Addendum to the

The Lansing Tri-County Bio-Manufacturing Feasibility Study:

Evaluating Regional Capacity and Performance in the Emerging Automotive Bio-Manufacturing Sector of the Global Bioeconomy

Supplemental Information on Biorefinery Capital Cost and Comparative Bio-Product Costs and Sustainability Factors

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Introduction

The following stand-alone addendum to the **The Lansing Tri-County Bio-Manufacturing Feasibility Study: Evaluating Regional Capacity and Performance in the Emerging Automotive Bio-Manufacturing Sector of the Global Bioeconomy** provides a review of capital costs associated with a third-generation biorefinery and a brief overview of comparative costs between bio-products and petroleum-based products and related markets.

In the full study, the MSU Center for Community and Economic Development (MSU CCED) examined five major areas to assess the Tri-County Region's future role in the emerging bio-manufacturing sector:

- Tri-County Regional Demographic and Employment Profile
- Agricultural/Natural Resources/Environmental Profile
- Industrial and Infrastructure Capacity
- Intellectual Capabilities
- Leadership Commitment

It was found that the Lansing Tri-County Region may be uniquely positioned with its historic competitive advantages in both the manufacturing and agricultural sectors to create jobs and increase wealth in the emerging bio-based economy. The study was partially funded by the U.S. Department of Commerce Economic Development Administration. The executive summary of the study is available at http://www.ced.msu.edu/researchreports/exectivesumfinwithcover.pdf.

Overview

This addendum is intended to provide preliminary cost data that can be used to help guide discussion of the Lansing Tri-County Region's role in the emerging global bioeconomy and to identify opportunities that increase the region's bio-manufacturing performance and capacity. The region already has a number of companies in the bioeconomy, including KTM Industries, EcoSynthetix, and the Michigan Brewing Company.

Information was more accessible in the examination of biorefinery processing capital costs than comparative cost information for bio-based and petroleum-based products. It should be emphasized, however, that the capital cost information is not based on any operating biorefineries as no such facilities are currently operating. The comparative bio-product and petroleum-based product cost information is subject to the limits of publicly available information and the routine confidentiality of cost information in competitive markets.

Information was obtained through Web review and analysis of current literature including scholarly articles, U.S. Securities and Exchange Commission (SEC) Form 10-Ks, corporate annual reports, marketing information, technical and trade journals, personal interviews, and symposium discussions. Additional due diligence is required to provide more specific cost information for both biorefinery process cost economics and comparative costs between bio-products and petroleum-based products.

As previously stated, there are no third-generation biorefineries as contemplated in the feasibility study currently operating. These biorefineries will have the capacity to use different types of cellulosic feedstocks to produce a range of bio-products in addition to ethanol.

However, Archer Daniels Midland (ADM) operates a huge processing operation at its Decatur, Illinois facility using 15,500 dry tons of grain feedstocks per day. ADM also has another significant project underway. The ADM-Metabolix Telles Partnership facility that will produce PHAs (polyhydroxyalkanoates under the Mirel™) is now scheduled for launch in the second quarter of 2009. The PHAs are extracted from switchgrass and sugarcane plants and the remaining biomass can be used for ethanol production. Its nameplate capacity is 110 million lbs per year.[1]

The Cargill-Tejin Limited partnership operates the NatureWorks facility at Blair, Nebraska that produces a bio-plastic, PLA (polylactide) with a wide range of fabric (marketed as Ingeo®) and packaging applications. The partnership between DuPont and UK-based Lyle and Tate, a global agri-processor, operates a commercial processing operation at Loudon, Tennessee that produces bio-based chemical feedstocks for eight different DuPont bio-based polymers. Indeed, DuPont has emphasized since 2007 that its goal is to replace nylon, its hugely successful petroleum-based polymer, with Bio-PDO™ (1,3 propanediol).

James Stoppert, senior director of Cargill's Industrial Bio- Products division, told *The Wall Street Journal* in April 2007 that he could envision 20 PLA bio-refineries springing up across the U.S. Midwest.[2] Current biorefineries are linked to wet mill operations using corn grain feedstocks. The ADM Illinois wet corn mill provides a model for the next generation of biorefineries. This facility uses high-fructose corn syrup (HFCS) technology developed in the 1970s to produce sweeteners (HFCS, glucose, dextrose), gluten feed and meal, ethanol, starch, and corn oil. HFCS has replaced for the most part sugar produced from cane in the U.S.

