DEVELOPING A BIOMATERIALS INDUSTRY IN NORTH DAKOTA

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mbi De-Risking and Scale-Up of Bio-Based Technologies

1.0 Executive Summary

A major untapped resource is agricultural biomass, the non-edible crop residues such as stalks and leaves that remain after grains are harvested. This biomass constitutes half to two-thirds of the weight of crop material; therefore, about 2 billion to 3 billion tons of biomass are produced every year, of which some must be left in the field to maintain soil quality. Biomass is composed mostly of sugar polymers that are tightly bound and intertwined with an indigestible structural material, lignin. If these sugars could be readily accessed, the biomass could potentially be converted into animal feed and renewable fuels and chemicals.

There are several major challenges in capturing the value of agricultural biomass: 1) cost-effectively altering the biomass to an upgraded form in which the constituent sugars are easily accessible, 2) handling, storing and hauling low-density biomass from the field to the site of eventual use, and 3) establishing the upgraded biomass as a readily tradable commodity with clear economic value for the diverse players involved in its production, processing and use. MBI, in collaboration with Michigan State University, is developing an innovative technology (AFEX) and implementation concept that simultaneously addresses all three challenges, and thus has the potential to fully unlock the value of biomass.

AFEX™, our transformative biomass processing technology, addresses the first challenge by using ammonia to treat agricultural biomass at moderate pressures and temperatures. As a result, the biomass microstructure is altered, and the sugar polymers are partially unwound and loosened from the lignin, rendering the sugars more accessible. AFEX can increase sugar access substantially; while only 20% of the sugars are accessible in untreated biomass, the accessible sugar *quadruples* to nearly 80% as a result of AFEX treatment. Another unique feature of AFEX is that the treated biomass can be easily and economically pelletized to increase its bulk density by a factor of 10, resulting in grain-like handling characteristics and improved transportation economics.

A biomass processing depot concept has been proposed as one way to reduce costs and overcome many of the logistic challenges of the lignocellulosic biomass feedstock supply chain (Hess et al., 2009; Hess et al., 2009b; Eranki et al., 2011). In this concept, raw biomass harvested from farmlands is transported relatively short distances to small-scale depots for processing into denser and more uniform stable commodities. Those commodity feedstocks can then be stored economically and transported readily over longer distances to large-scale biorefineries for conversion into biofuels and bio-based chemicals. Methods for pretreatment of biomass at depots may include mechanical treatments such as size reduction or pelletization, as well as chemical treatments (Thompson et al., 2013).

AFEX is one method that could be used for chemical pretreatment of biomass at regional depots. AFEX treatment involves contacting biomass at moisture levels from 20 to 80 wt% with ammonia liquid or vapor in a pressure vessel to achieve ammonia:biomass weight ratio of 0.2–4 at temperatures from 40 to 120°C and pressures from 2 to 40 atm for treatment times ranging from 10 to 60 min, followed by release of ammonia vapor from the vessel, residual ammonia removal from the biomass by drying or steam stripping and recovery of the treated biomass. AFEX does not significantly hydrolyze hemicellulose to soluble sugars or oligomers, does not generate any liquid side streams and does not significantly alter the composition of the biomass. AFEX has been shown to be a highly effective pretreatment for corn stover (Teymouri et al., 2005), and a wide range of other agricultural residues and energy crops, including *Miscanthus*, switchgrass and wheat straw (Murnen et al., 2007; Alizadeh et al., 2005; Bals et al., 2010). AFEX treatment has also been shown to mobilize lignin to act as a natural binder, facilitating densification of biomass (Dale et al., 2011).

We envision that AFEX technology will be implemented at local "depots," which will receive the raw biomass from farms located within a 5-10 mile radius. This eliminates the cost of creating expensive transportation networks for low-density raw materials. The AFEX pellets, which have a long shelf life and 8 times greater density than raw biomass, can be economically stored and shipped from depots to markets using existing grain infrastructure, addressing the second challenge.

The technology was originated by Professor Bruce Dale at Michigan State University, who has been researching the science underpinning AFEX for over two decades. In 2010, MBI made a significant design breakthrough, resulting in a novel reactor with reduced capital and operating cost. In 2011, MBI won a $4.3M U.S. Department of Energy award to scale up the technology from laboratory prototype (10 liter) to pilot scale (2 X 450 liter; Figure 20). In 2013, MBI commissioned the pilot AFEX reactor and initiated shakedown operations. The pilot reactor is being used to refine the technology and support small-scale animal feed trials and biorefinery applications development.

One of the key innovations in the new AFEX-3 design is that ammonia recovery and recycle is inherent in the operation. Recovery of ammonia as substantially dry vapor, suitable for recompression from vertical packed beds significantly simplifies the AFEX process compared with conventional AFEX designs. Direct recompression of the dry vapor stripped from a lead bed, coupled with the absorption of that compressed vapor on a lag bed, eliminates the need for an ammonia recovery dryer or column, or arrangements of ammonia flash and quench tanks, as required in conventional designs described in the literature (Sendich et al., 2008; Laser et al., 2009; Holtzapple et al., 1992). This reduction in equipment requirements yields

significant reduction in the capital cost of the system, particularly at the smaller scales anticipated for biomass processing depots. Our preliminary analysis of a depot processing 100 tons of corn stover per day shows that greater than 50% reduction in capital cost can be realized using a packed bed system in place of a conventional AFEX design. During the packed bed AFEX cycle, the compressor operates only intermittently, during bed-to-bed ammonia transfer and, consequently, the cost associated with the compressor electrical load is not a significant component of the overall treatment cost.

