass and carbon dioxide, with very little ethanol fermentation occurring during seed production.

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

Pre-seed and seed vessels are SS316, per recommendation of NREL PDU I&EC contractor (John Brown).

6) Provide the expected service life.

25 years (pre-seed and seed vessels were originally installed in 1994 and were used extensively through 1997). Another industrial collaboration project used these vessels extensively in 2007-2008 for both seed production and production fermentation runs.

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

Microbial contamination is an occasional issue. Good equipment sterilization techniques and sterile operating practices have been shown to limit the risk of such process upsets.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Information is provided in the PFD (Block 2) stream table.

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

Pre-seed and seed vessels are typically operated in batch mode. These vessels can be operated with continuous sugar solution feeding as well.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

Seed inoculum is transferred to the 9000 L production fermentors. Off-gas (containing CO2, water vapor, and ethanol) is condensed in off-gas condensers and measured and analyzed for mass balance closure. Any pre-seed or seed inoculum (including accidental spills) that contain live recombinant cells that is being disposed must be killed (with kill verification) prior to disposal or discharge. NREL has a Biosafety Authorization Program that specifies such disposal procedures on an individual project basis before authorization to operate is granted.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Each 160 L pre-seed vessel and control skid package was purchased in 1993 at a cost of $76,000 each. Each 1,450 L seed vessel and control skid package was purchased in 1993 at a cost of $201,000 each.

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

All pre-seed and seed vessels are fully outfitted with temperature measurement and control, pH measurement and control, adjustable agitation rate (with high solids hydrofoil impellers), dissolved oxygen measurement probes, and pressure measurement and control. These vessels also sit on load cells to measure net weight of vessel contents.

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

Yes.

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

Not applicable—the at-scale units for this project have already been operated.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

Several weeks of operation (around-the-clock operations) were conducted in the period from 1994-97 and periodically since then. These vessels were operated in support of an industrial collaboration for several weeks in 2007-08 and are intended to be operated in the 2009-2012 timeframe for other projects.

If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

Not applicable.

Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

Bench scale fermentation, including the development of pre-seed and seed production protocols using the ethanologen used in this project are planned to be conducted over a 9 month period in Phase 1 of this project. Additionally, bench-scale control fermentation runs are planned to be conducted in parallel with each pilot-scale fermentation run for this project.

Unit Operation 2.04 – {Ethanol Fermentors}

1. Name or title (Ethanol fermentor).

Ethanol Production Pilot Plant Fermentors (Unit Operation 2.04)

2. Description of the unit operation.

1) Capacity and throughput.

Four 9,000 L capacity fermentation vessels are installed in the NREL PDU. They have a nominal capacity of 1 day of fermentation time (with or without simultaneous enzymatic hydrolysis) per vessel at an initial solids loading of about 12% insoluble solids when operated in a continuous mode cascading through the four vessels. Additional residence time capacity and/or smaller volume requirements would be possible if higher solids loadings (enabled by high solids enzymatic hydrolysis in Unit Operation 2.02) were utilized. These vessels can also be operated independently in either batch or continuous mode.

2) Provide the heat and material balance (H&MB).

Material balance: Provided in PFD (Block 2)

Energy balance*:

	PFD Unit #		In	Out	Rel. diff.%
Fermentor	**2.04**	kg/hr	229.27	229.27	0
		kJ/hr	-2.74E+06	-2.74E+06	0

*Energy In and Out (kJ/hr) includes enthalpies of all material streams, as well as energy streams, as calculated using ASPEN PLUS. Relative difference indicates the convergence of the balance.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

Enzymatic hydrolysis is typically operated at 35-50 ^{o}C (lower temperatures are used when fermentation in also simultaneously occurring) and ethanol fermentation is typically operated at 32-38 ^{o}C. Vessels are generally operated at very slight overpressurization above atmospheric pressure to minimize contamination risk. Vessels are rated for 50 psig to accommodate steam sterilization. Residence time options are as stated in item 1.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

Depending on solids concentration, sugar yields, and ethanologen efficiency, ethanol concentrations of 4-7% (w/v) can be achieved. Ethanol yields from glucose can achieve 90%, with somewhat lower ethanol yields from xylose, depending on ethanologen used and toxicity of hydrolyzate.

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

Fermentor vessels are SS316, per recommendation of NREL PDU I&EC contractor (John Brown).

6) Provide the expected service life.

25 years (fermentors were originally installed in 1994 and were used extensively through 1997, but have only been utilized periodically since then.

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

Fermentor contamination is an occasional issue. Good equipment sterilization techniques and sterile operating practices have been shown to limit the risk of such process upsets.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Input streams: S207 and S210
Output streams: S208 and S 209
Information on the physical and chemical composition of the process streams are provided in the PFD (Block 2) stream table.

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

Fermentors can be operated in a continuous flow (cascaded through vessels or continuous fermentation in a single vessel) or in a single-vessel batch mode, as described in item 1.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

Fermentation beer is envisioned to be further processed in the downstream beer distillation column. Fermentor off-gas (containing CO2, water vapor, and ethanol) is condensed in off-gas condensers and measured and analyzed for mass balance closure. Any fermentation beer (including accidental spills) that contain live recombinant cells that is being disposed must be killed (with kill verification) prior to disposal or discharge.

NREL has a Biosafety Authorization Program that specifies such disposal procedures on an individual project basis before authorization to operate is granted.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Each 9000 L fermentor and control skid package was purchased in 1993 at a cost of $310,000 each.

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

All fermentors are fully outfitted with temperature measurement and control, pH measurement and control, adjustable agitation rate (with high solids hydrofoil impellers), dissolved oxygen measurement probes, and pressure measurement and control.

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

Yes.

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

Not applicable at the scale units for this project has already been operated.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

Several weeks of operation (around-the-clock operations) were conducted in the period from 1994-97. The fermentors have been operated periodically since that time, although they are intended to be operated in the 2009-2012 timeframe for other projects.

If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

Not applicable.

Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

Bench scale fermentation runs using the hydrolyzate streams and ethanologen for this project are planned to be conducted over a 9 month period in Phase 1 of this project. Additionally, bench-scale control fermentation runs are planned to be conducted in parallel with each pilot-scale fermentation run for this project.

Unit Operation 3.01 – {Beer Column}

1. Name or title (Beer column).

Beer column (Unit Operation 3.01)

2. Description of the unit operation.

1) Capacity and throughput.

1200 kg/hr of 2-5% w/v ethanol-containing fermentation beer (to allow processing of 24 hours of fermentation beer production in a 8 hour period), producing up to 60 kg/hr of 130 proof (95% v/v) ethanol from overhead stream and a distillation bottoms stream containing 0.02-0.08 % w/v at a rate of 6.5 gpm. Processing of higher strength beer streams should be possible with adjustments to column operating parameters.

2) Provide the heat and material balance (H&MB).

Material balance: Provided in PFD (Block 3)

Energy balance*:

	PFD Unit #		In	Out	Rel. diff.%
Beer column	**3.01**	kg/hr	83.6	83.6	0
		kJ/hr	-717723	-717644	0.01

*Energy In and Out (kJ/hr) includes enthalpies of all material streams, as well as energy streams, as calculated using ASPEN PLUS. Relative difference indicates the convergence of the balance.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

Beer is preheated to 180 ^{o}F via pre-heater and is then processed at 210 ^{o}F in the beer column. Distillation unit also contains an overhead condenser, vent condenser, bottoms cooler, feed bump, bottoms pump, and reflux pump. The system generally operates at atmospheric pressure, although all components are pressure-rated at 50 psig.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

Previous operations have shown that the system operates at its design specifications, as outlined in Item 1.

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

All beer column and ancillary components are SS304, per recommendation of NREL PDU I&EC contractor (John Brown).

6) Provide the expected service life.

25 years (unit was originally installed in 1994, but has not been used extensively in past 10 years).

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

No specific system upset causes. The beer column trays are designed to handle residual solids in the beer slurry and the system has been successfully operated with such slurries.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Input stream: S208
Output stream: S301, S302,S303
Information on the physical and chemical composition of the process streams are provided in the PFD (Block 3) stream table.

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

The distillation unit operates in a continuous mode, although it is designed with a flow capacity that is three-fold greater than the NREL PDU fermentation beer flow rate (to enable processing of 24 hours of fermentation beer in an 8 hour period). During continuous operation of the enzymatic saccharification and fermentation train, the distillation unit thus operates only periodically.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

Condensed overhead ethanol-rich streams are stored in the PDU ethanol storage tank. Once this vessel is full, ethanol product is disposed of according to NREL ESH standard procedure, per U.S. ATF requirements. Distillation bottoms stream is further processed in solid liquid separation unit operation prior to disposal.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Skid-mounted beer column distillation unit (including 16 inch by 33 ft column with 19 sieve trays, 2 feed pre-heaters, vent condenser, product cooler, bottoms, cooler, reflux pump, and bottoms pump) was purchased for $257,000 in 1993. All process-wetted contact surfaces are constructed of SS 304 and all components are pressure-rated for 50 psig.

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

The distillation unit is fully outfitted with temperature, pressure, and flow transmitters and associated control valves and is integrated into the NREL PDU data acquisition and control system (Gensym G2 software package with OPTO 22 control system hardware).

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

Yes—this is typical beer column stripping operation, considering the 2-5% ethanol concentration fermentation beer from low-solids enzymatic hydrolysis. Some operating adjustments would need to be made to process fermentation beer with higher ethanol concentrations.

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

Not applicable—the at-scale unit for this project has already been operated.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

Several weeks of operation (typically during 8 hour operating days) were conducted in the period from 1994-97. The unit has not been operated for significant periods since that time, although it is intended to be operated in the 2010-2012 timeframe for other projects.

If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

Not applicable.

Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

Applicable R&D is related to generation of representative whole stillage and clarified stillage for use as a recycle stream. The distillation systems need to be operated in order to generate this recycle water stream.

Unit Operation 3.02 – {Solid Liquid Separation}

1. Name or title (Solid liquid separation).

Solid Liquid Separator—Sharples Decanter Centrifuge (Unit Operation 3.02)

2. Description of the unit operation.

1) Capacity and throughput.

Up to 390 gallons/hr of beer column bottoms can be processed in the P3400 Sharples decanter centrifuge, matching flows generated from the beer column. Since the operation of the beer column is periodic, the centrifuge is larger than needed in a continuous operation. Also, relatively lower amounts of recycle water is needed, so an alternative smaller Western States filtering basket centrifuge with capability to general higher solids-content cakes will also be considered for use in this project.

2) Provide the heat and material balance (H&MB).

Material balance: Provided in PFD (Block 3)
Work load will be determined during this project.

3) Provide the processing conditions for the unit operation, including temperature, pressure, and residence time.

Beer column bottoms would be approximately 200 ^{o}F upon exiting the beer column and can be cooled in the bottoms cooler and/or in the centrifuge feed tank. The Sharples centrifuge is capable of operation at temperatures up to 200 ^{o}F and will be operated at atmospheric pressure. In this continuous centrifuge, residence time is a few minutes or less, depending on centrifuge internals configuration.

4) Provide designed and actual yield, conversion and efficiency data for each unit operation detailing the products, byproducts, and waste streams.

Process streams at up to 390 gallons/hr feed rate can be processed through the Sharples centrifuge to generate a solids stream with up to 30% solids content. The Western States filtering basket centrifuge would operate at lower feed rates and can generate a solids stream of up to 40% solids, depending on specific dewatering properties of the slurry. Centrate streams from either centrifuge would contain very little insoluble solids and could be used as recycle water in the process.

5) Provide the materials of construction and the basis for their selection for each critical piece of equipment.

Centrifuge wetted parts are SS316, per recommendation of NREL PDU I&EC contractor (John Brown).

6) Provide the expected service life.

25 years (unit was originally installed in 1994, but has not been used extensively in past 10 years). The Western States filtering basket centrifuge was installed in 2007.

7) Describe any known causes and the effects and impacts thereof for system upset and contaminants (including the source(s) of the contaminants).

Not applicable.

8) Provide a description, including physical and chemical composition, phase, temperature and pressure of all input and output streams.

Information is provided in the PFD stream table. Extremely high solids-containing solids streams (above 30% solids) are not necessary to generate representative recycle water streams in the quantities needed to demonstrate recycle water process effects.

9) Describe the mode of operation, i.e. batch, plug or continuous flow.

The decanter centrifuge operates in a continuous mode, although it is designed with a flow capacity that is three-fold greater than the NREL PDU fermentation beer flow rate (to enable processing of 24 hours of distillation bottoms in an 8 hour period. During continuous operation of the enzymatic saccharification and fermentation train, the centrifuge thus operates only periodically. The Western States filtering basket centrifuge operates in a semi-continuous mode, with plow discharge of sedimented solids during a no-feed cycle.

10) For all waste streams leaving the process describe the physical and chemical composition, phase, temperature and pressure, and the proposed method of treatment, storage and/or disposal.

Centrifuged solids that contain killed cells (from beer column) and other solids are kill-verified (per standard NREL PDU procedures) and are then re-slurried, pH-adjusted, and discharged per standard NREL PDU procedures. Excess recycle water is discharged following pH adjustment per standard NREL PDU procedures.

11) Provide the estimated capital cost of each unit operation and the basis for those costs.

Sharples P3000 decanter centrifuge was purchased for $73,000 in 1993. Western States filtering basket centrifuge was purchase for $275,000 in 2006.

12) Describe the instrumentation and controls that will be incorporated into this unit. This should complement the instrumentation and controls discussion in the Project Narrative.

Both centrifuges are fully outfitted with load, balance controls and are integrated into the NREL PDU data acquisition and control system (Gensym G2 software package with OPTO 22 control system hardware). The Western States Centrifuge also has a PLC control station.

3. Describe the state of technology for the unit operation.

1) If the technology is commercially available, is the proposed design and use within the manufacturer's normal operating parameters?

Yes—for both centrifuge systems

2) At what scale(s) has the technology been designed and tested? What is the scale-up factor for the proposed unit operation or integration step? (Scale up = proposed facility unit capacity divided by previous scale capacity.) That is, provide specific explanation and justification for the basis of assumed success in achieving the designed scale up.

Not applicable—the at-scale units for this project have already been operated.

3) How many runs were made at the stated scale, and for how many continuous hours/days? When (approximately) was the most recent test run?

For the Sharples decanter centrifuge, several weeks of operation (typically during 8 hour operating days) were conducted in the period from 1994-97. The unit has not been operated for significant periods since that time, although it is intended to be operated in the 2010-2012 timeframe for other projects. The Western States Centrifuge was installed in 2007 and has routinely been operated for various solid-liquid separation projects in the NREL PDU.

If R&D is the basis for the state of technology, describe the original goals and objectives of the R&D. If not discussed in #3, above, summarize the results of the R&D and discuss how the original goals and objectives were met or not met. Describe the quality and replicability of the results. (If data quality objectives were used to set minimum data quality standards, briefly describe them.)

Not applicable.

Is further R&D is needed? Describe the goal and summarize the work needed to obtain the needed information. In lieu of including the information here, if the work is planned to be conducted as part of the project within the scope of this proposal, reference the activity (preferably by WBS number or numbers).

Applicable R&D is related to acceptable solids-liquid separation performance on the specific streams. NREL has operated these units in similar corn stover biomass conversion process streams and expects only minor process adjustments for the process streams generated in this project.

Life Cycle Analysis of the proposed AFEX Biorefinery

A Life Cycle Analysis (LCA) has been conducted by MBI and MSU for an envisioned commercial AFEX Integrated Biorefinery to determine net GHG emission reductions for our primary product, ethanol, compared to petroleum-derived gasoline. The functional unit is defined as one mile driven by an E85- or gasoline- fueled Flex Fuel Vehicle. The system boundary for a cellulosic ethanol fuel system includes corn stover production, transportation of corn stover from farm to a biorefinery, AFEX treatment biorefinery, transportation and distribution of ethanol, gasoline production, an E85 fueled vehicle operation, and electricity as an alternative system that is displaced by surplus electricity exported from the biorefinery. The system boundaries for both fuel systems are illustrated in Figure 1. The analysis on the gasoline fuel system is based on the timeframe of 2010-2015.

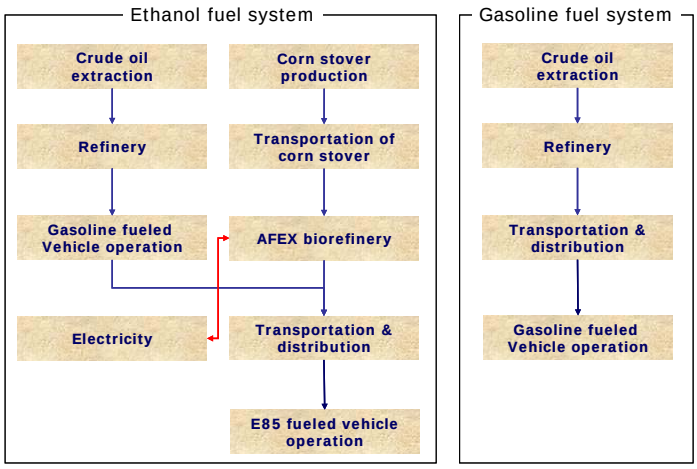


Figure 1. System boundaries for LCAs of AFEX Integrated Biorefinery (ethanol) and Gasoline fuel systems.

The environmental burdens associated with fertilizers, fuels, ammonia, enzyme and other materials are included in the calculations. The calculations are done via GREET 1.8b with modifying process information on the AFEX treatment biorefinery, which is summarized in Table 1. Life cycle inventory data in GREET 1.8b are used for most processes except for enzyme production, which is from a report by NREL (Sheehan et al., 2002). Lignin and biogas from wastewater treatment facility are burned to generate steam and electricity. There are no external energy sources required in the AFEX treatment biorefinery. Surplus electricity is exported to grid.

Table 1. Process information on the AFEX biorefinery

Ethanol yield: 90 gal/ dry ton
Biomass: NH_3: H_2O = 1 : 1 : 1 in AFEX treatment process
Solid content in fermentation: ~20%
Enzyme: 0.20 kg/ gal, Makeup ammonia 0.20 kg/gal
Electricity exported: 1.2 kWh/ gal

Vehicle Technologies, Passenger Cars: Well-to-Pump Energy Consumption and Emissions

(Btu or grams per mmBtu of Fuel Available at Fuel Station Pumps)

Year: 2010	EtOH FFV: E85, Biomass
Total Energy	831,349
WTP Efficiency	54.6%
Fossil Fuels	64,626
Coal	-42,392
Natural Gas	8,226
Petroleum	95,251
CO2 (w/ C in VOC & CO)	-46,523
CH4	35.410
N2O	10.240
GHGs	-42,584
VOC: Total	50.450
CO: Total	80.970
NOx: Total	131.790
PM10: Total	12.800
PM2.5: Total	6.360
SOx: Total	12.480
VOC: Urban	14.040
CO: Urban	1.198
NOx: Urban	3.906
PM10: Urban	0.518
PM2.5: Urban	0.309
SOx: Urban	-0.308

Vehicle Technologies, Passenger Cars: Well-to-Wheel Energy and Emission Changes (%, relative to gasoline vehicles fueled with

Year: 2010	EtOH FFV: E85, Biomass
Total Energy	46.4%
Fossil Fuels	-72.8%
Coal	-196.1%
Natural Gas	-91.2%
Petroleum	-66.6%
CO2 (w/ C in VOC & CO)	-69.1%
CH4	-65.6%
N2O	254.0%
GHGs	-65.5%
VOC: Total	33.3%
CO: Total	8.6%
NOx: Total	110.5%
PM10: Total	10.8%
PM2.5: Total	28.7%
SOx: Total	-48.7%
VOC: Urban	-6.8%
CO: Urban	-0.5%
NOx: Urban	-23.0%
PM10: Urban	-24.2%
PM2.5: Urban	-25.8%
SOx: Urban	-101.3%

Vehicle Technologies, Passenger Cars: Well-to-Wheel Energy Consumption and Emissions (per Mile)

EtOH FFV: E85, Biomass

Item	Btu/mile or grams/mile		
	Feedstock	Fuel	Vehicle Operation
Total Energy	419	3,662	4,908
Fossil Fuels	411	-94	1,296
Coal	37	-228	0
Natural Gas	165	-125	0
Petroleum	209	259	1,296
CO2 (w/ C in VOC	-240	12	370
CH4	0.150	0.024	0.015
N2O	0.011	0.039	0.012
GHGs	-233	24	374
VOC: Total	0.031	0.217	0.171
CO: Total	0.078	0.319	3.745
NOx: Total	0.197	0.450	0.141
PM10: Total	0.018	0.044	0.029
PM2.5: Total	0.012	0.019	0.015
SOx: Total	0.080	-0.019	0.002
VOC: Urban	0.001	0.068	0.107
CO: Urban	0.001	0.004	2.329
NOx: Urban	0.005	0.014	0.088
PM10: Urban	0.000	0.002	0.018
PM2.5: Urban	0.000	0.001	0.009
SOx: Urban	0.003	-0.005	0.001

Petroleum Displacement Analysis - AFEX Integrated Biorefinery

This Petroleum Displacement Analysis contains estimates of barrels of oil displaced via production of ethanol (primary product) and electrical power (co-product) using the AFEX Integrated Biorefinery (AIB) technology. The analysis was prepared following the format provided in DE-FOA-0000096, Appendix I, as required in Section IV.C.r.

Table 1 gives the petroleum displacement, in barrels of oil equivalents per annum, estimated for the proposed AIB pilot plant, and for the envisioned first commercial-scale AIB facility.

Table 1 – Petroleum displacement for pilot- and commercial-scale AFEX Integrated Biorefinery (AIB) facilities.

Facility	Product	Product Energy Content (BTU/L)	Annual Output of Facility		Equivalent Barrels of Oil (barrels per annum)
			Volume Output (L)	Energy Output (BTU)	
AIB Pilot Plant	Ethanol*	20,166	11,316	228,198,456	42
AIB Commercial Plant	Ethanol	20,166	454,200,000	9,159,397,200,000	1,681,814
	Electricity (BTU/kg stover)	407	491,754,240,000	491,754,240,000	90,294
	total				1,772,109

* Ethanol produced in the AIB Pilot Plant will not be fuel grade, so will not actually displace any petroleum.

Proposed Pilot-scale facility – The proposed AIB pilot plant, operating 720 hours per annum at a production rate of about 15.7 L of ethanol per hour, will have the capacity to produce 11,316 L per annum ethanol. Using crude oil and ethanol energy content values of 129,670 and 76,330 BTU per gallon, respectively, this ethanol production rate would displace 42 barrels of oil per annum. Note that the proposed pilot plant will not produce fuel-grade ethanol, so no petroleum will actually be displaced. (LHV data for ethanol and crude oil taken from the Hydrogen Analysis Resource Center website, http://hydrogen.pnl.gov/cocoon/morf/projects/hydrogen/datasheets/lower_and_higher_heating_values.xls)

Envisioned Commercial-scale facility – The first AIB commercial plant, envisioned to become operational in 2015, will have a production capacity of 120 million gallons per annum ethanol, or 454,200,000 L per annum, as the primary product. This output assumes that 1.33 million dry tons per annum of corn stover feedstock will be converted to ethanol at a yield of 90 gallons per ton. The ethanol product output will be equivalent to 1.68 million barrels per annum of oil. In addition to the ethanol primary product, this commercial AIB plant will also co-produce net electric power output. Electric power will be produced by combustion of the lignin-rich fermentation residue to produce steam, which will drive a turbo-generator unit. After subtracting out electricity used within the plant, we expect that annual electric power output from the plant will be 492 billion BTU per annum, which is 407 BTU of electricity

per dry kg of corn stover feedstock, and is equivalent to 90,294 barrels per annum of oil. The total petroleum displacement for the first commercial-scale AIB plant will be 1.77 million barrels per annum.

Market projections for AIB technology – Based on recent U.S. DOE Energy Information Agency (EIA) market projections, which take into account the effects of Recovery Act legislation on biofuels production (http://www.eia.doe.gov/oiaf/servicerpt/stimulus/aeostim.html), U.S. domestic ethanol production in 2015 will total 960,000 barrels per day, or 55.7 billion L per annum. Therefore, the 454 million L per annum output from the first commercial AIB plant will amount to only 0.8% of total domestic ethanol production in 2015. Over the period from 2015 to 2030, we anticipate that ethanol produced using AIB technology will increase to account for about 33% of total domestic ethanol production. We estimate 33% market penetration for AIB technology by assuming that about one-third of ethanol in 2030 will be produced from corn and other grains, one-third from woody biomass, and one-third from non-woody biomass, including agricultural residues and purpose-grown energy crops such as switchgrass and energy cane. Based on the considerable benefits of the AIB technology, as outlined in the Project Narrative, it is reasonable to expect that AIB plants will lead the market for conversion of non-woody biomass to ethanol. Figure 1 below shows projections for total U.S. domestic ethanol production, and ethanol production from all combined AIB plants, over the period from 2015 to 2030. A total of 68 commercial-scale AIB plants, each converting 1.33 million ton per annum of non-woody biomass feedstock to ethanol product at a yield of 90 gallons per ton, will produce a combined total of 30.8 billion L per annum, or 530,000 barrels per day in 2030, as shown in Figure 1. The petroleum displaced by these 68 AIB plants in 2030 will equal 120 million barrels per annum.

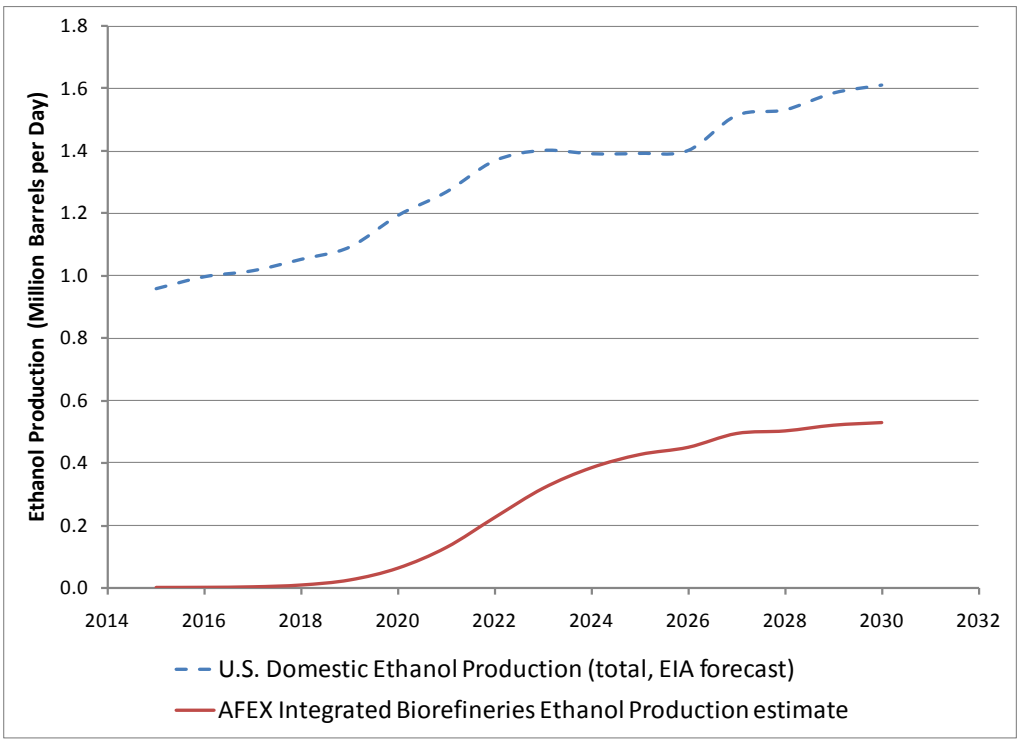


Figure 1 – Projections for total U.S. domestic ethanol production (EIA forecast), and AFEX Integrated Biorefinery ethanol production (our estimate), for the period 2015 to 2030.

Demonstration of an AFEX Integrated Biorefinery at Pilot Scale

Submitted by MBI International

DE-FOA-0000096

Project Execution Plan

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1.0 Introduction

This Project Execution Plan (PEP) document outlines Team MBI's plan for design, construction, shakedown, and operation of an integrated pilot-scale biorefinery for conversion of corn stover to ethanol as primary product. This proposal is in response to Topic Area 1 of the U.S. Department of Energy's Funding Opportunity Announcement (FOA) Number DE-FOA-0000096, titled "Recovery Act-Demonstration of Integrated Biorefinery Operations." Our biorefinery design will include several innovative features, including continuous Ammonia Fiber Expansion (AFEX) treatment of corn stover, recovery and re-use of the ammonia catalyst in the continuous AFEX treatment, densification of the AFEX-treated stover for enhanced storage and transport efficiency, and integrated hydrolysis and mixed sugar co-fermentation of the densified AFEX-treated stover at high solids loading using enzymes specifically selected for hydrolysis of AFEX-treated stover. We refer to this innovative process as the AFEX Integrated Biorefinery.

The PEP schedule for development of the AFEX Integrated Biorefinery pilot plant is divided into three Budget Periods in keeping with the three award periods described in the FOA. Budget Period 1 will include preliminary design of the biorefinery process, bids and permits for construction of a new addition to existing facilities at MBI International to house the continuous AFEX pilot plant, and limited bench-scale research efforts to support the process design. Budget Period 2 will include detailed engineering of the AFEX Biorefinery process, procurement of major equipment, construction of the new building addition at MBI, installation of new equipment and modification of existing equipment, shakedown trials of the installed and modified equipment, performance testing of the process by DOE's Independent Engineer, long-term continuous capstone runs of the integrated process, and techno-economic modeling of the process for commercial production. Budget Period 3 will include extended operation of the integrated biorefinery process to obtain data necessary for thorough characterization of the performance of the process, updates and improvements to the techno-economic model, life cycle analysis, and commercialization plan based on data from extended operations, and comprehensive technical, operating, and financial reporting. Execution of the project described in this PEP will follow a clearly-defined, Stage-Gated pathway to commercialization of AFEX Integrated Biorefinery technology, with specific milestones that must be completed to move the technology from one stage to the next. Completion of the critical success factors for our AFEX Integrated Biorefinery pilot plant will represent a significant step toward commercialization of cellulosic ethanol, which will reduce dependence on imported oil, create jobs, and help to spur the creation of the domestic bioindustry.

2.0 Bench-Scale Background Data

The proposed AFEX Integrated Biorefinery technology is based on years of investigation and development at the bench scale. This section of the PEP will present bench-scale background data to demonstrate that AFEX is an effective treatment for conversion of biomass to ethanol, ammonia can be recovered efficiently from AFEX-treated biomass, AFEX-treated biomass can be hydrolyzed and fermented at high solids loading, and commercial AFEX Integrated Biorefineries will produce ethanol at a competitive selling price. This background data will establish that our biorefinery approach is ready for development at pilot scale.

2.1 AFEX is an effective treatment for conversion of biomass to ethanol

The AFEX process has been developed by Prof. Bruce Dale (Michigan State University), and has been exclusively licensed by MBI. In the AFEX process (Figure 1) moist cellulosic biomass is treated with ammonia at moderate pressure and temperature. After a few minutes under these conditions, the pressure is released, causing some of the ammonia to flash to vapor, which may be recovered and re-used. The ammonia and water remaining with the biomass after flashing can be removed in subsequent

steps, and re-used. The treated biomass is now much more easily converted by acid or enzymes to fermentable sugars, and thence to ethanol. The treated biomass can be discharged from the process at about the same moisture content as the untreated biomass fed to the process, making AFEX a "dry-in, dry-out" treatment. The combination of mild processing conditions, fast conversion rates, low operating costs, and no waste streams makes AFEX highly competitive with other proposed biomass treatment schemes. In a 2005 comparative economic evaluation of advanced pretreatments by the National Renewable Energy Laboratory, AFEX performed much better than all other pretreatments studied except for the dilute acid process (Eggeman and Elander, 2005). AFEX and dilute acid treatments performed similarly. However, dilute acid pretreatment has been studied for years, and offers little further room for technological improvement. Dilute acid invariably degrades some sugars and requires expensive materials of construction.

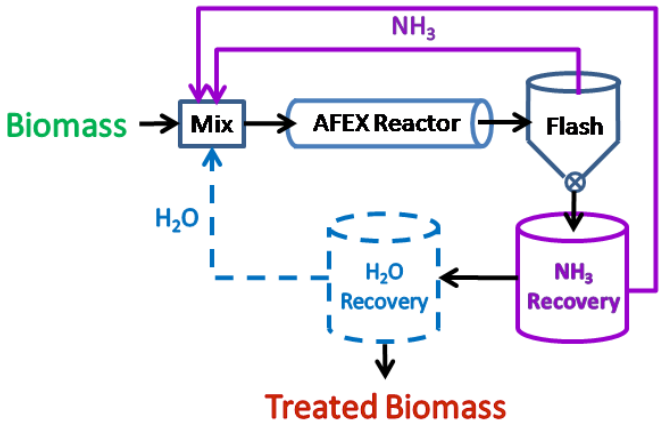


Figure 1. Conceptual sketch of an AFEX process for biomass treatment.

AFEX is an effective treatment for ethanol production from a variety of biomass feedstock types. Considering the seasonal nature of agricultural industries, it will likely be necessary for biorefineries to use several feedstocks with differing harvest times. Research at MBI and Michigan State University (MSU) has shown that AFEX treatment significantly increases enzyme digestibility of several cellulosic feedstocks (Figure 2).

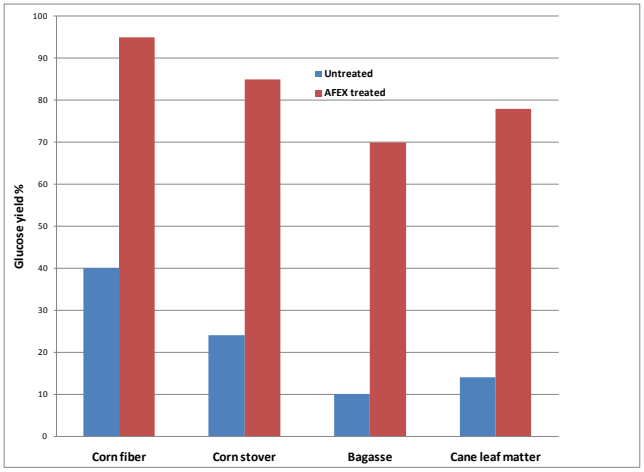


Figure 2. Glucose yields (based on the available sugar) of untreated and AFEX-treated biomass after 72 hr of hydrolysis with 15 FPU of cellulase and 42 CBU of Novo 188 per gram of cellulose.

Yields of fermentable sugars, and consequently yields of ethanol biofuel, depend heavily on the composition of the cellulosic material from which they are derived. Table 1 shows the composition (the three major components) of several lignocellulosic feed stocks. As these data show, the composition ranges are both species- and tissue-specific, thus plant selection for feedstock requires prior knowledge of the composition.

Table 1. Major components of different lignocellulosic biomass based on dry weight (Mosier et al., 2005)

Biomass	Cellulose%	Hemicellulose %	Lignin%
Corn stover	37.5	22.4	17.6
Corn Fiber	14.28	16.8	8.4
Pine wood	46.4	8.8	29.4
Poplar	49.9	17.4	18.1
Wheat straw	38.2	21.2	23.4
Switchgrass	31.0	20.4	17.6
Bagasse *	34.57	19.44	20

* MBI unpublished data

Corn stover is the selected feedstock for our proposed AFEX Integrated Biorefinery pilot plant. Corn stover meets the FOA definition of a high impact feedstock, that is, a feedstock that is domestically available and has the ultimate availability potential of at least 100 million dry metric tons of agronomically and ecologically sustainable biomass per year. According to the USDA (USDA, 2002), average total areas planted for major agriculture crops in the U.S. are as follows in millions of acres: corn 80, soybeans 73, hay 64.7, wheat 60.1, cotton 14.4, grain sorghum 9.3, oats 5.1, barley 5.1, rice 3.2, and rye 1.4. As these data show, corn is the most widely planted crop, and corn stover is the most abundant agriculture residue. Corn stover is a clear choice for large scale cellulosic ethanol production in U.S. as it represents about 80% of the total agricultural residue.

Current annual production of corn grain in the U.S. is about 196 million tons/year, and assuming a corn-to-stover ratio of 1:1, the average corn stover production can be estimated to be the same (Graham et al., 2007). Under current rotation and tillage practices roughly 30% of this stover (about 58.8 million tons/yr) can be sustainably collected. If all U.S. corn producers were to adopt mulch till practices, total collectible stover supply would increase to 70 million tons/yr, and if no-till practices were universally adopted the total collectible corn stover supply would increase to 101 million tons/yr. Under no-tillage practice sufficient stover can be collected to support large biorefineries with one million tons/ year of feed stock demand without causing erosion to exceed the tolerated soil loss. Even with these tillage practices, about 50% of the corn stover would remain uncollectible. Energy requirements for corn stover particle size reduction and properties of ground stover have been studied (Mani et al., 2004).

AFEX batch reaction conditions that are effective for corn stover are known. Batch AFEX treatment of corn stover at scales from a few grams to several hundred grams per batch, followed by enzymatic hydrolysis under standard conditions, have consistently demonstrated that hydrolysis yields improve significantly, as compared to untreated stover. In one published study (Wyman et al., 2005b), combined yields of glucose and xylose from corn stover were shown to exceed 94% of theoretical yield after AFEX treatment followed by enzyme hydrolysis. In another batch study of AFEX treatment (Teymouri et al., 2005a), the key independent variables were found to be ammonia loading, feedstock moisture level, temperature, and reaction time. Effective conditions for AFEX corn stover batch treatment were found to be ammonia mass loading of 1 kg/kg of dry stover, 60 to 80 wt% feedstock moisture (dry weight

basis), 90 to 110°C temperature, and 5 minutes reaction time. A more recent study (Sendich et al., 2008) has shown that lower ammonia loadings can be effective for AFEX-treatment of stover. The results in Figure 3 show that ammonia loading could be reduced to about 0.3 kg of ammonia per kg of dry biomass before AFEX treatment effectiveness declined.

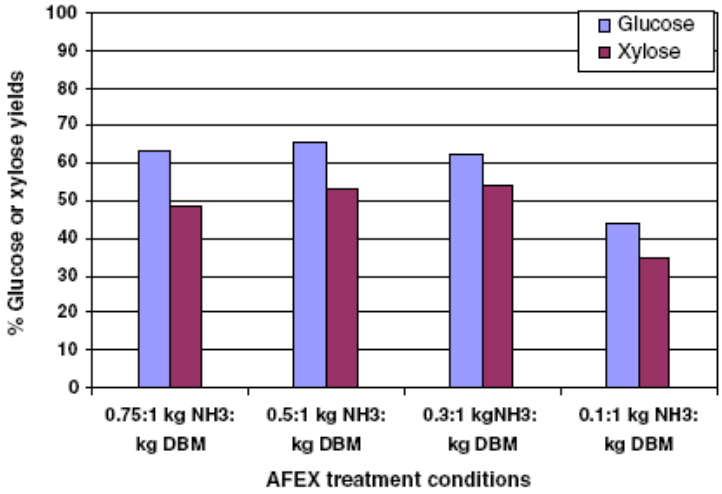


Figure 3. Glucose and xylose yields after enzyme hydrolysis of AFEX-treated corn stover at different ammonia loadings, 60% moisture content at 90 ºC. (Adapted from Sendich et al., 2008).

Figure 4 shows glucose and xylose yields at 72 h of hydrolysis as a function of moisture content at an ammonia loading of 0.5 kg ammonia per kg of dry stover (90°C and 5 min). There is apparently no significant effect of moisture content on hydrolysis under these conditions. Therefore, the AFEX process is adaptable to both quite dry and quite moist biomass, with little apparent effect on treatment effectiveness; this feature provides flexibility for the AFEX reactor design.

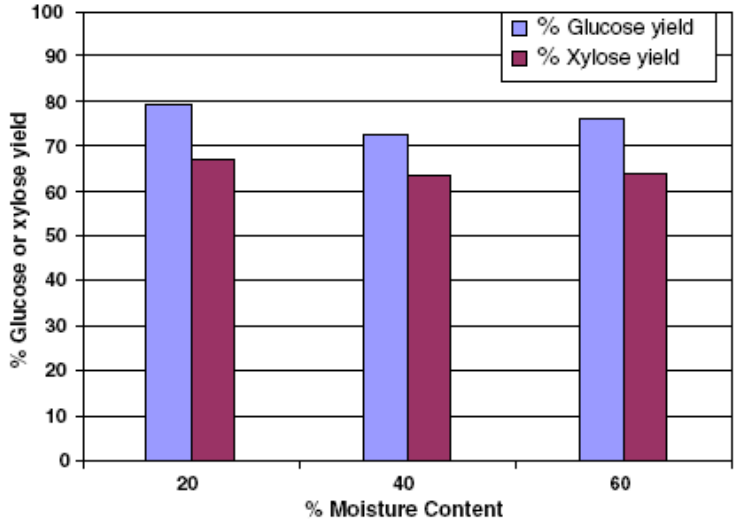


Figure 4. Glucose and xylose yields after enzyme hydrolysis of AFEX-treated corn stover at different moisture levels (Adapted from Sendich et al., 2008).

Based on these experimental results for ammonia loading and ammonia concentrations required in recycle streams, Sendich et al. (2008) concluded that an effective AFEX treatment for corn stover will result if 0.3 kg of ammonia is used to treat 1.0 kg of dry biomass, if the moisture is 0.25 kg per kg dry biomass.

AFEX treatment generates a unique biomass which is significantly different from the original untreated material. Although AFEX treatment does not change the macro appearance of stover (Figure 5), it disrupts the fiber micro-structure (Figure 6) and increases the available surface area for enzymes to access. These changes make AFEX-treated material more susceptible to enzyme hydrolysis.

Figure 5. Comparing macro appearance of untreated and AFEX treated corn stover

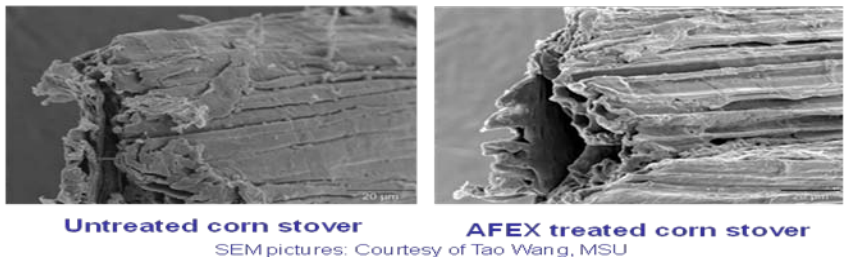


Figure 6. Comparing micro appearance of untreated and AFEX treated corn stover

AFEX treatment also decreases cellulose crystallinity. MSU researchers have performed a detailed investigation on the physical and chemical characteristics of AFEX-treated corn stover compared to untreated corn stover (Laureano-Perez et al., 2005). The X-ray diffraction analysis showed that AFEX reduced the crystallinity of the cellulose fraction. The same study revealed that AFEX also reduces acetyl linkages. DRIFT analysis showed a reduction of the carbonyl peak and a decrease in the lignin peak in AFEX-treated stover, which implies a decrease in the number of bonds associated with hemicellulose and a disruption in the lignin polymer. Furthermore, AFEX treatment alters the lignin structure of biomass as shown in Figure 7 (adapted from Balan et al., 2006). Lignin is one of the major

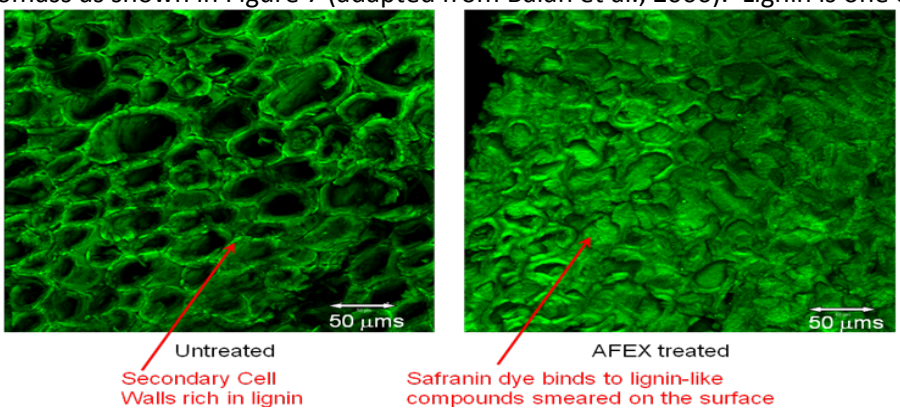


Figure 7. LSCM (Laser Scanning Confocal Microscope) using Safranin Fluorescent dye on corn cob fiber cell cross section.

recalcitrant components in biomass which binds irreversibly to enzymes and reduces net enzyme activity during hydrolysis. AFEX treatment improves enzyme accessibility by cleaving certain lignin and lignin-hemicellulose cross-linkages. It has been shown (Kumar et al., 2009) that lignin in AFEX-treated corn stover and poplar had lower cellulase adsorption capacity when compared to biomass treated under other pretreatments. Lower cellulase adsorption capacity may explain why AFEX-treated biomass can make efficient use of enzyme (see below), even though AFEX treatment removes little lignin. While AFEX causes changes in lignin structure, the carbohydrate composition of biomass is preserved during AFEX treatment, as the data in Table 2 shows.