An intense race is on to open the first commercial-scale cellulosic-based ethanol facility. The current leaders appear to be California-based Verenium Corporation, which has developed a pilot/demonstration cellulosic-based ethanol production operation using sugar cane at its Jennings, LA facility, and Colorado-based Range Fuels, which is building a 60-acre facility that will use wood chips in Soperton, GA. Verenium intends to scale up its facility to commercial levels within the next 12 months or possibly sooner.

In Michigan, the Mascoma Corporation announced plans this year to develop a cellulosic-based ethanol facility in the eastern Upper Peninsula. The Michigan Economic Development Corporation (MEDC) recently awarded Mascoma Corporation a Center of Energy Excellence (COEE) award of $20 million based on its partnership with Michigan

State University and Michigan Technological University. University researchers will focus on improving the supply chain for woody feedstocks.

There are approximately 12 other cellulosic-based ethanol production projects funded by the federal Department of Energy. All of these projects are in pre-construction stages of development obtaining permits and completing design plans.[3]

1. Biorefinery Process Cost Economics

Literature Review and Discussion

The Aden etal. National Renewable Energy Laboratory (NREL) study described in *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover* provides the most definitive cost study that has been conducted to identify capital, fixed, and operating costs of a biorefinery.

The Lynd etal. study, conducted by Lee R. Lynd of Dartmouth (a Mascoma Corporation co-founder and officer), relies exclusively on modeling and economic equations. It is worth noting here that Dartmouth College and Mascoma Corporation announced September 8, 2008 that engineering a new microorganism that makes ethanol its only fermentation product has been successful. This new organism could augment the still-expensive cellulase enzyme and thereby reduce processing costs.[4]

The Bohlman reference in the table below cites an article from *Chemical Engineering Progress* (American Institute of Chemical Engineers), not a research study.[5] Bohlman cited the Aden etal. NREL study in estimating the capital cost of $450,000,000 for a biorefinery. It is not clear how Bohlman derived $450,000,000 from the Aden study.

Table 1: Biorefinery Process Cost Economics Studies and Information

Date	Author/Source	Study Name/Proposed Biorefinery	Feedstock	Capacity (in MGY)	Est. Capital Cost
Jan, 2007	Leistritz etal[6]	Biorefineries Using Agricultural Residue (1) (e)	Wheat Straw	54.4	$185,000,000
Jun, 2002	Aden etal. (NREL)	Lignocellulosic Biomass to Ethanol Process Design (e)	Corn Stover	69.3	$197,000,000
Oct, 2005	Lynd etal.	Strategic Biorefinery Analysis: Analysis of Biorefineries (e)	CornStover Poplar	69.3 283.8	$121,397,227 $290,742,088
July, 2005	Shapouri and Gallagher[7]	2002 Ethanol Cost-of-Production Survey (e)	Corn	40-100 (2)	$1.05-3.00/gal
Oct, 2005	Bohlman	Biorefinery Capital Cost (m)	Whole Corn	N.A.	$450,000,000

(1) Using AFEX process and producing nanowhiskers for commercial markets.
(2) Proposed at Shelly, Idaho near Idaho Falls.
(3) Survey of 21 existing dry-mill ethanol plants conducted by the USDA Energy Policy & New Uses Office.
(a) Detail absent; (m) Moderate detail; (e) Extensive detail

Tables 2 and 3 below show total installed equipment and operating process cost data from the 2002 Aden etal. NREL study. The estimated total capital cost is $197,000,000 as indicated in Table 1 above and Table 3 below.

Table 2: Total Installed Equipment and Operating Costs[8]

Total Installed Equipment Costs	
Process Area	
Feed Handling	$7,500,000
Pretreatment	$19,000,000
Neutralization/Conditioning	$7,800,000
Saccharification/Fermentation	$9,400,000
Distillation and Solids Recovery	$21,800,000
Wastewater Treatment	$3,300,000
Storage	$2,000,000
Boiler/Turbongenerator	$38,300,000
Utilities	$4,700,000
Total Installed Equipment Costs	**$113,800,000**
Variable Operating Costs	
Feedstock	$23,170,000
Clarifier Polymer	$660,000
Sulfuric Acid	$760,000
Lime	$1,540,000
Corn Steep Liquor	$1,950,000
Cellulase	$6,980,000
Diammonium Phosphate	$210,000
Propane	$2,200
Make-up Water	$400,000
BFW Chemicals	$30,000
Cooling Water Chemicals	$40,000
WWT Chemicals	$170,000
WWT Polymer	$10,000
Ash Disposal	$780,000
Gypsum Disposal	$1,250,000
Electricity Credit	-$6,430,000
	$31,522,200
Fixed Operating Costs	
Total Salaries	$2,150,000
Overhead (60% total salaries)	$1,293,000
Maintenance (2% of Installed Equip. Cost	$2,273,000
Insurance Taxes	$1,819,000
	$39,057,200
Capital Depreciation	$9,900,000
Avg Income Tax	$7,300,000
Avg Return on Investment	$17,600,000
TOTAL OPERATING COSTS	**$73,857,200**

Source: Aden, A. etal. National Renewable Energy Laboratory.