The AFEX pellets can be used both as a feed for ruminant animals or as a feedstock for sugar-based fermentations to produce industrially important fuels and chemicals. Testing during this project has validated the efficacy in both applications.

Biomass production and total recoverable biomass from wheat straw and corn stover were estimated by crop reporting district and for the state using the Harvest Index Formula. Biomass production is a function of yields and using historic wheat and corn grain yields biomass production was estimated. Recoverable biomass was calculated using published biomass recovery rates using widely accepted methods and equipment for gathering, loading and transporting biomass. Sufficient quantities of recoverable biomass are available in every region of the state to support multiple AFEX pre-treatment depots. Based on an Olympic average of the last five years production of wheat and corn, the theoretical maximum number of 110 tons per day pretreatment deports that could be supplied with biomass in North Dakota is 195. While the theoretical maximum is not likely achievable, it does provide some to the quantity of available biomass in the state.

Biomass feedstock cost was estimated using feedstock soil nutrient value, custom harvesting rates for gathering, baling, and transportion and a producer incentive. Nutrient values were calculated on both a per ton and per acre basis. While biomass will likely be bought and sold on a per ton basis, a per acre valuation will enable producers to evaluate the potential value of biomass in terms that are compatible with operating budgets. Cost per ton of wheat straw was estimated to be $57.66 per ton or $46.87 per acre delivered to the AFEX pre-treatment depot. Cost per ton of corn stover was estimated to be $68.10 per ton for corn stover and $66.30 per acre delivered to the pre-treatment facility. More corn stover is produced per acre which accounts for some of the difference in cost per acre. Gathering corn stover also requires mowing and raking operations which also adds to the cost of collection.

One likely initial market for AFEX pre-treated biomass is ruminant livestock feed. Preliminary feeding trials suggest pre-treated biomass can be substituted for corn and achieve equivalent weight gain and carcass quality. While the assessment of available biomass suggests ample biomass to support multiple AFEX pre-treatment facilities, development and

commercialization will likely be driven by demand. North Dakota ranks 10th in nation for total beef cow numbers, however most the state's beef industry is characterized by cow calf operations. While most of the calves produced in North Dakota are fed to finished weights in other states, livestock producers do background cattle in place (on ranch) and there are backgrounding and finishing lots in North Dakota. An assessment of the number of cattle fed in feedlots with a capacity of 500 head or more would suggest the current fed cattle livestock industry in North Dakota could support ten 110-tons per day AFEX pretreatment facilities. The assessment did not include an assessment of the market potential for cattle backgrounded in place. Analysis of findings from preliminary feeding trials is still on going. Additional research examining nutritional value and relative cost is needed to more thoroughly assess market potential in North Dakota.

Three regional economic impact scenarios were examined: a 110-tons per day depot, a 220-tons per day depot and a ten 110-tons per day depot system. The ten depot system was based on the estimate of the potential market for AFEX pretreated biomass in the state's cattle feeding industry. The economic contribution for both construction and operations was estimated. An economic contribution assessment measures the economic effects from in-state expenditures related to depot construction and operations.

A single 110-tons per day depot has a capital cost of $9.7 million, a 220-tons per day depot a capital cost of $18.4 million and a ten depot system a capital cost of $97 million. The one time economic contribution from construction activities was estimated to be $3.8 million, $7.3 million and $38.3 million for a 110 tons per day, a 220 tons per day and a ten 110 tons per day depot system, respectively. Capital costs were dominated by expenditures for specialized equipment that will likely be purchased from out of state vendors. In-state construction expenditures were largest in the construction and retail sectors with $1.7 and $1 million in expenditures, respectively. Economic effects of a single plant would likely accrue during a construction period of one year or less. Construction impacts from a 10 depot system would likely accrue over a multi-year period. State-wide total economic effects associated with construction activities were estimated to be $9.7 million, $18.2 million and $97.2 million for a 110-ton per day depot, a 220-tons per day depot and a ten 110-tons per day depot system, respectively.

The direct economic contribution from depot operations is annual and ongoing as long as the depot remains in operation. Direct economic impacts represent payments to North Dakota entities. Unlike construction effects, nearly all of the operations expenditures accrue to North Dakota entities. Expenditures for most inputs for production; wheat straw, corn stover, natural gas, ammonia, electricity, water and labor are all available for purchase from in-state entities and were allocated to the appropriate sector. Total direct expenditures related to

operations were estimated to be $4.8 million, $8.9 million and $48 million for a 110-tons per day, 220-tons per day and a ten 110-tons depot system, respectively. Direct effects were greatest in Business and Personal Services which reflects payments for biomass collection and transportation. Payments to the Households sector reflect payment to farmers for biomass. A 110-tons per day depot would employ 16 full time equivalent workers while the 220-tons per day depot is more labor efficient and would employ 20 full time equivalent workers. A ten 110 tons per day depot system would employ 160 full time workers. Total operational impacts (direct and secondary) were estimated to be $13.3 million, $24.2 million and $133 million annually for a 110-tons per day, 220-tons per day and ten 110-tons per day depot system, respectively. The largest impacts would accrue to the Household and Retail Sectors.

While the economic effects are small relative to other major industries in North Dakota, AFEX pretreatment depots would be creating new economic activity using biomass that is largely underutilized. Further even though at this time the North Dakota state economy is very robust, economic conditions vary regionally. While some regions are growing rapidly other regions in the state are less robust. A system of AFEX pretreatment depots would likely be developed near livestock feeding operations which are concentrated in the southern tier and southwestern North Dakota. Those region's economies are still heavily dependent on agriculture and economic diversification and development is a priority.