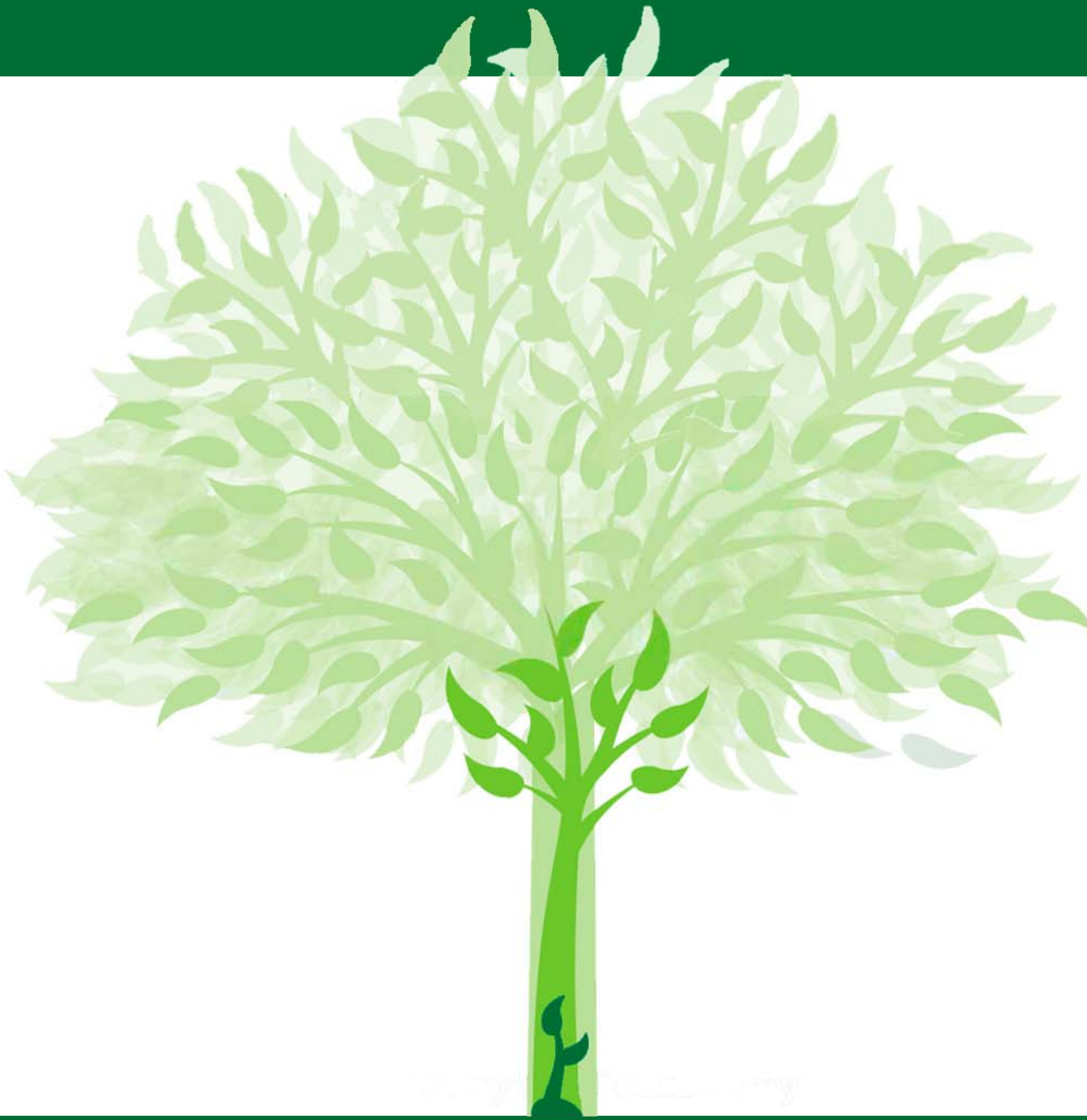
# Linking Knowledge and Resources to Support Michigan's Bioeconomy