Table 2. Composition of biomass before and after AFEX

	Glucan	Xylan	Galactan	Arabinan
Wheat straw	38.98	19.26	1.53	3.97
AFEX treated wheat straw	38.82	18.37	1.11	2.88
Corn stover	31.58	20.13	1.08	2.9
AFEX treated corn stover	32.14	19.4	1.9	2.9

High yields of fermentable sugars can be obtained from AFEX-treated biomass at relatively low enzyme loadings. The enzyme loading in the hydrolysis step is one of the factors that determines the rate and extent of polysaccharide hydrolysis. The pretreatment and hydrolysis steps are intimately coupled. The effects of a poor pretreatment can be overcome, to some extent, by higher enzyme loadings. Similarly, an effective pretreatment can reduce the required enzyme loading substantially. AFEX does indeed significantly reduce required enzyme loadings. Data in Figure 8 show that cutting enzyme levels 4 fold (60 FPU to 15 FPU/g of glucan) decreases the glucan conversion AFEX-treated corn stover only by 4% and xylan conversion by 5%. A further cut to 7 FPU/g of glucan results in 13% and 21% reduction in glucan and xylan conversion respectively. These results have great economic significance. It is likely that the cost of biomass ethanol can be reduced because of the high sugar yields obtained by AFEX at moderate to low enzyme loadings (Teymouri et al., 2005a).

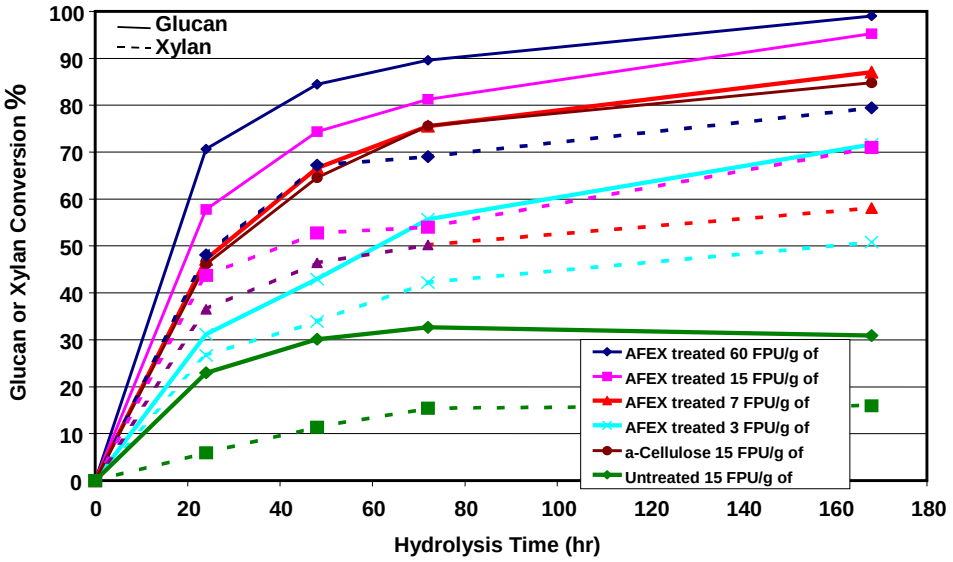


Figure 8. Hydrolysis of AFEX treated corn stover at different enzyme loadings.

AFEX treatment gives yields of fermentable sugars equivalent to or greater than yields from leading pretreatments. Table 3 summarizes the hydrolysis yields of each treatment method evaluated under the recent Biomass Refining Consortium for Applied Fundamentals and Innovation (CAFI) study (Wyman et al., 2005b). The consideration of sugar yields must account for the fact that the overall system consists of two stages for each treatment system evaluated, and that not all of the sugar is released as monomers. In Stage 1, biomass is treated to open up the structure of the residual solids and facilitate access by enzymes to obtain high yields. Enzymes are then added to the treated solids in Stage 2. For many operations, some amounts of glucose and xylose are released in Stage 1 and recovered in the liquid stream. Furthermore, although cellulase enzyme is added in Stage 2, it has enough xylanase activity to hydrolyze a substantial portion of the xylan, and both xylose and glucose are typically found in the liquid streams from Stage 2. Thus, yields of each sugar are reported for each stage as appropriate. Because some treatments produce sugar oligomers as well as monomers in Stage 1, the yields of each sugar from each stage are further differentiated to reflect this information. Comparison of the amount of each sugar monomer or oligomer produced to the maximum potential amount for that sugar would give the percent yield of each. However, it is important to recognize that corn stover, along with most other forms of cellulosic biomass, are richer in glucose than xylose, and as a result, yields of glucose have a greater impact than those of xylose. Thus, sugar yields were defined by dividing the amount of xylose or glucose, or the sum of the two, by the maximum potential amount of both sugars to better reflect the relative contribution to overall sugar production. It is clear from Table 3 that hydrolysis of AFEX-treated corn stover gave the higher sugar yield than corn stover pretreated with dilute acid or steam explosion.

Table 3. Overall sugar production from corn stover processed by different pretreatment technologies. Hydrolysis was performed with 15 FPU of cellulase / gram of cellulose.

Pretreatment system	Xylose yields*			Glucose yields*			Total sugars*		
	Stage 1	Stage 2	Total xylose	Stage 1	Stage 2	Total glucose	Stage 1	Stage 2	Combined total
Maximum possible	37.7	37.7	37.7	62.3	62.3	62.3	100.0	100.0	100.0
Dilute acid	32.1/31.2	3.2	35.3/34.4	3.9	53.2	57.1	36.0/35.1	56.4	92.4/91.5
SO_2 Steam explosion	14.7/1.0	20.0	34.7/21.0	2.5/0.8	56.7	59.2/57.5	17.2/1.8	76.7	93.9/78.5
Flowthrough	36.3/1.7	0.6/0.5	36.9/2.2	4.5/4.4	55.2	59.7/59.6	40.8/6.1	55.8/55.7	96.6/61.8
Controlled pH	21.8/0.9	9.0	30.8/9.9	3.5/0.2	52.9	56.4/53.1	25.3/1.1	61.9	87.2/63.0
AFEX		34.6/29.3	34.6/29.3		59.8	59.8		94.4/89.1	94.4/89.1
ARP	17.8/0	15.5	33.3/15.5		56.1	56.1	17.8/0	71.6	89.4/71.6
Lime	9.2/0.3	19.6	28.8/19.9	1.0/0.3	57.0	58.0/57.3	10.2/0.6	76.6	86.8/77.2

*Cumulative soluble sugars as total/monomers. Single number = just monomers.

Maximal utilization of all the biomass polymeric sugars is essential to make the economics of biomass processing feasible. Existing cellulase mixtures have been developed to hydrolyze mostly acid/high temperature treated biomass and are not optimal for AFEX-treated material. AFEX-treated

biomass, unlike acid-pretreated materials, has significant amounts of hemicellulose that needs to be hydrolyzed to monomeric sugars. Considering the necessity of reducing overall enzyme costs and the fact that hydrolysis of glucan and xylan are very closely linked, it is important to improve the balance between cellulase and xylanase activities in the hydrolysis mixture. As Figure 9 makes apparent, supplementing low cellulase (5 FPU vs. 15 FPU) hydrolysis with some xylanase activity allowed us to release about 82% of total available glucose and xylose compared to 85% with only cellulase hydrolysis.

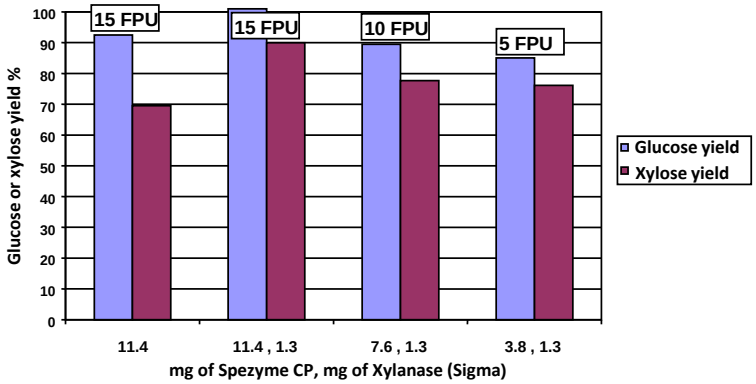


Figure 9. Glucose and xylose yields from 168-hour hydrolysis of AFEX treated corn stover with combination of cellulase and xylanase.

Table 4. Operating conditions for AFEX and various stover pretreatments (Wyman et al., 2005).

Process	Chemicals Used	Temp (^{o}C)	Pressure (atma)	Reaction Time	Solids Concentration (wt %)
AFEX treatment	Ammonia 100 wt%	70-90	15-20	<5 minutes	60-90
Dilute sulfuric acid cocurrent pretreatment	Sulfuric acid 0.5-3 wt%	130-200	3-15	2-30 minutes	10-40
Flowthrough pretreatment	Sulfuric acid 0.0-0.1 wt%	190-200	20-24	12-24 minutes	2-4
pH controlled water pretreatment	Water or stillage	160-190	6-14	10-30 minutes	5-30
ARP pretreatment	Ammonia 10-15 wt%	150-170	9-17	10-20 minutes	15-30
Lime pretreatment	$Ca(OH)_2$ 5-15 wt%	70-130	1-6	1-6 hours	5-20
Lime + air pretreatment	$Ca(OH)_2$ 5-15 wt%	25-60	1	2-8 weeks	10-20

Total amount of enzyme (cellulase + xylanase) used in this experiment was about 20% less than the amount of enzyme used in only cellulase (15 FPU) hydrolysis and resulted in only about 2% less total sugar release. These data show that cellulase and xylanase activities can be optimized to reduce the total enzyme loading in enzymatic hydrolysis of AFEX-treated biomass (Teymouri et al., 2005b).

AFEX reactors do not require acid-resistant materials of construction, so reactor capital cost is significantly lower than for dilute acid and SO_2-catalyzed steam explosion (Eggeman and Elander, 2005). Table 4 summarizes operating conditions for AFEX treatment and for various processes for pretreatment of corn stover. The AFEX process is operated at milder conditions compared to dilute acid and SO_2 catalyzed steam explosion.

Enzyme hydrolysis of AFEX-treated corn stover yields sugars that are readily fermented to ethanol. MSU researchers have recently performed a side by side test to compare fermentabilities of sugars generated from hydrolysis after AFEX treatment and dilute acid pretreatment of corn stover (Lau et al., 2007). Fermentations were performed at low initial density and at about 20% solid loading of treated biomass. *E. coli* KO11 and *Saccharomyces cerevisiae* 424A (LNH-ST) were used in this evaluation. It is clear from Figure 10 that both organisms were able to ferment hydrolyzates generated from AFEX-treated corn stover without any conditioning or detoxification. However in contrast, hydrolyzates generated from dilute acid treated corn stover were hardly fermentable without detoxification (not fermentable at all in *E. coli* KO11 case and exhibited a very long lag phase (almost 72 hr) in *S. cerevisiae* 424A (LNH-ST) case.

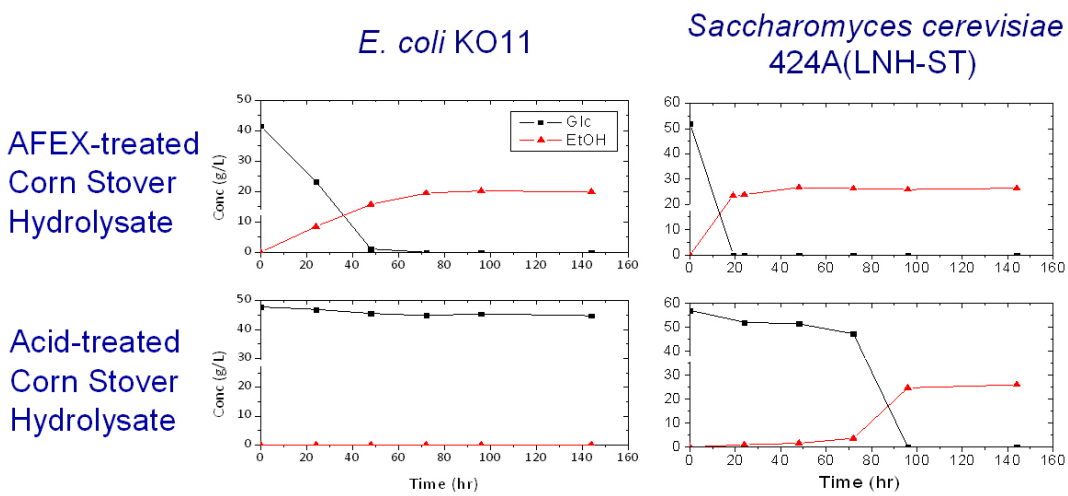


Figure 10. Comparing fermentability of AFEX and dilute acid pretreated corn stover

There is little or no (depending on biomass type) formation of degradation products during AFEX treatment. Consequently, AFEX-treated biomass is compatible with diverse organisms. In a recent study by MSU researchers (Balan et al., 2006) concentrations of inhibitory compounds in AFEX treatment are trace level and are much lower than those generated from leading pretreatments such as the dilute acid process. Furfural and hydroxymethylfurfural, inhibitory products from the degradation of pentose and hexose sugars, were not detected in hydrolyzate after AFEX treatment, but were present at concentrations of 1,797 mg/L and 88 mg/L, respectively, in acid hydrolyzate. The basis for this comparison was valid on a solid-to-liquid basis. For acid treatment, 1 gm of biomass was treated with 10 times liquid, while for AFEX-treated material, 1 gm of AFEX biomass was washed in 10 times the amount of water. Thus the amount of compounds produced in both liquid streams is on a comparable basis.

AFEX treatment offers significant advantages for densification, storage, and transport of treated biomass. Unlike leading pretreatments which result in wet treated biomass, AFEX-treated biomass is relatively dry and inert, and hence it is more easily storable and transportable. AFEX-treated biomass can also be densified to further improve bulk handling properties. Because of these unique features, biomass can be preprocessed and treated at a site close to the biomass source, then the treated materials can be shipped to a centralized biorefinery location. Initial trials at MSU have shown that the density and other properties of pellets of AFEX treated biomass are better than pellets of untreated biomass. AFEX treatment transfers some lignin and hemicellulose oligomers to the surface of biomass fibers, where it can act as a binding agent. Hard, durable pellets have been made from AFEX-treated corn stover with a specific gravity of up to 1.16 without using any binders, whereas untreated corn stover pellets are much less dense and are not durable at all (see Figures 11 and 12).

Figure 11. AFEX-treated and untreated corn stover pellets.

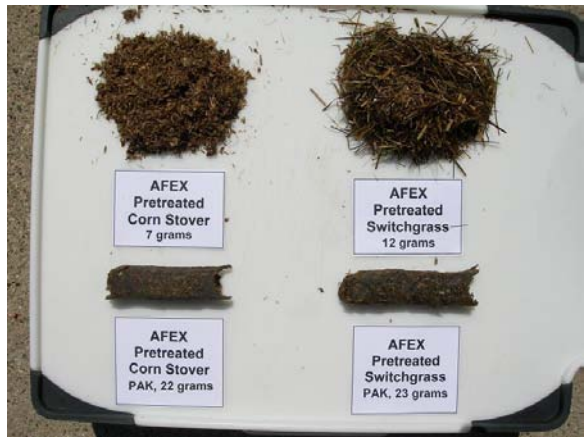


Figure 12. AFEX-treated and PAKed corn stover and switchgrass samples (AFEX treated material were densified using the ComPAKco device (Federal Machine, Fargo, ND).

MSU preliminary work has shown that AFEX-treated pellets are as readily dispersed in hydrolysis processes as unpelletized samples. Hydrolysis results have shown that pelletization has no adverse effects on hydrolysis yields of AFEX-treated biomass.

AFEX-treated biomass material is relatively dry (about 15 wt% moisture), and maintains its improved reactivity for long periods of time (up to several months) after treatment. Ammonia also exerts a strong antimicrobial action, thereby partially sterilizing the biomass. In one study (Dale and Moreira, 1982) it was observed that microbial growth on covered agar plates which had been streaked with AFEX-treated alfalfa had a much lower microbial load than untreated alfalfa after incubation at 37°C. Table 5 shows the carbohydrate compositions of untreated corn stover and AFEX-treated corn stover after 4 weeks of storage. Storage for 4 weeks after AFEX treatment did not cause any measurable loss of total carbohydrate content.

Table 5. Composition (dry weight basis) of untreated corn stover and AFEX-treated corn stover almost 4 weeks after the treatment.

	Glucan%	Xylan%	Galactan%	Arabinan%
Untreated corn stover	32.11	18.6	1.41	2.8
AFEX-treated corn stover (about 4 weeks after treatment)	32.8	18.8	1.4	2.7

2.2 Ammonia can be recovered efficiently from AFEX-treated biomass

Ammonia recovery will be a critical component of any commercially-viable AFEX treatment process. The cost of the ammonia catalyst, along with the environmental impacts of large-scale ammonia release or disposal, makes single-pass use of ammonia impractical. In any practical commercial AFEX plant, we estimate that greater than 95%, and probably as much as 98%, of the ammonia fed to the treatment reactor will have to be recovered downstream from the reactor and re-used. Despite the large amount of research that has been conducted on AFEX to date, very little experimental work has been done to develop effective methods for ammonia recovery from treated biomass. Nearly all of the studies of AFEX that have been conducted so far have used batch reactors without any ammonia recovery. It is practically impossible to demonstrate continuous AFEX with ammonia recovery at bench scale. Some of the operations necessary for continuous AFEX, such as feeding and discharge of biomass solids into and out of sealed pressurized reactor vessels, cannot practically be scaled down to bench level flow rates. Also, the dynamics of ammonia recovery in a continuous AFEX process are completely different from ammonia recovery from batch AFEX reactors. Designs for ammonia recovery in continuous AFEX processes are still only conceptual; real costs are unknown. The greatest barrier to development of the AFEX technology so far has been the inability to demonstrate the AFEX treatment system in a continuous operating mode wherein ammonia is removed from the biomass and reused in the process, and to fit this continuous AFEX system into an integrated processing system for producing fuel-grade ethanol. A pilot scale system is needed to evaluate the performance and measure material and energy requirements for the continuous AFEX process integrated with ethanol production and recovery.

There is bench-scale data to demonstrate that ammonia can be readily and efficiently recovered from AFEX-treated biomass. Preliminary work done at MBI (Figure 13) measured mass of ammonia charged to moist corn stover in a 1-gallon Parr reactor vessel, and mass of ammonia recovered after flash evaporation. The results showed that more than 98 wt% of the ammonia charge was recoverable, with less than 2 wt% trapped in the stover. In another preliminary study conducted by MSU researchers (Figure 14), it was shown that during AFEX treatment of corn stover, less than 3 wt% of ammonia is chemically bound to the stover. This small amount of residual ammonia remaining with the biomass may not be an economic loss, since it might serve as a nitrogen source for fermentation microorganisms during downstream processing for fuel and chemicals. However, both the cost of energy for ammonia recovery and the cost of ammonia recovery equipment will contribute to the overall operating and capital costs of commercial AFEX plants.

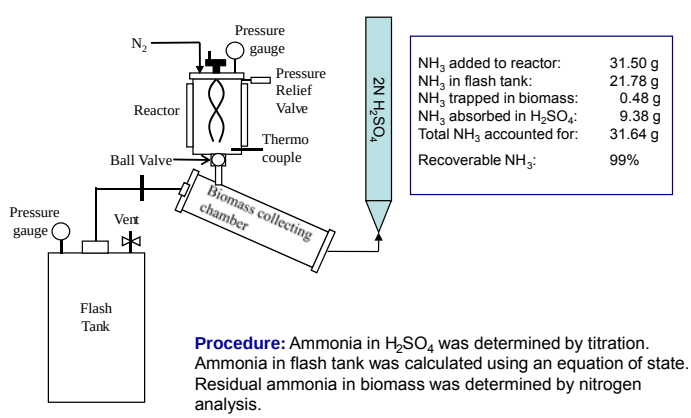
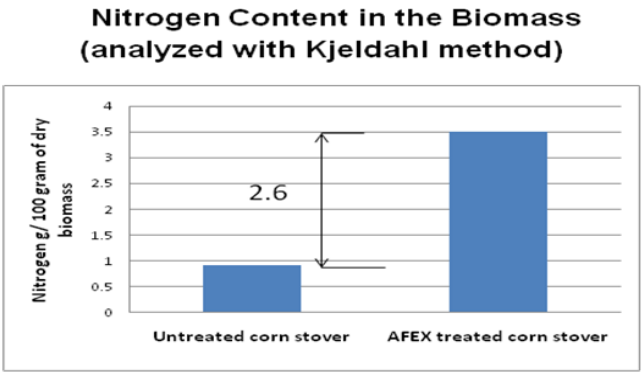


Figure 13. Procedure to investigate NH_3 recovery from corn stover.



Sources of Nitrogen:

1. De-acetylation reaction (Acetamide)
2. Reaction with protein/Lignin
3. Modification of acid functional group of Hemicellulose

Figure 14. Nitrogen analysis of corn stover before and after AFEX

The rate at which ammonia can be recovered from AFEX-treated biomass will determine the size and capital cost of recovery equipment. MBI researchers conducted a bench-scale study to measure rates of ammonia recovery from AFEX-treated wheat straw (Campbell et al., 2009). In the study, ammonia was recovered from a small batch of ground AFEX-treated wheat straw soaked in ammonia/water solution by indirect heating under nitrogen sweep gas. The results in Figure 15 show that 100 wt% ammonia recovery could be achieved in less than 15 minutes at an indirect heating flux of 2 watt/cm^2. This shows that residence time in an ammonia recovery dryer will be very similar to residence time in the AFEX reactor. It is reasonable to expect similar drying performance for AFEX-treated corn stover.

2.3 AFEX-treated biomass can be hydrolyzed and fermented at high solids loadings

AFEX treatment is better-suited for integration with high-solids hydrolysis and fermentation than leading pretreatments. In any process that involves fermentation of hydrolyzed biomass to produce ethanol, a significant concern is achieving a high enough ethanol concentration in the fermented beer to allow for cost-effective recovery of the ethanol product by distillation. Distillation energy cost per gallon of ethanol product increases as the beer concentration decreases, becoming prohibitive for ethanol concentrations below about 5 wt% (50 g/L). Stoichiometric conversion of sugars yields 51 wt% ethanol and 49 wt% carbon dioxide. Corn stover composition varies, but typically is composed of less than 60 wt% combined glucan and xylan (Aden et al., 2002, Table 1), and actual conversions of glucan and xylan to ethanol are normally less than 85% of stoichiometric conversion. As a result, to achieve 5 wt% ethanol concentration in the fermented beer requires at least 20 wt% loading of corn stover solids into a hydrolysis or Simultaneous Saccharification and Fermentation (SSF) process. This high solids loading can be difficult to achieve with acid-pretreated biomass, because the partial hydrolysis of cellulose and hemicellulose during acid pretreatment results in an aqueous stream containing diluted sugars. Co-loading of this dilute aqueous stream with the pretreated solids into an SSF process results in an effective solids loading less than 20 wt%. In contrast, AFEX treatment is a “dry in, dry out” process, meaning that the treated biomass can be completely recovered as a dry solid, without any dilute liquid sugar product streams. AFEX-treated stover can be loaded into SSF processes at concentrations of 20 wt% or higher, without any requirement for pre-concentration of dilute aqueous

sugar streams. AFEX treatment of corn stover is therefore more suitable for integration with SSF processes for ethanol production than are acid pretreatment methods. Figure 16 shows flasks containing SSF slurries of untreated and AFEX-treated corn stover at 18 wt% solids loads. The AFEX-treated stover SSF slurry was visibly less viscous and easier to mix than the untreated slurry.

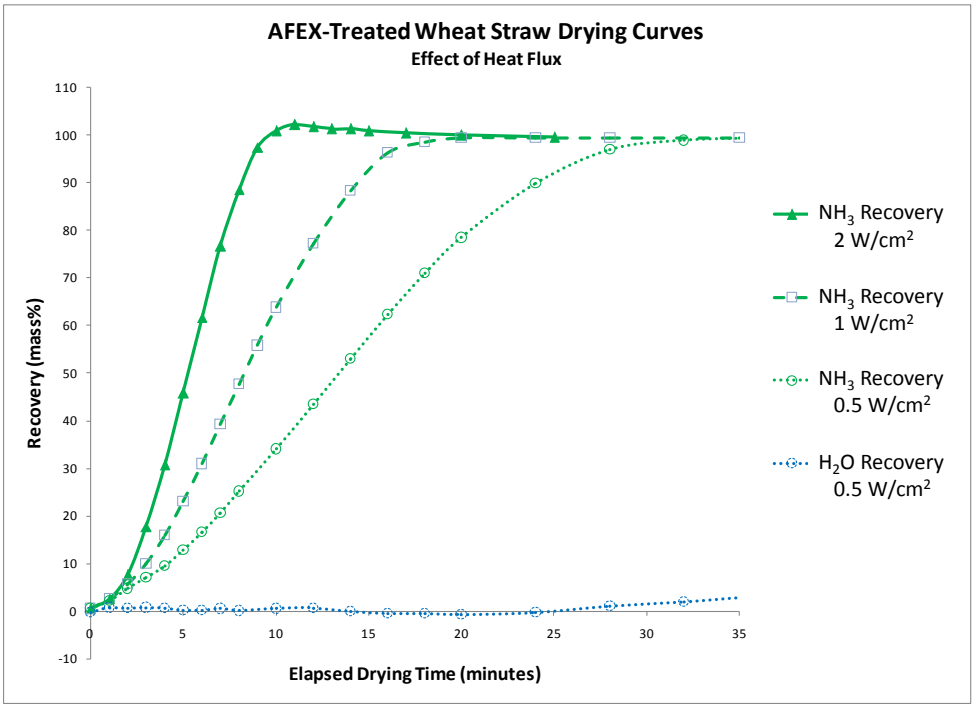


Figure 15. NH_3 and H_2O drying curves at different indirect heat fluxes for AFEX-treated wheat straw.

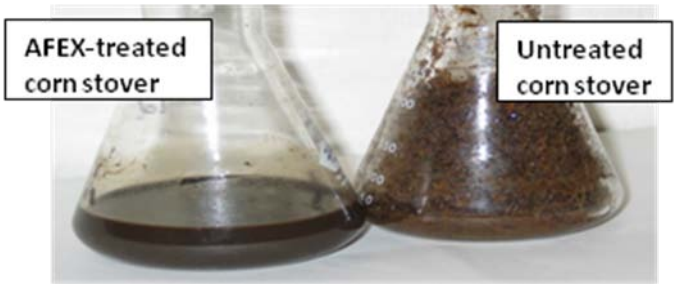


Figure 16. High solid loading (~18%) fermentation with untreated and AFEX-treated corn stover (adapted from Teymouri et al., 2005a).

For most of the leading biomass pretreatment methods, such as dilute acid or steam explosion, washing and detoxification steps are required to improve the fermentability of the treated biomass. These steps may well be prohibitively expensive and usually use large volumes of water, and generate a considerable wastewater treatment problem. Recent bench-scale studies at MBI and Michigan State

University have shown that even at high solid loading, washing or detoxification steps are not required to reach relatively high yields in hydrolysis and fermentation of AFEX-treated materials.

Lignocellulosic biomass is generally regarded to be nutrient-deficient. Results from a recent study by MSU researchers contradict this perception (Lau and Dale, 2008; Lau et al., 2008). The perceived nutrient deficiency is likely due to pretreatment at high temperature and acidic pH followed by washing, which degrades and/or removes nutrients. In contrast, nutrients provided through AFEX-treated corn stover were sufficient to support robust yeast growth. Residual ammonia left in the biomass after the AFEX process is an additional benefit as it can be used as a nitrogen source for the fermentation step. Using AFEX as a treatment method in an integrated biorefinery will help to reduce or eliminate the need for expensive commercial nutrient supplements such as yeast extract or corn steep liquor. The fermentation in Figure 17 was performed with minimal amount of corn steep liquor at 0.5% v/v, and the fermentation in Figure 18 was performed without any nutrient supplementation. The ethanol titer in Figure 18 reached 4 wt% (40 g/L). It is also important to note that both of these fermentations were inoculated at low initial cell density. Recent work by MSU researchers has shown that producing ethanol at bench scale at 5% v/v concentration from corn stover using AFEX as the treatment and a glucose- and xylose-utilizing microorganism is feasible without any washing, detoxification or nutrient supplementation at low initial cell density. This offers the potential to significantly improve the economics of cellulosic ethanol production by reducing the costs associated with raw materials, process water and capital equipment.

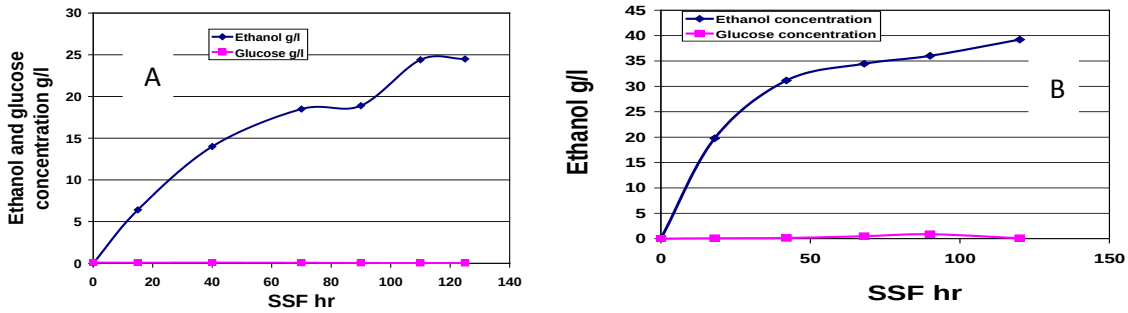


Figure 17. A: Fed batch SSF fermentation of unwashed AFEX treated cane leaf matter at 21% solid loading which resulted in 72% ethanol yield based on available glucose in biomass. B: Fed batch SSF fermentation of unwashed AFEX treated corn fiber 28% solid loading which resulted in 85% ethanol yield based on available glucose in biomass. *Saccharomyces cervisiae* was used in these fermentations.

The fermentation organism to be used in this pilot-scale project will be a recombinant strain of *Zymomonas mobilis*, developed at NREL specifically for ethanol production from biomass-derived sugars. This strain has been shown in bench-scale fermentations to be capable of utilizing both glucose and xylose for production of ethanol. In one bench-scale study conducted at MBI, AFEX-treated bagasse (treated at 100°C, 40% moisture content, 2:1 ammonia loading, 30 min treatment time) was hydrolyzed with Spezyme CP and Novozyme 188 at 50°C at a solid loading of 8 wt%, and the hydrolyzate then was used for ethanol production using the recombinant *Z. mobilis* at 28°C. The ethanol concentration reached 16 g/L after 72 hours of fermentation, which represented 66% of theoretical yield. Glucose and xylose concentrations after 72 hours were both < 0.2 g/L; this nearly complete utilization of both glucose and xylose clearly indicated the absence of inhibition to the microbial culture. Since bagasse usually gives lower fermentation yields than corn stover, it is reasonable to expect that this organism will perform as well or better on AFEX-treated stover.

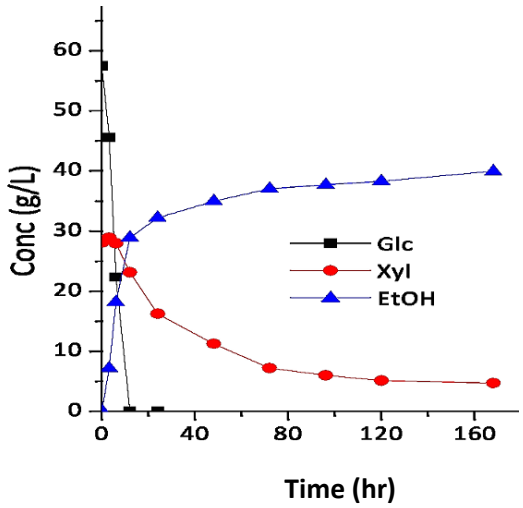


Figure 18. Separate Hydrolysis and fermentation (SHF) of unwashed AFEX treated corn stover with *Saccharomyces cervisiae* 424A(LNH-St), capable of utilizing both glucose and xylose in ethanol production. Hydrolysis was performed at about 18% solid loading the final ethanol yield based on available glucose and xylose is 65%

2.4 Commercial AFEX Integrated Biorefineries will produce ethanol at competitive MESP

AFEX treatment, along with several leading biomass pretreatment technologies, was evaluated by the Biomass Refining Consortium for Applied Fundamentals and Innovation (CAFI) group. A team of researchers from Auburn University, Dartmouth College, Michigan State University, The National Renewable Energy Laboratory (NREL), Purdue University and Texas A&M University coordinated a project to gather comparative information on the performance of leading pretreatment techniques. This work was performed by using a single feed stock (corn stover), common analytical methods, and a consistent approach to data interpretation. This evaluation (Mosier et al., 2005; Wyman et al., 2005a) showed that all these pretreatment methods have potential as cost-effective technologies. Along with AFEX treatment, the evaluated pretreatments were: dilute sulfuric acid cocurrent, flowthrough pretreatment, pH controlled water treatment, ammonia recycle percolation (ARP) and lime treatment. A comparison of the conditions used in these approaches is summarized in Table 4 above. In the second phase of the CAFI study (CAFI 2), the scope was expanded and University of British Columbia joined the team to evaluate the steam explosion pretreatment as one of the leading technologies. It was found that the Minimum Ethanol Selling Price (MESP) for ethanol produced using AFEX treatment was lower than for any pretreatment other than dilute acid (AFEX was only slightly higher than dilute acid).

Bench scale studies of AFEX biomass treatment have revealed a number of advantages over leading pretreatment technologies, including:

- AFEX treatment is effective on a variety of biomass feedstocks.
- AFEX treatment produces a stable intermediate, which can be densified, stored, and transported.
- AFEX treatment is compatible with diverse fermentation organisms.
- AFEX-treated biomass can be hydrolyzed and fermented with reduced enzyme and nutrient loads, without washing or conditioning steps.

Furthermore, the bench scale data presented above establishes that AFEX is an effective treatment for conversion of corn stover to ethanol, that ammonia can be recovered from AFEX-treated biomass, AFEX-treated corn stover can be hydrolyzed and fermented at high solids loadings, and that AFEX treatment

can be used to produce ethanol at competitive MESP. Based on these bench-scale findings, it is clear that the AFEX Integrated Biorefinery technology is ready for development at pilot scale.

3.0 Proposed AFEX Integrated Biorefinery

Description of Proposed Technology – The complete proposed field-to-fuel AFEX Integrated Biorefinery pilot process is described below. The process is divided into four steps at three locations: corn stover collection and pre-processing by Vermeer Corporation in Ames, Iowa; AFEX treatment and densification by MBI International in Lansing, Michigan; saccharification and fermentation by NREL in Golden, Colorado; and ethanol recovery also by NREL. This process is integrated in three key ways: 1) By producing ethanol as the primary product from 1 tonne/day (TPD) of corn stover through the entire process; 2) by linking each stage of the process to the next by the flow of a stable intermediate; and 3) by restricting energy and recycle streams within a given stage unless two stages are co-located. The only material transferred between separately-located stages is a stable intermediate. The major unit operations involved in each stage of the proposed process are described in detail below.

3.1 Corn Stover collection and preprocessing (Vermeer)

The corn stover will be supplied from land in either Mahaska or Marion County of Iowa. The current agricultural practices in these counties typically include frequent crop rotation between corn and soybeans with minimum or no-till practices. Fertilization and pest management is traditional, and depends on individual field characteristics. The stover will be harvested from crop lands up to a maximum of 9% slopes. The fields will be selected to provide typical crop properties, as possible. The specific hybrids, fertilization rates, and pest management tools utilized can be noted at the time of harvest, if so desired. The stover will be processed by grinding equipment located in Ames, Iowa, including a Vermeer BP-8000 bale processor, and a Vermeer HG-200 horizontal grinder. The process and equipment settings will be modified as required to produce material size of approximately ¼-inch particles. Electrical loads of milling equipment, water usage for washing (if any), and other relevant material and energy streams will be noted or measured as applicable. It should be noted that the transport of corn stover from Iowa to Michigan to Colorado is necessary to leverage the expertise of project partners at Vermeer, MBI, and NREL, while making use of existing facilities, in this pilot-scale project. We do not propose to transport biomass feedstocks over these distances as part of a commercial AFEX Integrated Biorefinery operation.

3.2 Continuous AFEX Technology (MBI)

Figure 19 shows a flow diagram of the continuous AFEX reactor system with ammonia recovery dryer.

3.2.1 Wash table or moisture adjustment

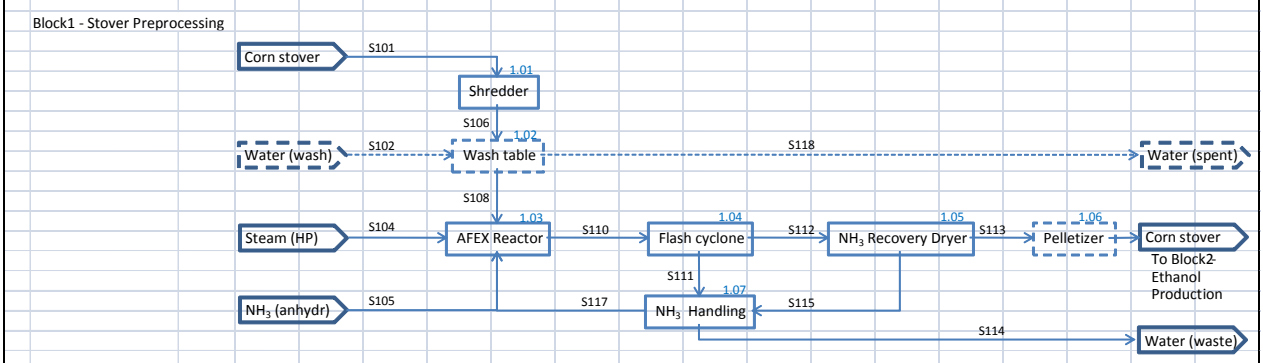
Corn stover shredded or milled to a particle size of ¼-inch will be fed from dry storage bins by conveyor or by loader truck into a wash table or pre-mixing vessel, where the moisture content of the stover will be increased from the storage moisture of less than 15 wt% to about 50 wt%. Water for moisture adjustment will be obtained from the ammonia recovery section of the process.

3.2.2 AFEX reactor

For continuous treatment of corn stover at pilot-scale processing rates (≥ one TPD), we propose to use a horizontal, Pandia-type digestor reactor vessel with plug screw feed and discharge devices. A diagram of a continuous AFEX Pandia-type reactor is shown in Figure 20. Horizontal Pandia-type reactor designs are commonly used for treatment of wood chips in pilot-scale pulping operations. Based on throughput of up to 100 kg dry stover/ hour (2.6 TPD), and using the estimated density of corn stover slurries in mixtures of ammonia and water, anticipated residence times of up to 30 minutes, and an estimated reactor volumetric fill fact of 35%, we can estimate the dimensions of the reactor vessel to be one meter diameter by 5 meters in length. Materials of construction for all wetted parts of the

continuous AFEX reactor system can be 300-series or DIN 1.4571 stainless steel, or equivalent. Double mechanical seals with water flush will be used for all of the transport screws in the reactor system. After moisture adjustment, the biomass will be loaded into a feed weighing conveyor. The feed weighing conveyor will transport the stover at a set mass flow rate into a feeder hopper. The feeder hopper uses twin feeder screws to force the moist stover particles into a plug screw feeder. The plug screw feeder is designed to form a compressed plug by forcing biomass against a choke cone.

MBI Proposed Pilot Plant - Unit Ops, Streams, and Mass Balances for Process Flow Diagram



Component	stream / Unit	S101	S102	S104	S105	S106	S108	S110	S111	S112	S113	S114	S115	S117	S118	Block1 MBal
Cellulose group	kg/hr	15				15	15	15		15	15					0
Hemicellulose group	kg/hr	11				11	11	11		11	11					0
Ash + Lignin	kg/hr	7.5				7.5	7.5	7.5		7.5	7.5					0
Crude protein	kg/hr	1.2				1.2	1.2	1.2		1.2	1.2					0
Acetate	kg/hr	1.2				1.2	1.2	1.2		1.2	1.2					0
Oils	kg/hr	3.6				3.6	3.6	3.6		3.6	3.6					0
Contaminants	kg/hr	1				1									1	0
Ammonia (NH_3)	kg/hr				0.7			50	23	27	0.7		26.3	49.3		0
Water/steam	kg/hr	7	40	20		7	19.3	73.6	1	72.6	4.5	34.8	68.1	34.3	27.7	0
Total mass flow	kg/hr	47.5	40	20	0.7	47.5	58.8	163.1	24	139.1	44.7	34.8	94.4	83.6	28.7	0.0
Pressure	psig	0	0	300	109	0	0	152	7	7	0	0	0	0	0	
Temperature	°C	20	20	217	20	20	20	90	26	26	80	20	80	20	20	
Moisture (wt%)		15	100	100	0	15	33	45	4	52	10	100	72	41	97	
Vapor fraction		0	0	1	0	0	0	0	1	0	0	0	1	0	0	
$NH_3/(NH_3+H_2O)$		0.00	0.00	0.00	1.00	0.00	0.00	0.40	0.96	0.27	0.13	0.00	0.28	0.59	0.00	

Figure 19. Flow diagram for the continuous AFEX reactor with ammonia recovery.

The compressed plug seals and segregates the pressurized sections of the reactor system from the hopper, which is at atmospheric pressure. The plug screw feeder will partially de-water the stover, and the water drained from the feeder will be returned to the pre-mixing vessel. The plug of biomass exiting the plug screw feeder will crumble as it falls into a mixing tee, where ammonia and steam will be added to achieve target composition and temperature of the slurry entering the reactor. The pneumatically- or hydraulically-activated choke cone positioned in the top of the mixing tee is used to prevent blowback of pressurized vapor from the mixing tee through the plug screw feeder in the event of imperfect plug formation in the feeder. Absorption of ammonia and steam will be enhanced by the expansion of the biomass fibers as the plug decompresses and crumbles into the vertical mixing tee. Complete mixing of ammonia and steam with the stover can be achieved by means of agitators within the mixing tee. The well-mixed slurry will fall from the outlet of the mixing tee into the first flight of the reactor screw. The reactor volumetric fill factor will be only about 35%, to allow for precise retention time control by preventing spillover from flight to flight along the reactor screw. The reactor operating pressure will depend on the ammonia concentration and the temperature of the mixed slurry. Vapor-Liquid Equilibrium (VLE) relationships of ammonia/water mixtures have been measured and studied

over wide ranges of temperature and concentration (Tillner-Roth and Friend, 1998; Smolen et al., 1991, Gillespie et al., 1987). The pressure, volume, temperature, and concentration (PVTx) behavior of ammonia/water mixtures can be accurately predicted over wide ranges using cubic equations of state with complex mixing rules (Duan et al., 1996), but can also be estimated with satisfactory accuracy over narrower ranges using simpler functions (Alamdari, 2007). Figure 21 shows VLE pressures of ammonia/water mixtures over ranges of temperature (25 to 120°C) and ammonia concentration (0 to 1 mole fraction) relevant to operation of a continuous AFEX reactor vessel. Under typical AFEX conditions, ammonia mole fraction would be about 0.4 (40 mole%), and temperature 90°C, making the saturation pressure 150 psig. The heavy line at 300 psig in Figure 21 indicates the anticipated pressure rating of the AFEX reactor vessel. Any ammonia concentrations or temperatures below this line will be allowable conditions for the reactor. It has been shown that the presence of biomass in ammonia/water systems has no effect on VLE pressures (Campbell et al., 2008). Residence time of the stover slurry in the reactor will be controlled by the transport screw rotation rate, which will be adjusted by a VFD controller. Residence time will be variable from 10 to 30 minutes. As the stover slurry reaches the end of the reactor vessel it will fall into a discharge plug screw, which will operate similar to the plug screw feeder, forming a seal to hold pressure in the reactor while allowing the slurry to discharge continuously from the reactor.