NREL's use of feedstock costs of $30 per ton (short (US) ton=2000 lbs) is likely underestimated. Increased feedstock transportation costs alone will likely boost overall feedstock costs. Using $40 per ton for feedstock requirements of 772,333 TPY results in feedstock costs of $30,893,320, that is, $7,733,325 higher than the NREL estimate of $23,170,000. Total operating costs, then, would be $81,590,525, instead of $73,857,200**.**

Table 3: Total Project Investment and Types of Equipment[9]

Total Project Investment	**2000 $**
Total Installed Equipment	$113,800,000
Warehouse	$1,700,000
Site Development	$5,900,000
Total Installed Cost	$121,300,000
Indirect Costs	
Field Expenses + Prorateable Expenses	$24,300,000
Home Office & Construction Fee	$30,300,000
Project Contingency	$3,600,000
Total Capital Investment	$179,500,000
Other Costs (start-up, permits, etc)	$17,900,000
Total Project Investment	**$197,400,000**

Types of Equipment
Agitators-Carbon Steel (CS)
Agitators-Stainless Steel (SS)
Boilers
Compressors (motor driven)
Cooling Towers
Distillation columns-CS
Distillation columns-SS
Filters
Heat Exchangers (S&T) CS/SS
Pumps-Lobe
Pumps-Centrifugal (CS)
Pumps-Centrifugal (SS)
Pressure Vessels-CS
Pressure Vessels-SS
Tanks-Field Erected CS
Tanks-Field Erected SS
Tanks-Field Erected CS with Lining
Solids Handling Equipment
Turbogenerator

Source: Aden, A. etal. National Renewable Energy Laboratory.

The cost data in this study was generated using 2000 dollars. Using the GDP deflator to correct for 2008 dollars, $236,041,854 may be a more appropriate starting point for estimating the capital costs of a biorefinery.

There are numerous other cost factors and considerations beyond the scope of this discussion. This discussion concludes with interim findings regarding biorefinery cost economics.

Interim Findings: Supply and Cost Issues

The cost of feedstock supplies is expected to be as much as 60% of biorefinery operating costs. In the case of the proposed Mascoma Corporation facility at Kinross (Chippewa County) in the eastern Upper Peninsula, the cost of clean wood chips for its feedstocks is thought to be in the $28-32 range. Cost issues may include the effort to restore a supplier network as logging supply networks have contracted over the past five years as a result of four large and two small Michigan mills shutting down since 2003. This issue may cause Mascoma's actual feedstock prices to increase, but that remains to be seen.

The Range Fuels' Georgia facility currently under construction is expected to use 1200 TPD (tons per day) of forest harvest residue and mill waste to produce 40 MGY (million gallons per year) of ethanol and 10 MGY of methanol in its first stage of commercial operation. At full capacity of 125 MGY, 23 logging crews will deliver an average of 25,000 tons per week, or approximately 1.25 million TPY. Concern has been raised about the cost pressures that will result on existing older mills that will be competing for mid-grade timber chips. The Georgia forest management agency, however, is confident that adequate supplies exist to meet the new supply needs of the ethanol facility in addition to established mills.[10]

Detailed data on supply chain logistics for a biorefinery in the Tri-County Region is needed. This type of supply analysis may use data from Michigan State University research on distributed bio-processing that uses regional biomass pre-processing facilities. The capital costs of such regional facilities are expected to be in the $9-37 million range depending on scale, with a range of 666 tons per day to 4,444 tons per day.[11] These pre-processing facilities are not regarded as biorefineries so this data was not included in Table 1.

Additional research is needed to adequately characterize the development and operations of a regional network of biomass pre-processing facilities supplying a Tri-County biorefinery. Facilities with the capacity to produce bioproducts like animal feed or bio-based polymers (e.g. succinic acid) may be considered. Approaches that incorporate multiple scenarios with investments and benefits extensively distributed may be more robust than other more traditional models.