Prepared for the Office of Biobased Technologies
by Centrec Consulting Group, LLC
in cooperation with
The Product Center
for Agriculture and Natural Resources

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CENTREC
Consulting Group, LLC

MICHIGAN STATE
UNIVERSITY

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## to Support Michigan's Bioeconomy

# Foreword

The following report reflects an initial effort to understand Michigan's potential role in the future bioeconomy. This effort was focused on two objectives. The first objective was to characterize the opportunities for Michigan as a player in the bioeconomy. The second objective was to begin identifying the challenges Michigan State University (MSU) faces as it moves to play a significant role in Michigan's emerging bioeconomy.

## Michigan Opportunities

At the beginning of this project, two sources of information were identified to help assess the scope and magnitude of the opportunities for Michigan as a player in the bioeconomy. First was a series of interviews with stakeholders who will most likely be impacted by the growth in the bioeconomy. A significant amount of insight was gained from interviews with over 30 individuals ranging from MSU researchers to representatives of private and public organizations. Knowledge from these interviews was augmented by information from literature reviews and participation in the Bio 2006 Conference in Chicago in early April 2006.

The second source of information identified was a pending report from Informa Economics, Inc. (Informa). It was believed that the Informa report would provide a significant amount of data estimating the economic impact of bioeconomy activity at the national and regional levels. A draft of this report was released in early March 2006. However, the report did not contain the expected economic impact numbers due to the complexity and uncertainty of what the bioeconomy will look like in the future. Thus, it was not possible to extrapolate numbers from that source and apply them to the state of Michigan.

Notwithstanding the lack of economic impact estimates, a solid characterization of the types of opportunities that exist as well as a summary of strengths for Michigan as a player in the bioeconomy were developed. A discussion of Michigan's opportunities is covered in the main section of the report and augmented by seven vignettes in the appendices that examine specific areas of current and potential areas where Michigan could play a lead role.

## The Role of MSU

While it is difficult to estimate the exact dollar impact of the bioeconomy, Michigan has the resources to be a serious contender in the future bioeconomy. However, there are other states and regions with similar assets at their disposal. It is clear that the bioeconomy will be complex and will require new business models. The winners will be those who can create the knowledge needed to assemble and mobilize resources for the bioeconomy most effectively. This creates a significant opportunity for MSU to provide a leadership role for the state of Michigan.

A significant portion of the report is devoted to a discussion of knowledge creation and presentation of insights relative to the role that MSU could play in stimulating knowledge and commerce to support the bioeconomy in the state of Michigan. This discussion will serve as the foundation for work in Phase II of this project. That effort will focus on building a deeper understanding of emerging value chains and how MSU can influence the success of bioeconomy growth in Michigan.

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## Executive Summary

The world economy is in a state of transition as it wrestles with the technological opportunities and societal issues surrounding biotechnology along side the high cost of and dependency on petroleum-based products. These two topics have thrust a new opportunity to the forefront of attention – a bioeconomy focused on the production of goods and services derived from materials from plants, animals, wood products, and other renewable resources often, but not exclusively, as substitutes or replacements for petroleum based goods and services. In tandem with this growing economic force is the recognition of academic opportunity to contribute in a significant manner, not only on a global front, but in a way that will initiate and sustain economic growth at the state level. Michigan State University's (MSU) President Simon has recognized this opportunity, and asserted her commitment to advancing the bioeconomy within the state of Michigan by recently stating "At MSU, research, development, and entrepreneurship for the bioeconomy are fundamental to who we are and what we do."

Recognizing this opportunity, MSU commissioned this study to evaluate, on a preliminary basis, Michigan's opportunities in the bioeconomy, and to begin crafting the role MSU could play in a growing and thriving bioeconomy. To accomplish these objectives, Centrec Consulting Group, with the assistance of MSU's Product Center for Agriculture and Natural Resources and MSU's Office of Biobased Technologies, conducted over 30 interviews with stakeholders from Michigan's private and public sectors. In addition, research was performed to gather additional and supporting evidence of Michigan's strengths, weaknesses and opportunities relative to a role in the bioeconomy.