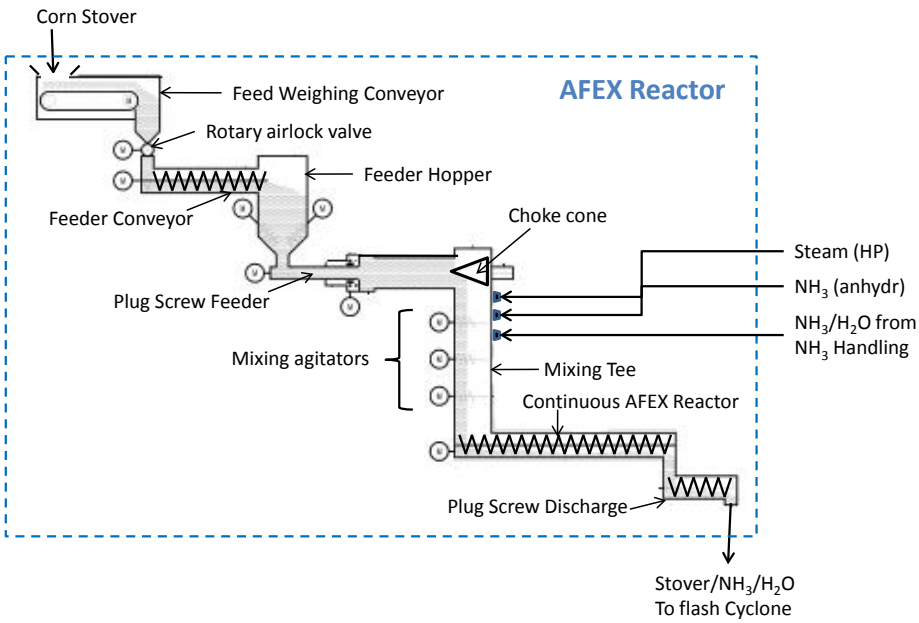


Figure 20. Continuous AFEX reactor system.

3.2.3 Flash cyclone

As the stover/ammonia/water slurry is discharged out of the reactor by the discharge screw, the pressure will rapidly drop from the reactor operating pressure to near atmospheric pressure, allowing for rapid expansion of ammonia vapor. This rapid expansion will drive flow through a transfer pipe to a flash cyclone, where separation of ammonia-rich vapor from wet solids will occur. The ammonia vapor from the flash cyclone will be transported to the ammonia handling section, while the wet solids will be discharged from the bottom of the cyclone by means of a discharge screw into the continuous ammonia recovery section.

3.2.4 Ammonia recovery dryer

Several possible approaches exist for recovery of ammonia from the biomass as it is discharged from the continuous AFEX reactor system. However, at present these approaches are only conceptual; none have been tested at any scale. Three general approaches to ammonia recovery that are worth considering are vacuum drying, steam stripping, and superheated ammonia stripping. Figure 22 shows flow sketches illustrating how each of these three approaches might work in practice. In a vacuum drying approach (Figure 22-a), an indirectly-heated (e.g. steam-jacketed) dryer is evacuated to a slightly sub-atmospheric pressure using a vacuum blower.

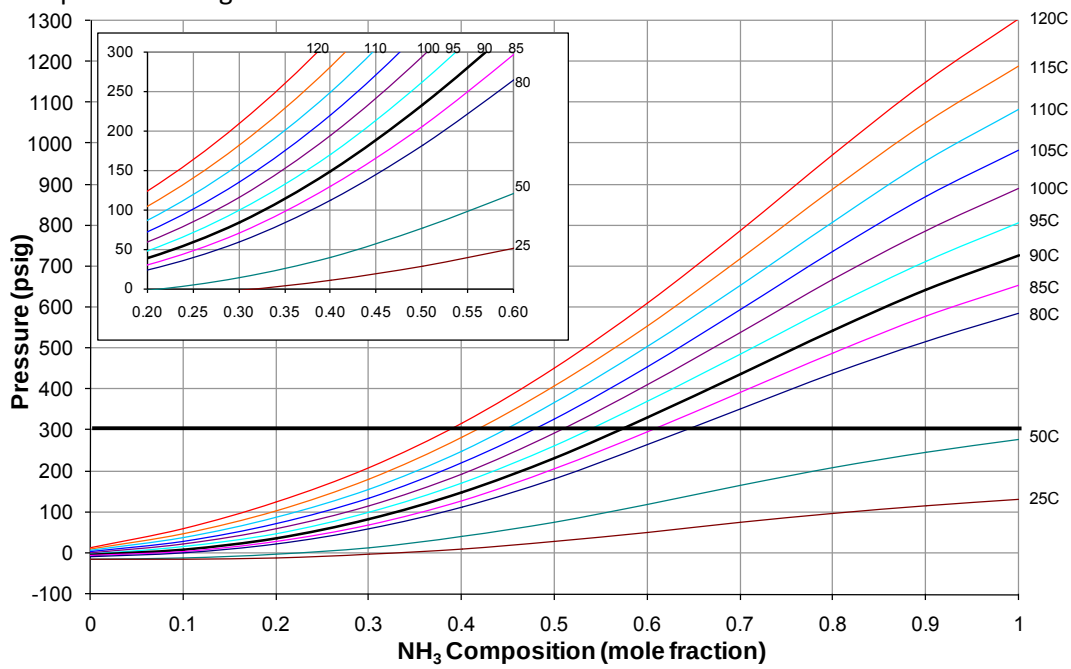


Figure 21. Pressures of saturated ammonia/water mixtures at temperatures from 25 to 120°C.

The vapor from the dryer is a mixture of water and ammonia, which is condensed and mixed with the condensed vapor from the flash cyclone. The condensed mixture is stored in a pressurized tank for recycle to the AFEX reactor. In a steam stripping approach (Figure 22-b, adapted from Laser et al., 2009), ammonia is stripped from the biomass in a contacting column using superheated steam. The vapor from the top of the column may then be quenched by mixing with cold water in the ammonia handling operations, and the ammonia/water mixture is condensed and pumped back into the AFEX reactor. In a superheated ammonia stripping approach (Figure 22-c), water and ammonia vapor are stripped from the biomass in a directly heated dryer. Vapor is drawn from the dryer using a blower, and mixed with vapor from the flash cyclone in the ammonia handling operations, where water is separated out with a condenser or distillation column, and the ammonia-rich stream is split into two streams, one of which is recycled to the AFEX reactor, while the other is superheated and recirculated to the dryer. Each of these conceptual approaches could be practiced in a variety of different specific configurations, using different hardware. The primary performance requirement for any ammonia recovery approach is that the total ammonia recovery must meet the minimum for economic operation of the process, which we anticipate will be at least 95 wt%, and probably greater than 98 wt% recovery. A secondary performance requirement is that the approach should minimize the energy input for recovering the ammonia.

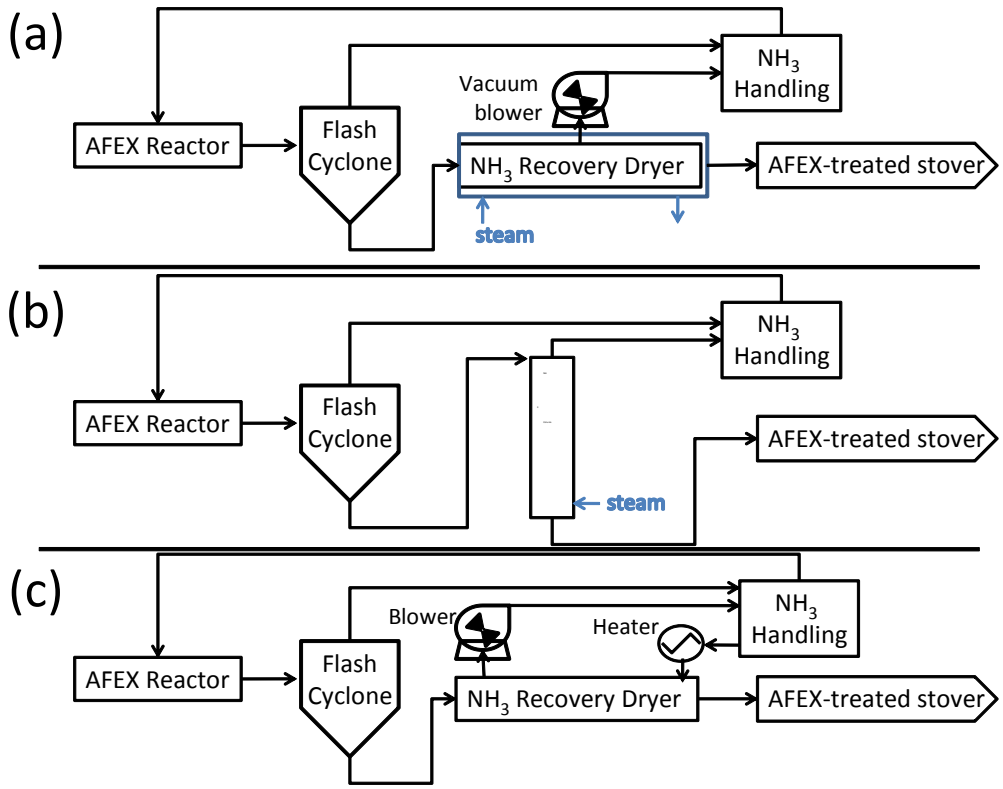


Figure 22. Three concepts for ammonia recovery from AFEX-treated corn stover. (a) Vacuum drying approach; (b) Steam stripping NH_3 Column approach; (c) Superheated ammonia stripping approach.

3.2.5 Ammonia handling

Any vapor or liquid streams arising from the Ammonia Recovery section of the continuous AFEX process will have to be consolidated and, if necessary, separated and purified to allow for recycle back to the AFEX reactor. Water recycle to the pre-mixing vessel for stover moisture adjustment must be low in ammonia concentration, because the pre-mixing vessel and live-bottom feeder will both be open to the atmosphere. Depending on the ammonia recovery approach used, the separation techniques used in the ammonia handling section may be simple condensers, or more complex distillation columns may be required. Design and operation of distillation columns for separation of ammonia/water mixtures have been studied and modeled, and the relevant thermodynamic and transport properties of these mixtures have been measured (Figueiredo et al., 2006; Chua et al., 2002). The design of an effective ammonia handling system integrated with an ammonia recovery approach will require a research effort to acquire design data during the first budgetary period of the project. The research effort needed to obtain ammonia recovery and handling data is outlined in the task descriptions below.

3.2.6 Densification

Treated corn stover will be densified for storage and transport to hydrolysis facilities. A number of options exist for densification equipment, including pellet presses, gear mesh particle compactors, etc. It is anticipated that the treated stover will need to be dried to less than 15 wt% moisture in the ammonia recovery section to allow for effective densification and storage without excessive spoilage. The detailed specification of the densification equipment to be used in this project will make use of the results from an ongoing research effort at MSU (Dale, 2009), which is studying densification of corn stover, switchgrass, and prairie cordgrass, with the intention of optimizing densification conditions at

bench scale. ComPaker densification equipment, manufactured by Federal Machine Co. of Fargo, ND, is an example of an efficient mechanical design that has proven in preliminary testing to be effective for densification of AFEX-treated corn stover.

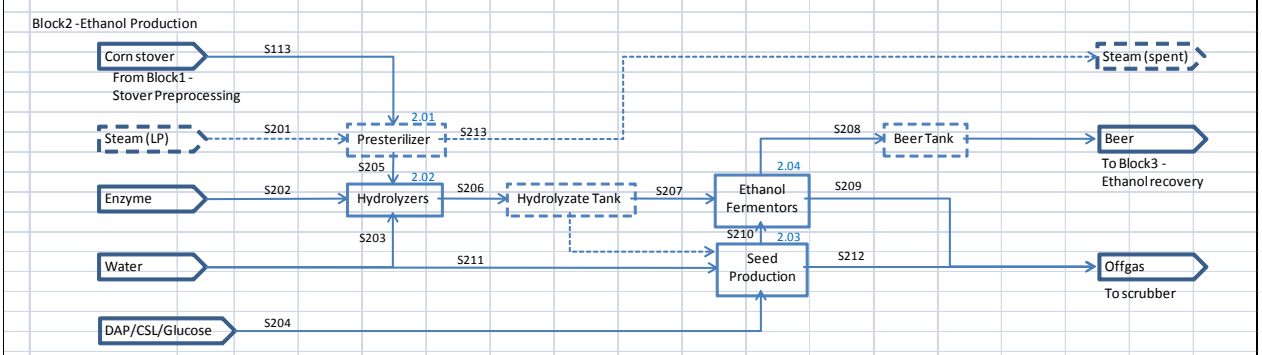
3.3 High Solids Hydrolysis and Fermentation Technology (NREL)

Figure 23 is a flow diagram of the hydrolysis and fermentation process.

3.3.1 High solids enzymatic hydrolyzers

The treated corn stover will be hydrolyzed enzymatically in modified ribbon blender-type reactors sized for approximately 24 hours of residence time at solids loadings of 20 wt% or greater. The details of the process for high solids enzymatic hydrolysis at pilot scale are unknown at this time. A research effort to determine the equipment and methods required for high solids hydrolysis of AFEX-treated corn stover is described in the task descriptions below. It is anticipated that the treated stover at 20 wt% solids will be a highly viscous slurry that will initially be difficult to mix with enzyme solutions. At least 24 hours of residence time in the hydrolyzers at 50°C minimum will be needed to break down the solids to the point at which the slurry viscosity will permit transfer by pump to the ethanol fermentors.

MBI Proposed Pilot Plant - Unit Ops, Streams, and Mass Balances for Process Flow Diagram



Component	stream Unit	S113	S201	S202	S203	S204	S205	S206	S207	S208	S209	S210	S211	S212	S213	Block2 MBal
Cellulose group	kg/hr	15					15	0.9	0.9	0.9						
Hemicellulose group	kg/hr	11					11	0.66	0.66	0.66						
Ash + Lignin	kg/hr	7.5					7.5	7.5	7.5	7.5						
Crude protein	kg/hr	1.2					1.2	1.2	1.2	1.2						
Acetate	kg/hr	1.2					1.2	1.2	1.2	1.1						
Oils	kg/hr	3.6					3.6	3.6	3.6	3.6						
Ammonia (NH3)	kg/hr	0.7					0.7	0.7	0.7	0						
Water/steam	kg/hr	4.5	45	0.6	160	2	4.5	165.1	165.1	187.1		22	20		45	0.0
Sugars (C6)	kg/hr					2.8		14.1	14.1	1.41		0.28				
Sugars (C5)	kg/hr							10.34	10.34	1.034						
Ethanol	kg/hr									12.5		1.29				
Cellulase	kg/hr			0.1				0.1	0.1	0.1						
CO2	kg/hr									0.01	12.0			1.23		
Others	kg/hr					0.3				0.148		0.3				
Total mass flow	kg/hr	44.7	45	0.7	160	5.1	44.7	205.4	205.4	217.3	11.97	23.87	20	1.23	45	0.0
Pressure	psig	0	125	0	0	0	0	0	0	0	0	0	0	0	0	
Temperature	°C	20	179	20	20	20	90	65	41	41	41	41	20	41	100	
Moisture (wt%)		10	100	86	100	39	10	80	80	86	0	92	100	0	100	
Vapor fraction		0	1	0	0	0	0	0	0	0	1	0	0	1	0	
Ethanol concentration	wt%	0	0	0	0	0	0	0	0	5.77	0	5.40	0	0	0	
NH3/(NH3+H2O)		0.13	0.00	0.00	0.00		0.13	0.00	0.00	0.00		0.00	0.00			

Figure 23. Flow diagram for pilot hydrolysis and fermentation operations.

3.3.2 Ethanol fermentors and seed production train

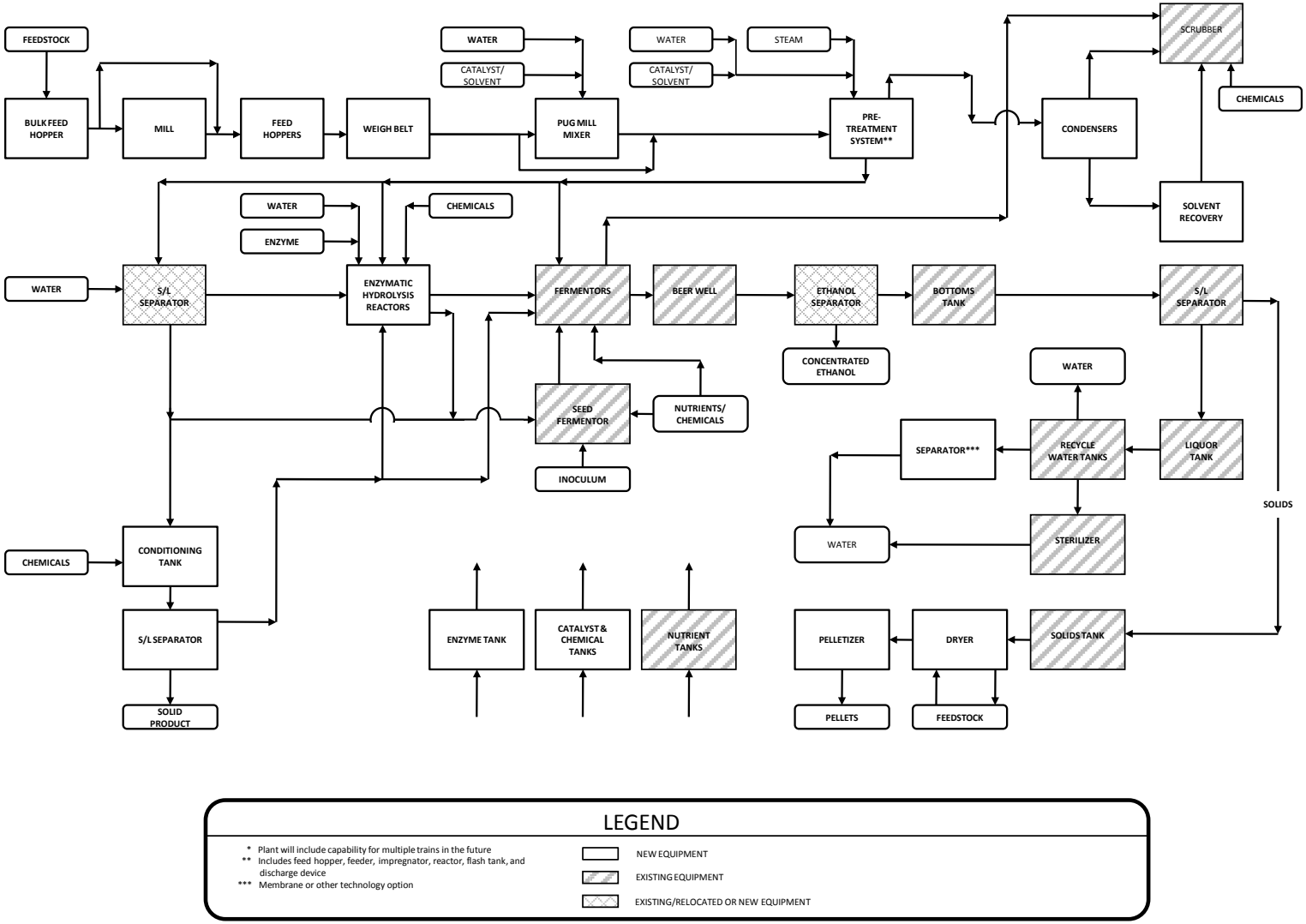
The partially hydrolyzed stover slurry from the enzyme hydrolysis reactors will be transferred by pump to large fermentor vessels for further hydrolysis and ethanol fermentation. Fermentation equipment at NREL's Integrated Biorefinery Research Facility (IBRF) includes four 9000-liter, two 1450-liter, and two 160-liter fermentors. All can be used for separate or combined hydrolysis, and all fermentors are equipped with temperature, pH, dissolved oxygen, and agitation control. The pilot plant fermentors can also process high solids material (greater than 20% total solids). The Process Development Unit (PDU) has a very sophisticated control and data acquisition system for all facets of plant operations in its control room. Spectroscopic monitoring of fermentation off-gas composition makes it possible to calculate oxygen transfer rates. The data acquisition system provides information to conduct material and energy balances. Figure 24 shows a concept flow diagram of NREL's Integrated Biorefinery Research Facility (IBRF), including the hydrolyzers, seed train, ethanol fermentors, and distillation equipment. After appropriate residence time in the fermentor vessels, it is expected that the alcohol titer in the beer will reach at least 5 wt%. At this point the beer can be transferred to the beer distillation column.

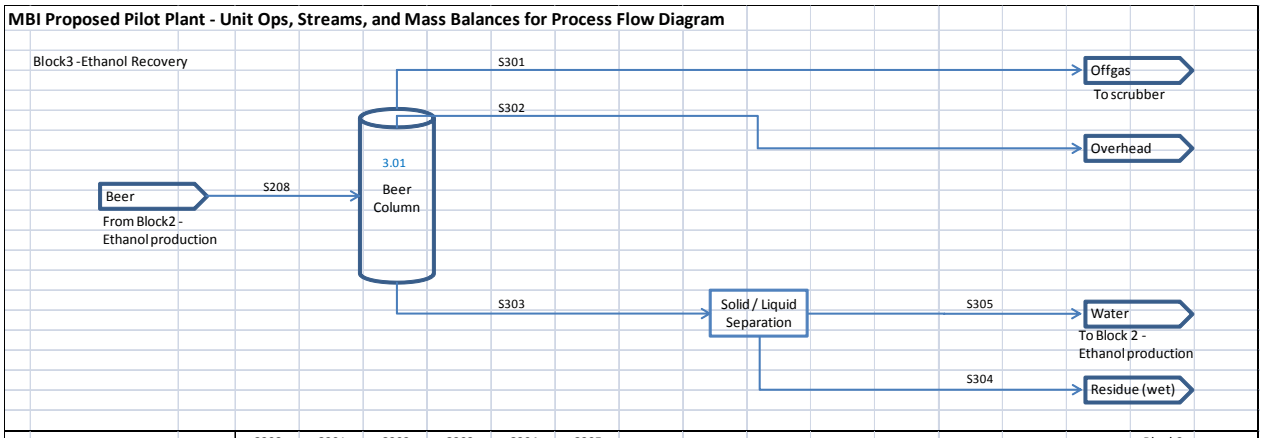
3.4 Ethanol Recovery Distillation Technology (NREL)

Distillation equipment at NREL's PDU includes a ten meter beer stripping column. This column will be used to remove dissolved carbon dioxide and concentrate the beer from an ethanol content of about 5% to approximately 40%. In the commercial biorefinery, the overhead vapor from the beer distillation column will be directed to a rectification column which will further concentrate the ethanol to a near-azeotropic composition, which can then be further dried using molecular sieves to yield fuel-grade ethanol. In this project, the overhead vapor from the beer distillation column will not be concentrated further, because the operation of rectification and molecular sieve dehydrating columns are established technologies that do not need further development. Solid/liquid separations of the beer distillation column bottom stillage can be achieved using a continuous Solid-Bowl Decanting Centrifuge (Sharples) with up to 1,200 L/hr capacity at up to 3,000 x g, and a continuous Solid-Bowl Centrifuge (Cepa) that can process up to 250 L/hr at up to 17,000 x g. Figure 25 shows a flow diagram of the pilot ethanol recovery operations. Backset water recovered from the beer distillation column by centrifugation will be recycled to the hydrolysis reactors. NREL's PDU is equipped to provide for recycle of backset water between distillation and hydrolysis processes.

Solids recovered from the centrifuges will be sampled for composition analysis. In commercial AFEX Integrated Biorefineries using corn stover feedstock, it is anticipated that the lignin-rich solid residue recovered from the beer stripping column bottoms will be separated, dried, and used as boiler fuel to generate steam for electric power generation. The residue generated in this pilot-scale project will not be collected, dried, and combusted at 1 TPD scale, because these operations use technology that is already highly developed and well characterized. Nevertheless, the heating value of the residue from AFEX-treated corn stover after high-solids hydrolysis and fermentation must be measured to provide data for techno-economic modeling of the commercial process. Representative samples of the solid residue will be drawn from the solid/liquid separation centrifuges for measurement of moisture content and composition, from which the Lower Heating Value (LHV) of the dry residue can be calculated.

FIGURE 24. IBRF PROCESS FLOW CONCEPT (SINGLE TRAIN*)





	stream	S208	S301	S302	S303	S304	S305	Block3
Component	Unit							MBal
Cellulose group	kg/hr	0.9			0.9	0.9		0
Hemicellulose group	kg/hr	0.66			0.66	0.66		0
Ash + Lignin	kg/hr	7.5			7.5	7.5		0
Crude protein	kg/hr	1.2			1.2	1.2		0
Acetate	kg/hr	1.1			1.1	1.1		0
Oils	kg/hr	3.6			3.6	3.6		0
Water/steam	kg/hr	187.1	0.010	18.5	168.59	8.4295	160.1605	0
Sugars (C6)	kg/hr	1.41			1.41	0.0705	1.3395	0
Sugars (C5)	kg/hr	1.034			1.034	0.0517	0.9823	0
Ethanol	kg/hr	12.530	0.027	12.4	0.095	0.004727	0.089818	0
Cellulase		0.100			0.1	0.005	0.095	0
CO2		0.012	0.012		0	0	0	0
Others	kg/hr	0.148		0.05	0.098	0.0049	0.0931	0
Total mass flow	kg/hr	217.3	0.049	31.0	186.3	23.53	162.76	0
Pressure	psig	0	12	12	12	15	15	
Temperature	°C	41	60	113	123	92	121	
Moisture (wt%)		86	20.41	59.76	90.50	36	98	
Vapor fraction		0	1	1	0	1	0	
Ethanol concentration	wt%	5.8	55.1	40.1	0.05	0.0	0.1	

Figure 25. Flow diagram of pilot ethanol recovery operations**.**

3.5 Demonstration-scale unit operations not included in pilot plant

Four unit operations or process steps will not be included in the proposed pilot plant, but will be required in the commercial technology, and therefore will be necessary in the demonstration-scale plant. These unit operations are listed below, along with their functions in the commercial process, and our justifications for omitting them from the pilot plant.

Rectification and dehydration columns – The rectification distillation column will be required in a commercial plant to enrich the overhead vapor from the beer distillation column to near-azeotropic ethanol concentration (> 90% ethanol). The vapor phase dehydration columns will use packed beds of molecular sieve adsorbent to reduce the water content of the overhead vapor from the rectification distillation column to acceptable levels (< 0.5% water) for fuel-grade ethanol. The beer column overhead vapor produced in this project should not be different in any significant way from the overhead vapor generated in commercial corn grain ethanol plants. The rectification and dehydration operations used in commercial grain ethanol plants are developed technologies, and do not need to be investigated or developed further as part of this project.

Denaturant addition – In commercial ethanol production, denaturant must be blended with the dehydrated ethanol. Since no dehydrated ethanol will be produced in the proposed pilot plant, denaturant addition is unnecessary.

Residual solids evaporator and dryer – Dewatered residual solids from the beer column will be dried for use as combustor fuel in the commercial plant. Equipment and methods for water evaporation and final drying of residual solids are developed technologies that are in widespread use in corn ethanol plants.

Combustor and Turbo-generator power plant – In a commercial ethanol plant, combustion of the dried residual solids from the beer column will be combusted in an air-blown boiler to generate superheated steam, which will drive a turbo-generator for electric power generation. Some of the electric power will be used to supply plant electricity requirements, with any excess power sold to the grid as a secondary product of the biorefinery. Technologies and practices for solid-fueled combustor-boiler-generator systems are known. Combustion of the solid residue will not be conducted at pilot scale as part of this project. However, samples of the residue will be drawn and analyzed for composition. From the composition, the Lower Heating Value (LHV) of the residue can be calculated, along with CO_2 and ash emissions from the combustor in a commercial plant.

3.6 Pilot plant waste streams and emissions

Different waste streams and emissions may be generated at the MBI or NREL pilot plant locations:

MBI Location. As shown in the overall process flow diagram (see the PFD document attached to this application), some water streams from NH_3 handling (S114) may be discharged to sewer during transient operations. It is also possible that washing of corn stover may be necessary prior to AFEX treatment, and this washing step could generate spent water (S118). Spent water from washing would also be discharged to sewer. The proposed project may discharge up to 120 gallons per day of water with residual biomass or ammonia to the East Lansing Public Owned Treatment Works. All discharges from MBI's facility are in accordance with an agreement with the City of Lansing. MBI workers are provided training addressing discharges. No hazardous waste is discharged.

NREL Location. Waste and emission streams from the proposed pilot plant are anticipated to include CO_2-rich offgas streams from fermentor vessels, seed train, and the beer column (streams S209, S212, and S301 in the PFDs). These offgas streams will be treated in a scrubber unit in the IBRF (see Figure 24 above). A lignin-rich solid residue waste stream will also be generated in solid/liquid separation of the beer column bottoms, and will be disposed of according to NREL's standard PDU discharge procedures. In the event that pre-sterilization of AFEX-treated stover is required before hydrolysis, some condensed spent steam may be generated from the pre-sterilizer, which can also be discharged to sewer. NREL prohibits the discharge of chemicals from research laboratories and facility operations. All discharges from NREL's ethanol pilot plant are in accordance with NREL's agreement with the Pleasant View Water and Sanitation District and the Metro Wastewater Reclamation District. The broth stillage (or its centrate/filtrate) and ethanol-rich condensed overhead vapor would be discharged under standard PDU discharge procedures. Any fermentation beer (including accidental spills) that contain live recombinant cells must be killed (with kill verification) prior to disposal or discharge. NREL has a Biosafety Authorization Program that specifies such disposal procedures on an individual project basis before authorization to operate is granted. The killed broth is then sent to the PDU Neutralization Tank (as are all liquid effluent that are being discharged from our pilot plant) for pH adjustment prior to discharge, per agreements with the local wastewater utility district.

3.7 Selection of sites for the proposed pilot plant

The proposed Integrated AFEX Biorefinery will be conducted at three locations: At Vermeer facilities in Ames, Iowa; at MBI International facilities in Lansing, Michigan; and at NREL facilities in Golden, Colorado. Vermeer's new facility in Ames is currently under construction, but is scheduled to receive all necessary permits for biomass processing before the scheduled start of this proposed project. MBI currently has permits in place for anhydrous ammonia storage and handling at their facility in Lansing. No new environmental permitting requirements for ammonia handling or any other materials are anticipated for the new pilot plant. MBI works with MSU's compliance experts on all environmental

permitting, site selection, and health & safety issues. NREL's PDU in Golden is already permitted for biomass handling at 1 TPD scale. The use of these existing permitted facilities will expedite the execution of the proposed project while minimizing costs. Section 8 of the Project Management Plan (PMP) discusses the project Safety Plan in more detail, including anhydrous ammonia storage and handling at MBI, and established safety systems at NREL.

3.8 Life Cycle Analysis of the proposed AFEX Biorefinery

A Life Cycle Analysis (LCA) has been conducted by MBI and MSU for an envisioned commercial AFEX Integrated Biorefinery to determine net GHG emission reductions for our primary product, ethanol, compared to petroleum-derived gasoline. The functional unit is defined as one mile driven by an E85- or gasoline- fueled Flex Fuel Vehicle. The system boundary for a cellulosic ethanol fuel system includes corn stover production, transportation of corn stover from farm to a biorefinery, AFEX treatment biorefinery, transportation and distribution of ethanol, gasoline production, an E85 fueled vehicle operation, and electricity as an alternative system that is displaced by surplus electricity exported from the biorefinery. The system boundaries for both fuel systems are illustrated in Figure 26.

The analysis on the gasoline fuel system is based on the timeframe of 2010-2015.
The environmental burdens associated with fertilizers, fuels, ammonia, enzyme and other materials are included in the calculations. The calculations are done via GREET 1.8b with modifying process information on the AFEX treatment biorefinery, which is summarized in Table 6. Life cycle inventory data in GREET 1.8b are used for most processes except for enzyme production, which is from a report by NREL (Sheehan et al., 2002). Lignin and biogas from wastewater treatment facility are burned to generate steam and electricity. There are no external energy sources required in the AFEX treatment biorefinery. Surplus electricity is exported to grid.

Results show that cellulosic ethanol derived from corn stover via the AFEX treatment biorefinery reduces fossil energy by about 73% and greenhouse gas emissions by about 65%. The results are summarized in Table 7.7, and the details of the LCA are found in the LCA_GHG.xls document. Corn stover production (feedstock) has a GHG credit because of carbon content in corn stover. The AFEX pre-treatment biorefinery also offers a GHG credit due to surplus electricity.

In the reference case, we assume that corn stover travels 30 miles to the AFEX treatment biorefinery, which is the assumption from GREET 1.8b. Sensitivity analysis shows that a one-mile increase in transportation of corn stover releases an additional 0.165 g CO_2 eq. of GHG per mile.

Table 6. Process information on the AFEX biorefinery

Ethanol yield: 90 gal/ dry ton
Biomass: NH_3: H_2O = 1 : 1 : 1 in AFEX treatment process
Solid content in fermentation: ~20%
Enzyme: 0.20 kg/ gal, Makeup ammonia 0.20 kg/gal
Electricity exported: 1.2 kWh/ gal

Table 7. Life Cycle Analysis results.

		BTU/mile	gram/mile			
		Fossil Fuels	CO_2	CH_4	N_2O	GHG*
EtOH Flexible-Fuel Vehicle	Feedstock	411	-240	1.50E-01	1.1E-02	-233
	Fuel	-94	12	-2.40E-02	4.00E-02	24
	Vehicle Operation	1296	370	1.5E-02	1.20E-02	374
	Total	**1613**	**142**	**1.8E-01**	**6.2E-02**	**165**
Baseline Gasoline Vehicle: CG and RFG	Feedstock	255	17	4.60E-01	4.4E-04	28
	Fuel	868	66	7.83E-02	5.3E-03	69
	Vehicle Operation	4806	377	1.46E-02	1.2E-02	381
	Total	**5928**	**459**	**5.53E-01**	**1.8E-02**	**478**

*Using Global Warming Potential (GWPs): CH_4: 25; N_2O: 298; CO_2:1

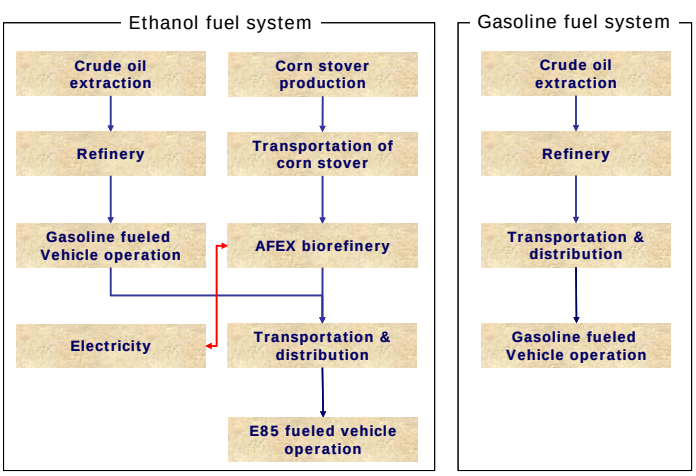


Figure 26. System boundaries for LCAs of AFEX Integrated Biorefinery (ethanol) and Gasoline fuel systems.

4.0 Proposed Project

4.1 Project Goals and Risks

The innovative operations to be developed in this project are continuous AFEX treatment of corn stover, continuous ammonia recovery, densification of AFEX-treated stover, and integrated high-

solids enzymatic hydrolysis and fermentation of AFEX-treated and densified stover. The major goals and aims of the pilot-scale AFEX Integrated Biorefinery are:

1) Operate a continuous AFEX treatment process with ammonia recovery and reuse at 1 TPD
2) Integrate the AFEX treated material with high-solids enzyme hydrolysis and mixed sugar co-fermentation system to demonstrate ethanol production from corn stover at the one TPD scale
3) Evaluate the fermentation residues and determine their value
4) Collect performance data and mass and energy balances from these operations and incorporate them into techno-economic models for a commercial AFEX Integrated Biorefinery

As described in greater detail in the Business and Commercialization Plan (BCP), our ultimate objective in proposing this project is to develop the AFEX biorefinery technology to a level sufficient for commercialization. Our strategy for commercialization of the AFEX Integrated Biorefinery is to: 1) Operate the AFEX Integrated Biorefinery at 1 TPD scale; 2) Generate techno-economic models of commercial plants using data from the pilot plant; 3) Partner with a commercial grain-ethanol plant operator to add an AFEX treatment unit; and 4) Proceed with a non-exclusive licensing plan for implementation in multiple commercial plants in various geographies. The overall goal of this project will be to acquire the pilot-scale data for the first step of the commercialization strategy. To interest a commercial partner in building a demonstration-scale plant, we will need to acquire sufficient data to quantify and mitigate the risks involved in building such a plant. Figure 28 below is a logic diagram showing the technical, economic, and environmental risks in the AFEX Integrated Biorefinery technology at its present level of development, and decision points for pilot-scale de-risking. A Risk Analysis Template listing the consequences, probabilities, magnitudes, and responses of risks is provided in Section 4.0 of the Project Management Plan. Each of these risks is explained in greater detail below:

Technical risks:

Feedstock logistics – raw feedstock unavailability. For a variety of reasons (drought, market demand, etc.), corn stover could become unavailable during the execution of this project or subsequent demonstration or commercial scale projects.

Feedstock logistics - milling failure. We are assuming that corn stover shredded or milled to approximately ¼-inch particle size will be appropriate for transport through the continuous treatment operations. If we learn during treatment equipment shakedown that a smaller particle size is required, it could prove impractical to produce enough milled feedstock to meet testing requirements.

Feedstock logistics – feedstock instability. Corn stover could prove unstable during storage between milling and treatment, due to mold or other agents.

Treatment – inability to reach target conditions in continuous reactor. The continuous AFEX reactor may be unable to reach the target temperature or other critical operating condition.

Treatment – inability to maintain steady state in continuous reactor. The continuous AFEX reactor could prove impossible to control at steady-state, due to poor mixing, plugging, blowback through screw feeder, or other unforeseen causes.

Treatment – safety system failure. Safe operation of continuous AFEX system with ammonia recovery has not yet been demonstrated, and could prove problematic.

Treatment - insufficient ammonia recovery. Ammonia recovery schemes are as yet only conceptual, and have not been proven. The ability to recover more than 98% of ammonia is unknown.

Treatment – recycle streams accumulate inhibitors/toxins. Both water and ammonia streams will be recycled in the AFEX treatment. It remains unknown if toxins will accumulate in the recycle streams and inhibit hydrolysis or fermentation of the treated biomass.
Treatment - inability to manage waste streams. Insufficient ammonia recovery could lead to waste streams with unmanageably high ammonia concentrations.
Storage/Transportation - Treated stover instability. AFEX-treated corn stover could prove unstable during storage between treatment and hydrolysis, due to mold or other agents.
Storage/Transportation – inability to densify treated stover. Treated corn stover could prove resistant to densification in pelletizer or other equipment.
Saccharification/Fermentation – inability to handle high solids loading in hydrolysis. Treated corn stover could prove difficult to handle in hydrolysis reactors at high solids loading.
Saccharification/Fermentation – inability to handle contaminant load. Microbial contaminant load that accumulates on corn stover between treatment and fermentation could interfere with fermentation.
Saccharification/Fermentation – poor microorganism performance. The microorganism used for fermentation could give poor performance with AFEX-treated corn stover at pilot scale.
Ethanol recovery – column fouling. The corn stover solids remaining in the beer after fermentation could cause fouling and poor performance of the beer distillation column.
Economic risks:
Commercial model – enzyme cost remains prohibitive. Costs of cellulase and other enzymes per unit of activity are projected to decrease over the next ten years. If they do not, production cost of the primary product from AFEX-treated corn stover, fuel-grade ethanol, could remain uncompetitive with conventional fuels.
Commercial model – Feedstock costs prohibitive. Costs of corn stover and other biomass feedstocks could prove higher than projected, making the proposed biorefinery technology uncompetitive with conventional fuels.
Commercial model – market volatility creates barriers to commercialization. Continued price volatility in conventional fuel markets could hinder investment in commercial facilities for production of ethanol and other renewable fuels.
Project management – project cost overruns. Costs for equipment, materials, construction, could exceed budgetary estimates.
Project management – cost share from major financial stakeholder not available. Cost share contributions from a financial stakeholder could become unavailable.
Environmental risks:
Life cycle analysis – GHG emissions, water or land usage higher than expected. Life cycle analysis of the proposed AFEX biorefinery technology, using pilot scale data inputs, could reveal that GHG emissions, water usage, or land use changes, are greater than anticipated.

4.2 Project Milestones

Table 8 lists milestones for the proposed project, with dates based on project start date of January 2010.

4.3 Key Decision Points and Go/No-Go Decision Criteria

As described in the PMP, MBI uses a Stage-Gate approach to project and portfolio management, including go/no-go decision points. Our Stage-Gate process is a method for making disciplined decisions about research and development that leads to focused process and/or product development efforts, and is coordinated with our resource loaded plan. Further details on our approach and how we employ this method to measure progress towards achieving our goals is seen in Section 3.2 of the PMP. Figure

27 shows the Budget Period stages and Gate Reviews for the proposed project and for subsequent demonstration-scale validation leading to commercial launch. There are four Stage-Gate Reviews planned for this project. Expected dates for the Stage-Gate reviews and their expected go/no decisions are as follows:

Stage-Gate I – September 2010

- NEPA determination must be complete
- Construction plan must be complete
- Building permits must be in hand

Stage-Gate II – November 2011

- Construction and equipment installation are complete and ready for shakedown

Stage-Gate III – January 2013

- Capstone runs are completed
- Techno-economic models are updated using capstone run data

Stage-Gate IV – July 2013

- Techno-economic models justify a demonstration scale project

In addition to the above, certain critical milestones in Budget Period 2 are go/no go decisions. If these milestones are not made on time, some recycling would need to be done and delays could be expected until each was completed. These important milestones and their expected dates of completion are:

1. MBI building construction passes inspection for occupancy – 6/2011
2. Independent Engineer approval of AFEX and Densification equipment at MBI – 12/2011
3. Independent Engineer approval of Hydrolysis and Fermentation equipment at NREL – 8/2012

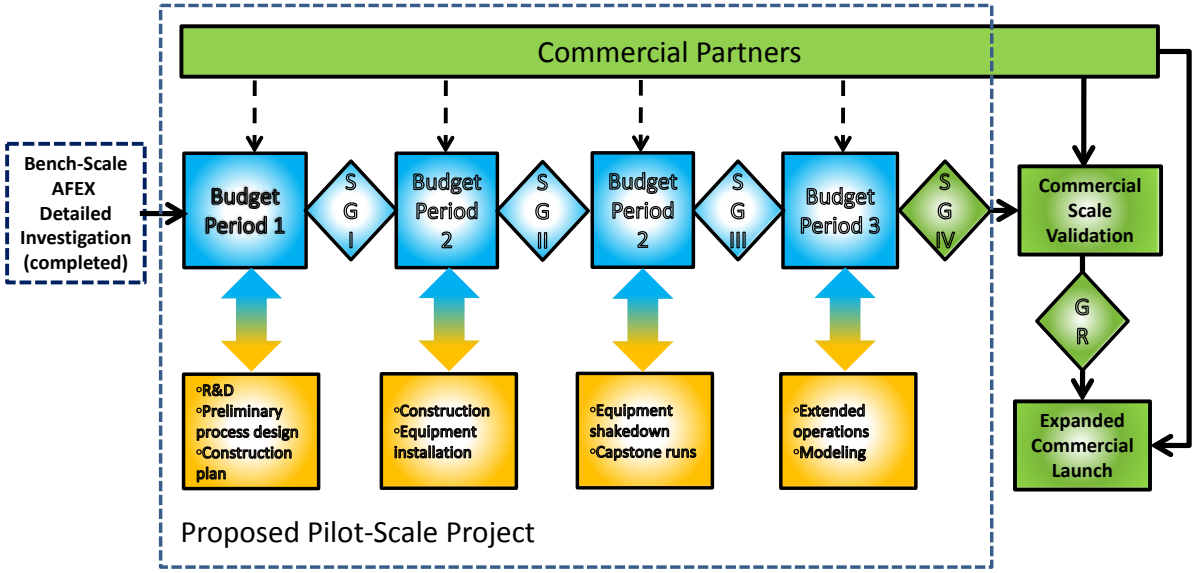


Figure 27. Budget Periods and Stage Gate (SG) Reviews for the proposed AFEX Biorefinery project, and subsequent commercial validation leading to expanded commercial launch.