Finally, the long range future for facilities producing cellulosic-based ethanol and other value-added products will be based on 3rd generation feedstocks. These feedstocks will consist of specifically-designed, genetically-engineered energy crops, i.e. new plants that currently do not exist. Innovations and discoveries in genetic research and molecular breeding conducted in university and private sector laboratories can be expected to produce fundamental scientific breakthroughs.[12]

Aggressive research on genotype engineering to develop super-efficient dedicated biomass energy crops could provide adequate feedstock supplies so that compromising sustainability objectives or causing unintended adverse consequences for agricultural or natural resource-based economic sectors do not occur.

2. Comparative Costs and Sustainability Factors for Bio-Based and Petroleum-based Automotive Components and Other Applications

Collaborative Partnerships to Develop Bio-Products and Global Markets

Bio-based products are increasingly finding strong markets as more consumers and companies demand renewable products that reduce greenhouse gas emissions and are recyclable. The political volatility in oil-producing areas, energy security issues associated with the U.S. reliance on petroleum, and escalating petroleum prices are of course acting as fierce economic drivers. In some cases too, the properties of bio-based products are superior to those of petroleum-based products. So although the cost economics of bio-based products can still be problematic, the long-range picture for bio-products is bright and attractive. Moreover in the current economic picture, bio-based products are becoming increasingly cost competitive.

This greener alignment of market factors has affected the development of new corporate business strategies. Global companies like Cargill, Archer Daniels Midland (ADM), DuPont, Lear, and many other companies have made significant investments in and positioned themselves in these growing markets for sustainable bio-products using renewable feedstocks.

The development of bio-product markets demands a new business model based on extensive collaboration between companies that operate in different markets, respectively, and have different types of marketing expertise. This type of market alignment is reflected in Table 4 on the next page. The capacity to research, develop, produce, and market bio-based products simply requires multiple companies and/or institutions. Without such collaboration, the necessary capacity simply does not exist to successfully compete in global bio-product markets. For example, Cargill formed a partnership with Japan-based Tejin Limited in late 2007 to operate the Natureworks facility at Blair, Nebraska that produces a bio-plastic, PLA (polylactide). Tejin brings chemical and fiber sector expertise to complement the agri-business expertise of Cargill in the partnership. Dow Chemical was Cargill's original partner but opted to withdraw.

A joint venture between DuPont and UK-based Lyle and Tate operates a commercial processing operation at Loudon, Tennessee (near Knoxville). This facility produces bio-based chemical feedstocks for eight different DuPont bio-based polymers. Indeed, DuPont stated in 2007 that its goal is to replace nylon with Bio-PDO™ (propanediol made from corn sugar). Nylon, a petroleum-based polymer with wide applications, has been one of DuPont's major product lines for over 70 years.[13]

The use of bio-based material in automotive seat foam represents one of the major success stories in transitioning from traditional manufacturing to sustainable bio-based automotive products and other applications. Polyurethane foam is ubiquitous. It is a huge market. Over 1.7 <u>billion</u> lbs of polyurethane foam are produced and used each year in the U.S.[14] In addition to automotive seat applications, flexible foam is widely used as a cushioning material in furniture and bedding as well as a packaging material, and many other applications. Annual U.S. polyurethane foam sales are $19 billion and the industry employs 200,000 workers.[15]

Table 4: Comparative Costs and Sustainability Factors for Bio-Based and Petroleum-based Automotive Components and Other Applications

Component/ Application	EST. Bio-Based Material Cost	EST. Petrol.-Based Material Cost	Supply Chain (c)	EST. Annual Volume of Bio-based Material lbs	EST. Reduction in Green House Gas Emissions	EST. Reduct. in Use of Petrol.	Recyclability (Y/N)	Improved Properties Y/N
Seat Cushion and Seat Back Foam	Cost Neutral (a)	$1.36-1.41/lb. (b)	Lear(T-1) Johnson Controls(T-1) Intier(T-1) Renosol(T-2) Woodbridge(T-2) USSC(T-3)	1.25 million (d)	5.3 million lbs (a)	1.25 million lbs (a)	Yes (e)	Yes (e)
Automotive Safety Fuel Lines	$6.00/lb. Rilsan polyamide 11	<$6.00/lb.	Arkema, Tier 1 suppliers	N.A.	N.A.	N.A.	N.A.	Yes. Spark Resistant. Preferred material.
Packaging/Fiberfill	$0.30-1.50[16] PLA (polylactide)	$0.60-0.90/lb. PET	Natureworks (Cargill-Teijin) broad customer base	Potential ~426 M[17]	N.A.	N.A.	Yes	Yes
Anti-Freeze, Solvents,Coatings Cosmetics, Heat Transfer Fluids	Competitively priced. Ethylene Glycol Propylene Glycol	$0.16-0.19/lb. $1.18/lb[18]	Ashland Inc.- Cargill Inc. Joint Venture	Potential 1.1 Billion[19]	N.A.	N.A.	Yes	N.A.
Carpets, fabrics	Competitively Priced Bio-PDO (1,3-propanediol)	$1.45-1.75-2.00 Nylon (f)	DuPont Tate & Lyle Bioproducts Mohawk Industries, Toyota	100 million	20% Reduction	40% Reduction	Yes	N.A.