The aforementioned activities resulted in an articulation of Michigan's resources, providing an opportunity for the state to fuel an emerging bioeconomy, and challenges for MSU as it begins to define its role in the promising bioeconomy. These findings and conclusions are presented in this report.

There are a number of key elements necessary for a thriving bioeconomy. Michigan possesses many of the assets critical to successful bio-based industries. These can be categorized as the natural resource base, industrial infrastructure, intellectual capabilities, and leadership commitment. While these attributes do not make Michigan unique compared to other states or regions, Michigan can definitely be a contender in the bioeconomy.

As in the petroleum industry, feedstocks serve as the key input for manufacturing fuel, energy, and products from biosources. Feedstocks can be derived from agricultural- and forest-derived biomass. Michigan resources include ample supplies of biomass from both these sources due to its strong, diverse agriculture and a growing and sustainable base of forest resources.

The state's diverse agricultural industry can be largely attributed to its culture, climate, and unique geographic qualities exemplified by relatively high-quality soils and numerous microclimates. This diversity is not typical of mid-western states and provides the opportunity for a diversified portfolio of agriculture-derived biomass and for future innovative feedstocks.

Michigan's abundant forestry resources, including available timber, harvesting and handling infrastructure, and mills capable of at least initial bioprocessing, is positioned to become a competitive biobased sector. Currently, the annual forest growth rate in Michigan exceeds harvest, thus providing an opportunity for greater harvest of fiber from the forests.

In addition to feedstocks, water is another required input for the processing of the feedstocks and manufacturing of the products. Michigan can provide the ample water required for industrial bioprocessing. Michigan's water resources also are of high quality.

Michigan has an established manufacturing industry that provides extensive industrial facilities, transportation and logistics infrastructure, and a skilled labor force. The state also possesses a budding biofuel industry with established bioeconomy support services. Another key element is Michigan's geographic location and access to consumers. It has proximity to major population markets, diverse manufacturing markets, Canada and the NAFTA highway.

Michigan is the home to extensive and vibrant research capabilities in the plant and biological sciences. MSU is a world-renowned university with particular strength in the crop and biological sciences. MSU's commitment to advancing the bioeconomy is made evident by numerous research efforts and centers throughout the university. Key independent research entities, such as MBI and NextEnergy, add to the dynamic capacity for discovery within Michigan.

There is a widespread understanding among leaders in Michigan of the potential importance of the bioeconomy to future economic growth. Further, there is a strong commitment to making Michigan a bioeconomy leader. This support comes at many levels including from political leaders and state agency managers. Particularly impressive is the commitment of senior MSU administrators, as illustrated by the establishment of the Office of Biobased Technologies.

Throughout the interviews conducted within this study, there was a general sense that key research universities, such as MSU, have tremendous potential to assist in developing Michigan's bioeconomy. However, that conclusion was accompanied by the perception that much of the potential is unrealized today. This unrealized potential exists as a wide gap between invention in the lab and innovation in the marketplace. Therefore, a challenge emerged to identify mechanisms and approaches by which MSU could close the gap between invention and innovation within Michigan's emerging bioeconomy.

Nonaka and Takeuichi (NT) developed a conceptual framework that can be used to understand the challenges faced by traditional research universities of moving from inventions to innovations. The framework, presented as the knowledge spiral, suggests that today's research universities excel at scientific discovery and invention; however, the institutional responsibilities do not include the conversion of those discoveries to marketplace innovation. The role of a successful R&D hub for a state's emerging bioeconomy will be to facilitate the movement of inventions from the labs to innovations in the marketplace. Thus, institutional responsibilities need to be expanded and the deficiencies need to be addressed.

Traditional Land Grant Universities have a history of an expanded outreach role within a relatively short supply chain. However, the biobased value chain is often characterized as having three general components: feedstock production; bioprocessing; and biomanufacturing. As a result, a university's institutional responsibilities need to be expanded across the feedstock, bioprocessing, and product levels if it is to focus on being a R&D hub for a state's bioeconomy.