Other milestones are detailed in Section 4.5: Work Breakdown Structure (WBS) and include completion of NEPA determination and Risk Mitigation Plan in Budget Period 1; completion of detailed engineering in Budget Period 2.

We expect to follow a quarterly meeting and reporting schedule with reports due 30 days following each quarter after the start date. All partners would attend quarterly meetings in person or by telephone. All outcomes and reportable data will be included in the quarterly report following the completion of a work plan or a milestone. Critical success factors will be discussed in appropriate committees and reported in the quarterly meetings and in the appropriate quarterly report.

Table 8. Project milestones with completion dates based on project start in January 2010.

Budget Period	Milestone	Date
1	Complete preliminary process design	3/2010
1	Complete R&D efforts	9/2010
1	Obtain building permits	9/2010
2	Complete MBI building addition preliminary engineering	10/2010
2	MBI building addition full notice to proceed	11/2010
2	Complete major equipment orders	10/2010
2	Complete MBI building addition detailed engineering	6/2011
2	Complete MBI building construction	5/2011
2	Pass MBI building addition construction inspection	6/2011
2	Attain mechanical completion	8/2011
2	Initial stover shipment from Vermeer received at MBI	6/2011
2	Complete AFEX equipment shakedown	11/2011
2	AFEX equipment Independent Engineer approval	12/2011
2	Densification equipment Independent Engineer approval	12/2011
2	Hydrolysis equipment Independent Engineer approval	8/2012
2	Demonstrate AFEX reactor continuous operation	11/2012
2	Demonstrate integrated high-solids hydrolysis/fermentation	1/2013
2	Complete techno-economic model of commercial AFEX Integrated Biorefinery using capstone run data	1/2013
2	All CSFs complete on schedule, budget	1/2013
3	Extended operations complete	7/2013
3	Commercialization plan complete	7/2013

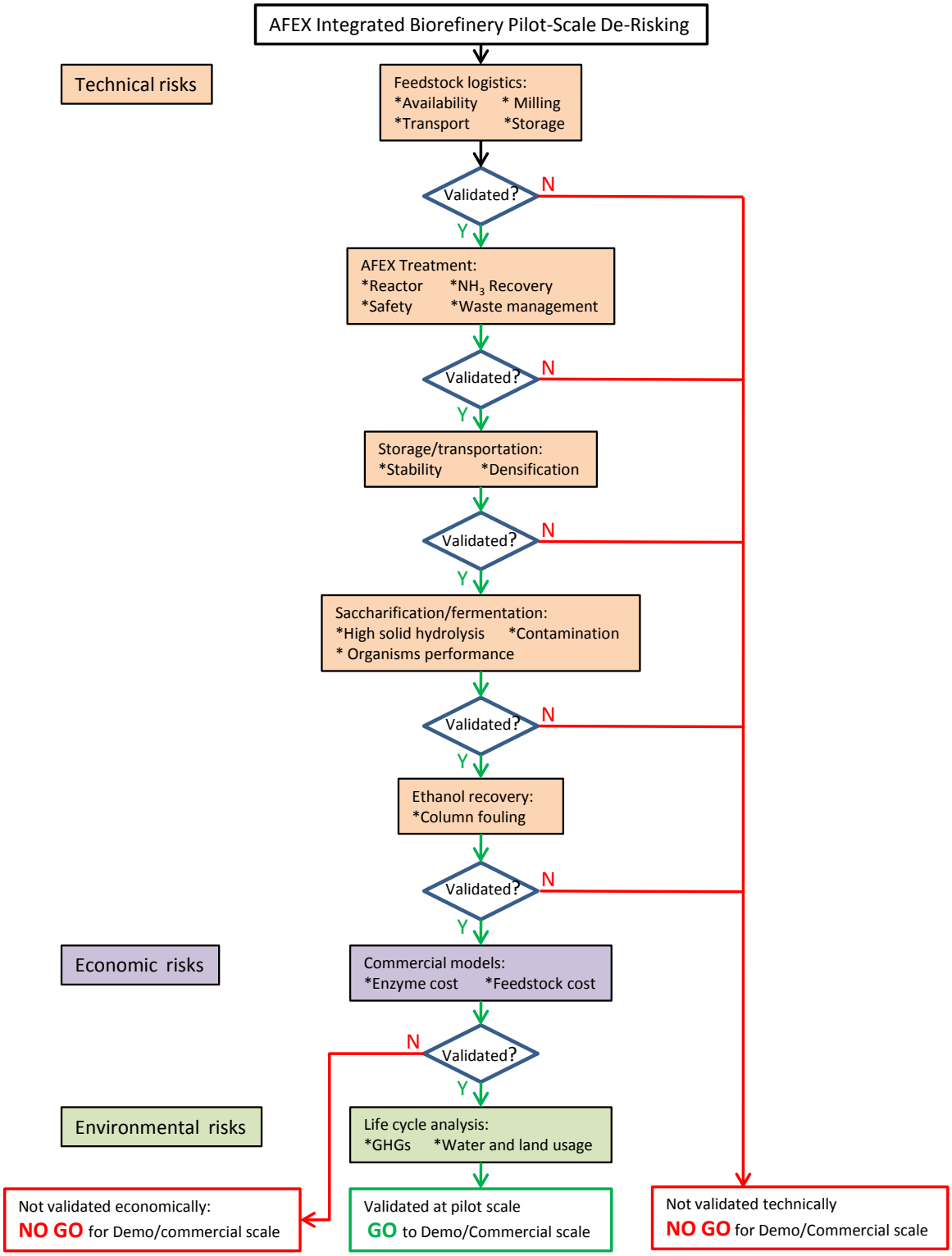


Figure 28. Overall logic diagram for AFEX Integrated Biorefinery de-risking at pilot scale.

4.4 Critical Success Factors

Bench-scale efforts to develop AFEX Biorefinery technology have already led to completion of several critical success factors. As explained in greater detail in the Background section of this PEP above, bench-scale AFEX batch experiments have already demonstrated that:

- Enzyme hydrolysis yield of fermentable sugars from AFEX-treated corn stover reaches 94% of theoretical yield;
- Ethanol titer in high-solids hydrolysis and fermentation of AFEX-treated corn stover reaches 4 wt%;
- Ammonia recovery from AFEX-treated corn stover exceeds 98 wt%.

Completion of these bench-scale success factors demonstrates that AFEX technology has significant commercial potential and is ready for validation at pilot scale. However, several barriers to commercialization remain, which can only be addressed at pilot scale. Barriers that remain include uncertainty in the cost and GHG emissions of ethanol production using AFEX Biorefinery technology, and uncertainty regarding the practicality of continuous AFEX reactor operation and ammonia catalyst recovery. Therefore, the factors critical to successful pilot-scale development of the proposed technology in this project are:

<u>CSF1</u> – Complete Techno-Economic model of a commercial AFEX Integrated Biorefinery, and determine the minimum selling price and GHG emissions for ethanol produced at a commercial facility, using mass and energy flows determined in pilot-scale performance

<u>CSF2</u> – Demonstrate continuous operation of an AFEX reactor with ammonia recycle at pilot-scale

<u>CSF3</u> – Integrate high-solids enzymatic hydrolysis and mixed-sugar co-fermentation steps with AFEX-treated stover at pilot scale

<u>CSF4</u> – Achieve the critical factors above and complete all tasks within the scope, budget, and schedule shown in the WBS

Completion of CSF1, CSF2, and CSF3 will require accurate quantitative determination of several mass and energy flows, stream compositions, and other metrics during operation of the pilot-scale AFEX Biorefinery. These metrics will be required for inclusion in the techno-economic model to determine the commercial ethanol MESP for CSF1, and to quantify the extent of ammonia recovery for CSF2. Some of the key parameters to be accurately measured will include:

- Total ammonia loss during steady-state operation of the continuous AFEX reactor.
- Enzyme hydrolysis yield of fermentable sugars from the AFEX-treated corn stover.
- Titer of ethanol in beer from fermentation of sugars from high-solids hydrolysis of AFEX-treated stover.

The experimental methods to be employed for determination of these parameters are described in detail in the Proposed Biorefinery section of this PEP above.

Successful commercialization of the AFEX Biorefinery technology will rely on several critical external factors that will not be addressed in this project. These external critical success factors include development of low-cost enzymes, availability and cost of corn stover feedstock, and development of fermentation organisms capable of rapidly converting xylose and minor sugars to ethanol at improved conversion yields. It is widely accepted that the current state of biochemical cellulosic ethanol technology is likely to improve over the next three years. Table 9 (adapted from Aden, 2008) lists past and future targets for key values, indicating values that will be measured or calculated in this project.

Table 9. Past and future State of Technology values (adapted from Aden, 2008).

	2007 Targets	2007 Results	2008	2010	2012 Market Target
Minimum Ethanol Selling Price		$2.43			$1.33
TPI/Annual Gallon		$4.17			$3.17
Yield (Gallon/dry ton)	68	72			90
Feedstock Cost ($/dry ton)		$60	$60		$46
Enzyme Contribution ($/gal EtOH)	$0.32	$0.32	$0.32	$0.16	$0.10
Saccharification and Fermentation Solids Loading (wt%)	20%	20%	20%	20%	20%
Saccharification and Fermentation Time (days)	7	7	7	5	3
Overall Cellulose to Ethanol	85%	85%	85%	85%	85%
Xylose to Ethanol	76%	76%	80%	80%	85%
Minor Sugars to Ethanol	0%	0%	40%	80%	85%

To be measured for the AFEX Biorefinery Technology as part of this project.
To be determined by techno-economic model of a commercial-scale AFEX Biorefinery in this project.
External factors not addressed in this project.

4.5 Work Breakdown Structure/Resource loaded plan

A Work Breakdown Structure (WBS) for the proposed pilot plant project is shown below. This WBS corresponds to the resource loaded schedule and spend plan found in Section 1 of the PMP and the Project Budget and Budget Justification files. Detailed task descriptions with corresponding WBS numbers are given following the WBS. The schedule in the PMP shows that the project can be executed, with completion of all critical success factors, in a duration of less than four years. Given a project start date of January 2010, the project can be completed by the third quarter of 2013, in keeping with the goals of the FOA. January 2010 was chosen as a convenient reference start date for the project. The actual project start date will be known only after negotiation of an award, and the resource loaded schedule will then be adjusted accordingly.

Demonstration of an AFEX Integrated Biorefinery at Pilot Scale – Work Breakdown Structure

1 Budget Period 1: Design and Supporting R&D

- 1.1 Design
  - 1.1.1 Full notice to proceed (milestone)
  - 1.1.2 "Select Engineering, Procurement, and Construction firm"
  - 1.1.3 Preliminary process design
  - 1.1.4 Complete preliminary process design (milestone)
  - 1.1.5 NREL design review of pilot-scale AFEX equipment and other systems
- 1.2 AFEX Pilot plant new construction - bids and permits
  - 1.2.1 Complete final site plan
  - 1.2.2 Complete final construction plan
  - 1.2.3 Bid preparation and responses
  - 1.2.4 Building permit applications
  - 1.2.5 Obtain building permits (milestone)
  - 1.2.6 Complete NEPA determination
- 1.3 R&D
  - 1.3.1 Produce stover feedstock material
  - 1.3.2 NH_3 recovery design

1.3.2.1 Measure heat and mass transfer coefficients in AFEX-treated stover
1.3.2.1.1 Design bench scale NH_3 recovery experiments.
1.3.2.1.2 Set up experiments in lab.
1.3.2.1.3 Conduct experiments and calculate coefficients.
1.3.2.2 Aspen model of NH_3 recovery process using coefficients
1.3.2.3 Design or specify NH_3 recovery equipment using Aspen model
1.3.3 AFEX Integration with Saccharification and Fermentation
1.3.3.1 Prepare AFEX-treated stover in batch reactor
1.3.3.2 Design high-solids enzyme hydrolysis reactor
1.3.3.3 Fabricate high-solids enzyme hydrolysis reactor
1.3.3.4 Shakedown high solids enzyme hydrolysis reactor
1.3.3.5 NREL Bench scale enzymatic saccharification and fermentation process validation
1.3.3.6 SSF trials using NREL's organism with AFEX-treated stover at MBI
1.3.3.7 SSF trials using other organisms with AFEX-treated stover at MBI
1.3.3.8 SSF trials using improved enzymes with AFEX-treated stover at MBI
1.3.3.9 SSF trials using antibiotics
1.3.3.10 Novozymes enzyme screening, loading, inhibitors study
1.3.4 Complete R&D Efforts (milestone)
1.4 Complete Risk Mitigation Plan
1.5 Business and Commercialization Plan update
1.6 Project Management Support
1.7 Reporting
1.8 Meetings / Communications

2 Budget Period 2 - Construction, shakedown, and operation

2.1 Project Start
2.1.1 Completion of preliminary engineering (milestone)
2.1.2 Management review
2.1.3 Contract negotiation
2.1.4 Full notice to proceed (milestone)
2.2 Procurement - Major Equipment
2.2.1 Finalize spec and order feeder/reactor/discharge equipment
2.2.2 Finalize spec and order NH_3 recovery equipment
2.2.3 Finalize spec and order densification equipment
2.2.4 Complete major equipment orders (milestone)
2.3 Engineering
2.3.1 Finalize P&IDs
2.3.2 Finalize equipment layouts
2.3.3 Mechanical
2.3.4 Civil, structural, architecture
2.3.5 Electrical
2.3.6 Instrumentation
2.3.7 Site specific design
2.3.8 Final engineering review

- 2.3.9 Completion of detailed engineering (milestone)
- 2.4 AFEX plant building construction
  - 2.4.1 Site prep
  - 2.4.2 Concrete
  - 2.4.3 Structural
  - 2.4.4 Masonry
  - 2.4.5 Thermal & moisture
  - 2.4.6 Mechanical
  - 2.4.7 Complete building construction (milestone)
  - 2.4.8 Construction inspection (milestone)
- 2.5 AFEX pilot plant equipment installation
  - 2.5.1 Install feeder/reactor/discharge equipment
  - 2.5.2 Install NH_3 recovery equipment
  - 2.5.3 Install densification equipment
  - 2.5.4 Piping & electrical
  - 2.5.5 Install instrumentation
  - 2.5.6 Attain mechanical completion (milestone)
  - 2.5.7 Commissioning and startup
  - 2.5.8 Write and issue SOPs for all new equipment
  - 2.5.9 Operator safety training for all new equipment
- 2.6 NREL PDU/IBRF saccharification and fermentation equipment modification
- 2.7 Equipment shakedown trials
  - 2.7.1 Produce stover for shakedown trials
    - 2.7.1.1 Acquire raw corn stover
    - 2.7.1.2 Stover milling and other preparation
    - 2.7.1.3 Prepared stover shipping to MBI
    - 2.7.1.4 Stover receiving and storage at MBI
    - 2.7.1.5 Initial stover received at MBI (milestone)
  - 2.7.2 AFEX plant equipment shakedown trials
    - 2.7.2.1 "Stover throughput trial, atmos P"
    - 2.7.2.2 Reactor P test (air or N_2)
    - 2.7.2.3 "Stover throughput trial, design P (air or N_2)"
    - 2.7.2.4 Stover mixing trial
    - 2.7.2.5 Stover NH_3 trials with NH_3 recovery
      - 2.7.2.5.1 Stover NH_3 trial - no steam
      - 2.7.2.5.2 Stover NH_3 trial - live steam
      - 2.7.2.5.3 AFEX equipment shakedown complete (milestone)
    - 2.7.2.6 AFEX Independent Engineer performance test
    - 2.7.2.7 AFEX equipment Independent Engineer approval (milestone)
  - 2.7.3 Densification equipment shakedown
    - 2.7.3.1 Densification equipment shakedown
    - 2.7.3.2 Densification equipment Independent Engineer test
    - 2.7.3.3 Densification Equipment Independent Engineer approval (milestone)
    - 2.7.3.4 Monitor hydrolysis and fermentation yields of densified AFEX-treated stover
    - 2.7.3.5 Demonstrate < 10% yield loss over 6 weeks storage of AFEX-treated stover (milestone)

2.7.4 NREL saccharification and fermentation equipment shakedown trials
2.7.4.1 NREL saccharification and fermentation equipment shakedown
2.7.4.2 NREL saccharification and fermentation equipment Independent Engineer approval (milestone)

2.8 Capstone Runs
2.8.1 AFEX equipment capstone runs
2.8.2 Demonstrate continuous operation of AFEX reactor with NH_3 recovery (milestone)
2.8.3 Densification capstone runs
2.8.4 NREL saccharification and fermentation capstone runs
2.8.5 Demonstrate integrated high-solids enzyme hydrolysis and mixed-sugar co-fermentation (milestone)

2.9 AFEX shakedown and capstone run support
2.10 Project Management Support
2.11 Update techno-economic model using data from demonstration runs
2.12 Business and Commercialization Plan Update
2.13 Complete techno-economic model using capstone run data (milestone)
2.14 All CSFs completed within scope, schedule, and budget (milestone)
2.15 Reporting
2.16 Meetings / Communications

3 Budget Period 3: Operation

3.1 Extended Operation of Pilot Plant
3.1.1 MBI pilot scale AFEX and densification extended operations
3.1.2 NREL PDU/IBRF pilot scale saccharification and fermentation extended operations
3.1.3 Extended operations complete (milestone)

3.2 Modeling and BCP Development
3.2.1 Economic modeling
3.2.2 Business & Commercialization Plan Development
3.2.3 Business & Commercialization Plan Complete (milestone)

3.3 Project Management Support
3.4 Reporting
3.5 Meetings / Communications

4.6 Task Descriptions by Budget Period

Budget Period 1 Tasks

1.1 Design – This task will include selection of an Engineering, Procurement, and Construction (EPC) firm for the AFEX Pilot Plant, and completion of preliminary process design for the AFEX pilot plant. The preliminary design will include complete mass and energy balances of the AFEX process using performance data for the selected process equipment as supplied by the vendors. MBI and the selected EPC firm will complete the preliminary process design. NREL will provide a limited amount of technical review and guidance of the design, based upon NREL's expertise in pilot-scale pretreatment equipment.

1.2 AFEX Pilot Plant Construction Bids and Permits – By the end of Budget Period 1, MBI along with the EPC firm will have obtained bids for the construction of the new addition to the MBI building to house the AFEX pilot plant. Applications for construction permits and NEPA determination will be completed. Completion of these tasks by the end of Budget Period 1 will allow construction to begin early in Budget Period 2, which will reduce the overall time for project completion.

Final Site Plan – A site plan for the MBI Building addition to house the new AFEX pilot plant will be finalized during Budget Period 1. This site plan will include all information needed to complete the NEPA determination as above.

Final Construction Plan – A plan for construction of the MBI Building addition will be completed during Budget Period 1. The construction plan will include tasks and schedule for completion of preliminary engineering and Full Notice to Proceed, completion of detailed engineering, construction of building addition, and installation of AFEX pilot plant equipment. The plan will include a detailed construction budget.

Applications for Construction Permits – Applications for any City of Lansing construction permits required for construction of the MBI Building addition to house the AFEX pilot plant will be completed during Budget Period 1. Environmental, Health and Safety permits already in place for ammonia storage and handling at the MBI facility will be reviewed and updated if necessary.

NEPA determination – NEPA documentation for all of the major activities occurring at Vermeer, MBI, and NREL facilities will be completed during the first Budget Period. NEPA documentation to be completed as part of this task will include waste stream management and pollution control plans, justification and benefits of the new construction at MBI, and justification and benefits of using existing facilities at Vermeer and NREL sites.

1.3 R&D – The technical risks in this project are listed in the section on Project Goals and Risks above. Four of these technical risks can be mitigated by performing some preliminary bench-scale research and development tasks. First, there is the risk that insufficient ammonia recovery will be achieved in the continuous ammonia recovery operation. Second is the risk associated with high-solids loading hydrolysis and fermentation of AFEX-treated corn stover. Third is the risk of poor microorganism performance in fermentation of AFEX-treated stover at high solids loadings. And fourth is the risk of inability to handle the contaminant load introduced to the stover after AFEX treatment. None of these operations have been demonstrated at pilot scale before. Our R&D plan for reducing these risks includes the tasks described below:

NH_3 Recovery Design Support- Specification of equipment for ammonia recovery will require bench-scale measurement of ammonia mass transfer and heat transfer coefficients under conditions relevant to the recovery options described in the Ammonia Recovery Dryer section above. The measured coefficients can then be used in Aspen models of the various ammonia recovery approaches. The results from the models can be reviewed by vendors of drying equipment and drying operations engineering experts at Michigan State University. After consulting with technical experts and vendors, the most energy efficient, practical, and cost-effective approach for ammonia recovery will be selected. Once an approach has been selected, the equipment required for that approach can be specified (if commercially available) or designed in detail for custom fabrication. Detailed plans for installation and shakedown of the ammonia recovery equipment can be made once the equipment is specified.

AFEX Integration with Saccharification and Fermentation- Specification of equipment and procedures for enzymatic hydrolysis of stover with high solids loading will require bench-scale experimentation, and measurement of the properties of the stover slurry as hydrolysis proceeds. The reactors used for enzyme hydrolysis will have to be compatible with both the wet solids that will be charged to the reactor initially, and with the more liquid slurry that will be present after several hours of digestion. Reactor vessel dimension for one TPD capacity will depend on the hydrolysis rate, and on the effective fill factor, both of which will be measured in bench-scale experiments. The results from the bench-scale hydrolysis experiments will be used to specify or design the pilot-scale hydrolysis reactors. Finally, the risks of poor microorganism performance and inability to handle contaminant loads can be mitigated by conducting bench-scale simultaneous saccharification and fermentation (SSF) trials of the AFEX-treated

stover at high solids loading with different enzymes and different organisms, at various conditions. It is anticipated that new cellulase and xylanase enzyme products may be available by the time the research effort of this project is underway. Also, various ethanologen microorganisms will be available for SSF trials with AFEX-treated stover. NREL has developed a unique strain of *Zymomonas mobilis* which has capacity for conversion of pentose sugars to ethanol. Bench scale trials with this strain will be conducted at both NREL and MBI using batch AFEX-treated stover to compare performance. Other available organisms will also be tested at MBI using identical SSF procedures to compare to the *Z. mobilis* performance. Any problems that arise due to contamination of the stover will be identified during these bench SSF trials. If necessary, contamination issues will be addressed by developing new techniques for handling the stover after AFEX treatment, or by the use of antibiotics during SSF trials.

Novozymes bench scale enzyme and inhibitor studies- Novozymes' ongoing biofuels application research has shown convincingly that the enzymatic hydrolysis unit process cannot be developed in isolation. A systems approach to the development of treatment, hydrolysis and fermentation must be conducted to allow optimization of these three unit processes as a whole. A commercially viable treatment technology might generate substantial inhibitors of enzymatic or fermentation processes, thereby having a negative effect on over all process economics. Novoymes will conduct bench-scale R&D efforts to help MBI efficiently integrate enzymatic hydrolysis with treatment and fermentation. Novozymes' R&D efforts will consist of two sub-tasks:

Novozymes subtask 1*: Hemicellulase screening on AFEX-treated corn stover.* Novozymes will provide expertise on choosing the optimal conditions of pH, temperature, enzyme dosage, and enzyme cocktail, as determined by laboratory evaluation. After development of a detailed experimental plan, optimization efforts will begin with small scale hydrolyses (5-20 g reactions) using AFEX treated corn stover monitored for sugar release over 72-120 hours. Hemicellulases will be screened in combination with our most advanced cellulase product. Novozymes has available an extensive collection of fungal xylanases as well as auxiliary enzymes for hemicellulase depolymerization, including arabinofuranosidases, β-xylosidases, β-glucuronidases, acetylxylan esterases, and ferulic acid esterases. The minimal auxiliary activities necessary for efficient glucose and xylose conversion yields will be identified. The ratios of each activity will be optimized for hydrolysis performance using a mixture response surface design. After the optimization of the enzyme mix, larger scale (0.50 – 2 L) hydrolyses will be conducted at higher total solids concentration to confirm the enzyme ratio and total protein dosage. Dosages of the optimal enzyme mix identified in mini-scale hydrolysis studies will be varied in order to maximize fiber hydrolysis as well as process economy. These initial tests will be used to prepare recommendations for hydrolysis conditions (temperature, pH, dosage and mixture) in the pilot plant. When the pilot plant treatment system is operational, the hydrolysis optimization studies will be repeated and the recommendations for hydrolysis conditions in the pilot plant refined as necessary.

Novozymes subtask 2*: Analysis of soluble enzyme inhibitors formed during AFEX treatment*. A survey of predominant enzyme inhibitors will be conducted and correlated with AFEX treatment severity using AFEX corn stover batches of varying severity generated in the laboratory. The focus will be on the identification and quantitation of potent inhibitor classes such as sugar and lignin degradation products and not by individual compound. In parallel, hydrolysis performance using an optimized enzyme mix will be determined for the same treated samples, and this will provide valuable information to guide pilot-scale treatment optimization.

Novozymes Task Management. The two subtasks described above will be led by Don Higgins, Senior Scientist in the Biomass Hydrolysis Discovery Department of Novozymes North America, and will commence immediately upon award beginning with the acquisition of necessary materials and preparation of a detailed experimental design. Actual testing will begin with the acquisition of treated

samples from MBI, initially with treated corn stover from laboratory runs until material is available from the pilot plant.

NREL Bench Scale Enzymatic Saccharification and Fermentation Process Validation- NREL will perform several bench-scale enzymatic saccharification tests using existing equipment (shake flasks and/or small high-solids reactor systems) to validate the enzymatic saccharification performance data of MBI-supplied AFEX-treated feedstocks. Following a selected number of these runs, the resulting hydrolyzate will be fermented using an agreed-upon available recombinant ethanologen strain to determine fermentation performance data. Fermentation will be performed in appropriate bench scale equipment (shake flasks and/or bench-top fermentor units). NREL will perform chemical compositional analysis of appropriate samples to generate process performance data and will provide process performance data to MBI.

1.4 Complete Risk Mitigation Plan – By the end of Budget Period 1, a Risk Mitigation Plan will be completed for the project. This will include input from the EPC firm, and will incorporate any technical changes to the process design arising from results of the R&D efforts. The plan will address each of the risks identified in the Risk Analysis Template above, with our team's approach for minimizing the effects of those risks on successful commercialization of the AFEX Biorefinery technology.

1.5 Business and Commercialization Plan Update – Throughout Budget Period 1, updated values for equipment capital and operating costs, including costs of ammonia recovery and enzyme hydrolysis equipment based on results of R&D efforts, will be used to update the commercialization plan.

1.6 Project Management Support - This task encompasses administrative and management requirements, including organizing meetings, and all reporting requirements.

1.7 Reporting – Three quarterly reports and a final report are planned for Budget Period 1. Each of these reports will include technical progress and results, milestones achieved, updated spending plans and EVMS reports, Recovery Act status reports, and updated management plans.

1.8 Meetings/Communications – A budget period 1 kickoff meeting will occur within three weeks of the scheduled project start date, to include representatives of all project partners. A stage gate review meeting will take place near the midpoint of Budget Period 1. A final review meeting will take place within three weeks of the scheduled end of Budget Period 1. Each of these meetings will include discussions of technical progress and research results, progress toward milestones, review of project financials, and review of go/no go decision criteria for Budget Period 2.

Budget Period 2 Tasks

Budget Period 2 will include construction of the MBI Building addition to house the new AFEX pilot plant, major equipment procurement, engineering, equipment modification, installation and shakedown, and capstone runs.

2.1 Construction Project Start - This summary task will include subtasks for management review of preliminary engineering, negotiation of construction contracts, and issuance of a Full Notice to Proceed for construction of the MBI Building addition.

2.2 Major equipment procurement – Major equipment to be procured includes the AFEX reactor system (including feeder, reactor, and discharge equipment), ammonia recovery dryer, and densification equipment such as the ComPaker pelletizer. These will be specified and orders placed early in Budget Period 2 to allow for lead times before delivery and installation near the completion of construction.

2.3 Engineering – Engineering of the AFEX pilot plant will require finalization of the AFEX process P&IDs and equipment layouts, completion of detailed mechanical, civil, structural, architectural, and electrical engineering. A final engineering review will be conducted before proceeding to construction.

2.4 AFEX Plant Building Addition Construction – Construction of the MBI Building addition is anticipated to take approximately one year, including final inspections. A more detailed list of construction subtasks and schedule will be prepared as part of the AFEX Plant Engineering summary task above.

2.5 AFEX Pilot Plant Equipment Installation – Orders for AFEX pilot plant equipment will be placed during Budget Period 1, with lead times scheduled for delivery after completion of MBI Building addition construction. Installation of the AFEX reactor, ammonia recovery, densification, and ancillary equipment will be based on the layouts and P&IDs finalized during AFEX Plant Engineering. Equipment will be installed by the vendors with assistance as needed from MBI Building Facilities personnel. Following installation of major equipment, a Standard Operating Procedure (SOP) will be drafted, to include equipment start-up, safe operation, shutdown, lock-out tag-out procedures for maintenance and repair. SOPs will be modified and re-issued as necessary following equipment shakedown and capstone runs.

2.6 NREL PDU/IBRF Saccharification and Fermentation Equipment Modification - In preparation for operation of pilot-scale enzymatic saccharification and fermentation equipment at NREL's PDU/IBRF in subsequent phases of this project, NREL will identify and perform any needed equipment modifications to permit processing of AFEX-treated feedstocks in available equipment. It is envisioned that only minor modifications will be necessary and that no major equipment items will need to be purchased and installed to support these activities. Additionally, NREL will provide limited technical support to the installation and initial shake-down of the pilot-scale AFEX treatment reactor equipment and associated systems at MBI.

2.7 Equipment Shakedown Trials – Shakedown trials will require delivery of the first large quantities of preprocessed stover from Vermeer in Iowa to MBI in Lansing.

Stover Production- A total of approximately 60 tons of milled corn stover at about 15 wt % moisture will be required for R&D, shakedown trials, and capstone runs in this project. As described in the Description of Proposed Technology section above, the stover will be located, collected, and preprocessed by Vermeer Corporation in Iowa. The milled stover will be transported from Ames, Iowa and received in Lansing, Michigan in Super Sacks. The schedule for stover production and shipping to Lansing is shown in the WBS above. This includes approximately three tons of stover for R&D tasks in Budget Period 1, followed by three shipments of twelve to twenty-five tons to be used for shakedown trials and capstone runs in Budget Period 2.

AFEX Plant Equipment Shakedown Trials- Shakedown of the installed AFEX pilot plant equipment will begin after the first shipment of milled stover is received at MBI. The AFEX equipment shakedown will follow a logic path as shown in Figure 29. The outcomes of the AFEX plant shakedown will be either progress to Independent Engineer testing, or redesign or abort the continuous AFEX reactor approach. Subtasks in the shakedown process are listed in the WBS and reflected in the logic diagram as six iterative loops to troubleshoot any problems that should arise. The reactor hydrostatic pressure test will be conducted by closing the blowback cone valve and sealing the blow line between the discharge screw and flash cyclone using a ball valve, then charging the reactor to operating pressure with air or nitrogen through one of the ammonia inlet ports. The criterion for passing the pressure test will be a loss of less than 10 psig static pressure over a period of four hours. The stover throughput trial will involve feeding and discharge of milled stover through the reactor at a representative moisture level with the reactor at atmospheric pressure. The criterion for passing the throughput trial will be operation at mass steady state ± 10 wt% for at least ten reactor volumes, or about five hours. Possible problems could include bridging or plugging of the stover in the hopper, feed screw, mixing tee, reactor, or discharge screw. Troubleshooting these throughput problems could involve simple fixes such as adjusting the feedstock moisture or particle size, or more complex solutions like modifying or replacing reactor equipment. When the throughput trial is passed, a mixing test will be conducted using milled

stover with injection of a dye solution through the ammonia inlet ports. Criterion for passing the mixing test will be visibly well-mixed dye and stover exiting the discharge screw. Poor mixing could require equipment modification, such as installation of an agitator in the mixing tee. Following successful stover throughput trial at atmospheric pressure and a successful hydrostatic pressure test, a pressurized reactor throughput trial can be conducted, with the stover feed and discharge through the reactor under air or nitrogen pressure. Problems that could be encountered in the pressurized throughput trial include the plugging or bridging, but also blowback of gas through the feed screw. Criteria for passing the pressurized throughput trial should include operation at mass steady state ± 10 wt% for at least ten reactor volumes, while maintaining reactor pressure at target ± 10 psig during that period. After passing the pressurized throughput trial and mixing test, the reactor will be ready for testing with ammonia. First, a through put trial will be conducted with stover and ammonia, but without steam. The temperature in the reactor will be greater than the temperature of the feeds due to the exotherm of ammonia/water mixing. The pressure in the reactor during this trial will be maintained above the saturation pressure of the ammonia/water mixture at the measured temperature. Since the ammonia recovery equipment shakedown can't occur until after the AFEX reactor shakedown is complete, the ammonia-rich stover slurry discharged from the reactor during these trials will be quenched in a collection mixing vessel containing citric acid. Criteria for passing the stover throughput trial with ammonia will include measured feed flows within ± 5 wt% of targets for at least five reactor volumes. After passing the throughput trial without steam, the reactor system will be ready for a trial run under AFEX conditions with both ammonia and steam. Criteria for passing this trial with ammonia and steam will include maintaining temperature, pressure and all flows at targets for at least ten reactor volumes, or about five hours. The criteria will not include hydrolysis results of the AFEX-treated stover, as the purpose of these trials is to shakedown the equipment, not to evaluate the process.

Ammonia Recovery Equipment Shakedown Trials- Shakedown of ammonia recovery equipment will necessarily follow shakedown of the AFEX reactor equipment, since there will be no way to test the ammonia recovery systems without using the reactor. A detailed plan for shakedown of the ammonia recovery equipment will be formed after the ammonia recovery process is designed and the equipment is specified in Budget Period 1.

Densification Equipment Shakedown Trials- The densification equipment shakedown will use AFEX-treated corn stover. The shakedown experiments will build on a research effort (Dale, 2009) that is currently being conducted (not funded by this project) by Michigan State University's Biomass Conversion Research Laboratory (BCRL). BCRL will study pelletization of various biomass feedstocks, including corn stover, using a ComPAKco device, featuring an innovative gear mesh system to compress biomass through a tapering channel between adjacent gear teeth. The BCRL project will determine optimal ComPAKco operating conditions, evaluate storage of the pelletized biomass, and analyze the economics and energy requirements of the pelletizing process. The effort required to shakedown the densification equipment will be reduced by building on the results of the BCRL study. Densification equipment shakedown subtasks will include generation of several hundred pounds of pelletized AFEX-treated stover at various pellet sizes.

NREL PDU/IBRF Saccharification and Fermentation Shakedown trial- NREL will conduct a series of pilot-scale enzymatic saccharification and fermentation runs in appropriate PDU/IBRF equipment. Prior to conducting these runs, NREL/DOE safety reviews will occur and NREL Safe Operating Procedures for the equipment being used will be modified and/or developed as appropriate to be consistent with the processing of AFEX-treated feedstocks that will be provided by MBI. All equipment will be appropriately

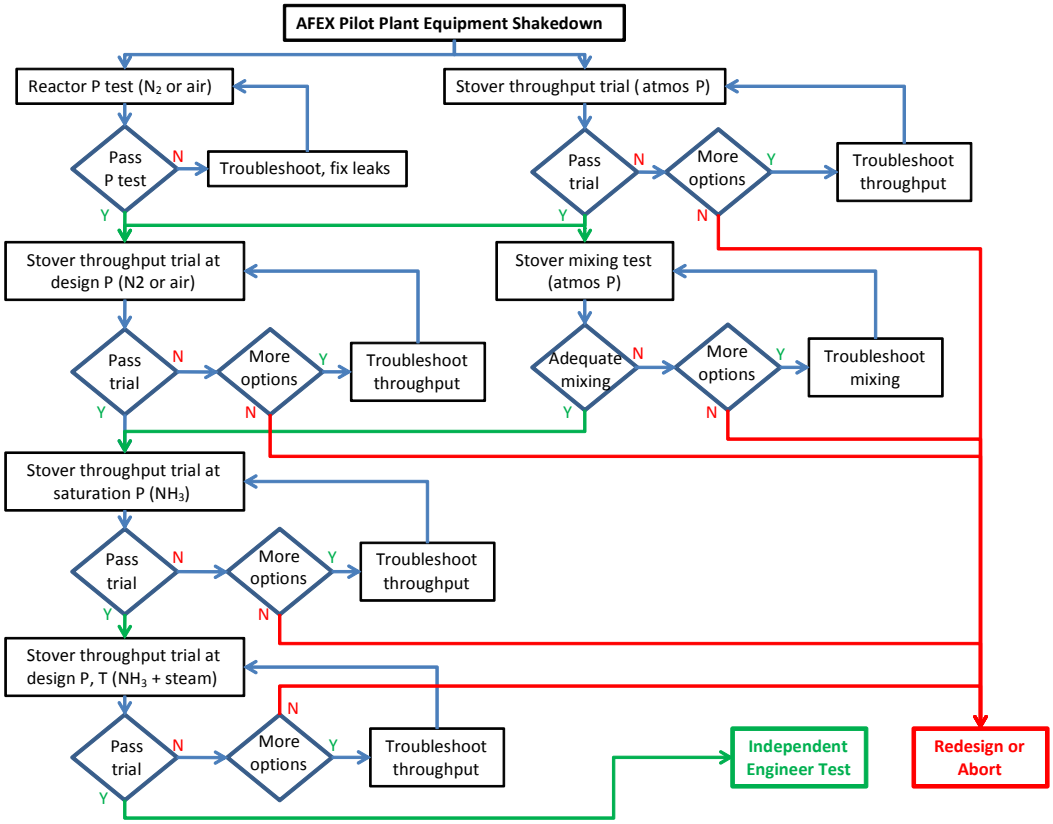


Figure 29. Logic diagram for shakedown of continuous AFEX pilot-scale reactor.

prepared for operations prior to the start of the shakedown/optimization campaign. NREL will appropriately receive and store AFEX-treated feedstocks supplied by MBI on a run-by-run basis in PDU/IBRF storage facilities. Approximately five enzymatic saccharification and fermentation runs will be conducted during the shakedown/optimization campaign. Each run will require about 10 days of continuous staffing by NREL operations technicians and engineers, including weekends. Chemical analysis of enzymatic saccharification and fermentation process samples to generate process performance data will be conducted by NREL scientists and analytical technicians during regular business and the process performance data will be provided to MBI. After each pilot-scale run is completed, all process equipment will be cleaned and prepared for future runs per standard NREL procedures. In parallel with each pilot-scale shakedown/optimization run, a bench-scale enzymatic saccharification and fermentation control run will be conducted using the same AFEX-treated feedstock provided by MBI. These control runs will be conducted in appropriate bench scale enzymatic saccharification equipment (shake flasks and/or small high-solids reactor systems) and fermentation equipment (shake flasks and/or bench-top fermentor units). NREL will perform chemical compositional analysis of appropriate samples to generate process performance data and will provide process performance data to MBI. MBI personnel will be provided access to the NREL PDU/IBRF during these operations and will be permitted to be involved in operational activities, per NREL ES&H and Security regulations. Additionally, NREL will provide limited technical and engineering support to MBI during MBI's operation of its pilot-scale AFEX treatment equipment and associated systems.

2.8 Capstone Runs – After completion of equipment shakedown trials and Independent Engineer tests, extended continuous runs, or capstone runs, will be conducted to collect extensive mass and energy

balance data, to produce significant quantities of intermediate and primary products, and to generate samples of fermentation residue for analysis. Section 6.1 of the PMP discusses justification for the planned duration of AFEX capstone runs.

AFEX equipment capstone run- MBI will conduct capstone runs of the continuous AFEX reactor with ammonia recovery and re-use. Capstone runs are anticipated to be approximately 10 to 14 days in duration each. These runs will allow for collection of extensive energy and mass balance data on the integrated AFEX process, and will also produce the AFEX-treated stover for use in densification capstone runs at MBI, and integrated saccharification and fermentation capstone runs at NREL.

Densification capstone run- AFEX-treated stover produced during the AFEX equipment capstone runs will be used for densification capstone runs. It is anticipated that the densification equipment capacity will be significantly greater than 1 TPD, so that AFEX-treated material from several days of AFEX runs will be densified within a few hours operation of the densification equipment. The densified AFEX-treated stover will be shipped to NREL for integrated saccharification and fermentation capstone runs.

NREL PDU/IBRF Saccharification and Fermentation Capstone Run- NREL will conduct a series of pilot-scale enzymatic saccharification and fermentation capstone runs in appropriate PDU/IBRF equipment. Prior to conducting these runs, NREL/DOE safety reviews will occur and NREL Safe Operating Procedures for the equipment being used will be modified, per any changes identified during the execution of Phase 2b. All equipment will be appropriately prepared for operations prior to the start of the demonstration campaign. NREL will appropriately receive and store AFEX-treated feedstocks supplied by MBI on a run-by-run basis in PDU/IBRF storage facilities. Approximately three enzymatic saccharification and fermentation runs will be conducted during the capstone campaign. Each run will require about 10 days of continuous staffing by NREL operations technicians and engineers, including weekends. Chemical analysis of enzymatic saccharification and fermentation process samples to generate process performance data will be conducted by NREL scientists and analytical technicians during regular business hours and the process performance data will be provided to MBI. After each pilot-scale run is completed, all process equipment will be cleaned and prepared for future runs per standard NREL procedures. In parallel with each pilot-scale capstone run, a bench-scale enzymatic saccharification and fermentation control run will be conducted using the same AFEX-treated feedstock provided by MBI. These control runs will be conducted in appropriate bench scale enzymatic saccharification equipment (shake flasks and/or small high-solids reactor systems) and fermentation equipment (shake flasks and/or bench-top fermentor units). NREL will perform chemical compositional analysis of appropriate samples to generate process performance data and will provide process performance data to MBI. MBI personnel will be provided access to the NREL PDU/IBRF during these operations and will be permitted to be involved in operational activities, per NREL ES&H and Security regulations.

2.9 AFEX shakedown and capstone run support – This task will include all safety and analytical support for the AFEX shakedown and capstone runs. Support required before and during these runs will include drafting and updating equipment SOPs, sampling and analytical protocols, and operator training.

2.10 Project Management Support – This task encompasses administrative and management requirements, including organizing meetings, and all reporting and other documentation requirements.

2.11 Techno-economic Model Update – As capstone run data is collected, it will be incorporated into updated Aspen techno-economic models to determine the impact on MESP. Techno-economic models based on both centralized and de-centralized commercial AFEX Integrated Biorefinery designs will be developed.

2.12 Business and Commercialization Plan Update – Throughout Budget Period 2, updated values for equipment capital and operating costs, as well as updated outputs from the techno-economic model will

be acquired, which will be used to update the commercialization plan. The updated commercialization plan will include a comparison of centralized and de-centralized AFEX Integrated Biorefinery options.

