Contract No. BM0-001-001
"Developing a Biomaterials Industry in North Dakota"

Submitted by North Agricultural Experiment Station, North Dakota State University
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PARTICIPANTS

Sponsor	**Cost Share**
North Dakota Industrial Commission	$ 800,000
MBI (including USDA ARS funding)	$ 828,000
NDSU (including USDA funding)	$ 139,998
Great River Energy (In-Kind)	$ 25,000
Total Project Funding	$1,792,998

Project Schedule – 12 months
Contract Date – August 15, 2008

Project Deliverables:
Status Report: December 31, 2008 √
Final Report: December 31, 2009 √

OBJECTIVE/STATEMENT OF WORK:

The goal of this project is to complete a front end engineering and design (FEED) study for a pilot scale plant to demonstrate the commercial potential of technology to produce materials and fuel from biomass feedstock. Initial efforts will be focused on technical and economic requirements for commercializing technology to produce bio-based cellulose nanowhiskers. Specific objectives include:

1. Completing detailed investigations to define:
    a. Scalable process design
    b. Mass and energy balances necessary to determine process cost
    c. Analysis of the structural materials available from wheat straw
    d. 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 capital costs and manufacturing yields.
3. Preparation 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.

STATUS

Interim status report has been received. The full interim report is posted on the Industrial Commission website. The interim report states in part:

The CAFEX II pretreatment system has been designed and constructed. All safety systems are installed and tested. Initial trials have been conducted to assess operational processes including: 1) feeding and pumping of biomass; 2) introduction of moisture and ammonia; 3) mixing of biomass with water and ammonia; 4) mixing and heating; and 5) maintenance of temperature and pressure within the reactor. In this system ammonia is not recovered. Samples are taken at the end of the reactor and the rest of the material is quenched with water and acid and discarded. Our approach has been to demonstrate the CAFEX concept using DDGs and corn fiber, which can be pumped using current equipment, while at the same time developing techniques to pump high-impact feedstocks. Tests with DDGs in the continuous reactor during the reporting period revealed problems with pressure and temperature control. With the original configuration we typically observe a relatively stable temperature that is significantly lower than the target, and widely fluctuating reactor pressure. Also during this period, the physical characteristics of wheat straw such as water absorption saturation capacity and hydraulic conductivity were measured. Pumpability of wheat straw slurry was tested with our current pump. Even at high moisture levels the current pump was not able to pump the wheat straw slurry. However, using additives to modify the slurry properties improved the pumpability of the wheat straw. Quantitative recovery of NH_3 from AFEX-pretreated wheat straw was investigated during this period.

In regards to the development of a strategic business plan, activities have focused on identifying potential private sector investors who have a strategic interest in commercializing this technology. Initial interactions have been encouraging, and more detailed discussions with one or more investors will be pursued in the coming months. The study team has also begun to investigate public sector resources that could be mobilized for a commercialization effort.

June, 2009. A request was made and granted for a no-cost, six-month extension for the submission of the final report.

January, 2010. The final report has been delivered and is available through a link on the Industrial Commission/Renewable Energy Program website.

The Executive Summary states the following:

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: Micofibrillated 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 65percent 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 high-solid enzymatic hydrolysis and fermentation AFEX pre-treated corn stover. This data demonstrates that an AFEX integrated biorefinery has significant commercial potential.

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