Michigan is not alone in its quest to build a strong bioeconomy sector. Every state or region has a blend of resources which comprise their competitive position. Michigan has an attractive mix of natural resources that could foster growth in the bioeconomy. The industrial infrastructure in Michigan is well developed but currently exhibits excess capacity. Significant intellectual capabilities focused on the bioeconomy exist within Michigan's universities. MSU President Simon and her administration have made a strong commitment to cultivating and sustaining growth of the bioeconomy in Michigan, with the intent of becoming a vibrant research and development hub for that sector. Despite these strengths, achieving this aspiration is likely to require organizational innovation, within the university, to link its science and technological capabilities better to the needs for innovation within Michigan.

# 1. The Setting

## 1.1. A Commitment to the Bioeconomy

The state of Michigan is a potential and attractive location for developing economic activities associated with a growing bioeconomy. Many of the assets critical to successful biomass-based industries exist in abundance within the state. These can be categorized as:

- Natural resource-based,
- Industrial infrastructure,
- Intellectual capabilities, and
- Leadership commitment.

> **Bioeconomy Definition**
>
> *For purposes of this report, the segment of the bioeconomy being focused on is "the production of goods and services derived from materials from plants, animals, wood products, and other renewable resources often, but not exclusively, as substitutes or replacements for petroleum based goods and services."*

Because of its strong history of research and scholarship in the plant sciences and its leaders' commitment to developing a bioeconomy, Michigan State University (MSU) is positioned to play a key leadership role in the development of Michigan's bioeconomy. A visual depiction of this setting is provided in Figure 1. Of particular importance is President Simon's assertion, "At MSU, research, development, and entrepreneurship for the bioeconomy are fundamental to who we are and what we do." (Simon, 2006). This leadership commitment is essential for establishing and sustaining the processes by which MSU can fuel and support an emerging bioeconomy in Michigan.

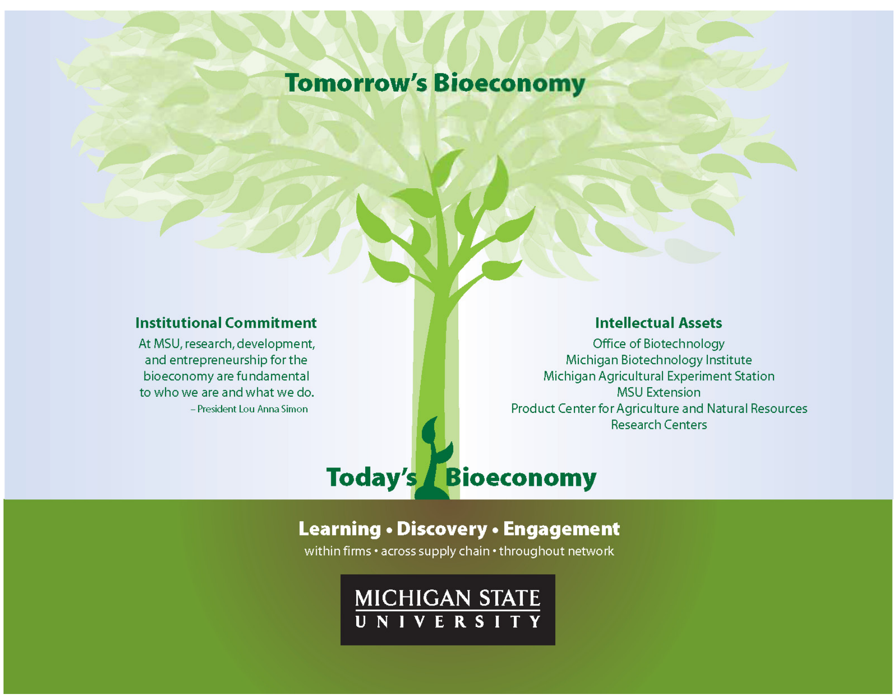



Figure 1. Bioeconomy Evolution

## 1.2. Competitive Landscape

Michigan is not alone in its quest to build a strong bioeconomy sector. Every state or region has their own unique blend of resources that will define their competitive position. The question is "where does Michigan stack up relative to other states?" This question cannot be answered in a straightforward manner because it is not clear exactly what the bioeconomy will produce or how it will be produced. Notwithstanding this uncertainty, there are some attributes that will be important to support the evolving bioeconomy. The table below summarizes Michigan's position in four key areas relative to other states based on feedback from interviews and other research.