2.15 Reporting - Eight quarterly reports and a final report are planned for Budget Period 2. Each of these reports will include technical progress and results, milestones achieved, updated spending plans, EVMS reports, Recovery Act status reports, and updated management plans.

2.16 Meetings/Communications - A budget period 2 kickoff meeting will occur within three weeks of the scheduled project start date, to include representatives of all project partners. A Stage-Gate review meeting will take place near the midpoint of Budget Period 2. A final review meeting will take place within three weeks of the scheduled end of Budget Period 2. Quarterly review meeting will be conducted by teleconference when appropriate to minimize travel costs. Each of these meetings will include discussions of technical progress and research results, progress toward milestones, review of project financials, and review of go/no go decision criteria for Budget Period 3.

Budget Period 3 Tasks

3.1 Operation – Up to eight months of extended operations of the AFEX treatment and densification equipment at MBI, the hydrolysis and fermentation equipment at NREL, or both, may occur during Budget Period 3. The scope of the extended operation efforts will be determined after the capstone runs and techno-economic modeling are completed in Budget Period 2.

3.2 Model and BCP Development – The techno-economic model, Business and Commercialization Plan, Life Cycle Analysis will each be updated with any data from extended operations, and then finalized for the Budget Period 3 Final Report. The final report will include detailed techno-economic analyses of the centralized and de-centralized options for deployment of AFEX Integrated Biorefineries.

3.3 Project Management Support - This task encompasses administrative and management requirements, including organizing meetings, and all reporting and other documentation requirements.

3.4 Reporting – A first quarter progress review report, and a Final Report, will be deliverables for Budget Period 3. The first quarter report will include technical progress and results, milestones achieved, updated spending plans and EVMS reports, Recovery Act status reports, and updated management plans. The Final Report will also include all data and analyses from Budget Periods 1 and 2, as well as the finalized techno-economic model results, Business and Commercialization Plan, and Life Cycle Analysis for the AFEX Biorefinery technology.

3.5 Meetings - A budget period 3 kickoff meeting will occur within three weeks of the scheduled project start date, to include representatives of all project partners. A single stage gate review meeting and a Final Review meeting will take place. The Final Review meeting will include discussion of the go/no-go decision for construction of a Demonstration-scale AFEX Biorefinery, and updates to the Business and Commercialization Plan.

4.7 Description and Justification of New Construction at MBI

The continuous AFEX pilot plant process equipment described in Section 3.2 above will be installed and operated in a new facility to be constructed as an addition to the existed MBI Building in Lansing, Michigan.

Equipment cost estimation - Process equipment, piping and electrical costs were prepared by Dick Engineering, a full service design firm serving the process industries for 40 years. The cost estimate is an order-of-magnitude estimate with an accuracy of +/-30%. The methodology used was based on PFDs created from an Aspen simulation model of the AFEX process. Preliminary P&IDs and layouts were then made. Budget quotations for major equipment were obtained. Piping, electrical, and instrumentation costs were based on the preliminary P&IDs and layouts. Other costs are based on Dick Engineering's opinions, and are made on the basis of Dick Engineering's experience.

Building cost estimation - The building cost estimate was prepared by EPS, an engineering design firm with 14 years experience in the biotech and energy industries. The cost estimate was based on the development of detailed drawings, vendor quotations on major components, and several site visits to determine the scope of the effort. Other costs were based on EPS' past experience and industry standards.

Process control and data acquisition - MBI anticipates using the OPTO 22 system for the AFEX pilot plant process control and data collection. The OPTO 22 system would communicate with the pretreatment and ammonia recovery system PLCs and serve as the primary operator interface. OPTO 22 is an integrated PC based system of hardware and software for industrial process control, remote monitoring, and data acquisition. MBI has a long history of successfully using OPTO 22 in fermentation and reactor control applications and has the applications programming and system maintenance expertise to keep the system functioning.

Building - In order to house the AFEX treatment and ammonia recovery equipment, MBI will need to make an addition to its facility. The addition would be built adjacent to the existing facility, as shown in Figure 30, in order to use the existing infrastructure. Steam, water, waste disposal, and electrical power distribution capacity already exists that is sufficient to supply the AFEX treatment pilot plant. The existing MBI facility is permitted for anhydrous ammonia storage and handling. In addition, support services (analytical instruments and staff) and Professor Bruce Dale's research labs are housed in the existing building, and would be a readily accessible resource. The addition would match the original construction and appearance of the existing building. Interior architectural details will match MBI's existing building including the masonry walls. The south side of the building addition will have a receiving and storage area for biomass feedstock with direct access to the processing equipment. The building will also feature an electrical/utilities room, control/lab room, and a laboratory area. An employee workstation and meeting area will be located in the building.

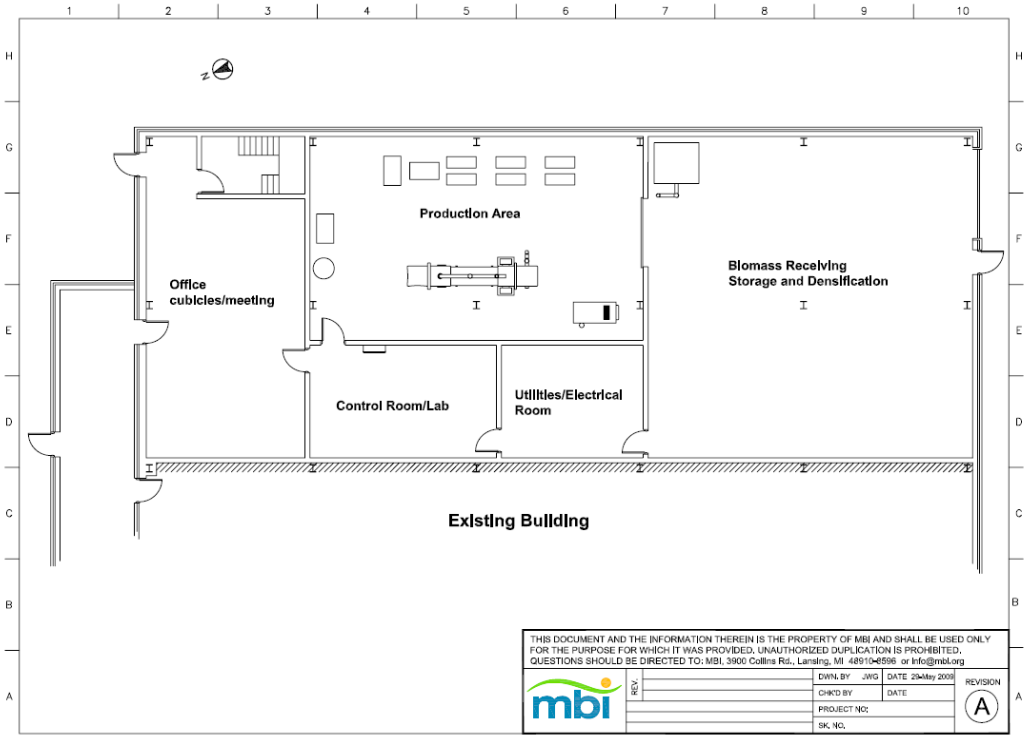


Figure 30. Sketch of planned new construction at MBI, including biomass receiving and storage area, production area to house AFEX processing equipment, control room, utilities, and offices.

Disposition plan for new facility at MBI –The facility constructed at MBI as part of this project will not be decommissioned at the end of the project. It is envisioned that the AFEX treatment facility will meet an ongoing need for pilot-scale biomass processing studies at MSU long after the proposed project is complete. Therefore, MBI plans to continue operation and maintenance of the facility after completion of this project.

4.8 Project Management Structure

Overall management of the AFEX Biorefinery pilot plant project will be the responsibility of a Project Manager and a Project Management Team, who will have oversight and decision-making authority over all project aspects. Specific project functions will be managed by nine functional teams. Brief descriptions of the teams and their responsibilities are given below; more detailed team descriptions and a Project Organization chart are in the PMP (Section 2).

Project Management Team - has oversight and decision-making authority over all project aspects, including technical, administrative, and financial, and will be responsible for selection of an Engineering, Procurement and Construction (EPC) firm. The Project Manager is a member of this Team.

Project Manager - oversees the research agenda, prepares reports for DOE, and is the primary contact with DOE staff.

Feedstock Team - will be lead by Vermeer and has oversight for all activities regarding feedstock growth, harvesting, pre-processing, storage and transportation to the primary work site at MBI/MSU. This team is responsible for on-time delivery of required feedstock to meet project specifications.

Research & Development Team - The R&D Team has oversight for all early research and development activities aimed at enabling a robust final design of the proposed facilities. MBI, MSU, Novozymes and NREL will all be represented on this team.

Design Team - The Design Team has oversight on finalizing the design of the proposed integrated biorefinery facilities. They will select a design engineering firm to assist with final design. This firm will become a member of the Design Team. This Team will incorporate results from the R&D Team into the final design. They are also responsible for design of all safety systems for the proposed facilities.

Construction Team – will oversee modifications to existing facilities as detailed above. The EPC firm selected by the Project Management Team will become part of the Construction Team and will interact with the Design Team and equipment vendors to ensure construction efforts remain on schedule, on budget and adhere to all EH&S guidelines.

Shakedown Team - will consist of senior MBI and NREL team members as well as representative of the EPC firm, the equipment vendors, and appropriate safety managers. They are responsible for testing and troubleshooting of installed equipment to ensure that all equipment meets operational and safety specifications.

Demonstration & Operations Team - will consist of MBI, MSU, Novozymes, Vermeer and NREL team members well-experienced in the processes being demonstrated, including AFEX treatment, enzyme hydrolysis and fermentation for production of ethanol. They are responsible for meeting the project objectives and requirements for demonstration of the proposed technology.

Environmental Health & Safety Team - will consist of MBI, NREL, MSU and Airgas personnel trained in all aspects of environmental health and safety required for this project.

Administrative & Finance Team - This team will consist of MBI, NREL, and MSU personnel and oversee documentation of all project related activities. They will assist in contract negotiation, report and presentation preparation, and budget monitoring and management, including oversight of procurement budget cost share activities.

Business & Commercialization Team - will consist of senior business development personnel at MBI, MSU, ICM and The Andersons. They are responsible for updating the business and commercialization plan and maintaining strong communications with our potential commercial partners.

Personnel – CVs of key MBI, MSU, NREL, Vermeer, and Novozymes, personnel are contained in the Resume.pdf document. The experience and core competencies of these personnel are discussed in greater detail in Section 9 of the BCP.

Senior Management Buy In – Senior Management of MBI International, MSU, and the MSU Foundation are committed to this project, as demonstrated by the letters of support attached to our application. Senior management buy-in is discussed in greater detail in Section 10 of the BCP.

4.9 Financial Management

Section 10 of the PMP outlines the project financial management plan, including the spend plan. The Financial Contingency Plan is addressed in Section 7 of the PMP. A Change Control Plan for the project is outlined in Section 9.1 of the PMP. This project will include subcontracts, managed by MBI, with MSU, Novozymes, Vermeer and an EPC firm, as described in the PMP (Section 1) and the budget justification file attached to this proposal.

5.0 Merit Review Criteria

As required in Appendix D of the FOA, this section of the PEP is formatted to address each criterion and sub-criteria listed in Part V.A. of the FOA.

1. Criterion 1 – The application demonstrates the technical merit and rationale for the proposed project. The technical description of the proposed project convincingly presents and justifies that the proposed project:

   1.1. has data from previous bench- or pilot-scale work or other credible, validated sources to support the goals and objectives of the proposed project and is likely, from a technical perspective, to achieve the yields, conversion, and efficiency of each unit operation necessary to validate the goals and objectives of the proposed project;

The four major goals of this project (from the Project Narrative, Section 3) are listed below, along with descriptions of previous bench-scale data that supports the likelihood of the project successfully achieving those goals.

1.) Operate a continuous AFEX treatment process with ammonia recoveryand reuse at 1 TPD.

This goal incorporates the objectives of continuous AFEX reactor operation to obtain high enzyme hydrolysis yields of fermentable sugars from corn stover, and continuous ammonia recovery. Detailed data from bench-scale AFEX batch treatment of corn stover is given in the Bench-Scale Background Data (Section 2) of this PEP above. As Table 3 above shows, combined yields of monomeric and oligomeric

sugars from enzyme hydrolysis of AFEX-treated stover are 89 and 94 percent, respectively. Figure 10 illustrates that fermentation of sugars hydrolyzed from AFEX-treated stover provides high conversion to ethanol. In addition, a substantial body of research describing AFEX treatment of corn stover and other biomass feedstocks has been published over the past thirty years (Dale and Moreira, 1982; Dale, 1987; Teymouri et al., 2004; Teymouri et al., 2005a and b; Mosier et al., 2005; Eggeman and Elander, 2005; Wyman et al., 2005a and b; Balan et al., 2006; Kumar et al., 2009; Lu et al., 2009; Sendich et al., 2008; Laser et al., 2009). The bench-scale data and model calculations in these papers clearly establish the effectiveness of AFEX as a treatment for conversion of corn stover and other biomass feedstocks to fermentable sugars and ethanol. The bench-scale data supports the hypothesis that a continuous AFEX reactor unit operating with the same conditions as a bench-scale reactor should be able to provide results that validate the goal. The risks associated with continuous AFEX reactor operation are clearly defined in Section 4 "Proposed Project" of this PEP.

The second objective incorporated in this goal is to operate the AFEX reactor with continuous ammonia recovery. Two simple bench-scale investigations of ammonia recovery from AFEX-treated corn stover are shown in Figures 13, 14 and 15 above. The batch experiment in Figure 13 measured 98% recoverable ammonia from AFEX-treated stover. Figure 14 shows that the total Kjeldahl nitrogen in corn stover increased by only 2.6 grams per hundred grams of stover after AFEX treatment; since the ammonia load was one hundred grams of NH_3 per hundred grams stover (1:1 wt:wt), less than 3 percent of the ammonia loaded remained on the stover after AFEX treatment. Figure 15 shows 100% ammonia recovery from wheat straw within 15 minute of drying time in a bench-scale experiment. As explained in the Bench-Scale Background Data Section above, it is practically impossible to conduct bench-scale experiments on continuous ammonia recovery from biomass. Nevertheless, the batch data above shows that high ammonia recovery should be achievable from AFEX-treated corn stover.

2.) Integrate the AFEX-treated material with high solids enzyme hydrolysis and mixed sugar co-fermentation steps to demonstrate ethanol production from corn stover at the 1 TPD scale.

Ethanol production from fermentation of AFEX-treated corn stover has been investigated extensively at bench scale. The bench-scale data is reviewed in the Background section of this PEP above. Figures 2, 3, 4, 8, and 9 in the Bench-Scale Background Data (Section 2) show yields of glucose and xylose from enzyme hydrolysis of AFEX-treated stover. Figure 10 compares the fermentability of sugars derived from AFEX-treated and dilute acid-pretreated corn stover, using two different fermentation organisms. Figure 18 above shows that 4 wt% (40 g/L) ethanol concentration has been achieved in bench-scale fermentation of AFEX-treated corn stover at 18% solid loading. The fermentation organism that we plan to use in this project, *Zymomonas mobilis* 31821 (pZB5), has been shown in bench-scale experiments to give 66% of theoretical ethanol yield from AFEX-treated biomass, with high utilization of both glucose and xylose. Based on these bench-scale results, we are confident that, with the combined efforts of MBI and NREL researchers, AFEX-treated corn stover can be integrated into the pilot scale high-solids hydrolysis and mixed sugars co-fermentation operations.

3.) Evaluate the fermentation residues and determine their value.

The composition and heating value of fermentation residues from dilute acid-pretreated corn stover have been determined previously (Aden, 2002). However, fermentation studies of AFEX-treated stover have only been conducted at bench scale, so only small quantities of fermentation residues have been available for evaluation. In this project, we will produce significant quantities of lignin-rich fermentation residue for analysis. The fermentation and solid-liquid separation operations at the NREL PDU that will be used to produce and collect fermentation residues are described in more detail in the Proposed Biorefinery Section (Sections 3.3 and 3.4) of this PEP. Both MBI and NREL have extensive experience with sampling, chemical composition analysis, and computation procedures for characterization of solid

residues. The composition and heating value of the fermentation residues will be key inputs for mass and energy balances to be used in modeling commercial AFEX Biorefinery plants.

4.) Collect performance data and mass and energy balances from these operations and incorporate them into techno-economic models for a commercial AFEX Integrated Biorefinery.

The performance data to be collected from pilot plant unit operations will include mass throughput measurements and operating loads of equipment, and stream temperatures, pressures, and mass flows. Our plan for collection of this performance data is outlined in the WBS and the Task Descriptions in the Proposed Project section (Section 4) of this PEP. An Aspen model of the entire AFEX Biorefinery process will be developed, incorporating all of the data acquired during pilot capstone runs. MBI, MSU, and NREL all have considerable experience modeling biomass-to-biofuel conversion processes at scales from pilot to large commercial plants. Many of these process model studies have been published in peer-reviewed publications (Eggeman and Elander, 2005; Sendich et al., 2008; Laser et al., 2009).

1.2. will be able to demonstrate the full integration of all unit operations in producing the "primary product", as defined in the FOA, Part I - Description section;

Our fully integrated biorefinery technology is described in detail in the "Proposed Biorefinery" section of this PEP above. The primary product, ethanol, will be produced from the feedstock, corn stover, in three stages: Stover collection and preprocessing, AFEX treatment, and bioconversion. Integration of the overall process is achieved in three key ways:

a) Linking each stage to the next by flow of a stable intermediate.
b) Maintaining integrity by restricting energy and recycle streams within a given stage unless two stages are co-located. The only material transferred from one stage to the next is a stable intermediate.
c) Producing ethanol as the primary product from 1 TPD of biomass through the entire process.

All aspects of the process will be integrated, all waste streams will be identified and managed and mass and energy balances from all processes will be identified to update the Life Cycle Analysis (LCA) and Techno-Economic Model to determine viability of particular implementations at the demonstration and commercial levels.

1.3. has clearly defined the critical success factors and has a research, development and demonstration plan to successfully complete them at the proposed scale-up factor(s);

The Critical Success Factors (CSFs) for the proposed project are listed in the Proposed Project section of this PEP above. The research, development, and demonstration effort to complete the CSFs is outlined in the WBS in the PMP. A brief discussion of how the proposed effort will complete each CSF at pilot scale is included below:

CSF1 - Complete techno-economic model of a commercial AFEX Integrated Biorefinery, and determine the minimum selling price and GHG emissions for ethanol produced at a commercial facility, using mass and energy flows determined in pilot-scale performance runs.

MESP and GHG emissions will be determined using an ASPEN process model of a commercial AFEX Biorefinery. This Aspen model will use data inputs from two sources: First, mass and energy balance data, equipment thermal and electrical loads, fermentation residue LHV, and other quantities specific to our AFEX Integrated Biorefinery will be determined in this pilot project. The methods to be used to collect this data are described in more detail in the task descriptions in the Proposed Project section of this PEP above. Second, operating costs such as feedstocks, enzymes, and electricity will be based on 2012 State of Technology values, which are published by NREL and updated periodically (Aden, 2008). The ASPEN model will be reviewed by all project partners for accuracy, completeness, and realistic assumptions for commercial ethanol production. The MESP and GHG reductions determined

from the Aspen model will be the basis of the final decision point of the project, which will be a go/no-go decision for construction of a commercial AFEX Integrated Biorefinery (see Figure 28 above).

CSF2 - Demonstrate continuous operation of an AFEX reactor with ammonia recycle at pilot-scale.

Operation of a continuous AFEX reactor with ammonia recovery has never been demonstrated at any scale. Our plan for construction, shakedown, and operation of a 1 TPD continuous AFEX reactor pilot plant is outlined in the WBS. Continuous operation of the AFEX reactor with ammonia recovery will be demonstrated by achieving and maintaining steady-state AFEX reactor operating conditions during capstone runs, by measuring enzyme hydrolysis yields of treated stover samples drawn from the reactor, and by measuring makeup ammonia requirement during steady-state operation of the reactor.

CSF3 - Integrate high-solids enzymatic hydrolysis and mixed-sugar co-fermentation steps with AFEX-treated stover at pilot scale.

The tasks and schedule for modification, shakedown, and operation of pilot-scale enzyme hydrolysis and fermentation equipment at NREL's PDU are outlined in the WBS, and are described in more detail in the Proposed Project section. Risks associated with development of high-solids saccharification/fermentation are listed in the Proposed Project section of this PEP above. Anticipated challenges include handling and mixing of AFEX-treated corn stover at high solids loading, potential for contamination of the stover before inoculation in the fermentor, and performance of the fermentation organism. MBI and NREL have years of combined experience with enzyme hydrolysis and fermentation of biomass feedstocks. Our research and development plan in Budget Period 1 includes some limited bench-scale tasks to determine effective operating conditions for high-solids hydrolysis, including enzyme type and loading, and residence time and temperature requirements. Mixed sugar co-fermentation will also be studied at bench scale in Budget Period 1 to determine effects of solids loading and contaminant loads on fermentation performance. Bench-scale SSF trials with antibiotics will be conducted to determine their effectiveness in the event that they are needed to control contamination in pilot fermentor operations. These bench-scale trials in Budget Period 1 will support the pilot-scale shakedown trials and capstone runs in Budget Period 2, increasing the likelihood of successful on-schedule completion of CSF3.

CSF4 - Achieve the critical factors above and complete all tasks within the scope, budget, and schedule shown in the WBS.

We believe that the schedule shown in the WBS is realistic and achievable, and will allow for completion of our goals, objectives, and CSFs as rapidly as possible.

1.4. has clearly defined the scope, schedule, and budget, that in combination demonstrate that the project will be able to achieve its goals and objectives as planned;

The scope and schedule of the proposed effort are detailed in the WBS and task descriptions in the Proposed Project Section of this PEP, and in the resource loaded schedule in Figure 3 of the PMP. The only parts of the scope of effort that are not clearly defined are the iterative efforts in the equipment shakedown tasks in Budget Periods 1 and 2. These iterative tasks are described using the logic diagram shown in Figure 29 above. The logic diagram indicates the decision points that will be used to determine whether to continue or abort each iterative loop in the development process. The project budget is shown in detail in the SF 424A Excel Budget file attached to this application. The budget and the spend plan in Section 10.1 of the PMP demonstrate how the budget will cover the proposed effort to achieve the project goals. Team MBI's core competencies and experience in managing projects to successful completion of goals is detailed in Section 9 of the BCP and Sections 2 and 3 of the PMP. Our management strategy, project management process, and the Project Organization chart showing how we will organize the team's capabilities and efforts to achieve the project goals are in the PMP (Section

2). It is clear from these documents that the scope of the proposed project will achieve the goals, and the budget and schedule are adequate to complete the scope.

1.5. validates that the selected feedstock availability, site selection, and environmental permitting are understood and will be successfully addressed;

Present and future availability of corn stover as a feedstock for ethanol production has been studied thoroughly (DOE, 2003; Graham et al., 2007), and is discussed in the Background section of this PEP above, as well as in Section 7 of the BCP. Corn stover, as a "high impact" feedstock, is generally anticipated to be available in quantities sufficient for commercial biofuel production across the Midwestern U.S. in the foreseeable future. Site selection and environmental permitting for the proposed AFEX Biorefinery pilot plant is discussed in the Proposed Biorefinery section above. Briefly, all three sites for the pilot-scale operations are either currently fully permitted or will have all necessary permits by the start of the proposed project. Environmental input for the proposed pilot plant is provided in the Environmental Questionnaire document (Enviro.pdf) attached to this application. Site selection and environmental permitting issues for future demonstration- and commercial-scale plants are discussed in Section 8 of the BCP. Our deployment plan includes partnering with a current commercial ethanol producer to build a demonstration plant as an add-on to an existing ethanol plant, thereby minimizing site selection and permitting difficulties.

1.6. incorporates novel or breakthrough technologies and/or technology applications;

Our proposed AFEX Biorefinery process will incorporate six innovations that have never been demonstrated at pilot scale. These are 1) continuous AFEX-treatment of biomass feedstock; 2) continuous ammonia recovery and re-use; 3) high-solids enzyme hydrolysis and mixed sugar co-fermentation of AFEX-treated corn stover; 4) hydrolysis of AFEX-treated stover using enzymes specifically selected for that purpose; 5) densification of AFEX-treated stover for efficient and stable storage and transport; 6) flexible location and operation of biorefinery facilities. Each of these technologies is described in more detail in the Proposed Biorefinery section of this PEP above. These innovations, when de-risked at pilot scale, will present clear advantages for cellulosic ethanol production over competing technologies, and will be of significant interest to commercial ethanol producers, as explained in greater detail in our Business and Commercialization Plan.

1.7. has clearly defined and established the applicant's rights to use and commercialize the technology.

Team MBI owns or has license to all of the intellectual property necessary to execute the proposed project. Over the past ten years, MBI International and Michigan State University have filed more than thirty patent applications on AFEX technology. Patent applications have been filed with the U.S. PTO, the E.U. EPO, the WIPO, as well as in Canada, Mexico, Brazil, Argentina, Australia, New Zealand, Japan, and China. MBI International has obtained exclusive worldwide license from Michigan State University to develop and commercialize the AFEX technology. MBI's rights to commercialize the proposed technology are therefore clearly defined and established. More detailed information can be found in the "IP Statement and Supporting Documentation" form attached to this application. The strain of *Z. mobilis* to be used as fermentation organism in this project is available for license from project partner NREL. It is anticipated that before the start of Budget Period 1, teaming agreements will be executed between all team members. These teaming agreements will explain in detail the distribution of ownership of any IP that may be developed during execution of the proposed project.

1.8. has a clearly described, technically and financially sound, implementable plan (including resource allocation) to successfully complete the scope by September 30, 2015, while accelerating job creation and economic benefit.

Our project scope and plan for completing it are described in detail in section 4 of this PEP, titled "Proposed Project", and in Section 1 of the PMP. The PMP also includes the resource loaded schedule. The detailed project budget and budget justification files are attached to the application. To support the DOE's goals, our project team's pilot-scale biorefinery will have the capability to proceed rapidly and become operational within three years after selection. As the resource loaded schedule shows, the total project duration is less than four years. Our plan is implementable and technically and financially sound, and can be completed well before September 2015. Job creation and economic benefits of the proposed project are explained in Section 6 of the Project Narrative.

1.9. has the resources with core competencies to cover all project aspects.

Core competencies of MBI, NREL, Vermeer, Novozymes, and other partners are described in Section 9 of the BCP. MBI's experience with AFEX technology, combined with its mission of de-risking and scale-up of bio-based technologies, makes it uniquely qualified to lead the proposed project. Vermeer has corn stover collection, processing, and handling expertise. MBI and NREL both have extensive experience operating pilot-scale facilities for development of bioconversion processes. Novozymes brings experience with biotechnology pilot plant operation along with enzyme development for hydrolysis of lignocellulosics. Resources available at MBI, MSU, and NREL are described in detail in Section 2.3 of the PMP. The collective core competencies and resources of the project partners are more than adequate to cover all aspects of the proposed project.

2. Criterion 2 – The applicant demonstrates credible economics and competitive advantages that justify the costs of research, development and demonstration of the proposed integrated biorefinery technology in order to proceed to commercial scale.

2.1. The plan for commercialization and deployment and the technological advancement provided by the proposed project towards reaching the goals and objectives detailed in this FOA justify the use of Federal funding.

Sections 3 and 4 of the BCP discuss in detail the alignment of the proposed project with the budget, and the alignment of the project value proposition with the goals of the FOA. The budget and spend plan for the proposed project are shown in detail in the SF 424A Excel Budget file attached to this application. Section 4 of this PEP above contains the WBS on which the budget is based, Section 6 of the PMP discusses how the schedule for the proposed project was estimated, and Section 10 of the PMP contains an overview of the project spend plan. Both the schedule and the budget are based on the experience and capabilities of our unique team, which will enable us to start the project rapidly after selection, and then reach our project goals and complete the critical success factors for our innovative AFEX Biorefinery pilot plant expeditiously. The use of Federal funding to support this project is justified by the close alignment of the goals of our project with the EERE performance goals of reduced dependence on imported petroleum and the creation of a U.S. bioindustry, as discussed in Section 3 of the Project Narrative.

2.2. The application describes the value proposition and demonstrates a clear understanding of it, and how the value proposition supports the goals and objectives of the FOA.

Team MBI's value proposition, as stated in Section 3 of the Project Narrative, and in more detail in Section 4 of the BCP, makes it clear that our innovative AFEX biorefinery technology will address at least

five of the key technical barriers to commercialization of cellulosic ethanol, including biomass recalcitrance, treatment catalyst (ammonia) recovery, biomass saccharification and fermentation at high solids loading, enzyme cost, and compatibility of hydrolyzed sugars with fermentation. Furthermore, the unique group of collaborators who make up Team MBI represent an unusual set of skills, experiences, and capabilities to develop the AFEX biorefinery technology from pilot scale to commercialization in a short period of time.

The goals of the proposed project are described in Section 3 of the Project Narrative. These project goals clearly support the goals and objectives of the FOA. As explained in Section 2 of the BCP, the DOE's Office of Energy Efficiency and Renewable Energy (EERE) has listed several key objectives for renewable energy policy, including reduced dependence on imported petroleum, reduced GHG emissions, and the creation of a domestic renewable bio-based industry. Pilot-scale validation of the proposed AFEX biorefinery technology will clearly represent a significant step toward these objectives.

2.3. The goals and objectives of the project proposed under this FOA are likely to lead to the eventual commercialization of the technology and biofuel. The applicant provides a credible explanation as to how the liquid transportation fuel(s) will be produced as the "primary product" and will be a profitable commodity at the time a commercial facility is forecast to be operational.

The goals and CSFs of the proposed project are listed in Sections 3 of the Project Narrative, and in Section 4 "Proposed Project" of this PEP above. Team MBI's plan for developing the proposed AFEX Integrated Biorefinery technology from pilot scale to commercialization is described in detail in Section 5 of the BCP; the current technological and market conditions for commercialization are described in Section 6. Achievement of the project goals and completion of the CSFs will provide the data needed for construction of an AFEX treatment unit as an add-on to an existing grain ethanol plant. As described in more detail in the Business and Commercialization Plan, successful operation of the demonstration unit will lead to licensing of the technology for implementation in multiple commercial plants in various geographies. Ethanol, the primary product of our proposed technology, is already a widely accepted liquid transportation biofuel when used as an oxygenate blended at 10 % with petroleum-derived gasoline blendstock (E10), and is gradually gaining acceptance at higher blend rates (E85) for use in Flex-Fuel vehicles. Section 3 "Proposed Biorefinery" of this PEP explains in detail how ethanol will be produced as the primary product from corn stover using the proposed AFEX Integrated Biorefinery technology. Section 5 of the BCP discusses our Pro Forma projection, which shows that an envisioned commercial AFEX Integrated Biorefinery in 2015 will produce ethanol for $2.19 per gallon with a 21.6% return on Total Project Investment.

2.4. The applicant presents a credible life-cycle analysis of the estimated greenhouse gas emission reductions of the primary product over a petroleum alternative as outlined in Part IV.C.q.

Our Life Cycle Analysis (LCA) for the proposed AFEX Biorefinery technology is contained in detail in the LCA_GHG.xls document attached to this application. The LCA uses reasonable inputs and assumptions to show that ethanol produced commercially from corn stover using our AFEX Biorefinery technolog will reduce GHG emissions by 65% compared to petroleum-derived gasoline as a motor fuel. This GHG reduction calculation was done via the GREET 1.8b model, based on E85 fuel consumption in a Flex-Fuel vehicle. The environmental burdens associated with fertilizers, fuels, ammonia, enzyme and other materials are included in the calculations. Total GHG emissions for the Flex-Fuel vehicle burning E85 containing AFEX Biorefinery-produced ethanol were 127 grams/mile in the GREET model output, compared with 478 grams/mile for the baseline gasoline vehicle. The LCA includes a sensitivity analysis estimating the effects of increasing stover transport distance on GHG emissions.

2.5. The applicant presents a credible petroleum displacement analysis of the primary product over a petroleum alternative as outlined in Part IV.C.r.

Our petroleum displacement analysis is presented in the file Petro.doc, attached to this application. The primary product of our proposed pilot plant will be ethanol; however, it should be noted that the pilot plant facility will not produce fuel-grade ethanol, and therefore will not actually displace any barrels of petroleum. If the ethanol produced by the proposed pilot plant were to be recovered as fuel, it would displace approximately 42 barrels of oil/year. The envisioned first commercial AFEX Integrated Biorefinery facility is anticipated to produce 454,200,000 L/annum of ethanol, combined with 492 billion BTU/ annum of electricity, which together will displace 1.77 million barrels/annum of oil. We project that by 2030, 68 commercial AFEX Integrated Biorefinery plants will be producing a total of 30.8 billion L/annum of ethanol, displacing 120 million barrels/annum of oil.

2.6. For Topic 5 and 6 applications only: The applicant provides a credible life cycle analysis for the "primary product" that demonstrates at least an 80 percent reduction in lifecycle greenhouse gas emissions when compared to the comparable motor vehicle fuel lifecycle emissions during calendar year 2005.

This sub-criterion is not applicable to our proposal. Our application is for Topic Area 1.

2.7. The applicant demonstrates that it has the core competencies necessary to cover all commercialization and deployment aspects including but not limited to, feedstocks, engineering, conversion operations, process development, financing, and product marketing. Any partnerships with organizations such as industrial, academic, and national laboratories must be clearly defined, and the collective core competencies must cover all project aspects.

Section 9 of the BCP discusses in detail the relevant capabilities of Team MBI for execution of the proposed project. CVs for key personnel are contained in the Resume.pdf document. Our project team includes core competencies in corn stover harvesting, collection, and pre-processing (Vermeer and MSU), AFEX treatment and biomass densification (MBI, MSU), high-solids hydrolysis and fermentation (MBI, NREL), ethanol recovery (NREL, ICM), as well as process development and engineering (MBI, NREL, ICM), enzyme screening and optimization (Novozymes), and commercial ethanol production (ICM, Andersons). Sections 2 and 3 of the PMP describes how personnel from these industrial, academic, and national laboratory organizations will work together in management and functional teams to achieve the goals and objectives of the project. This world-class team of collaborators represents a unique set of core competencies for commercialization and deployment of the AFEX Integrated Biorefinery technology.

2.8. The applicant or applicant team demonstrates:

2.8.1. experience with operating pilot-scale (for Topic Areas 1, 2, and 5) or demonstration-scale (for Topic Areas 3, 4, and 6) facilities including the ability to collect and analyze data, manage unexpected contingencies, and to troubleshoot problems;

MBI and NREL both have extensive experience operating pilot-scale facilities for development of bioconversion processes. This experience includes data acquisition and analysis, shakedown and troubleshooting of fermentation processes, and management of unexpected contingencies. MBI has operated a 3-level, 20,000-ft^2 fully-equipped pilot plant facility since 1981, housing three 3,700-liter fermentors, along with separation and purification equipment, laboratory facilities, and a machine shop with custom fabrication capabilities. NREL's PDU is described in greater detail in the Proposed Biorefinery section of this PEP. Project contingency management is discussed in more detail in Section 7

of the PMP. Quarterly review meetings will be conducted to monitor progress and compliance with the schedule and budget. Significant changes that arise due to weather delays, cost overruns, design changes, etc., will be evaluated for cause, impact on schedule and budget, and appropriate response to minimize impact.

2.8.2. that it has the knowledge, experience, and a record of successful scale-up and commercialization of new technologies;

The core competencies of our project team members are detailed in Section 9 of the BCP. MBI International has a successful 27-year history of bringing renewable products from academic research to the commercial market. One example is polylactic acid, or PLA. Engineering, scale-up and applications research for production of lactic acid and PLA biodegradable plastics technology were conducted at MBI and MSU with collaboration and support of Cargill Inc., one of the world's largest agribusinesses. Today, this biodegradable polymer is broadly in use around the world in both plastics and fibers in clothing and carpets, containers for food and garbage bags, car parts, etc. Another example, Evercorn, Inc., was a successful joint venture between an MBI subsidiary and Japan Corn Starch (one of Japan's leading starch-based industrial products company) to develop a family of polymer resins that are processed into films and moldable products for disposable use applications. These polymers are strong, water-resistant thermoplastics used in disposable cutlery, plastic containers, and paper coatings. Evercorn's biodegradable products were featured at the Nagano Olympic Games (1998).

NREL's leadership in renewable energy, and particularly in biofuels technology development, is well-established. NREL's National Bioenergy Center (NBC) has led the nation's efforts in the R&D of bioprocess conversion technology for lignocellulosic ethanol and other fuels and chemicals from biomass for over 30 years. In addition to its world-class bioprocessing laboratories and pilot plant facilities, the NBC is home to over 100 technical and support staff who are focused on R&D of biochemical and thermochemical conversion process for lignocellulosic biomass. Many researchers in the NBC have over 15 years of experience in the development of such processes, including key personnel who will be leading and contributing to the MBI-led project team.

Our project team of collaborators represents a unique combination of experience, practical know-how, and capabilities to successfully scale-up and commercialize the AFEX Biorefinery technology.

2.8.3. commercial-scale experience, including plant ownership and operation, permitting, environmental and siting compliance, feedstock acquisition, and raw material management, solids handling, solids separation, conversion, purification of products, etc.

Our project team includes:

- ICM Inc., a world leader in design, construction, and support of ethanol plants. ICM has extensive experience with permitting and environmental and siting compliance for ethanol plant construction.
- Novozymes, Inc., a world leader in industrial enzymes production and distribution.
- Vermeer, Inc., a premier agricultural, construction, environmental, and industrial equipment manufacturing company, with extensive experience in biomass feedstock acquisition and processing.
- The Andersons are national leaders in clean, renewable domestic energy.
- Airgas Specialty Products, a primary supplier of ammonia to the fast-growing market segment of power plants, oil refineries and other manufacturing facilities nationwide.

Each of these team members will play a role in project review, and commercial plan development for the AFEX Biorefinery technology. The combined experience of these collaborators represents a formidable body of commercial-scale knowledge and expertise.

3. Criterion 3 – The application demonstrates knowledge and experience in project management techniques, methods, and practices and describes how the applicant will use them to successfully manage the project proposed for this FOA.

3.1. A Stage Gate method, including go/no-go decision points, is described and coordinated with a resource loaded schedule including how it will be employed to measure progress towards achieving the stated critical success factors.

MBI manages its technology development and de-risking portfolio using a Stage-Gate approach similar to that used by the Department of Energy to manage its Biomass Program (DOE, 2005). Section 3.2 of the PMP discusses the merits of the Stage-Gate method and how the method will be applied to the proposed project. This includes the use of Gate review meetings including the appropriate management and technical teams to measure progress toward project goals. It is anticipated that Stage-Gate reviews will be held with DOE at the end of each major project phase to assess progress and make recommendations for moving to the next phase.

3.2. The application demonstrates through the Project Management Plan and related documents that the applicant is likely to successfully complete the project scope within the total project budget and on schedule.

The Project Management Plan document attached to our application clearly describes the approach to be used to complete the project scope described in the Proposed Project section of this PEP above. The resource loaded schedule is shown in Figure 3 of the PMP. Section 6 of the PMP discusses the justification for the schedule for completion of the proposed pilot plant construction, and equipment installation and shakedown. Section 6.1 discusses the planned period of operation of the pilot plant. Section 10 of the PMP covers financial management and the role of the Administrative and Finance Teams. Section 1 of the PMP discusses the Spend Plan for the project. The project budget and Budget Justification file are attached to the application. These documents make it clear that the project scope is consistent with the schedule and budget, and the PMP provides for expeditious execution of the project in keeping with the goals of the FOA.

3.2.1. The application demonstrates that project management practices will be fully integrated with financial and business systems to measure project progress and enhance the probability of successful completion.

Section 3.2 of the PMP describes the tools and approaches to be used for integration of project management practices with financial and business systems. MBI's current project management practice is consistent with DOE O 413.3A. MBI uses a modified Stage-Gate approach to project and portfolio management, and uses Microsoft Project integrated with SharePoint as its primary project management software tools. MBI's accounting system is run on Deltek Costpoint software, which utilizes a project job costing method. This allows MBI to track expenses and invoice in detail on a project basis and to the appropriate WBS level. The Earned Value Management System (EVMS) software MBI uses is an integrated Microsoft Project/ Web Access/ SharePoint system. During the proposed project, regular review meetings will be conducted as shown in the schedule in section 4 of this PEP above. These review meetings will identify and analyze significant variances from the plan, forecast impacts, and estimate completion based on performance to date and work to be performed. Subcontracts will be

managed to adhere to all requirements with regard to MBI's project management practices and the EVMS. This integrated management approach will increase the probability of successful completion of this pilot plant project.

3.2.2. The application demonstrates the identification and consideration of risk, and the use of effective risk management and change control systems that will be put into full effect very early in the project and used to mitigate impacts.

The risk management plan for the proposed project is summarized in section 4 of the PMP, including a Preliminary Technical Risk Assessment (Table 1 of the PMP). Potential technical, economic, and environmental risks for the AFEX Integrated Biorefinery technology are listed under Project Goals and Risks in the Proposed Biorefinery section of this PEP above. The components of our change control plan, outlined in Section 9.1 of the PMP, are integrated with the Risk Management Plan through the interactions of the technical teams with the Project Manager and the Project Management Team. Team leaders are responsible for recognizing the need to modify the project. Proposed modifications are documented as to scope and justification and submitted to the Project Manager as a Change Request. If necessary the Change Request is submitted to the Project Management Team or other appropriate Change Review Team for review and approval. Approved changes are documented and incorporated into the project plans and communicated to all project teams.

3.2.3. The application demonstrates the knowledge of and a plan to address all environmental, health and safety, permitting, and compliance concerns.

The AFEX Integrated Biorefinery project will involve several environmental and health and safety issues which will require careful management. Section 8 of the PMP gives some background information on health and safety issues associated with the AFEX process and working with ammonia. MBI works with the MSU Office of Radiation, Chemical and Biological Safety (ORCBS) for help in managing environmental health and safety issues, and adheres to all applicable environmental health & safety guidelines. A Process Hazard Analysis of existing AFEX equipment at MBI is given in Table 2 of the PMP. The NREL facility operates under an established safety plan and as a DOE facility meets all safety requirements of the Department of Energy.

Demonstration of an AFEX Integrated Biorefinery at Pilot Scale

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Appendix C

MSU Report

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Cellulose Nanowhisker Technology Development:

Investigation into Utilization of Wheat Straw Residue from Ethanol Production (AFEX + SSF)

Lawrence T. Drzal and Tao Wang

Michigan State University

Final Report – November 2009

ABSTRACT

The compositional, morphological, and surface chemical changes introduced into wheat straw as a result of AFEX and SSF treatments were studied. Cellulose Microfibrillated cellulose (MFC) was extracted from the fermentation residue at reasonable yields. The ability to produce microfibrillated cellulose through a mechanical homogenization approach has significant potential to generate a material with comparable properties to the nanowhiskers but through a much simpler and less costly process.

MFC appears to be the most reasonable cellulose product that has useful properties as an additive to polymers in composites and can be produced at a reasonable cost. Good dispersion is a key to producing a polymer composite with high mechanical properties and to fully realize their potential as a reinforcing material. Once dried, the MFC cannot be easily re-dispersed in a polymer dictating the need for a water based processing method to make MFC reinforced composites. Further research is necessary in order to identify a water based processing method that provides good dispersion of the MFC in PLA or other water based polymers.

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1. Motivation and Objectives

1.1. Motivation

As one of the most abundant agricultural residue, wheat straw can serve as a cheap feedstock for cellulose. Cellulose fibers, comprised of highly ordered microfibrils are well known to have good mechanical properties. These bio-based plant fibers coupled with bio-based polymers offer a unique opportunity to produce light weight structural materials for automotive and other applications. On the other hand, cellulose chains can also be hydrolyzed to its monomer building unit – glucose, which can then be converted to ethanol by fermentation. In recent years cellulosic ethanol has attracted great interest as a promising alternative liquid fuel of both environmental and strategic importance. Unlike corn ethanol and sugar ethanol, in the production of cellulosic ethanol, a large amount of solid residue is also generated as a byproduct. A profitable use of this residue will contribute to the target of making the cellulosic ethanol biorefinery even more economically competitive.