Explanatory Notes for Seat Foam
Ford Motor Company's use of soy-based seat foam is the single greatest success story of bio-product market penetration in the U.S. automotive sector. This bio-based seat foam application has attracted very high levels of interest both within the automotive sector as well as other sectors.
(a) It is Ford Motor Company policy not to disclose component cost information. Non-economic information was provided. Cynthia Flanigan, Ford Motor Company Material Research & Advanced Engineering Department, Personal Interview. Sept 4, 2008.
(b) March 2008 prices: $1.36-1.41/lb. for high resilience molded foam retrieved August 28, 2008 from http://www.icispricing.com/il_shared/Chemicals/SubPage399.asp. This estimated cost may not reflect the full cost of producing molded flexible foam for automotive seat applications.
(c) T refers to tier level.
(d) Based on anticipated sales of 1 million Ford Mustang, Expedition, F150, Focus, Escape, Mercury Mariner, Mazda Tribute vehicles with soy material 5% by weight of 20-30 lbs of seat foam avg.(~25 lbs.) used in seat cushions and seat backs by August, 2009.
(e) Mohini Sain, CSO, Ontario BioAuto Council, Bioplastics, Market, Technology, and Environment

Because information is extensive and Ford Motor staff members are enthusiastic about reporting on their results and data, it was feasible to identify reductions in greenhouse gas (GHG) emissions and the amount of petroleum from the production of soy-based seat foam. Similar data for most other bio-plastics was scarce or absent. For the other bioplastics where that data is absent, it is estimated that one ton of a bio-based plastic eliminates three tons of carbon dioxide from the production of a petroleum-based plastic.[20]

Cost issues are complicated. In 2006, OmniTech International reported that petroleum-based polyol was $1.05/lb. and soy-based polyol was $.60/lb.[21] However, the different mixes of isocyanates used to produce flexible foam from different polyols and for specific applications affect base prices.[22] As a result, it is extremely difficult to establish reliable cost points to facilitate comparative analysis.

Other Bio-Products

As previously stated, PLA is polylactide that is produced by converting lactic acid from corn (and other grains in the future). PLA is currently produced by NatureWorks, a partnership of Cargill and Tejin Ltd (announced in late 2007). The capacity of the facility, located at Blair, Nebraska, is 300 million lbs/yr.

Rilsan polyamide 11 (PA 11) is produced by France-based Arkema, a global chemical producer. Earlier this year, German-based automotive supplier Fraenkische announced the launch of enhanced safety fuel lines for fuel pump modules using technology based on Rilsan polyamide 11. The new fuel lines comply with the SAE J1645 automotive standard. This standard is designed to prevent spark ignition in the fuel system and reduce the hazard of fuel line combustion. General Motors already replaced its non-conductive fuel-pump modules for new North American car models.[23]

DuPont produces Sorona® thermoplastic polymers made from their Susterra® (BioPDO) product for use in a range of applications, including automotive parts and components, electrical/electronic systems, and other consumer and industrial products. DuPont markets eight bio-based products, including Hytrel® elastomers, Biomax® resins, and others. Hytrel® applications include automotive hoses and tubing, boots for CV joints, air bag doors, and energy dampers. DuPont has publicly declared since 2007 that it expects Bio-PDO™ (1,3-propanediol) to replace nylon and has very aggressively marketed Bio-PDO™.

The Metabolix-Archer Daniels Midland Telles joint venture is developing a facility with a production capacity of 110 million lbs/year in Clinton, Iowa using dextrose from ADM's adjacent wet corn mill to produce polyhydroxyalkanoate (PHA) bioplastics. This bioplastic, marketed as Mirel™, has an extremely wide range of applications; it can be used in injection molding, extrusion coatings, cast film and sheets, blown film, and thermoforming, according to Metabolix reports. Metabolix supplied Mirel ™ used in the production of Target store gift cards last Christmas. According to Bruce Dale, MSU expert in bio-products and production, PHA will reduce the use of nonrenewable energy by over 95% and will also provide a 200% reduction in greenhouse gases compared to petroleum-based plastics.[24]

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