| Natural Resources | Michigan's Relative Position |
|---|---|
| Diverse crop base | Very strong and second only to California in terms of diversity. |
| Forest resources | A strong contender - with capacity to grow. |
| Water | A diversity of water resources that are well managed. |
| Climate | Michigan has a number of different micro climates that support a diverse production base and potential. |
| Overall | Crop production is a good asset, but not sufficiently strong to put Michigan significantly ahead of other top ag states. Diversity and specialty production is a strong suit, but cannot compete with neighboring states to the south and west in terms of production quantity of grain crops. However, the overall combination of crop production and the significant forestry resources is somewhat unique. |
| **Industrial Infrastructure** | |
| Biomass handling capacity | Considerable experience with lots of underutilized capacity in the handling of forest products. |
| Labor | An abundance of skilled labor is available throughout the state - higher concentrations near urban centers where manufacturing jobs have been lost, but also in rural areas as a result of the economic slowdown in the forest products sector. |
| Manufacturing capacity | Significant amount of surplus manufacturing capacity that may be suitable for conversion to biobased products. |
| Transportation | Generally strong - nice balance of highway, rail, and water. Access to Canada and international waterways. |
| Overall | Fairly strong. Challenge is whether the bioeconomy will grow in time to utilize these resources before they exit (labor) or become obsolete (manufacturing capacity). |
| **Intellectual Capabilities** | |
| Public sector research | Strong, but other states and regions also have formidable presence in the areas of biomass conversion. |
| Private sector research | Strong overall and diverse. Not notably ahead of other states and regions in the area of biomass conversion. |
| Other research/incubator | Strong with MBI International and NextEnergy being unique assets. |
| **Leadership Commitment** | |
| Government | Strong support of the bioeconomy concept. Grant and incentive programs are available to be used for bioeconomy-related development. |
| University | Very strong and unique commitment on the part of President Simon. |
| Industry promotion groups | Strong and ready to respond - seems to be a willingness of these groups to work together, which is unique. |
| Private sector | Not clear. No notable examples of commitment to the bioeconomy on the part of the private sector were identified. |

In summary, Michigan is definitely positioned to be a contender in the bioeconomy, but overall does not have the resource base that makes it exceptionally unique or stand head and shoulders above other states or regions. Perhaps the most outstanding element is the level of commitment that has been expressed by the administration at MSU. While many other universities have identified the bioeconomy as an important part of their future, to our knowledge, none have made the level of commitment that Dr. Simon and her administration have made in recent months.

## 2. Michigan Resources

### 2.1. Introduction

As a part of the project, Centrec participated in a number of interviews with stakeholders across the state to develop a better understanding of what resources are available to support the bioeconomy in Michigan. This information was augmented by a review of relevant literature. This section contains a description of the various areas where Michigan appears to hold a solid position or have strategic advantages in the bioeconomy. Note that a bullet list summary of these resources was included in the collateral provided at the BIO 2006 conference in the "Michigan Advantages" document which can be found in Appendix B.