The underlying assumption in this project is that cellulose nanofibers for production of biocomposite materials can be a value-added byproduct in a cellulose-to-ethanol biorefinery when they are extracted from wheat straw biomass. Production of cellulosic ethanol from wheat straw is dependent on the Ammonia Fiber Expansion (AFEX) pretreatment process for conversion of cellulosic biomass to fermentable sugars. The residual materials from ethanol fermentations contain cellulose nanofibers. We explore the opportunity of using wheat straw and its fermentation residue as feedstock for extracting two forms of cellulose nanofibers (CNF) namely Cellulose Nanowhiskers (CNW) and Microfibrillated Cellulose (MFC). The possibilities of using the extracted MFC and CNW in polymer nanocomposite applications will then be investigated.

1.2. Objectives

The main objectives of this project include:

- Extraction of CNW and MFC from wheat straw
- Evaluation of the solid residue from the AFEX pretreated ethanol production process as a feedstock for the CNW and MFC extraction
- Nanocomposite fabrication using biobased polymers such as Polylactic Acid (PLA)
- Characterization of nanocomposite mechanical and thermal properties
- Determination of mass balances for the process

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2. Extraction of CNW and MFC from Wheat Straw

2.1. Introduction to CNW and MFC

In the plant cell wall, cellulose microfibrils are embedded in a hemicellulose and lignin matrix to provide structural and mechanical support for the plant body. Cellulose microfibrils have both crystalline regions and disordered amorphous regions. The elastic modulus (stiffness) of crystalline cellulose I in the direction parallel to the chain axis was measured to be 138 GPa [i] which agreed with theoretical values determined by molecular simulation techniques to be between 124 to 155 GPa [ii] . The high elastic modulus of the crystalline cellulose in the microfibrils gives them the potential to replace traditional reinforcement materials such as glass fibers and carbon fibers in structural composite materials.

Since as early as the 1950s, microcrystalline cellulose (MCC) has been extracted from native cellulose by acid hydrolysis and later used in the pharmaceutical industry mainly as a tablet substrate[iii]. It was not until about three decades ago did researchers start investigating the application of separated cellulose crystals, also called cellulose nanowhiskers (CNW), as a strengthening material in nanocomposites [iv] . In 1983 Herrick et al and Turbak et al published their work on using a high pressure homogenizer to individualize microfibrils from pure cellulose fibers and gave the resulted product the name Microfibrillated Cellulose (MFC) [v, vi]. In early 2005, Nakagaito and Yano published their work on preparing MFC reinforced phenol-formaldehyde composites [vii]. MFC was also used by Fujii et al to improve bending strength and fracture toughness of a bamboo fiber reinforced polylactic acid composite[viii] .

2.2. Extraction of MFC from Wheat Straw

The process to produce MFC from biomass is relatively uncomplicated. After a large fraction of the lignin and hemicellulose in wheat straw are removed, the cellulose fiber water suspension is passed through a small orifice utilizing a high pressure homogenizer. The high shear force generated as the suspension is passed through the narrow opening in this process causes disintegration of the structure and separates microfibrils in the cell wall. The process steps consist of the following:

Experimental:

Raw wheat straw was dried in a 95 °C vacuum oven overnight and then ground and sieved to 35-60 mesh size powder. The wheat straw was then bleached with 10wt% peracetic acid at 90 °C for 30 min and washed repeatedly with a warm distilled water and acetone-ethanol (1:1) mixture. After being dried in a vacuum oven overnight, the sample was treated with 17.5 wt% NaOH water solution at 25 °C for 30 min. At the end of the 30min, an equal amount of distilled water was added and the reaction was continued for another 30 min. The

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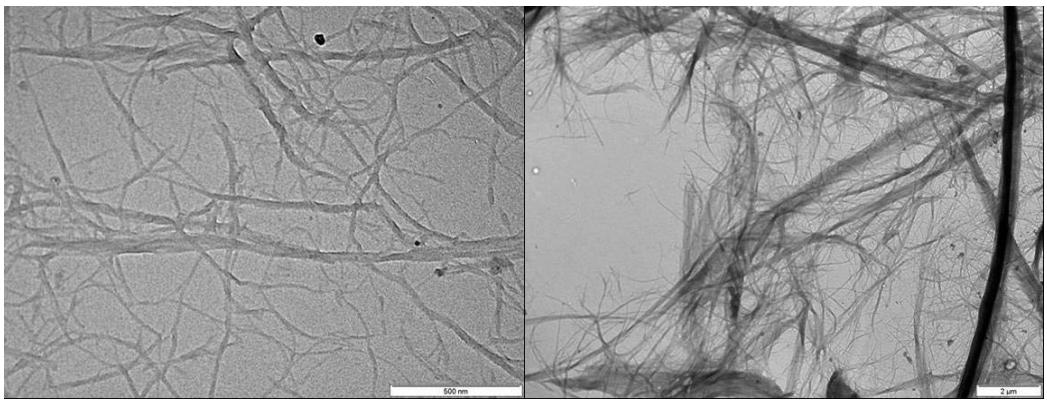
treated sample was washed with warm distilled water (~50 °C) until the pH of the wash stream was neutral. The pulp thus obtained was homogenized in 20 passes either on an APV-1000 high pressure homogenizer (Invensys APV, Lake Mills, Wisconsin) operated at about 11,000 psi (75.8 MPa) or on a Mini DeBEE homogenizer (BEE International, South Easton, Massachusetts) operated at about 40,000 psi (276 MPa).

The morphology of the obtained sample was observed using a Transmission Electron Microscope (JEOL 100CX TEM) with accelerating voltage of 100 kV.



(a) **(b)**

Figure 1. TEM micrographs of the MFC extracted from wheat straw. Scale bar in (a) 500 nm (b) 2 μm

Result:

During the homogenization operation, the viscosity of the suspension increased substantially with the number of passes through the homogenizer, which indicated a progressive disintegration of the cellulose microfibril bundles into individual microfibrils. After 20 passes, a stable milky suspension of the MFC was obtained. As can be seen from the TEM images (Figure 1), defibrillation of the cellulose fibers in the wheat straw cell wall was achieved. Although some of the fibrils have diameters as large as 100 to 200nm (Figure 1b), the majority of the extracted micrifibrils have a width of 15-20 nm (Figure 1a). The length of the MFC has a broad distribution, ranging from several tens of μm to a few hundreds of μm.

The yield of the MFC based on the dry weight of untreated wheat straw was 34.6 wt%.

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2.3. Wheat straw CNW

As discussed earlier, cellulose microfibrils in the cell wall have both crystalline and amorphous regions. By controlled acid hydrolysis, the amorphous domain of the cellulose microfibrils can be solubilized to yield cellulose nanocrystals – CNW.

Experimental:

The wheat straw MFC sample was hydrolyzed with 55wt% sulfuric acid at 50 °C for 2 hours to produce nanowhiskers. After acid hydrolysis, the residual acid was removed by repeated dialysis against DI water. The sample was further treated by ultrasonication for 2 min and then stored in a refrigerator.

Result:

The extracted CNWs exhibited a rod-like crystals with width and length in the range of 5-10 nm and 100-200 nm respectively (Figure 2). The yield of CNW from dry wheat straw was 13.6 wt%.

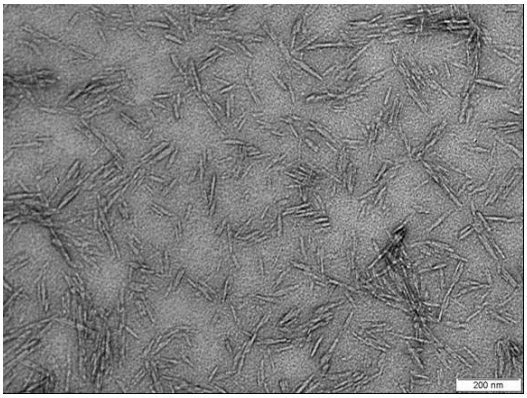

Figure 2. TEM micrograph of the CNW extracted from wheat straw. Scale bar: 200 nm

3. Extraction of CNW and MFC from Wheat Straw Ethanol Production Residue

3.1. Justification

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If the cellulose contained in wheat straw cell wall is completely hydrolyzed to its monomer building unit – glucose, the glucose can then be converted to ethanol by fermentation. Bioethanol, ethanol obtained from natural resources such as corn, sugarcane and biomass has been widely considered as a promising alternative liquid fuel thanks to its economic, environmental and strategic advantages. Furthermore, cellulosic ethanol does not threaten our food supply, as corn ethanol and cane ethanol have been considered to do. On the other hand, unlike corn ethanol and cane ethanol, when ethanol is produced from lignocellulosic materials, a large amount of solid residue is also generated as a byproduct. A profitable use of this residue is very important in making the cellulosic ethanol production process more economically competitive.

In the production of cellulosic ethanol, biomass is usually treated in 3 steps: pretreatment, saccharification and fermentation. The pretreatment step is needed to make the cellulose embedded in the plant cell wall more accessible to cellulolytic enzyme hydrolysis. Pretreatment is achieved by various ways such as removing the lignin and hemicellulose components, altering the lignin structure and increasing the surface area in the inner cell wall. Examples of leading pretreatment techniques include steam explosion, dilute acid hydrolysis and Ammonia Fiber Expansion (AFEX), etc [ix]. In AFEX process, biomass is treated with liquid ammonia at elevated temperatures and pressures for 5 to 30 min before the pressure is abruptly released. [x] The combined chemical and physical effects of AFEX on the cell wall components including lignin, hemicellulose and cellulose and cellulose wall structure dramatically enhances enzymatic conversion of cellulose and hemicellulose to fermentable sugars.

Cellulose conversion varies with different biomass species and different pretreatment and hydrolysis techniques. For corn stover and switchgrass, cellulose conversion of nearly 100% can be achieved [xi, xii]. However, for straw material, the cellulose conversion is often much less than 100%. Abedinifar et al[xiii] and Ko et al [xiv]reported 50% conversion and 71.1% digestibility for rice straw respectively. For wheat straw, Georgieva et al achieved 70% cellulose conversion after wet-explosion pretreatment and simultaneous saccharification and fermentation (SSF) [xv] . If in the ethanol production process, a significant amount of lignin and hemicelluose is also removed along with cellulose, the small fraction of unhydrolyzed cellulose can still be moderate contribution to the residue. In study published by Yang et al, the wheat straw residue after ethanol production by steam explosion and SSF still contained 25.9 wt% of cellulose[xvi]. Our own analysis showed 36 wt% glucan content in the residue after AFEX and SSF, which is not significantly lower than the glucan content in the untreated wheat straw 43 %.

While higher cellulose conversion is constantly pursued in the production of cellulosic ethanol, this often calls for more complex or harsher pretreatment, higher enzyme loading, and longer hydrolysis time, etc., which all lead to higher capital cost. Furthermore, in the fermentation step one often faces the dilemma of higher substrate content or higher glucose content [xvii]. Lower substrate content gives higher hydrolysis efficiency but also leads to lower absolute content of glucose in the hydrolysate stream, which contributes negatively to the subsequent fermentation step. If the solid residue coming out of fermentation reactors can be utilized as a feedstock for extracting value-added cellulose nanofibrils, a

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near complete cellulose conversion of biomass may become less favorable in the overall economic optimization.

3.2. Surface morphology changes

Observation of surface morphology changes provides clues of the structural damage induced by the AFEX and SSF process on the wheat straw cellulose fibers and the possible relocation of some of the cell wall components such as lignin.

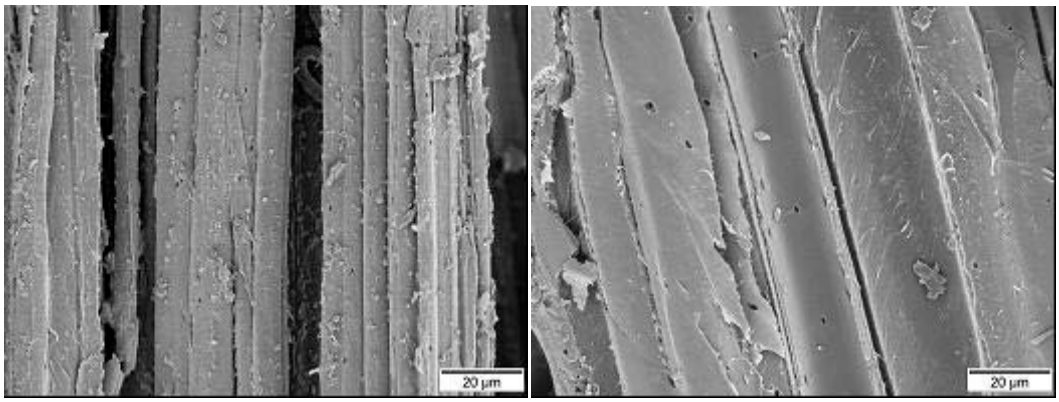
Method:

Scanning Electron Microscopy (SEM)

Small samples of the untreated wheat straw and the AFEX+SSF residue were mounted on Aluminum stubs and coated with a thin layer of Osmium Tetroxide. Observation was made using a JEOL 6300-F Field Emission Scanning Electron Microscope (FE-SEM) operated at 5 kV.

Result:

From the SEM images (Figure 3), it can be seen that after being utilized for ethanol production, the cellular structure of the wheat straw is still largely preserved. The outer surface of the cell walls has become rougher and more heterogeneous. This change results from both the physical treatments experienced by the straw fiber during the AFEX pretreatment, the saccrification and fermentation processes, repeated warm water washings, and the chemical modifications due to the loss of some of the extractives, hemicellulose and cellulose.



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(a) **(b)**

Figure 3. SEM images of the surfaces of (a) the untreated wheat straw and (b) the wheat straw AFEX+SSF residue

3.3. Surface chemistry changes

Method:

FT-IR and XPS

FT-IR spectra of both the untreated wheat straw and the AFEX+SSF residue were recorded on PerkinElmer System 2000 FTIR spectrometer equipped with an Attenuated Total Reflectance (ATR) sampling attachment.

The surface atomic concentrations were measured by X-ray Photoelectron Spectroscopy (XPS) using Physical Electronics 5400 ESCA.

Result:

(1)FT-IR

A comparison of the FT-IR spectra of untreated wheat straw and the AFEX+SSF residue is shown in Figure 4. Compared with the untreated wheat straw, the AFEX+SSF residue does not have a peak at 1731 cm-1, which is characteristic of hemicellulose, but has more prominent peaks at 1420 cm-1 , 1458 cm-1 , 1505 cm-1 and 1593 cm-1, which are all characteristic peaks of lignin [xviii,xix].

(2) XPS

The theoretical values of O/C ratios for cellulose, hemicellulose, lignin and extractives are 0.83, 0.80, 0.33 and 0.04-0.12 respectively [xx]. From table 1, it can be seen that the O/C ratio for the untreated wheat straw is 0.17 which is indicative of a surface covered by extractives. The AFEX+SSF residue surface has an O/C ratio of 0.30 which corresponds to a surface covered with lignin.

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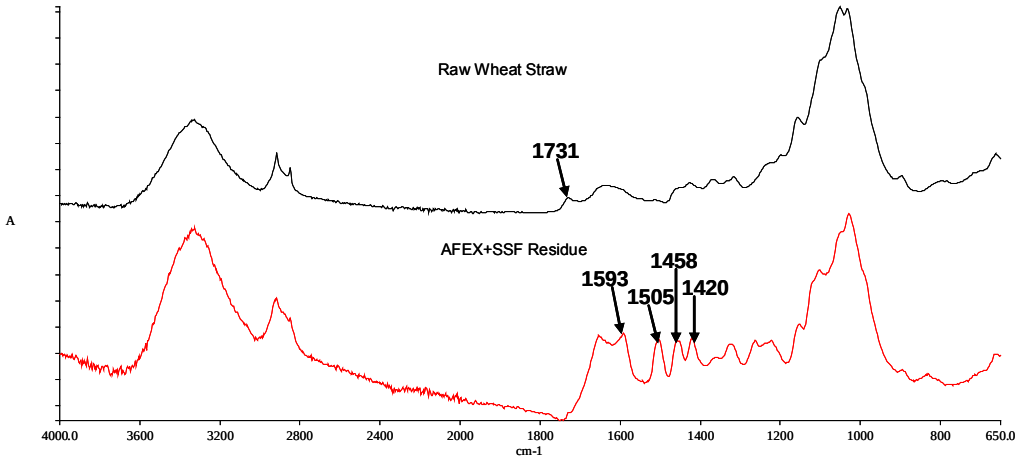

Figure 4. FT-IR spectra of the untreated wheat straw and the AFEX+SSF residue

Table 1. The O/C ratio and the relative C1, C2 and C3 peak areas of the deconvoluted C1s peak from XPS analysis

	O/C	C1 (%)	C2 (%)	C3 (%)
Raw wheat straw	0.17	81.8	13.5	4.8
AFEX+SSF Residue	0.30	62.7	32.6	4.7

Note: O/C: Oxygen/Carbon atomic ratio; C1: C-C; C2: C-O; C3: O-C-O or C=O.

3.4. MFC extraction from the residue

Since both the cellulose content and the cell wall structure of the residue did not differ significantly from those of the raw wheat straw, in this initial investigation, the same method was used to extract MFC from the residue as in the extraction from raw wheat straw.

Method:

Same as in Section 2.2.

Result:

MFC extracted from the fermentation residue is shown in Figure 5. Compared with the MFC extracted from untreated wheat straw (Figure 1), the size of these fibrils appeared to be larger in width and shorter in length.

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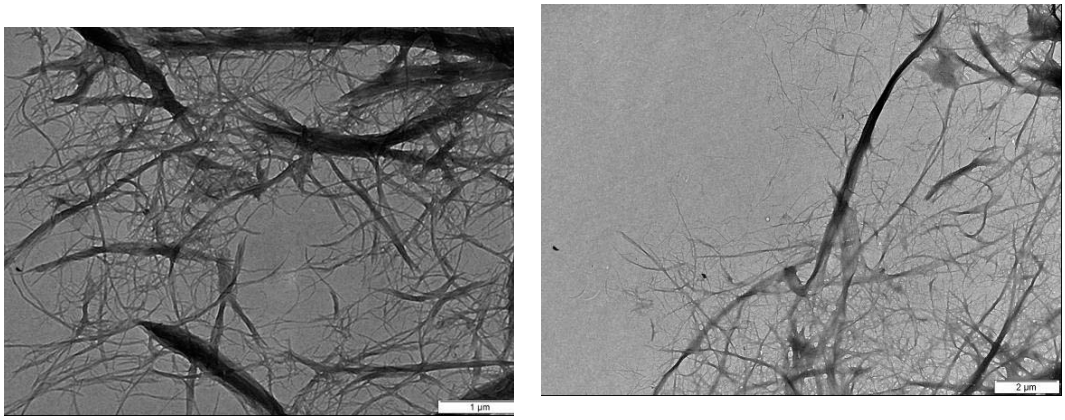

(a) **(b)**

Figure 5. TEM images of the MFC extracted from the wheat straw AFEX+SSF residue. Scale bar in (a) 2 µm; (b) 500 nm.

4. CNW and MFC reinforced Polylactic acid (PLA) composites

4.1. Justification

The attractiveness of a biobased nanoreinforcements is enhanced when it can be combined with a biobased polymer resin. The biocomposites thus obtained will be completely renewable and biodegradable. Very few biobased resin systems are available. The ones that have been studied extensively in recent years include Cellulose Acetate (CA), Polylactic Acid (PLA), Polycaprolactone (PCL), Polyhydroxybutyrate (PHB) and thermoplastic starch (TPS) [xxi] .

PLA is a biodegradable aliphatic polyester derived from renewable resources such as corn starch and cane sugar. PLA is a polymer of lactic acid (2-hydroxypropanoic acid), which is a chemical compound naturally present in humans and animals. Lactic acid is a chiral molecule, existing as two stereo isomers, L-lactic acid and D-lactic acid. Two molecules of lactic acid can be dehydrated to a cyclic diester – lactide, which can then be polymerized to polylactide usually by ring-opening polymerization using suitable catalysts. Polymerizations of L-lactide and D-lactide lead to the synthesis of Poly-L-lactide (PLLA) and poly-D-lactide (PDLA) respectively. And the polymerization of a racemic mixture of L- and D-lactides gives poly-DL-lactide (PDLLA), which, unlike PLLA and PDLA, is not semi-crystalline but amorphous.

PLA can be processed like most thermoplastics into fibers, films and various molded articles. Although the process of making PLA has been known for almost a century, this polymer did not attract too much commercial interest in the past mainly due to its high production cost and inferior thermal properties compared to petroleum based plastics. In recent years, advances in fermentation and polymerization

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technologies have made the price of PLA considerably cheaper. Development in the material science of PLA has also helped to improve its mechanical and thermal properties. And the fact that PLA is biodegradable and can be produced from renewable resources makes the polymer an attractive environmentally friendly alternative to conventional commodity plastics. Increased demand of PLA products has led to fast growth in its production around the world. Higher production volume in turn is driving down its production cost even further. Today PLA materials are finding uses in many areas of applications including packaging, paper coating, biomedical products such as sutures and drug delivery devices and consumer goods such as toys and beverage bottles.

Although PLA has relatively high modulus, it is known to be extremely brittle. In other words, PLA is strong but not tough. The low toughness of PLA hinders its applications in structural materials such as automotive parts and housings of portable electronic devices. Adding high aspect ratio cellulose nanofibers may toughen the PLA matrix by a bridging mechanism. And thanks to the high Young's modulus of the nanofibers, the polymer may become both tougher and stronger, which is often highly desirable. Furthermore, for semi-crystalline PLLA, adding cellulose nanowhiskers is expected to change its crystallization behaviour. Nanoparticles and nanofibers have been shown to act as nucleating agents for thermoplastics [xxii]. Thus incorporation of cellulose nanowhiskers may lead to faster crystallization rate, higher crystallinity and smaller spherulite size, which will further improve the polymer's mechanical properties.

4.2. Composite fabrication strategies

After the extraction of cellulose nanofibers from wheat straw and its fermentation residue, the challenge is to disperse the nanofibers in a non-water soluble polymer matrix without causing the hydrophilic particles to aggregate together. Because of the very high density of hydroxyl groups on the surface of cellulose microfibrils, both CNW and MFC form stable suspensions in water but aggregate when dried from water. Since most of the commercial plastics including PLA are not soluble in water, the fabrication of CNW and MFC reinforced polymer composite is a challenging task. When using PLA as a matrix for CNW and MFC, there are 4 possible distinct routes that can be considered for composite fabrication.

- Direct mixing

  In this approach, cellulose water suspensions are mixed directly into PLA melt in an extruder. Water removal takes place in the extruder by evaporation. There have been mixed results on the quality of dispersion by this approach. Chakraborty et al reported good dispersion of microfibrils in PLA at low fiber content [xxiii]. However, Oksman et al found that feeding Microcrystalline Cellulose (MCC) water dispersion directly into the extruder caused agglomeration of cellulose in the polymer matrix as well as some thermal degradation [xxiv].

- Co-solvent approach

  PLA can be dissolved in selected organic solvents such as dichloromethane, chloroform and DMF. In this approach, CNW or MFC is first transferred from water to an appropriate

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organic solvent either by solvent exchange or by drying and re-dispersing and then mixed with PLA that has been dissolved in the same solvent. The solvent can then be easily removed by evaporation. Solvent exchange is a lengthy and expensive process, especially considering the cellulose content in the original water suspension is often very small. Cellulose fibers always aggregate when dried out from water because of the high concentration of hydroxyl groups and the resulting high force of attractions between them making redispersion in other solvents and even in water difficult, which in-turn then leads to poor dispersion in the polymer matrix[xxv].

- Mixing MFC and CNW with monomer before polymerization.

  Technically, CNW and MFC can be mixed with the water soluble lactic acid, before the lactic acid is polymerized into PLA. But the difficulty of carrying out the polymerization in a water medium and the harsh conditions involved in the polymerization make this route impractical.

- PLA water emulsion

  In the pharmaceutical industry, PLA and its co-polymer poly(lactic-co-glycolic acid) (PLGA) are among the most popular substrates used for controlled release of drugs due to their proved biocompatibility. The drug substances are usually encapsulated in polymer microspheres by a well-established method called the "solvent evaporation technique" [xxvi]. The size of the microspheres is determined by many factors including but not limited to surfactant chemistry, surfactant concentration, solvent-to-water ratio and the mixing method and speed. Indeed, nanospheres with diameters smaller than 200 nm can been prepared [xxvii,xxviii].

  Although PLA cannot be dissolved in water, if it is emulsified into water as microor nanospheres and if the size of the microspheres are small enough to be comparable to the dimension of the CNW and MFC, it is reasonable to expect good mixing of the two components in the water medium.

If a water based processing route can be found that does not require the MFC or CNW to be dried, dispersion with water based polymer emulsions is a practical and cost effective processing step to produce MFC or CNW nanocomposites. The overall biorefinery process can then be designed as shown in the diagram in Figure 6.

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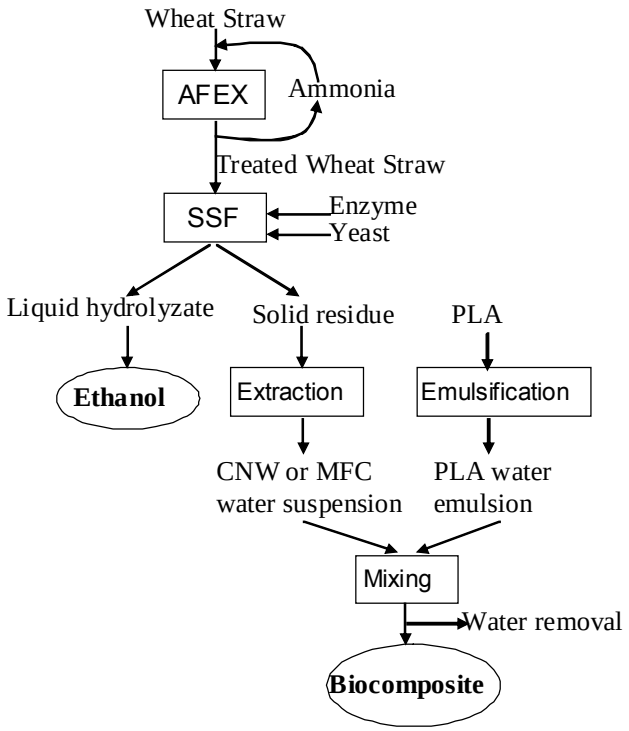

Figure 6. Schematic diagram of the proposed wheat straw biorefinery

4.3. PLA water emulsions

The solvent evaporation technique was used to prepare PLA water emulsions. The morphology of the PLA microspheres in the emulsion was examined by using Scanning Electron Microscope. And the emulsification yield was estimated by measuring the weight content of the suspended solids in the emulsion.

4.3.1 Finding a suitable surfactants

Various surfactants can be used for producing microspheres from PLA. Polyvinyl Alcohol (PVOH) is the most commonly used in the pharmaceutical industry for drug encapsulation. But since PVOH is a semi-crystalline polymer and PDLLA is amorphous, PVOH phase separates from PDLLA after compression molding. After trying common surfactants and electrolytes such as SDS (sodium dodecyl sulfate), Carbopol 940, Triton X-100, GAENPE (Glycolic acid ethoxylate 4-nonylphenyl ether), GAEBPE (Glycolic acid ethoxylate 4-tert-butylphenyl ether), PSS (Sodium polystyrene sulfonate), we found that TWEEN 80

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(also called Polysorbate 80) showed the highest emulsification capability. A typical experiment with TWEEN 80 is shown below.

Experimental:

0.135 g TWEEN 80 was dissolved in 360 ml RO water.

4.50 g PLA was dissolved in 90 ml ethyl acetate.

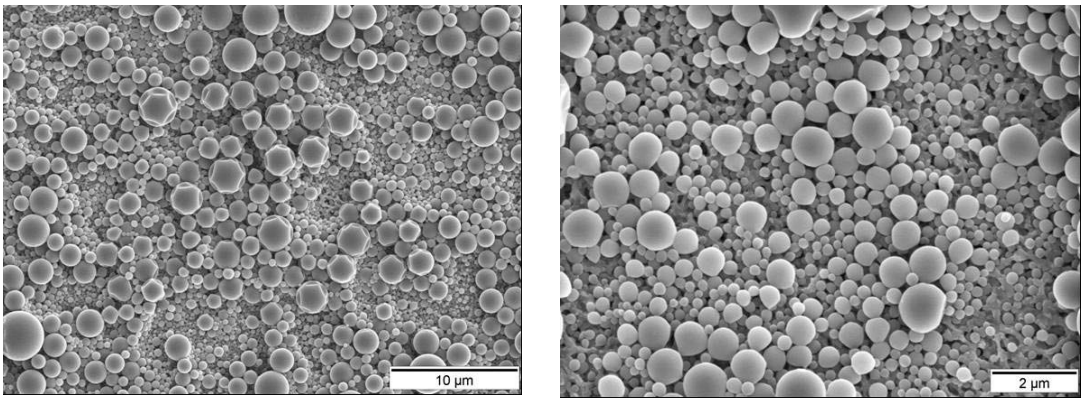
The mixture was blended with the Ultra-Turrax T25 homogenizer equipped with a S25N-25F disperser at 12,000 rpm for 10 min and then ultrasonicated at 120 Watts for 2min using a Cole-Parmer Sonicator equipped with a 1 inch probe. The ethyl acetate was evaporated in a 35-40 °C water bath overnight under mechanical stirring.

The weight content of solids in this emulsion was measured by heating to constant weight at 105 °C using a Thermal Gravimetric Analyzer (TGA).

The morphology of the microsphere of PLA in the emulsion was observed with Scanning Electron Microscope by using either a JEOL 6300-F Field Emission SEM operated at 5 kV or a JEOL 6400 SEM operated at 10 kV. The sample was made conductive by coating with a thin layer of Osmium Tetroxide before being examined.

Result:

After solvent evaporation, a milky PLA emulsion was obtained. The size and morphology of the microspheres are shown in Figure 7.



(a) **(b)**

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Figure 7. PLA microspheres prepared by solvent evaporation technique using TWEEN 80 as a surfactant (weight ratio to polymer: 3:100). Scale bar in (a) 10 μm; (b) 2 μm.

4.4. Composite preparation and evaluation

Once PLA is emulsified into water as microspheres, MFC and PLA can be easily mixed in the water based emulsion. After mixing, water needs to be removed in a fast and efficient way so that "demixing" will not happen. Several methods were investigated to achieve removal of water without demixing.

4.4.1 Freeze drying method

In this method, the mixture of MFC and PLA is quickly frozen, thus locking the dispersed state of the two components. Removal of water by sublimation of the ice in a freeze dryer was expected to produce a solid product that would then be molded into a composite. MFC extracted from the wheat straw ethanol production residue (WS AFEX+SSF residue) was used for this process.

Experimental:

(1) Composite fabrication

A PLA emulsion was prepared following the same protocol as in Section 4.3.1 using PDLLA purchased from Polysciences, Inc. (Warrington, Pennsylvania).

The MFC suspension (from AFEX+SSF residue) and PLA emulsion were sonicated at 80 Watts for 30 sec respectively and then mixed together. After mixing, sonication was continued at 120 Watts for 2 min. The mixture was then quickly frozen by immersing in a liquid nitrogen bath and dried in a Labconco FreeZone 1 Liter Freeze Dry System (Labconco Corporation, Kansas City, Missouri).

After freeze drying for about 1 week, the mixture changed into a fluffy white powder. This powder was packed into a stainless steel mold and compression molded into 1.4mm and 3.0mm thick sheets at 105 °C and 0.62 MPa on a Carver Laboratory Press Model 2518 (Fred S. Carver Company, Wabash, Indiana).

(2) Property evaluation

Dynamic Mechanical Analysis (DMA)

Dynamic mechanical analysis was performed in 3-point bending mode on TA Instruments Dynamic Mechanical Analyzer Model 2980 (New Castle, Delaware). Temperature scan was from 20 °C to 60 °C at 3 °C/min.

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Main parameters: Frequency = 1.0 Hz; Amplitude = 70 μm; Static force = 0.010 N.

Flexural modulus and strength

The flexural properties were measured according to ASTM Standard D 790 by using UTS SFM-20 (United Testing Systems Inc., Flint, Michigan).

Notched Izod Impact Strength

The Izod impact strength was tested by using TMI 43-02-01 Monitor/Impact system (Testing Machines Inc., Ronkonkoma, New York) according to ASTM Standard D 256.

Differential Scanning Calorimetry (DSC)

DSC tests were from 0 °C to 200 °C at a heating rate of 10 °C/min using TA Instruments Differential Scanning Calorimeter Model 2920.

Thermal Gravimetric Analysis (TGA)

The thermal stability of the sample was measured by using TA Instruments Thermal Gravimetric Analyzer Model 2950.

Samples were heated from room temperature to 580 °C at 25 °C/min with high resolution 4 °C/min.

Result:

After compression molding, it was found that the compressed specimen has areas of varying opacity. Since neat PLA is clear, the darker areas in the composite indicated higher MFC concentration in these areas. MFC had formed aggregates inside the PLA matrix. Nevertheless, the mechanical properties of the resulting composites were measured.

(1)Dynamic Mechanical Analysis DMA

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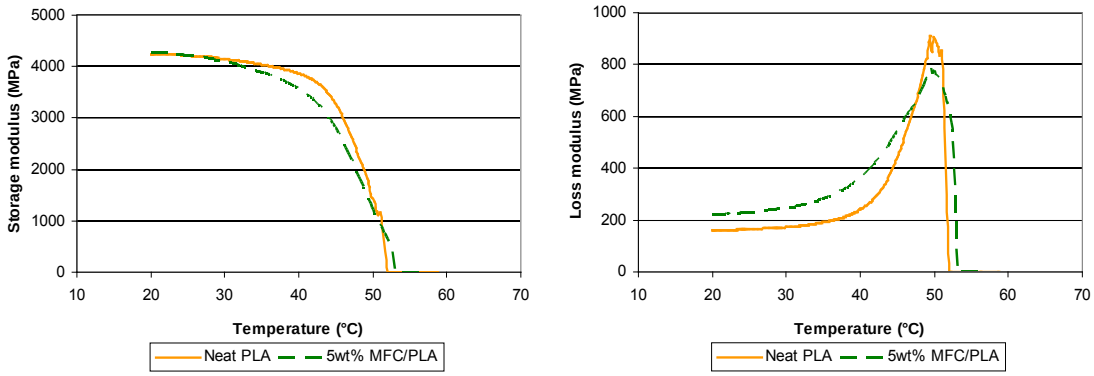

(a) **(b)**

Figure 8. Comparison of (a) the storage modulus and (b) loss modulus of the neat PLA and the 5wt% MFC/PLA composite from DMA measurements.

The storage modulus of the 5wt% MFC/PLA composite was the same as that of the neat PLA over the entire temperature range tested. The glass transition temperature (Tg) as measured by DMA indicated that it was not affected by the addition of the cellulose microfibrils.

(2) Flexural modulus

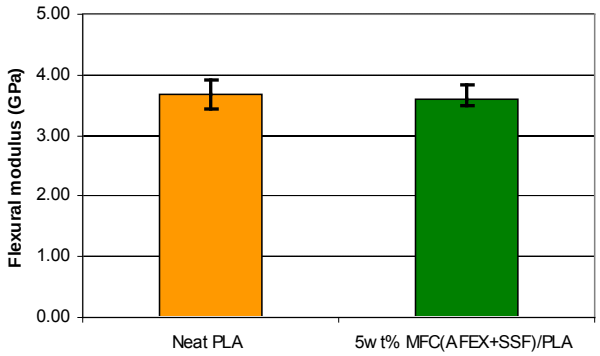

Figure 9. Comparison of the flexural modulus of the neat PLA and 5wt% MFC/PLA composite

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The flexural modulus of the 5wt% MFC/PLA composite was also the same as that of the neat PLA.

(3) Notched Izod Impact Strength

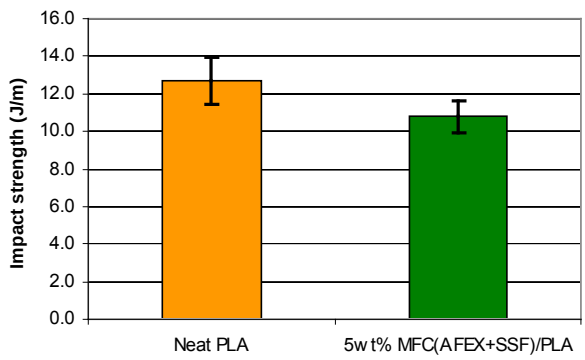

Figure 10. Izod Impact strength of the neat PLA and the 5wt% MFC/PLA composite

The Izod impact strength of the 5wt% MFC/PLA composite (10.8 J/m) was found to be slightly lower than that of the neat PLA (12.7 J/m). The result for each sample was the average of 3 tests with 3 fresh specimens.

(4) The glass transition temperature by DSC

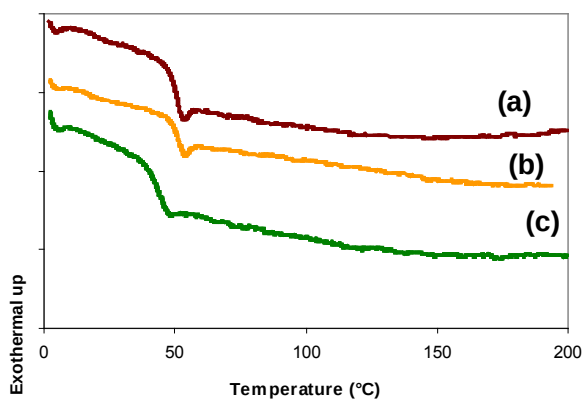

Figure 11. The DSC curves of (a) The as-received PLA pellets; (b) Molded neat PLA sample; (c) The 5wt% MFC/PLA composite

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From the DSC curves, it can also be seen that the glass transition temperature (T_g) of PLA did not change after adding the 5 wt% MFC.

The lack of measurable increases in the mechanical properties is attributed to the poor dispersion of MFC in the PLA matrix. Aggregated MCF is not able to reinforce the PLA matrix and contribute to the overall mechanical properties of the composites.

(5) Thermal stability by TGA

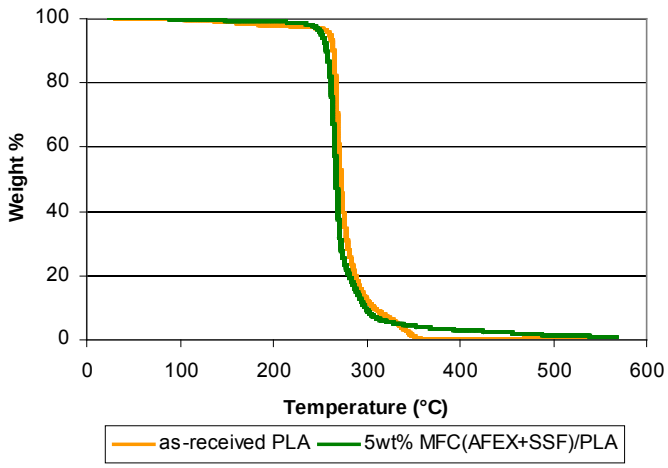

Figure 12. Thermal stability of the as-received PLA pellets and the 5wt% MFC/PLA composite

Both the as-received polymer and the 5wt% composite start to degrade at about 250 °C. The thermal stability of PLA was not affected by the addition of the MFC.

One possible explanation for these disappointing results may be due to the poor dispersion of the MFC may result from the dynamics of the freezing process. During freezing, water molecules solidify into its crystalline form - ice. Impurities and non compatible materials are excluded from water as it solidifies. This pushes the substances dissolved or dispersed in the water out from the ice and into areas between the ice particles concentrating and aggregating them in the solid,. The agglomeration of the MFC might have happened during this time. Hence the immobility of the MFC rendered by the subsequent sublimation process of freeze dry would no longer be able to prevent the de-mixing from happening.

Another possible explanation for the lack of a measurable increase in the properties of the composite reinforced with MFC extracted from the wheat straw residue suggested that the high stiffness of the cellulose microfibrils in the wheat straw cell wall might have been compromised by the physical and chemical treatment associate with the AFEX+SSF process. As a check on this possibility, another set of experiments were conducted with a MFC sample that had been previously prepared in our laboratory

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from a commercial pure wood cellulose product called CreaTech TC90 (CreaFill Fibers Corp, Chestertown, Maryland).

As can be seen from Figure 13, the flexural modulus of the MFC(TC90) filled PLA remained the same as that of the neat PLA too. Therefore it was concluded that the poor dispersion of the MFC in the composite was responsible for the poor mechanical results. Alternative preparation techniques were sought to ensure better distribution of the fibers.

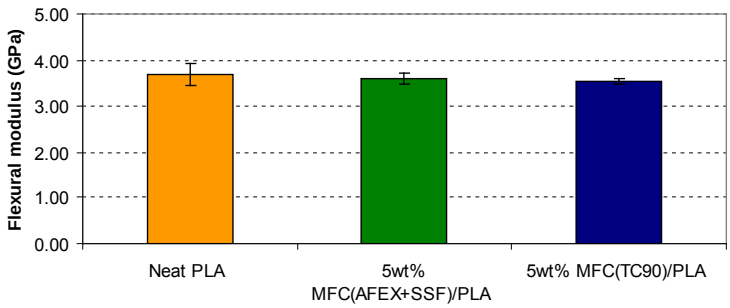

Figure 13. Comparison of the flexural modulus of the neat PLA and 5wt% MFC(AFEX+SSF residue)/PLA, and MFC(TC90)/PLA composites

4.4.2 Lamination method

In this method, the MFC and PLA water suspensions are rapidly filtered is alternating steps onto the same substrate, forming alternating thin layers of MFC and PLA. It was expected that the cellulose microfibrils would form a porous network structure, which, when heated up, would allow the PLA melt to penetrate through, thus forming a laminated composite.

Method:

PLA was emulsified into water using TWEEN 80 as surfactant. The PLA water emulsion and the MFC suspension were divided into 7 and 6 equal portions respectively and filtered alternatively onto the same filter membrane (0.2 μm Whatman Anopore™ Anodisc 47). The filtered sample was dried in a vacuum oven and then compression molded to a disc at 105 °C.

Result:

After compression molding, the cellulose and polymer layers de-laminated, i.e. the molten polymer did not effectively wet the microfibril network as expected. The composite fabrication was unsuccessful.

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4.4.3 Emulsion-Filtration method

Fast removal of water from the MFC and PLA mixture is the key to prevent de-mixing. When the entire MFC and PLA mixture is filtered together, the gradual decrease of the filtration speed caused by sample buildup on the filter will lead to long water drainage time. As water is slowly drawn away, the suspended solids get more and more concentrated, causing the separation of MFC and PLA, whose affinities with water molecules are different. In this method, the MFC and PLA water suspensions are mixed together in very small portions and filtered. The sample collected on each filter was then be assembled together and molded at high temperatures into a single piece. The short water drainage time associated with the filtration of divided small portions was expected to keep the cellulose microfibrils and PLA microspheres in a separated state.

4.4.3.1 The 1st trial

This trial was conducted with the pure cellulose MFC sample obtained from CreaTech TC90.

Method:

PLA (Polysciences PDLLA) water emulsion was prepared with the same method as in Section 4.3.1. Both the MFC suspension and the PLA emulsion were divided into 10 equal portions. Each portion of the MFC suspension was mixed with one portion of the PLA emulsion, thus forming 10 equal mixtures. After being ultrasonicated at 30 Watts for 1 min, the mixtures were immediately vacuum filtered with 0.2 μm Whatman Anodisc filter membranes. A fresh filter membrane was changed after two mixtures were filtered. Five sample cakes were collected and dried in a 40 °C vacuum oven overnight. They were then stacked in 5 layers and compression molded into a thin sheet (1.4 mm thick) at 105 °C. The sample sheet was cut and polished into rectangular test specimens.

Mechanical properties were measured with the same method as in Section 4.4.1. Briefly, the flexural modulus and strength were tested according to ASTM Standard D 790 by using United Testing Systems (UTS) SFM-20. Dynamic mechanical analysis was performed in 3-point bending mode on TA Instruments Dynamic Mechanical Analyzer Model 2980. Temperature ramp was from room temperature to 85 °C at 3 °C/min.

The fracture surface of the composite from UTS flexural testing was coated with Osmium Tetroxide and examined with a Scanning Electron Microscope (JEOL 6300 FE-SEM operated at 5 kV or JEOL 6400 SEM operated at 10 kV).

Results:

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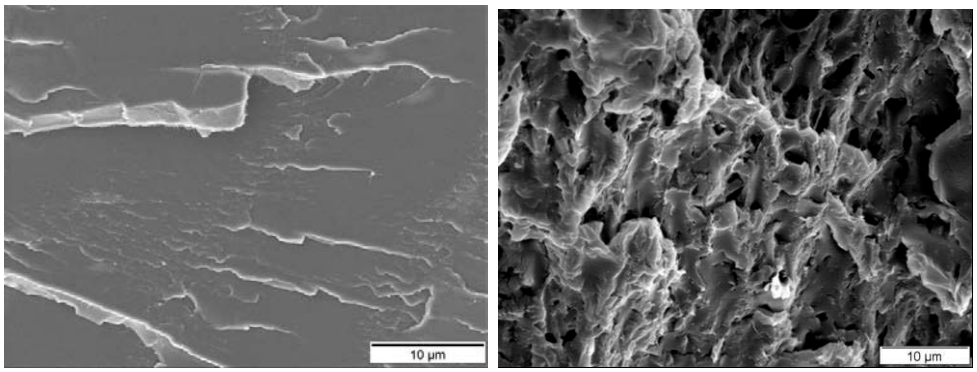
After compression molding, an opaque sample sheet was obtained. The homogeneity in the opacity throughout the sample was high indicating uniform distribution of MFC inside the PLA matrix. This was later confirmed by SEM examination of the composite's fracture surface (Figure 14).



(a) **(b)**

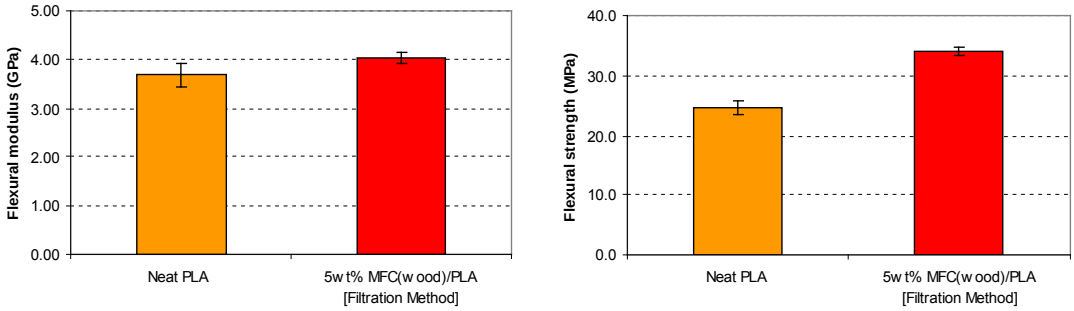
Figure 14. SEM micrographs of the fracture surfaces of (a) neat PLA and (b) the 5wt% MFC(TC90)/PLA composite prepared by the Emulsion-Filtration method.

Flexural modulus and strength

Figure 15 shows that, with the addition of 5wt% MFC, the flexural modulus and strength of PLA increased 9.5% and 37.5% respectively. The result was the average of 2 tests.

Dynamic Mechanical Analysis DMA

It can be seen from Figure 16 that the storage modulus of the composite is increased over the whole temperature range studied. In addition, the shifting of the curve to the right indicates higher glass transition temperature (Tg) for the composite. This is a very positive result supporting the potential use of MFC as a polymer reinforcement.



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(a) **(b)**

Figure 15. Comparison of the (a) flexural moduli and (b) strength of the neat PLA and the 5wt% MFC/PLA composite

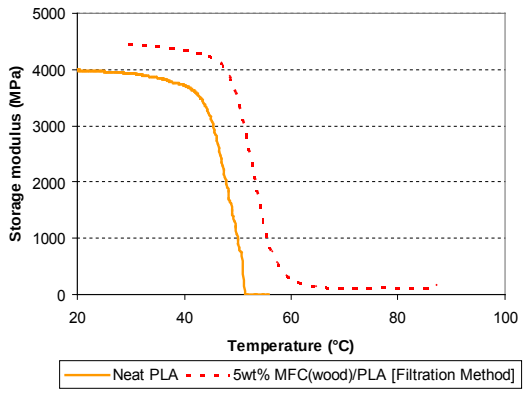

Figure 16. Comparison of the storage moduli of the neat PLA and the 5wt% MFC(TC90)/PLA composite

4.4.3.2 Trial with Resomer R 203 H PDLLA

The PLA resin used in the previous experiments was purchased from Polysciences Inc. (Warrington, PA). Because of the inconsistency in the quality of this product appearing from late 2008, another source had to be located. Resomer **R 203 H PDLLA** from Boehringer Ingelheim GmbH (Ingelheim, Germany) and **PDL 04** from Purac (Gorinchem, The Netherlands) were selected.

- **Neat Resomer R 203 H**

Method:

0.360 g TWEEN 80 was dissolved in 360 ml RO water. 4.50 g PLA was dissolved in 90 ml ethyl acetate.

The mixture was homogenized with the Ultra-Turrax T25 homogenizer at 12,000 rpm for 10 min and then ultrasonicated at 120 Watts for 2min. Solvent evaporation was carried out in a ~35 °C water bath overnight under mechanical stirring.

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The weight content of solids in this emulsion was measured by heating to constant weight at 105 °C using a Thermal Gravimetric Analyzer (TGA).

The morphology of the microsphere of PLA in the emulsion was observed with JEOL 6400 SEM operated at 10 kV.

The emulsion was then filtered with 0.22 μm pore size Millipore Durapore filter membranes and dried in a 40 °C vacuum oven overnight. The dried sample was compression molded into a thin sheet at 105 °C.

Results:

It was found that at 8:100 surfactant loading, over 90% of the polymer can be emulsified into water. The morphology of the microspheres generated is shown in Figure 17. Compared with the microspheres prepared from the Polysciences PDLLA, these microspheres are larger and have a wider variation in their sizes also.

However, the attempts at testing the mechanical properties of these composites was unsuccessful. It was found that this material was too brittle to withstand sample preparation operations such as cutting and polishing and the preload force often needed in 3-point bending tests.

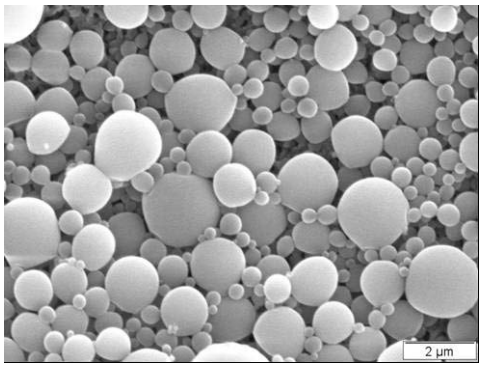

Figure 17. PLA microspheres produced from Resomer R 203 H

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4.4.3.3 Trial with Purac PDL 04

- **Neat PDL 04**

Method:

The polymer water emulsion and testing samples were prepared and tested with the same method as in the previous section.

Result:

Both the size and the size distribution of the particles in this emulsion are much smaller than those in the emulsion of Resomer R 203 H. This should be beneficial in achieving good dispersion.

The sample coupons formed by compression molding were tested for their dynamic mechanical properties and flexural properties. The flexural modulus and strength at break of the control sample were found to be 3.69 GPa and 27.4 MPa respectively. The stress – strain curves of the three specimens tested also agreed very well. Thus, the Purac PDL 04 PLA was used in the following studies to replace the Polysciences PLA as polymer matrix.

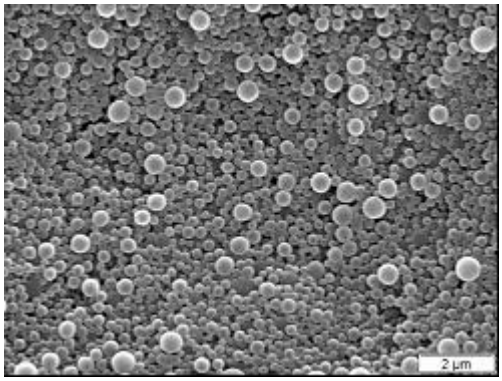

Figure 18. PLA microspheres produced from Purac PDL 04 with TWEEN 80 as surfactant (Surfactant to polymer ratio: 8:100)

- **5wt% MFC (wheat straw) / PLA**

Experimental:

MFC extracted from untreated wheat straw was combined with PLA (Purac PDL 04) that was emulsified into water with the solvent evaporation technique. Both the MFC suspension and the PLA emulsion were divided into 10 equal portions. One portion of the MFC

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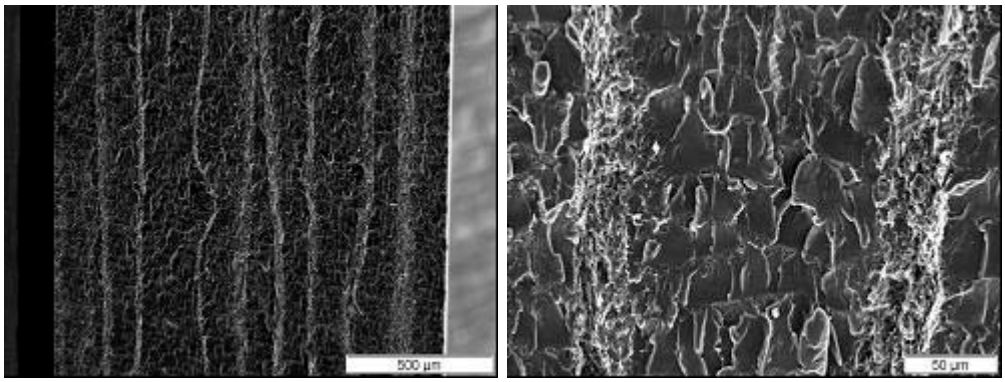
suspension was mixed with one portion of the PLA emulsion and ultrasonicated at 80 Watts for 1 min. The mixture was then vacuum filtered with a Millipore Durapore 0.22 μm membrane filter. Ten fresh membrane filters were used for filtering the 10 mixtures. The 10 sample cakes obtained after filtration were dried in a 40 °C vacuum oven overnight, stacked in 10 layers and compression molded into a sheet at 105 °C. The sample sheet was then cut and polished into rectangular test specimens. The quality of the fiber dispersion in the matrix was evaluated by examining the fracture surface of the specimen on JEOL 6400 SEM.

Results:

Although the composite sample appears to be homogenous, from Figure 19 it can be seen that the cellulose fibrils have aggregated into thin layers which are easily distinguishable from the thicker polymer layers. In other words, instead of getting a homogeneous distribution of the fibrils, a laminate structure was obtained.



(a) **(b)**

Figure 19. SEM micrographs of the fracture surface of the 5wt% MFC(TC90)/PLA composite sample. (a) The layered structure can be seen in the sample thickness direction. (b) A close-up image of the cellulose-rich region (lighter and narrower strips) and the polymer-rich region.

Flexural modulus and strength

Figure 20 shows that, with the addition of 5wt% wheat straw MFC, the flexural modulus and strength of PLA are slightly increased.

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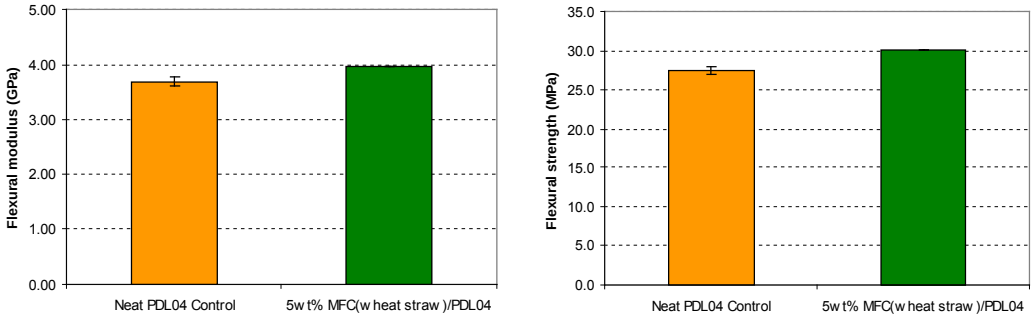

(a) **(b)**

Figure 20. Comparison of the (a) flexural moduli and (b) strength of the neat PLA and the 5wt% MFC(wheat straw)/PDL04 composite

Note: only one test was done for the composite sample**.**

- **Reduced surfactant content**

When the PLA source was switched from Polysciences to Purac, in order to achieve the same emulsification yield and to produce the same particle sizes, the surfactant-to-polymer ratio was increased from 3:100 to 8:100. The higher surfactant concentration may have contributed to the de-mixing problem. Another 5wt% MFC/PLA composite was prepared with surfactant ratio reduced to 3:100 in the emulsion preparation step.

Result:

Comparing Figure 21 to Figure 18, it can be seen that with the amount of surfactant reduced, the size of the microspheres has grown bigger.

An examination of the fracture surface of the composite revealed that although the mixing of the MFC and PLA may have been slightly improved, the MFC have aggregated into separate layers inside the matrix in a manner similar to what was observed earlier (Figure 22). Further reduction of the surfactant ratio (below 3:100) was not acceptable since it resulted in very low emulsification yield.

The flexural modulus and strength of the composite was about the same as those of the neat PLA (Figure 23).

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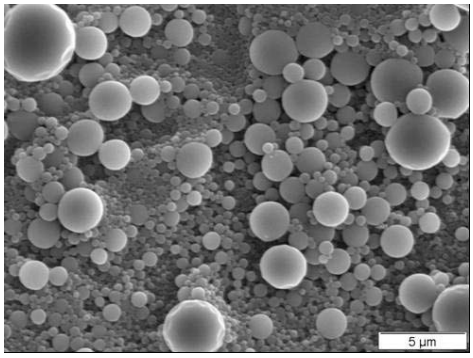
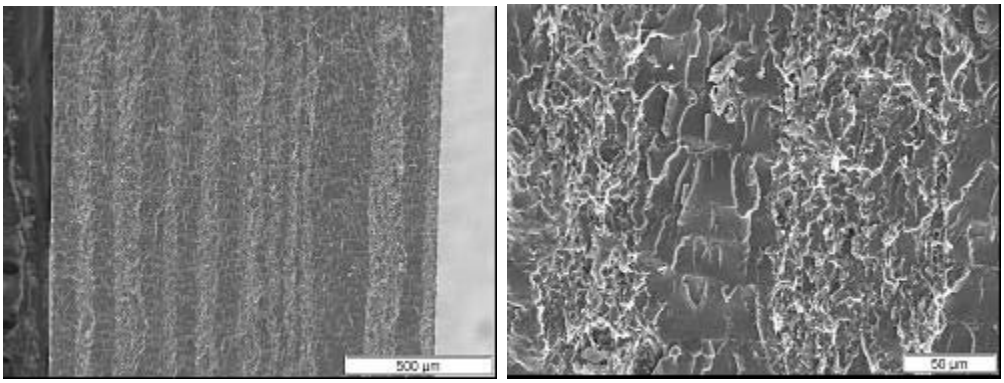
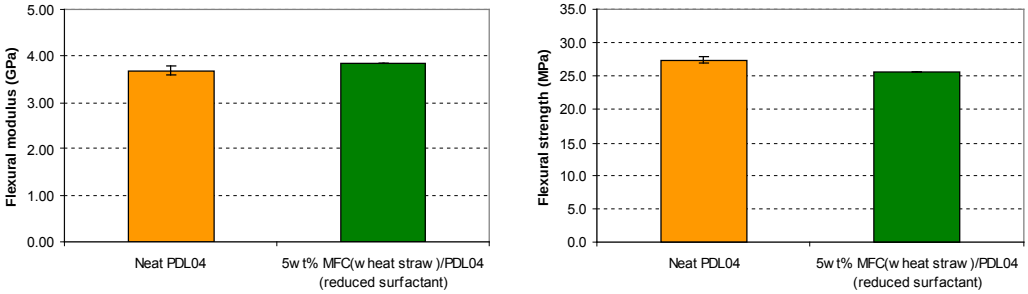


Figure 21. PLA microspheres produced from Purac PDL 04 with TWEEN 80 to polymer ratio at 3:100



(a) **(b)**

Figure 22. The fracture surface of the 5wt% MFC(TC90)/PLA composite prepared using less surfactant..



(a) **(b)**

Figure 23. Comparison of the (a) flexural moduli and (b) strength of the neat PLA and the 5wt% MFC(wheat straw)/PDL04 with reduced surfactant content

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Note: (a) The control sample was prepared with the higher surfactant content of 8:100; (b) Only one test was done for the composite sample.

- **Spray method for composite formation**

When the MFC+PLA+water 3-component mixture is poured into a filter, although the PLA microspheres are stopped by the filter membrane and get deposited there, the cellulose microfibrils tend to remain suspended in the residual water phase above the filter. If the mixture is instead sprayed onto the filter membrane and the water is quickly removed by vacuum suction from the bottom and evaporation from the top, the "free water phase" above the filter can be eliminated, thus preventing the mixture from "de-mixing".

In order to have finer droplet size and better control of the spray pattern, air brushes were chosen as opposed to simple spray bottles. Both external mix and internal mix air brushes were tried to spray the MFC + PLA mixture onto a filter membrane.

These experiments turned out to be not only slow, but also very hard to perform. It was difficult to get a uniform coverage of the filter membrane when a large amount of sample (compared with painting) had to be deposited. Furthermore, when the liquid droplets reach the filter, they bounce around everywhere, causing lot of sample loss.

- **Filtration with membranes with larger pore sizes**

To increase filtration speed, filter membranes with larger pore sizes were considered. Although these pore sizes are larger than the size of the cellulose nanowhiskers, sample loss through the filtrate should slow down quickly after the initial filtration stage when a layer of sample has been built up on the filter surface. Since a large amount of sample is processed in composite preparation as compared to in fields such as analytical chemistry, a reasonable amount of sample loss can be tolerated.

- 0.65 μm Millipore Durapore filter

  According to company specifications, the water flow rate of the 0.65 μm filter (69 mL/min/cm2) is more than 10 times higher than that of the 0.22 μm filter (6.7 mL/min/cm2).

  However, although the filtration speed was greatly increased by using these filters , the cellulose microfibrils again separated from the PLA.

- 5 μm Polycarbonate filter and 41 μm Nylon net filter

  Filtrate was very cloudy. Severe sample loss through the filters.

- 1 μm Mixed Cellulose Easter (MCE) filter

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Although the filtration of each portion took only 25-30 seconds, thin layers of microfibrils were again formed inside the PLA matrix (Figure 24).

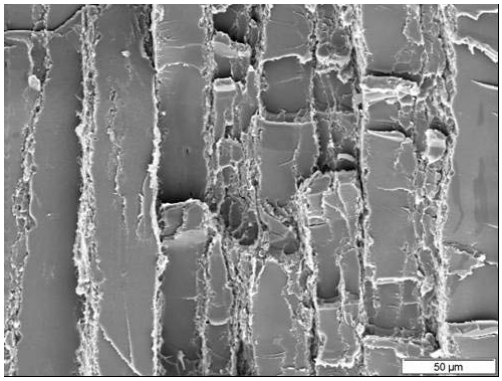

Figure 24. Fracture surface of 5wt% MFC(TC90)/PDL04 prepared with the 1μm MCE filters

5. Summary and Conclusions

The compositional, morphological, and surface chemical changes introduced into wheat straw as a result of AFEX and SSF treatments were studied. Cellulose nanowhiskers (CNW) and Microfibrillated cellulose (MFC) were extracted from this ethanol production residue at reasonable yields. The ability to produce microfibrillated cellulose through a mechanical homogenization approach has significant potential to generate a material with comparable properties to the nanowhiskers but through a much simpler and less costly process.

In order to produce a totally biobased composite material, several methods to combine the wet wheat straw based MCF and CNW with Poly Lactic Acid (PLA) were investigated at concentrations up to about 5 wt% including an a new emulsification-freeze drying process, filtration and lamination and spray processing.

Mechanical properties of the composites did not show improvement consistent with the values expected for a reinforcement with properties similar to MFC and CHW. The lack of measurable increases in the composite properties has been attributed to poor dispersion within the PLA matrix.

Good dispersion of the cellulose nanofibers is a key to producing a polymer composite with high mechanical properties and to fully realize their potential as a reinforcing material. Although some preliminary studies had appeared to show that the Emulsion-Filtration technique we developed had solved the fiber aggregation problem, after switching to a new source of PLA resin, we have not been able to achieve the same degree of dispersion so far. The cellulose fibrils separate from the polymer particles after filtration and then form a stratified microstructure consisting of thin sheets of cellulose

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fibrils inside the polymer matrix after compression molding. As the volume of the dispersion agent – water solution is gradually reduced by filtration, the PLA particles precipitate out of solution and segregate from the MFC, which results in the de-mixing the MFC and PLA. Further research is necessary in order to identify a processing method that provides good dispersion of the MFC in PLA or other water based polymers.

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Appendix B

"Cellulose Nonowhisker Technology Development: Investigation into Utilization of Wheat Straw Residue from Ethanol Production (AFEX + SSF)"

Cellulose Nanowhisker Technology Development:
Investigation into Utilization of Wheat Straw Residue from Ethanol Production (AFEX + SSF)

Lawrence T. Drzal and Tao Wang
Michigan State University

Final Report – November 2009

ABSTRACT

The compositional, morphological, and surface chemical changes introduced into wheat straw as a result of AFEX and SSF treatments were studied. Cellulose nanowhiskers (CNW) and Microfibrillated cellulose (MFC) were extracted from this ethanol production residue at reasonable yields. The ability to produce microfibrillated cellulose through a mechanical homogenization approach has significant potential to generate a material with comparable properties to the nanowhiskers but through a much simpler and less costly process.

MFC appears to be the most reasonable cellulose product that has useful properties as an additive to polymers in composites and can be produced at a reasonable cost. Good dispersion is a key to producing a polymer composite with high mechanical properties and to fully realize their potential as a reinforcing material. Once dried, the MFC cannot be easily re-dispersed in a polymer dictating the need for a water based processing method to make MFC reinforced composites. Further research is necessary in order to identify a water based processing method that provides good dispersion of the MFC in PLA or other water based polymers.

1. Motivation and Objectives

1.1. Motivation

As one of the most abundant agricultural residue, wheat straw can serve as a cheap feedstock for cellulose. Cellulose fibers, comprised of highly ordered microfibrils are well known to have good mechanical properties. These bio-based plant fibers coupled with bio-based polymers offer a unique opportunity to produce light weight structural materials for automotive and other applications. On the other hand, cellulose chains can also be hydrolyzed to its monomer building unit – glucose, which can then be converted to ethanol by fermentation. In recent years cellulosic ethanol has attracted great interest as a promising alternative liquid fuel of both environmental and strategic importance. Unlike corn ethanol and sugar ethanol, in the production of cellulosic ethanol, a large amount of solid residue is also generated as a byproduct. A profitable use of this residue will contribute to the target of making the cellulosic ethanol biorefinery even more economically competitive.

The underlying assumption in this project is that cellulose nanofibers for production of biocomposite materials can be a value-added byproduct in a cellulose-to-ethanol biorefinery when they are extracted from wheat straw biomass. Production of cellulosic ethanol from wheat straw is dependent on the Ammonia Fiber Expansion (AFEX) pretreatment process for conversion of cellulosic biomass to fermentable sugars. The residual materials from ethanol fermentations contain cellulose nanofibers. We explore the opportunity of using wheat straw and its fermentation residue as feedstock for extracting two forms of cellulose nanofibers (CNF) namely Cellulose Nanowhiskers (CNW) and Microfibrillated Cellulose (MFC). The possibilities of using the extracted MFC and CNW in polymer nanocomposite applications will then be investigated.

1.2. Objectives

The main objectives of this project includ:

- Extraction of CNW and MFC from wheat straw
- Evaluation of the solid residue from the AFEX pretreated ethanol production process as a feedstock for the CNW and MFC extraction
- Nanocomposite fabrication using biobased polymers such as Polylactic Acid (PLA)
- Characterization of nanocomposite mechanical and thermal properties
- Determination of mass balances for the process

2. Extraction of CNW and MFC from Wheat Straw

2.1. Introduction to CNW and MFC

In the plant cell wall, cellulose microfibrils are embedded in a hemicellulose and lignin matrix to provide structural and mechanical support for the plant body. Cellulose microfibrils have both crystalline regions and disordered amorphous regions. The elastic modulus (stiffness) of crystalline cellulose I in the direction parallel to the chain axis was measured to be 138 GPa [1] which agreed with theoretical values determined by molecular simulation techniques to be between 124 to 155 GPa [2] . The high elastic modulus of the crystalline cellulose in the microfibrils gives them the potential to replace traditional reinforcement materials such as glass fibers and carbon fibers in structural composite materials.

Since as early as the 1950s, microcrystalline cellulose (MCC) has been extracted from native cellulose by acid hydrolysis and later used in the pharmaceutical industry mainly as a tablet substrate[3]. It was not until about three decades ago did researchers start investigating the application of separated cellulose crystals, also called cellulose nanowhiskers (CNW), as a strengthening material in nanocomposites [4] . In 1983 Herrick et al and Turbak et al published their work on using a high pressure homogenizer to individualize microfibrils from pure cellulose fibers and gave the resulted product the name Microfibrillated Cellulose (MFC) [5, 6]. In early 2005, Nakagaito and Yano published their work on preparing MFC reinforced phenol-formaldehyde composites [7]. MFC was also used by Fujii et al to improve bending strength and fracture toughness of a bamboo fiber reinforced polylactic acid composite[8] .

2.2. Extraction of MFC from Wheat Straw

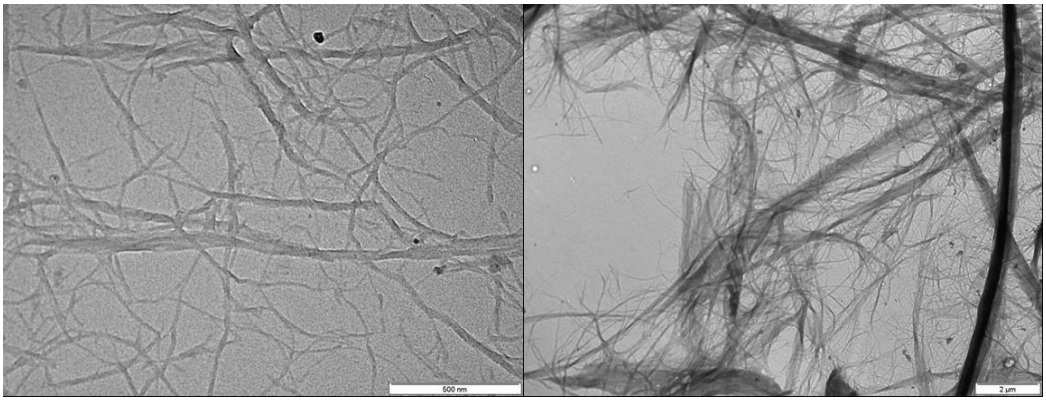
The process to produce MFC from biomass is relatively uncomplicated. After a large fraction of the lignin and hemicellulose in wheat straw are removed, the cellulose fiber water suspension is passed through a small orifice utilizing a high pressure homogenizer. The high shear force generated as the suspension is passed through the narrow opening in this process causes disintegration of the structure and separates microfibrils in the cell wall. The process steps consist of the following:

Experimental:

Raw wheat straw was dried in a 95 °C vacuum oven overnight and then ground and sieved to 35-60 mesh size powder. The wheat straw was then bleached with 10wt% peracetic acid at 90 °C for 30 min and washed repeatedly with a warm distilled water and acetone-ethanol (1:1) mixture. After being dried in a vacuum oven overnight, the sample was treated with 17.5 wt% NaOH water solution at 25 °C for 30 min. At the end of the 30min, an equal amount of distilled water was added and the reaction was continued for another 30 min. The treated sample was washed with warm distilled water (~50 °C) until the pH of the wash stream was neutral. The pulp thus obtained was

homogenized in 20 passes either on an APV-1000 high pressure homogenizer (Invensys APV, Lake Mills, Wisconsin) operated at about 11,000 psi (75.8 MPa) or on a Mini DeBEE homogenizer (BEE International, South Easton, Massachusetts) operated at about 40,000 psi (276 MPa).

The morphology of the obtained sample was observed using a Transmission Electron Microscope (JEOL 100CX TEM) with accelerating voltage of 100 kV.



(a) **(b)**

Figure 1. TEM micrographs of the MFC extracted from wheat straw. Scale bar in (a) 500 nm (b) 2 μm

Result:

During the homogenization operation, the viscosity of the suspension increased substantially with the number of passes through the homogenizer, which indicated a progressive disintegration of the cellulose microfibril bundles into individual microfibrils. After 20 passes, a stable milky suspension of the MFC was obtained. As can be seen from the TEM images (Figure 1), defibrillation of the cellulose fibers in the wheat straw cell wall was achieved. Although some of the fibrils have diameters as large as 100 to 200nm (Figure 1b), the majority of the extracted micrifibrils have a width of 15-20 nm (Figure 1a). The length of the MFC has a broad distribution, ranging from several tens of μm to a few hundreds of μm.

The yield of the MFC based on the dry weight of untreated wheat straw was 34.6 wt%.

2.3. Wheat straw CNW

As discussed earlier, cellulose microfibrils in the cell wall have both crystalline and amorphous regions. By controlled acid hydrolysis, the amorphous domain of the cellulose microfibrils can be solubilized to yield cellulose nanocrystals – CNW.

Experimental:

The wheat straw MFC sample was hydrolyzed with 55wt% sulfuric acid at 50 °C for 2 hours to produce nanowhiskers. After acid hydrolysis, the residual acid was removed by repeated dialysis against DI water. The sample was further treated by ultrasonication for 2 min and then stored in a refrigerator.

Result:

The extracted CNWs exhibited a rod-like crystals with width and length in the range of 5-10 nm and 100-200 nm respectively (Figure 2). The yield of CNW from dry wheat straw was 13.6 wt%.

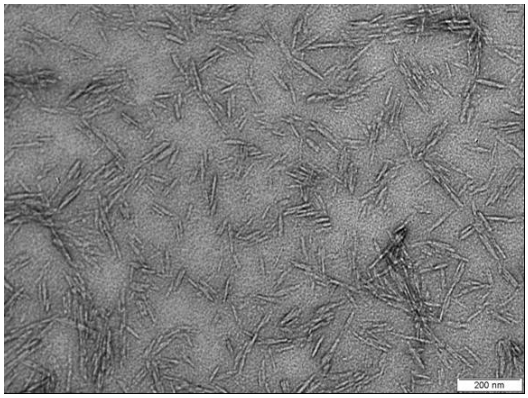


Figure 2. TEM micrograph of the CNW extracted from wheat straw. Scale bar: 200 nm

3. Extraction of CNW and MFC from Wheat Straw Ethanol Production Residue

3.1. Justification

If the cellulose contained in wheat straw cell wall is completely hydrolyzed to its monomer building unit – glucose, the glucose can then be converted to ethanol by fermentation. Bioethanol, ethanol obtained from natural resources such as corn, sugarcane and biomass has been widely considered as a promising alternative liquid fuel thanks to its economic, environmental and strategic advantages. Furthermore, cellulosic ethanol does not threaten our food supply, as corn ethanol and cane ethanol have been considered to do. On the other hand, unlike corn ethanol and cane ethanol, when ethanol is produced from lignocellulosic materials, a large amount of solid residue is also generated as a byproduct. A profitable use of this residue is very important in making the cellulosic ethanol production process more economically competitive.

In the production of cellulosic ethanol, biomass is usually treated in 3 steps: pretreatment, saccharification and fermentation. The pretreatment step is needed to make the cellulose embedded in the plant cell wall more accessible to cellulolytic enzyme hydrolysis. Pretreatment is achieved by various ways such as removing the lignin and hemicellulose components, altering the lignin structure and increasing the surface area in the inner cell wall. Examples of leading pretreatment techniques include steam explosion, dilute acid hydrolysis and Ammonia Fiber Expansion (AFEX), etc [9]. In AFEX process, biomass is treated with liquid ammonia at elevated temperatures and pressures for 5 to 30 min before the pressure is abruptly released. [10] The combined chemical and physical effects of AFEX on the cell wall components including lignin, hemicellulose and cellulose and cellulose wall structure dramatically enhances enzymatic conversion of cellulose and hemicellulose to fermentable sugars.

Cellulose conversion varies with different biomass species and different pretreatment and hydrolysis techniques. For corn stover and switchgrass, cellulose conversion of nearly 100% can be achieved [11,12]. However, for straw material, the cellulose conversion is often much less than 100%. Abedinifar et al[13] and Ko et al [14]reported 50% conversion and 71.1% digestibility for rice straw respectively. For wheat straw, Georgieva et al achieved 70% cellulose conversion after wet-explosion pretreatment and simultaneous saccharification and fermentation (SSF) [15] . If in the ethanol production process, a significant amount of lignin and hemicelluose is also removed along with cellulose, the small fraction of unhydrolyzed cellulose can still be moderate contribution to the residue. In study published by Yang et al, the wheat straw residue after ethanol production by steam explosion and SSF still contained 25.9 wt% of cellulose[16]. Our own analysis (Section 3.2) showed 36 wt% glucan content in the residue after AFEX and SSF, which is not significantly lower than the glucan content in the untreated wheat straw 43 %.

While higher cellulose conversion is constantly pursued in the production of cellulosic ethanol, this often calls for more complex or harsher pretreatment, higher enzyme loading, and longer hydrolysis time, etc., which all lead to higher capital cost. Furthermore, in the fermentation step one often faces the dilemma of higher substrate content or higher glucose content [17]. Lower substrate content gives higher hydrolysis efficiency but also leads to lower absolute content of glucose in the hydrolysate stream, which contributes negatively to the subsequent fermentation step. If the solid residue coming out of fermentation reactors can be utilized as a feedstock for extracting value-added cellulose nanofibrils, a near complete cellulose conversion of biomass may become less favorable in the overall economic optimization.

3.2. Surface morphology changes

Observation of surface morphology changes provides clues of the structural damage induced by the AFEX and SSF process on the wheat straw cellulose fibers and the possible relocation of some of the cell wall components such as lignin.

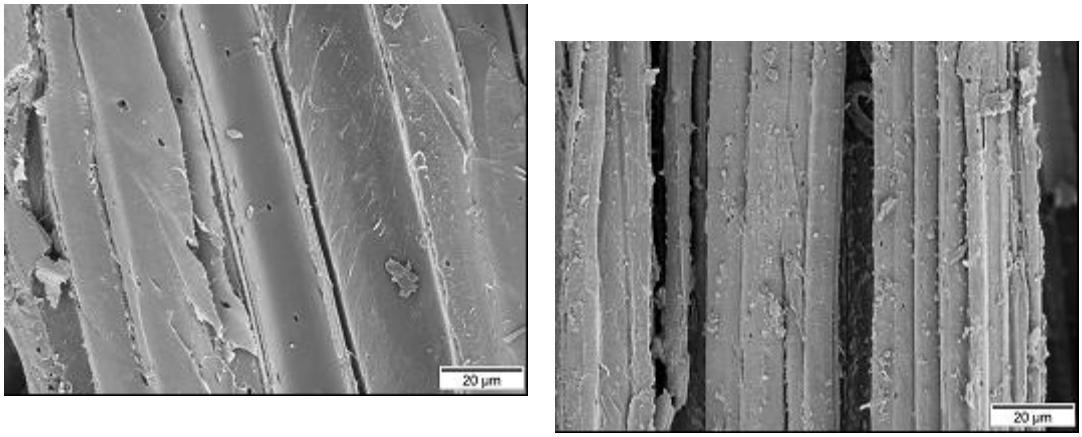
Method:

Scanning Electron Microscopy (SEM)

Small samples of the untreated wheat straw and the AFEX+SSF residue were mounted on Aluminum stubs and coated with a thin layer of Osmium Tetroxide. Observation was made using a JEOL 6300-F Field Emission Scanning Electron Microscope (FE-SEM) operated at 5 kV.

Result:

From the SEM images (Figure 3), it can be seen that after being utilized for ethanol production, the cellular structure of the wheat straw is still largely preserved. The outer surface of the cell walls has become rougher and more heterogeneous. This change results from both the physical treatments experienced by the straw fiber during the AFEX pretreatment, the saccrification and fermentation processes, repeated warm water washings, and the chemical modifications due to the loss of some of the extractives, hemicellulose and cellulose.



(a) **(b)**

Figure 3. SEM images of the surfaces of (a) the untreated wheat straw and (b) the wheat straw AFEX+SSF residue

3.3. Surface chemistry changes

Method:

FT-IR and XPS

FT-IR spectra of both the untreated wheat straw and the AFEX+SSF residue were recorded on PerkinElmer System 2000 FTIR spectrometer equipped with an Attenuated Total Reflectance (ATR) sampling attachment.

The surface atomic concentrations were measured by X-ray Photoelectron Spectroscopy (XPS) using Physical Electronics 5400 ESCA.

Result:

(1)FT-IR

A comparison of the FT-IR spectra of untreated wheat straw and the AFEX+SSF residue is shown in Figure 4. Compared with the untreated wheat straw, the AFEX+SSF residue does not have a peak at 1731 cm-1, which is characteristic of hemicellulose, but has more prominent peaks at 1420 cm-1 , 1458 cm-1 , 1505 cm-1 and 1593 cm-1, which are all characteristic peaks of lignin [18,19].

(2) XPS

The theoretical values of O/C ratios for cellulose, hemicellulose, lignin and extractives are 0.83, 0.80, 0.33 and 0.04-0.12 respectively [20]. From table 1, it can be seen that the O/C ratio for the untreated wheat straw is 0.17 which is indicative of a surface covered by extractives. The AFEX+SSF residue surface has an O/C ratio of 0.30 which corresponds to a surface covered with lignin.

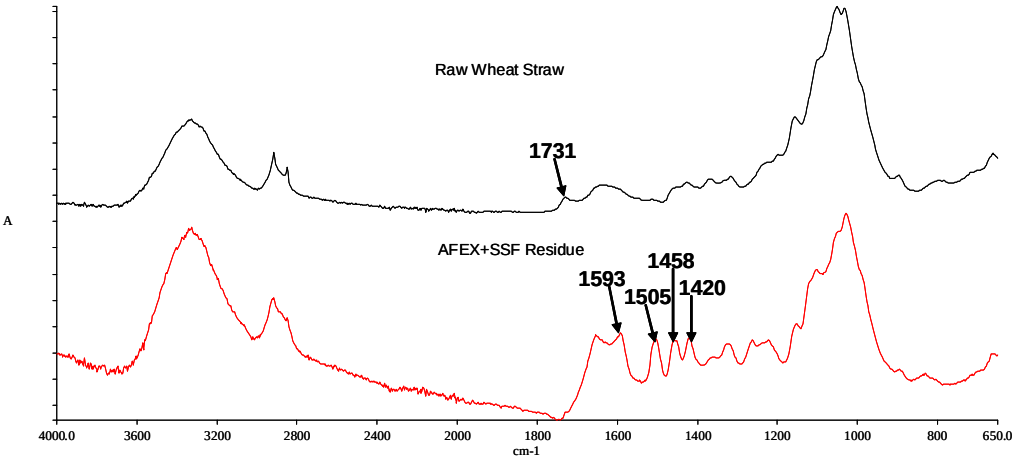


Figure 4. FT-IR spectra of the untreated wheat straw and the AFEX+SSF residue

Table 1. The O/C ratio and the relative C1, C2 and C3 peak areas of the deconvoluted C1s peak from XPS analysis

	O/C	C1 (%)	C2 (%)	C3 (%)
Raw wheat straw	**0.17**	**81.8**	**13.5**	**4.8**
AFEX+SSF Residue	**0.30**	**62.7**	**32.6**	**4.7**

Note: O/C: Oxygen/Carbon atomic ratio; C1: C-C; C2: C-O; C3: O-C-O or C=O.

3.4. MFC extraction from the residue

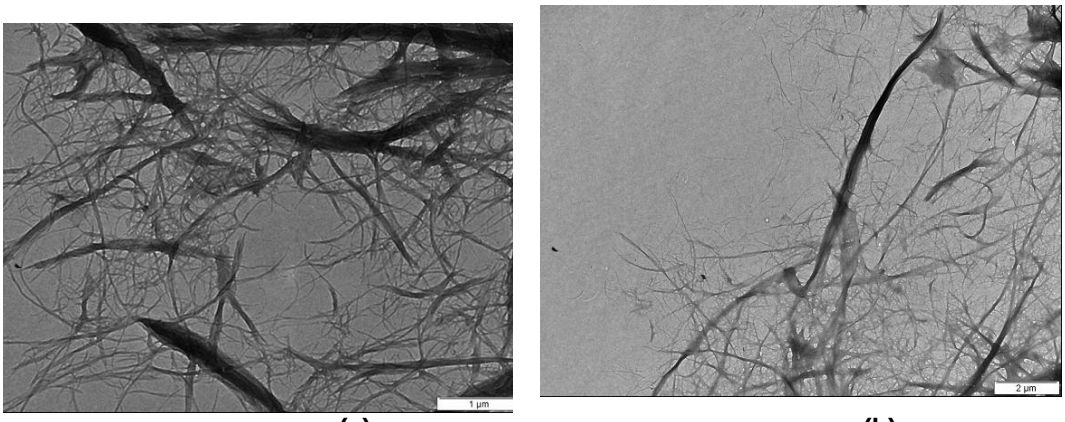
Since both the cellulose content and the cell wall structure of the residue did not differ significantly from those of the raw wheat straw, in this initial investigation, the same method was used to extract MFC from the residue as in the extraction from raw wheat straw.

Method:

Same as in Section 2.2.

Result:

MFC extracted from the fermentation residue is shown in Figure 5. Compared with the MFC extracted from untreated wheat straw (Figure 1), the size of these fibrils appeared to be larger in width and shorter in length.



(a) **(b)**

Figure 5. TEM images of the MFC extracted from the wheat straw AFEX+SSF residue. Scale bar in (a) 2 µm; (b) 500 nm.

4. CNW and MFC reinforced Polylactic acid (PLA) composites

4.1. Justification

The attractiveness of a biobased nanoreinforcements is enhanced when it can be combined with a biobased polymer resin. The biocomposites thus obtained will be completely renewable and biodegradable. Very few biobased resin systems are available. The ones that have been studied extensively in recent years include Cellulose Acetate (CA), Polylactic Acid (PLA), Polycaprolactone (PCL), Polyhydroxybutyrate (PHB) and thermoplastic starch (TPS) [21] .

PLA is a biodegradable aliphatic polyester derived from renewable resources such as corn starch and cane sugar. PLA is a polymer of lactic acid (2-hydroxypropanoic acid), which is a chemical compound naturally present in humans and animals. Lactic acid is a

chiral molecule, existing as two stereo isomers, L-lactic acid and D-lactic acid. Two molecules of lactic acid can be dehydrated to a cyclic diester – lactide, which can then be polymerized to polylactide usually by ring-opening polymerization using suitable catalysts. Polymerizations of L-lactide and D-lactide lead to the synthesis of Poly-L-lactide (PLLA) and poly-D-lactide (PDLA) respectively. And the polymerization of a racemic mixture of L- and D-lactides gives poly-DL-lactide (PDLLA), which, unlike PLLA and PDLA, is not semi-crystalline but amorphous.

PLA can be processed like most thermoplastics into fibers, films and various molded articles. Although the process of making PLA has been known for almost a century, this polymer did not attract too much commercial interest in the past mainly due to its high production cost and inferior thermal properties compared to petroleum based plastics. In recent years, advances in fermentation and polymerization technologies have made the price of PLA considerably cheaper. Development in the material science of PLA has also helped to improve its mechanical and thermal properties. And the fact that PLA is biodegradable and can be produced from renewable resources makes the polymer an attractive environmentally friendly alternative to conventional commodity plastics. Increased demand of PLA products has led to fast growth in its production around the world. Higher production volume in turn is driving down its production cost even further. Today PLA materials are finding uses in many areas of applications including packaging, paper coating, biomedical products such as sutures and drug delivery devices and consumer goods such as toys and beverage bottles.

Although PLA has relatively high modulus, it is known to be extremely brittle. In other words, PLA is strong but not tough. The low toughness of PLA hinders its applications in structural materials such as automotive parts and housings of portable electronic devices. Adding high aspect ratio cellulose nanofibers may toughen the PLA matrix by a bridging mechanism. And thanks to the high Young's modulus of the nanofibers, the polymer may become both tougher and stronger, which is often highly desirable. Furthermore, for semi-crystalline PLLA, adding cellulose nanowhiskers is expected to change its crystallization behaviour. Nanoparticles and nanofibers have been shown to act as nucleating agents for thermoplastics [22]. Thus incorporation of cellulose nanowhiskers may lead to faster crystallization rate, higher crystallinity and smaller spherulite size, which will further improve the polymer's mechanical properties.

4.2. Composite fabrication strategies

After the extraction of cellulose nanofibers from wheat straw and its fermentation residue, the challenge is to disperse the nanofibers in a non-water soluble polymer matrix without causing the hydrophilic particles to aggregate together. Because of the very high density of hydroxyl groups on the surface of cellulose microfibrils, both CNW and MFC form stable suspensions in water but aggregate when dried from water. Since most of the commercial plastics including PLA are not soluble in water, the fabrication of CNW and MFC reinforced polymer composite is a challenging task. When using PLA as a matrix for CNW and MFC, there are 4 possible distinct routes that can be considered for composite fabrication.

- Direct mixing

  In this approach, cellulose water suspensions are mixed directly into PLA melt in an extruder. Water removal takes place in the extruder by evaporation. There have been mixed results on the quality of dispersion by this approach. Chakraborty et al reported good dispersion of microfibrils in PLA at low fiber content [23]. However, Oksman et al found that feeding Microcrystalline Cellulose (MCC) water dispersion directly into the extruder caused agglomeration of cellulose in the polymer matrix as well as some thermal degradation [24].

- Co-solvent approach

  PLA can be dissolved in selected organic solvents such as dichloromethane, chloroform and DMF. In this approach, CNW or MFC is first transferred from water to an appropriate organic solvent either by solvent exchange or by drying and re-dispersing and then mixed with PLA that has been dissolved in the same solvent. The solvent can then be easily removed by evaporation. Solvent exchange is a lengthy and expensive process, especially considering the cellulose content in the original water suspension is often very small. Cellulose fibers always aggregate when dried out from water because of the high concentration of hydroxyl groups and the resulting high force of attractions between them making redispersion in other solvents and even in water difficult, which in-turn then leads to poor dispersion in the polymer matrix[25].

- Mixing MFC and CNW with monomer before polymerization.

  Technically, CNW and MFC can be mixed with the water soluble lactic acid, before the lactic acid is polymerized into PLA. But the difficulty of carrying out the polymerization in a water medium and the harsh conditions involved in the polymerization make this route impractical.

- PLA water emulsion

  In the pharmaceutical industry, PLA and its co-polymer poly(lactic-co-glycolic acid) (PLGA) are among the most popular substrates used for controlled release of drugs due to their proved biocompatibility. The drug substances are usually encapsulated in polymer microspheres by a well-established method called the "solvent evaporation technique" [26]. The size of the microspheres is determined by many factors including but not limited to surfactant chemistry, surfactant concentration, solvent-to-water ratio and the mixing method and speed. Indeed, nanospheres with diameters smaller than 200 nm can been prepared [27,28].

  Although PLA can not be dissolved in water, if it is emulsified into water as microor nanospheres and if the size of the microspheres are small enough to be comparable to the dimension of the CNW and MFC, it is reasonable to expect good mixing of the two components in the water medium.

If a water based processing route can be found that does not require the MFC or CNW to be dried, dispersion with water based polymer emulsions is a practical and cost effective

processing step to produce MFC or CNW nanocomposites. The overall biorefinery process can then be designed as shown in the diagram in Figure 6.

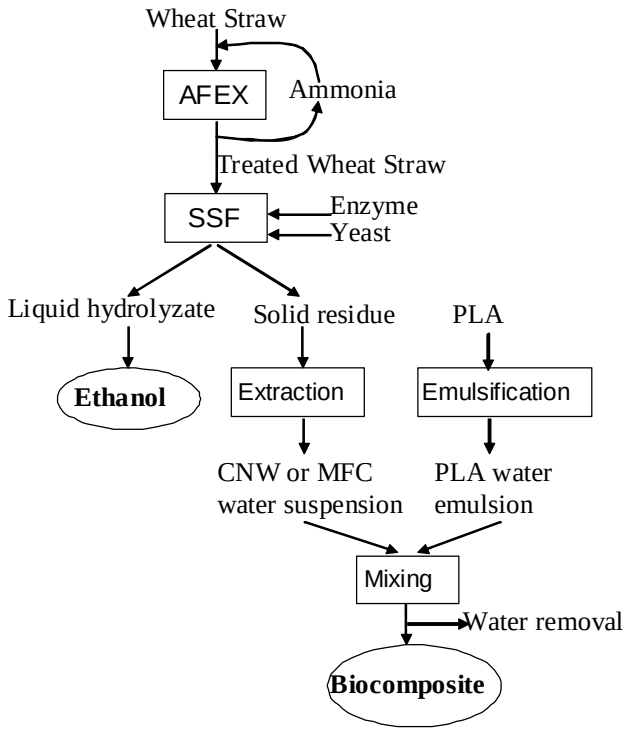


Figure 6. Schematic diagram of the proposed wheat straw biorefinery

4.3. PLA water emulsions

The solvent evaporation technique was used to prepare PLA water emulsions. The morphology of the PLA microspheres in the emulsion was examined by using Scanning Electron Microscope. And the emulsification yield was estimated by measuring the weight content of the suspended solids in the emulsion.

4.3.1 Finding a suitable surfactants

Various surfactants can be used for producing microspheres from PLA. Polyvinyl Alcohol (PVOH) is the most commonly used in the pharmaceutical industry for drug encapsulation. But since PVOH is a semi-crystalline polymer and PDLLA is amorphous, PVOH phase separates from PDLLA after compression molding. After trying common surfactants and electrolytes such as SDS (sodium dodecyl sulfate), Carbopol 940, Triton X-100, GAENPE (Glycolic acid ethoxylate 4-nonylphenyl ether), GAEBPE (Glycolic acid ethoxylate 4-tert-butylphenyl ether), PSS (Sodium polystyrene sulfonate), we found that TWEEN 80 (also called Polysorbate 80) showed the highest emulsification capability. A typical experiment with TWEEN 80 is shown below.

Experimental:

0.135 g TWEEN 80 was dissolved in 360 ml RO water.

4.50 g PLA was dissolved in 90 ml ethyl acetate.

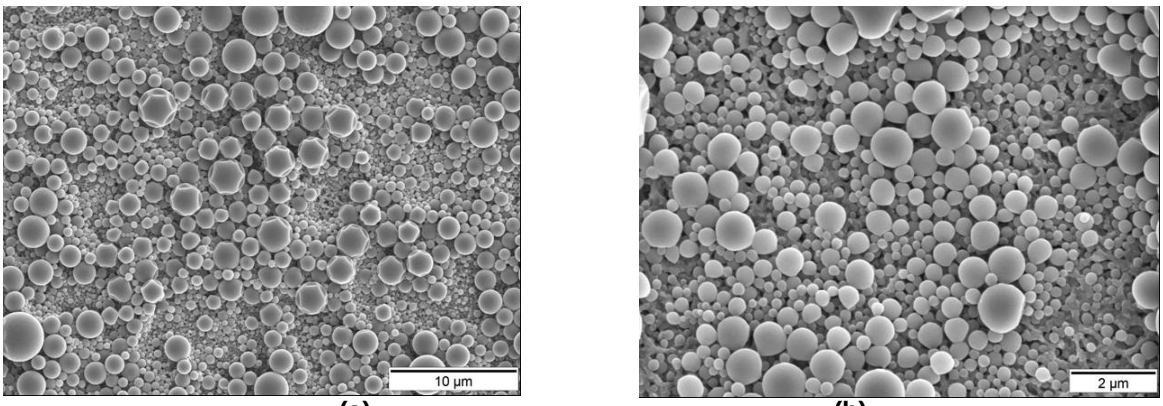
The mixture was blended with the Ultra-Turrax T25 homogenizer equipped with a S25N-25F disperser at 12,000 rpm for 10 min and then ultrasonicated at 120 Watts for 2min using a Cole-Parmer Sonicator equipped with a 1 inch probe. The ethyl acetate was evaporated in a 35-40 °C water bath overnight under mechanical stirring.

The weight content of solids in this emulsion was measured by heating to constant weight at 105 °C using a Thermal Gravimetric Analyzer (TGA).

The morphology of the microsphere of PLA in the emulsion was observed with Scanning Electron Microscope by using either a JEOL 6300-F Field Emission SEM operated at 5 kV or a JEOL 6400 SEM operated at 10 kV. The sample was made conductive by coating with a thin layer of Osmium Tetroxide before being examined.

Result:

After solvent evaporation, a milky PLA emulsion was obtained. The size and morphology of the microspheres are shown in Figure 7.



(a) **(b)**

Figure 7. PLA microspheres prepared by solvent evaporation technique using TWEEN 80 as a surfactant (weight ratio to polymer: 3:100). Scale bar in (a) 10 μm; (b) 2 μm.

4.4. Composite preparation and evaluation

Once PLA is emulsified into water as microspheres, MFC and PLA can be easily mixed in the water based emulsion. After mixing, water needs to be removed in a fast and efficient way so that “demixing” will not happen. Several methods were investigated to achieve removal of water without demixing.

4.4.1 Freeze drying method

In this method, the mixture of MFC and PLA is quickly frozen, thus locking the dispersed state of the two components. Removal of water by sublimation of the ice in a freeze dryer was expected to produce a solid product that would then be molded into a composite. MFC extracted from the wheat straw ethanol production residue (WS AFEX+SSF residue) was used for this process.

Experimental:

(1) Composite fabrication

A PLA emulsion was prepared following the same protocol as in Section 4.3.1 using PDLLA purchased from Polysciences, Inc. (Warrington, Pennsylvania).

The MFC suspension (from AFEX+SSF residue) and PLA emulsion were sonicated at 80 Watts for 30 sec respectively and then mixed together. After mixing, sonication was continued at 120 Watts for 2 min. The mixture was then quickly frozen by immersing in a liquid nitrogen bath and dried in a Labconco FreeZone 1 Liter Freeze Dry System (Labconco Corporation, Kansas City, Missouri).

After freeze drying for about 1 week, the mixture changed into a fluffy white powder. This powder was packed into a stainless steel mold and compression molded into 1.4mm and 3.0mm thick sheets at 105 °C and 0.62 MPa on a Carver Laboratory Press Model 2518 (Fred S. Carver Company, Wabash, Indiana).

(2) Property evaluation

Dynamic Mechanical Analysis (DMA)

Dynamic mechanical analysis was performed in 3-point bending mode on TA Instruments Dynamic Mechanical Analyzer Model 2980 (New Castle, Delaware). Temperature scan was from 20 °C to 60 °C at 3 °C/min.

Main parameters: Frequency = 1.0 Hz; Amplitude = 70 μm; Static force = 0.010 N.

Flexural modulus and strength

The flexural properties were measured according to ASTM Standard D 790 by using UTS SFM-20 (United Testing Systems Inc., Flint, Michigan).

Notched Izod Impact Strength

The Izod impact strength was tested by using TMI 43-02-01 Monitor/Impact system (Testing Machines Inc., Ronkonkoma, New York) according to ASTM Standard D 256.

Differential Scanning Calorimetry (DSC)

DSC tests were from 0 °C to 200 °C at a heating rate of 10 °C/min using TA Instruments Differential Scanning Calorimeter Model 2920.

Thermal Gravimetric Analysis (TGA)

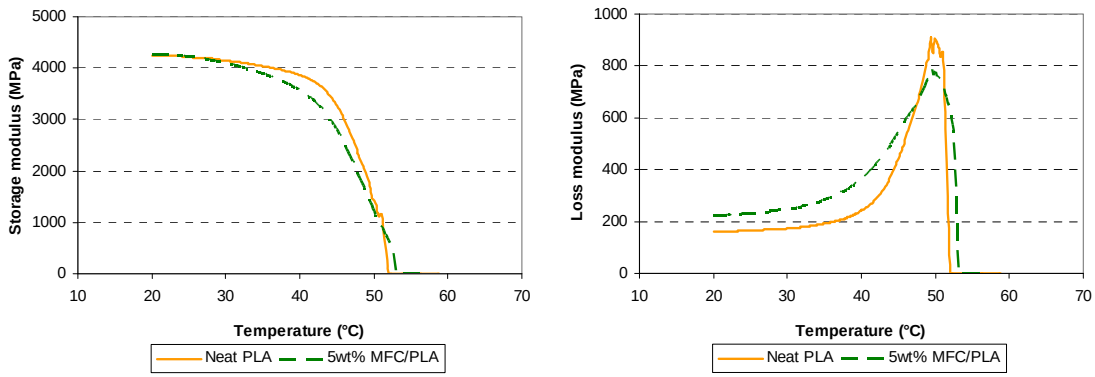
The thermal stability of the sample was measured by using TA Instruments Thermal Gravimetric Analyzer Model 2950.

Samples were heated from room temperature to 580 °C at 25 °C/min with high resolution 4 °C/min.

Result:

After compression molding, it was found that the compressed specimen has areas of varying opacity. Since neat PLA is clear, the darker areas in the composite indicated higher MFC concentration in these areas. MFC had formed aggregates inside the PLA matrix. Nevertheless, the mechanical properties of the resulting composites were measured.

(1)Dynamic Mechanical Analysis DMA



(a) **(b)**

Figure 8. Comparison of (a) the storage modulus and (b) loss modulus of the neat PLA and the 5wt% MFC/PLA composite from DMA measurements.

The storage modulus of the 5wt% MFC/PLA composite was the same as that of the neat PLA over the entire temperature range tested. The glass transition temperature (Tg) as measured by DMA indicated that it was not affected by the addition of the cellulose microfibrils.

(2) Flexural modulus

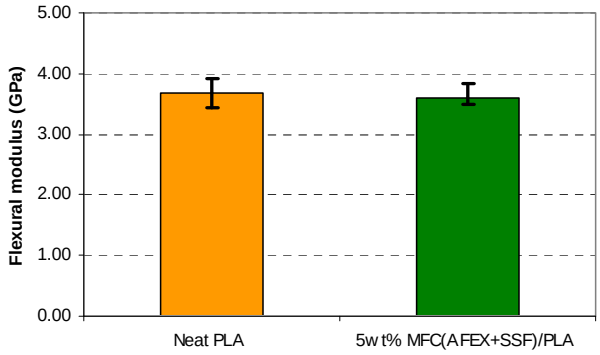


Figure 9. Comparison of the flexural modulus of the neat PLA and 5wt% MFC/PLA composite

The flexural modulus of the 5wt% MFC/PLA composite was also the same as that of the neat PLA.

(3) Notched Izod Impact Strength

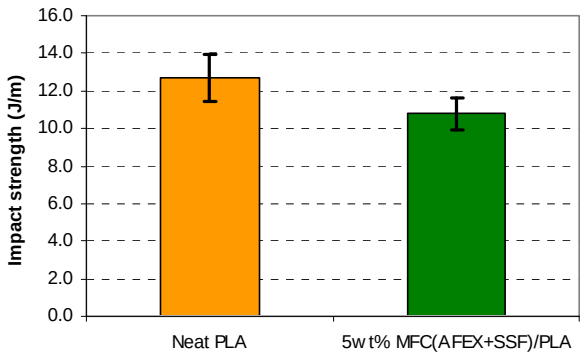


Figure 10. Izod Impact strength of the neat PLA and the 5wt% MFC/PLA composite

The Izod impact strength of the 5wt% MFC/PLA composite (10.8 J/m) was found to be slightly lower than that of the neat PLA (12.7 J/m). The result for each sample was the average of 3 tests with 3 fresh specimens.

(4) The glass transition temperature by DSC

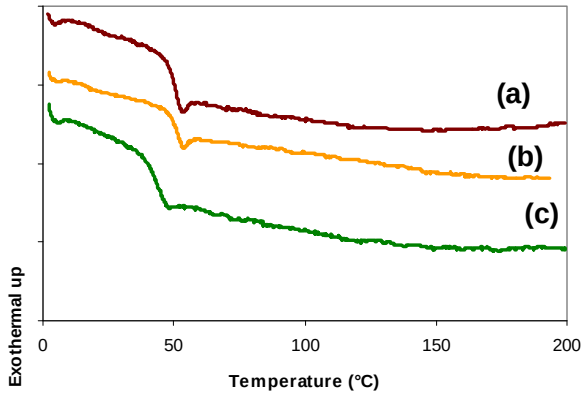


Figure 11. The DSC curves of (a) The as-received PLA pellets; (b) Molded neat PLA sample; (c) The 5wt% MFC/PLA composite

From the DSC curves, it can also be seen that the glass transition temperature (T_g) of PLA did not change after adding the 5 wt% MFC.

The lack of measurable increases in the mechanical properties is attributed to the poor dispersion of MFC in the PLA matrix. Aggregated MCF is not able to reinforce the PLA matrix and contribute to the overall mechanical properties of the composites.

(5) Thermal stability by TGA

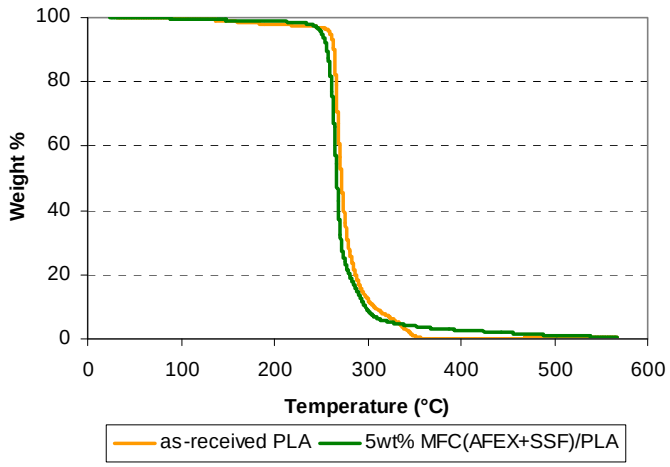


Figure 12. Thermal stability of the as-received PLA pellets and the 5wt% MFC/PLA composite

Both the as-received polymer and the 5wt% composite start to degrade at about 250 °C. The thermal stability of PLA was not affected by the addition of the MFC.

One possible explanation for these disappointing results may be due to the poor dispersion of the MFC may result from the dynamics of the freezing process. During freezing, water molecules solidify into its crystalline form - ice. Impurities and non compatible materials are excluded from water as it solidifies. This pushes the substances dissolved or dispersed in the water out from the ice and into areas between the ice particles concentrating and aggregating them in the solid,. The agglomeration of the MFC might have happened during this time. Hence the immobility of the MFC rendered by the subsequent sublimation process of freeze dry would no longer be able to prevent the de-mixing from happening.

Another possible explanation for the lack of a measurable increase in the properties of the composite reinforced with MFC extracted from the wheat straw residue suggested that the high stiffness of the cellulose microfibrils in the wheat straw cell wall might have been compromised by the physical and chemical treatment associate with the AFEX+SSF process. As a check on this possibility, another set of experiments were conducted with a MFC sample that had been previously prepared in our laboratory from a commercial pure wood cellulose product called CreaTech TC90 (CreaFill Fibers Corp, Chestertown, Maryland).

As can be seen from Figure 13, the flexural modulus of the MFC(TC90) filled PLA remained the same as that of the neat PLA too. Therefore it was concluded that the poor dispersion of the MFC in the composite was responsible for the poor mechanical results. Alternative preparation techniques were sought to ensure better distribution of the fibers.

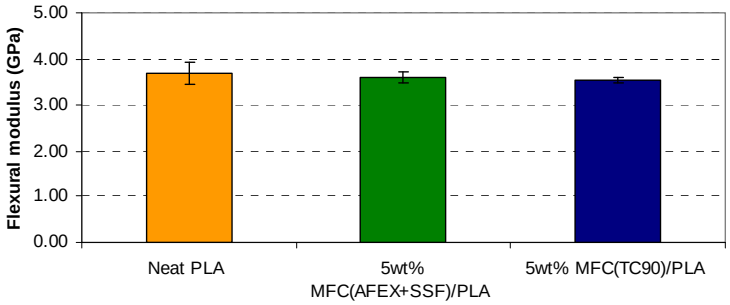


Figure 13. Comparison of the flexural modulus of the neat PLA and 5wt% MFC(AFEX+SSF residue)/PLA, and MFC(TC90)/PLA composites

4.4.2 Lamination method

In this method, the MFC and PLA water suspensions are rapidly filtered is alternating steps onto the same substrate, forming alternating thin layers of MFC and PLA. It was expected that the cellulose microfibrils would form a porous network structure, which, when heated up, would allow the PLA melt to penetrate through, thus forming a laminated composite.

Method:

PLA was emulsified into water using TWEEN 80 as surfactant. The PLA water emulsion and the MFC suspension were divided into 7 and 6 equal portions respectively and filtered alternatively onto the same filter membrane (0.2 μm Whatman Anopore™ Anodisc 47). The filtered sample was dried in a vacuum oven and then compression molded to a disc at 105 °C.

Result:

After compression molding, the cellulose and polymer layers de-laminated, i.e. the molten polymer did not effectively wet the microfibril network as expected. The composite fabrication was unsuccessful.

4.4.3 Emulsion-Filtration method

Fast removal of water from the MFC and PLA mixture is the key to prevent de-mixing. When the entire MFC and PLA mixture is filtered together, the gradual decrease of the filtration speed caused by sample buildup on the filter will lead to long water drainage time. As water is slowly drawn away, the suspended solids get more and more concentrated, causing the separation of MFC and PLA, whose affinities with water molecules are different. In this method, the MFC and PLA water suspensions are mixed together in very small portions and filtered. The sample collected on each filter was then be assembled together and molded at high temperatures into a single piece. The short water drainage time associated with the filtration of divided small portions was expected to keep the cellulose microfibrils and PLA microspheres in a separated state.

4.4.3.1 The 1st trial

This trial was conducted with the pure cellulose MFC sample obtained from CreaTech TC90.

Method:

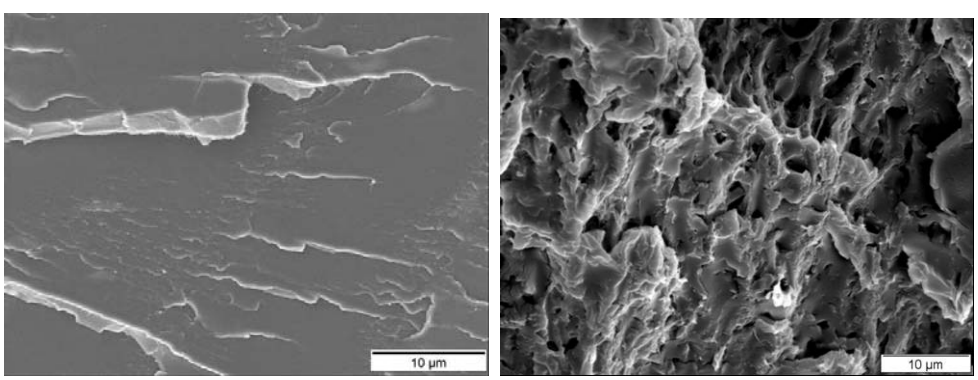
PLA (Polysciences PDLLA) water emulsion was prepared with the same method as in Section 4.3.1. Both the MFC suspension and the PLA emulsion were divided into 10 equal portions. Each portion of the MFC suspension was mixed with one portion of the PLA emulsion, thus forming 10 equal mixtures. After being ultrasonicated at 30 Watts for 1 min, the mixtures were immediately vacuum filtered with 0.2 μm Whatman Anodisc filter membranes. A fresh filter membrane was changed after two mixtures were filtered. Five sample cakes were collected and dried in a 40 °C vacuum oven overnight. They were then stacked in 5 layers and compression molded into a thin sheet (1.4 mm thick) at 105 °C. The sample sheet was cut and polished into rectangular test specimens.

Mechanical properties were measured with the same method as in Section 4.4.1. Briefly, the flexural modulus and strength were tested according to ASTM Standard D 790 by using United Testing Systems (UTS) SFM-20. Dynamic mechanical analysis was performed in 3-point bending mode on TA Instruments Dynamic Mechanical Analyzer Model 2980. Temperature ramp was from room temperature to 85 °C at 3 °C/min.

The fracture surface of the composite from UTS flexural testing was coated with Osmium Tetroxide and examined with a Scanning Electron Microscope (JEOL 6300 FE-SEM operated at 5 kV or JEOL 6400 SEM operated at 10 kV).

Results:

After compression molding, an opaque sample sheet was obtained. The homogeneity in the opacity throughout the sample was high indicating uniform distribution of MFC inside the PLA matrix. This was later confirmed by SEM examination of the composite's fracture surface (Figure 14).



(a) **(b)**

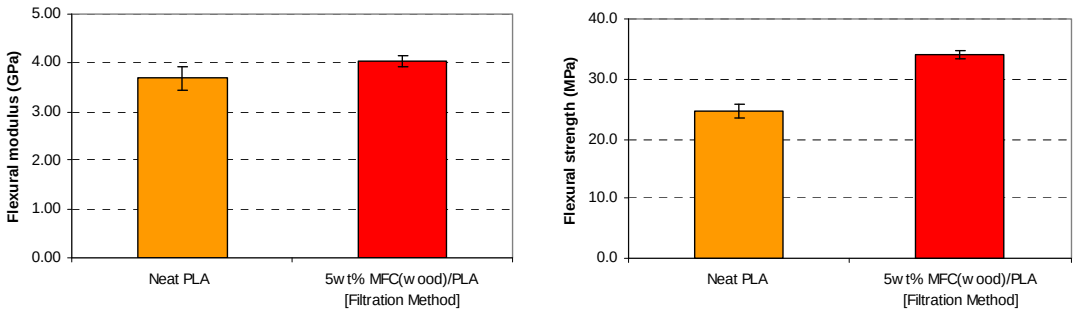
Figure 14. SEM micrographs of the fracture surfaces of (a) neat PLA and (b) the 5wt% MFC(TC90)/PLA composite prepared by the Emulsion-Filtration method.

Flexural modulus and strength

Figure 15 shows that, with the addition of 5wt% MFC, the flexural modulus and strength of PLA increased 9.5% and 37.5% respectively. The result was the average of 2 tests.

Dynamic Mechanical Analysis DMA

It can be seen from Figure 16 that the storage modulus of the composite is increased over the whole temperature range studied. In addition, the shifting of the curve to the right indicates higher glass transition temperature (Tg) for the composite. This is a very positive result supporting the potential use of MFC as a polymer reinforcement.



(a) **(b)**

Figure 15. Comparison of the (a) flexural moduli and (b) strength of the neat PLA and the 5wt% MFC/PLA composite

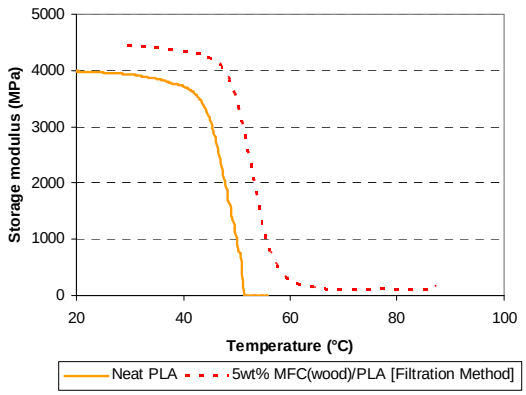


Figure 16. Comparison of the storage moduli of the neat PLA and the 5wt% MFC(TC90)/PLA composite

4.4.3.2 Trial with Resomer R 203 H PDLLA

The PLA resin used in the previous experiments was purchased from Polysciences Inc. (Warrington, PA). Because of the inconsistency in the quality of this product appearing from late 2008, another source had to be located. Resomer **R 203 H PDLLA** from

Boehringer Ingelheim GmbH (Ingelheim, Germany) and **PDL 04** from Purac (Gorinchem, The Netherlands) were selected.

- **Neat Resomer R 203 H**

Method:

0.360 g TWEEN 80 was dissolved in 360 ml RO water. 4.50 g PLA was dissolved in 90 ml ethyl acetate.

The mixture was homogenized with the Ultra-Turrax T25 homogenizer at 12,000 rpm for 10 min and then ultrasonicated at 120 Watts for 2min. Solvent evaporation was carried out in a ~35 °C water bath overnight under mechanical stirring.

The weight content of solids in this emulsion was measured by heating to constant weight at 105 °C using a Thermal Gravimetric Analyzer (TGA).

The morphology of the microsphere of PLA in the emulsion was observed with JEOL 6400 SEM operated at 10 kV.

The emulsion was then filtered with 0.22 μm pore size Millipore Durapore filter membranes and dried in a 40 °C vacuum oven overnight. The dried sample was compression molded into a thin sheet at 105 °C.

Results:

It was found that at 8:100 surfactant loading, over 90% of the polymer can be emulsified into water. The morphology of the microspheres generated is shown in Figure 17. Compared with the microspheres prepared from the Polysciences PDLLA, these microspheres are larger and have a wider variation in their sizes also.

However, the attempts at testing the mechanical properties of these composites was unsuccessful. It was found that this material was too brittle to withstand sample preparation operations such as cutting and polishing and the preload force often needed in 3-point bending tests.

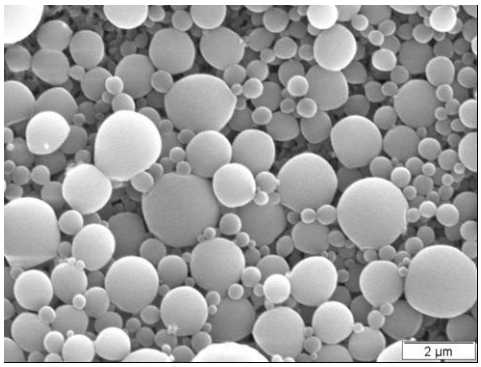


Figure 17. PLA microspheres produced from Resomer R 203 H

4.4.3.3 Trial with Purac PDL 04

- **Neat PDL 04**

Method:

The polymer water emulsion and testing samples were prepared and tested with the same method as in the previous section.

Result:

Both the size and the size distribution of the particles in this emulsion are much smaller than those in the emulsion of Resomer R 203 H. This should be beneficial in achieving good dispersion.

The sample coupons formed by compression molding were tested for their dynamic mechanical properties and flexural properties. The flexural modulus and strength at break of the control sample were found to be 3.69 GPa and 27.4 MPa respectively. The stress – strain curves of the three specimens tested also agreed very well. Thus, the Purac PDL 04 PLA was used in the following studies to replace the Polysciences PLA as polymer matrix.

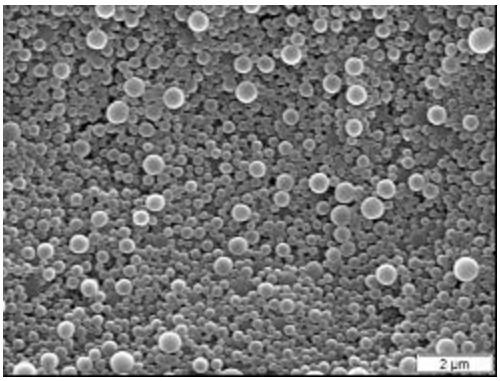


Figure 18. PLA microspheres produced from Purac PDL 04 with TWEEN 80 as surfactant (Surfactant to polymer ratio: 8:100)

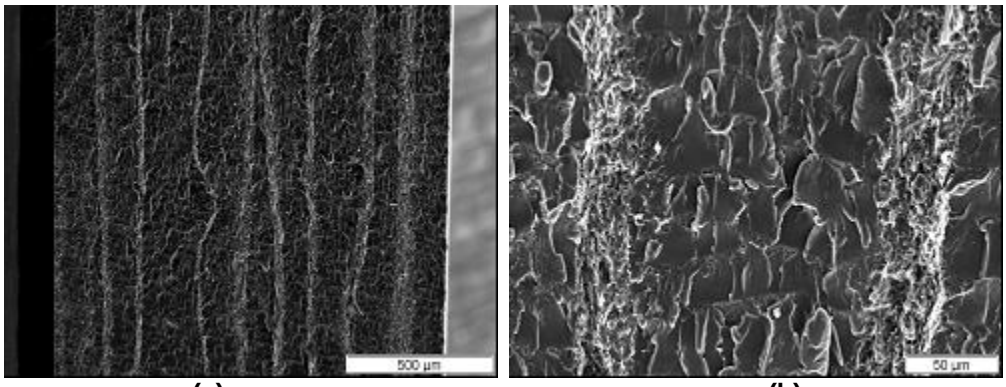
- **5wt% MFC (wheat straw) / PLA**

Experimental:

MFC extracted from untreated wheat straw was combined with PLA (Purac PDL 04) that was emulsified into water with the solvent evaporation technique. Both the MFC suspension and the PLA emulsion were divided into 10 equal portions. One portion of the MFC suspension was mixed with one portion of the PLA emulsion and ultrasonicated at 80 Watts for 1 min. The mixture was then vacuum filtered with a Millipore Durapore 0.22 µm membrane filter. Ten fresh membrane filters were used for filtering the 10 mixtures. The 10 sample cakes obtained after filtration were dried in a 40 °C vacuum oven overnight, stacked in 10 layers and compression molded into a sheet at 105 °C. The sample sheet was then cut and polished into rectangular test specimens. The quality of the fiber dispersion in the matrix was evaluated by examining the fracture surface of the specimen on JEOL 6400 SEM.

Results:

Although the composite sample appears to be homogenous, from Figure 19 it can be seen that the cellulose fibrils have aggregated into thin layers which are easily distinguishable from the thicker polymer layers. In other words, instead of getting a homogeneous distribution of the fibrils, a laminate structure was obtained.

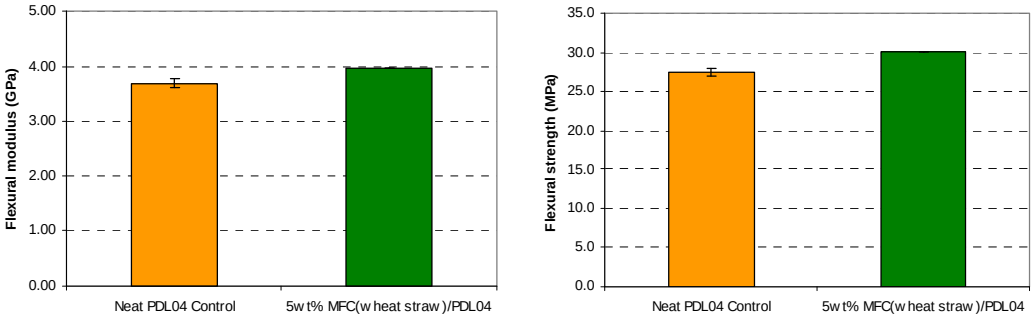


(a) **(b)**

Figure 19. SEM micrographs of the fracture surface of the 5wt% MFC(TC90)/PLA composite sample. (a) The layered structure can be seen in the sample thickness direction. (b) A close-up image of the cellulose-rich region (lighter and narrower strips) and the polymer-rich region.

Flexural modulus and strength

Figure 20 shows that, with the addition of 5wt% wheat straw MFC, the flexural modulus and strength of PLA are slightly increased.



(a) **(b)**

Figure 20. Comparison of the (a) flexural moduli and (b) strength of the neat PLA and the 5wt% MFC(wheat straw)/PDL04 composite

Note: only one test was done for the composite sample**.**

- **Reduced surfactant content**

When the PLA source was switched from Polysciences to Purac, in order to achieve the same emulsification yield and to produce the same particle sizes, the surfactant-to-polymer ratio was increased from 3:100 to 8:100. The higher surfactant concentration may have contributed to the de-mixing problem. Another

5wt% MFC/PLA composite was prepared with surfactant ratio reduced to 3:100 in the emulsion preparation step.

Result:

Comparing Figure 21 to Figure 18, it can be seen that with the amount of surfactant reduced, the size of the microspheres has grown bigger.

An examination of the fracture surface of the composite revealed that although the mixing of the MFC and PLA may have been slightly improved, the MFC have aggregated into separate layers inside the matrix in a manner similar to what was observed earlier (Figure 22). Further reduction of the surfactant ratio (below 3:100) was not acceptable since it resulted in very low emulsification yield.

The flexural modulus and strength of the composite was about the same as those of the neat PLA (Figure 23).

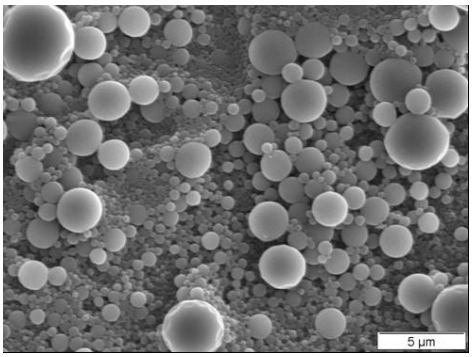
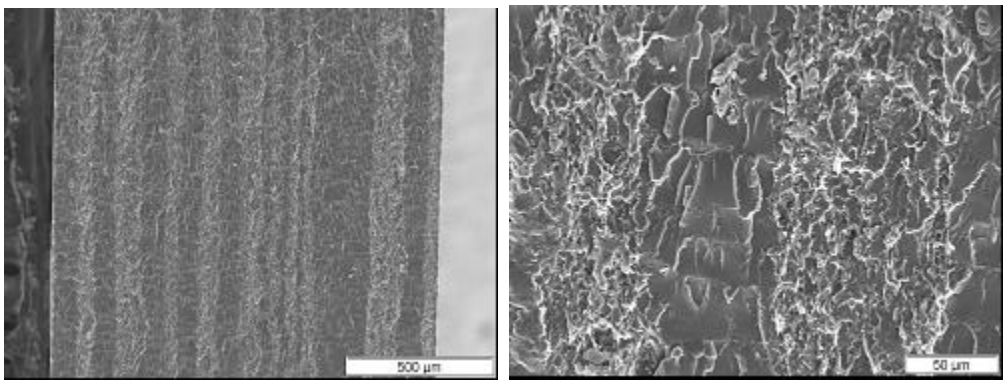
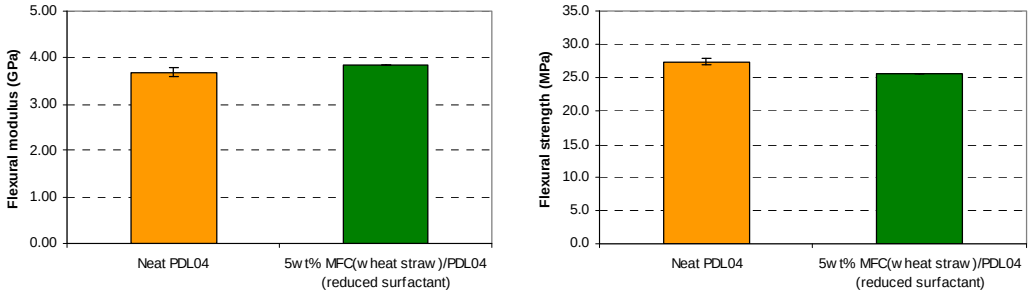


Figure 21. PLA microspheres produced from Purac PDL 04 with TWEEN 80 to polymer ratio at 3:100



(a) **(b)**

Figure 22. The fracture surface of the 5wt% MFC(TC90)/PLA composite prepared using less surfactant..



(a) **(b)**

Figure 23. Comparison of the (a) flexural moduli and (b) strength of the neat PLA and the 5wt% MFC(wheat straw)/PDL04 with reduced surfactant content
Note: (a) The control sample was prepared with the higher surfactant content of 8:100; (b) Only one test was done for the composite sample.

- **Spray method for composite formation**

When the MFC+PLA+water 3-component mixture is poured into a filter, although the PLA microspheres are stopped by the filter membrane and get deposited there, the cellulose microfibrils tend to remain suspended in the residual water phase above the filter. If the mixture is instead sprayed onto the filter membrane and the water is quickly removed by vacuum suction from the bottom and evaporation from the top, the "free water phase" above the filter can be eliminated, thus preventing the mixture from "de-mixing".

In order to have finer droplet size and better control of the spray pattern, air brushes were chosen as opposed to simple spray bottles. Both external mix and internal mix air brushes were tried to spray the MFC + PLA mixture onto a filter membrane.

These experiments turned out to be not only slow, but also very hard to perform. It was difficult to get a uniform coverage of the filter membrane when a large amount of sample (compared with painting) had to be deposited. Furthermore, when the liquid droplets reach the filter, they bounce around everywhere, causing lot of sample loss.

- **Filtration with membranes with larger pore sizes**

To increase filtration speed, filter membranes with larger pore sizes were considered. Although these pore sizes are larger than the size of the cellulose nanowhiskers, sample loss through the filtrate should slow down quickly after the initial filtration stage when a layer of sample has been built up on the filter surface. Since a large amount of sample is processed in composite preparation as compared to in fields such as analytical chemistry, a reasonable amount of sample loss can be tolerated.

  - 0.65 μm Millipore Durapore filter

According to company specifications, the water flow rate of the 0.65 μm filter (69 mL/min/cm2) is more than 10 times higher than that of the 0.22 μm filter (6.7 mL/min/cm2).

However, although the filtration speed was greatly increased by using these filters , the cellulose microfibrils again separated from the PLA.

- 5 μm Polycarbonate filter and 41 μm Nylon net filter

  Filtrate was very cloudy. Severe sample loss through the filters.

- 1 μm Mixed Cellulose Easter (MCE) filter

  Although the filtration of each portion took only 25-30 seconds, thin layers of microfibrils were again formed inside the PLA matrix (Figure 24).

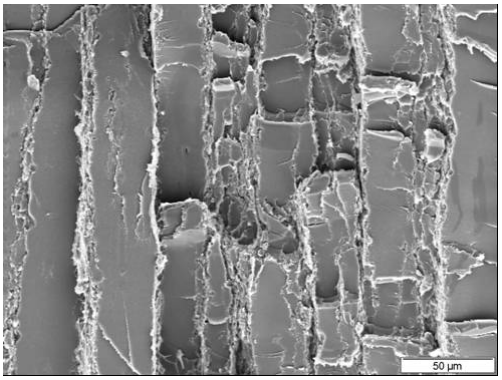


Figure 24. Fracture surface of 5wt% MFC(TC90)/PDL04 prepared with the 1μm MCE filters

5. Summary and Conclusions

5.1. Summary

The compositional, morphological, and surface chemical changes introduced into wheat straw as a result of AFEX and SSF treatments were studied. Cellulose nanowhiskers (CNW) and Microfibrillated cellulose (MFC) were extracted from this ethanol production residue at reasonable yields. The ability to produce microfibrillated cellulose through a mechanical homogenization approach has significant potential to generate a material with comparable properties to the nanowhiskers but through a much simpler and less costly process.

In order to produce a totally biobased composite material, several methods to combine the wet wheat straw based MCF and CNW with Poly Lactic Acid (PLA) were investigated at concentrations up to about 5 wt% including an a new emulsification-freeze drying process, filtration and lamination and spray processing.

Mechanical properties of the composites did not show improvement consistent with the values expected for a reinforcement with properties similar to MFC and CHW. The lack

of measurable increases in the composite properties has been attributed to poor dispersion within the PLA matrix.

Good dispersion of the cellulose nanofibers is a key to producing a polymer composite with high mechanical properties and to fully realize their potential as a reinforcing material. Although some preliminary studies had appeared to show that the Emulsion-Filtration technique we developed had solved the fiber aggregation problem, after switching to a new source of PLA resin, we have not been able to achieve the same degree of dispersion so far. Tthe cellulose fibrils separate from the polymer particles after filtration and then form a stratified microstructure consisting of thin sheets of cellulose fibrils inside the polymer matrix after compression molding. As the volume of the dispersion agent – water solution is gradually reduced by filtration, the PLA particles precipitate out of solution and segregate from the MFC, which results in the de-mixing the MFC and PLA. Further research is necessary in order to identify a processing method that provides good dispersion of the MFC in PLA or other water based polymers.

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