In 2004, Battelle identified the following bioscience sub-sectors:

1. Agricultural feedstock and chemicals
2. Drugs and pharmaceuticals
3. Medical devices and equipment
4. Research, testing, and medical laboratories

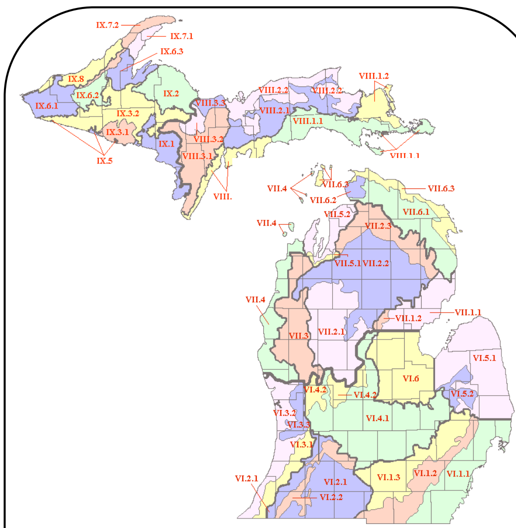
Due to the MSU-centric focus of this analysis, the following discussion deals primarily with #1, and with a portion of #2 to the extent that it relates to drugs and pharmaceuticals derived from agricultural feedstocks.

The discussion is broken into three major sections. The first is an overview of the natural resources in Michigan including its ag production base, forests, and water resources. The second section outlines a broader range of infrastructure resources ranging from industrial facilities to geographic location. The last section contains a discussion of the institutional resources available, which includes both the intellectual capabilities and leadership commitment elements identified earlier.

### 2.2. Michigan's Natural Resource Base to Support the Bioeconomy

#### 2.2.1. Biomass Production Potential

Michigan has a vibrant agricultural industry exemplified by its diversity of products including fruits and vegetables, nursery items, and dairy. The diversity of this industry is largely a function of Michigan's climate, geography and culture. Michigan's unique geographic qualities include relatively high-quality soils and a wide range of microclimates (a local external atmospheric zone where the climate differs from the surrounding area) created by glacial landforms and the surrounding Great Lakes. These multiple microclimates contribute to the creation of the numerous ecosystems (an assemblage of organisms living together with their environment, functioning as a loose unit) that exist in Michigan (Figure 2)[1], and encourage the production of a wide variety of agricultural crops, with more than 125 agricultural commodities (food and fiber products) grown in the state.



Source: Regional Landscape Ecosystems of Michigan, Minnesota, and Wisconsin: A Working Map and Classification by Dennis A. Albert.

**Figure 2. Michigan's Ecosystems**

[1] Michigan has about 45 ecosystems compared to Wisconsin (31) and Minnesota (28).

As a result of the diverse geography and microclimates, Michigan is one of the most diverse agricultural states in the country, second only to California. This diversity is not typical of mid-western states. Michigan's top 10 commodity share of total cash receipts in 2004 was 85.7 percent, compared to Minnesota (2003 – 91.8 percent) and Iowa (2004 – 99.4 percent). Table 1 shows the state's top ten commodities in terms of cash receipts in 2004. Three of the commodities were livestock while the balance was field crops, fruits, vegetables or nursery/greenhouse. In 2004, production volume of several Michigan commodities ranked first in the U.S. including several types of dry beans, blueberries, tart cherries, pickling cucumbers, and several types of flowers. Michigan was ranked third in apple and asparagus production, sixth in maple syrup production, and eighth in milk production.

**Table 1. Michigan's Top Agricultural Commodities, 2004**

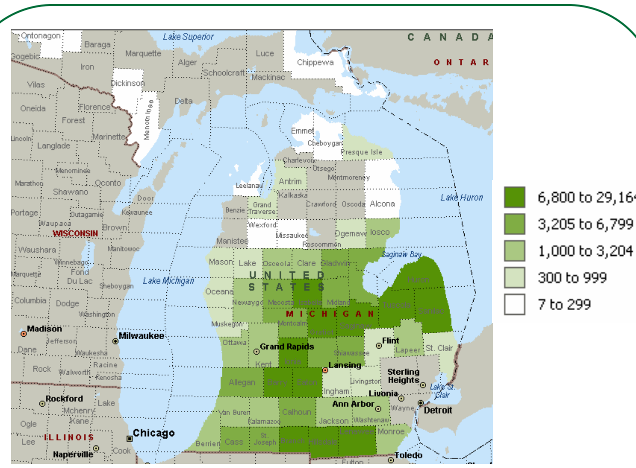
| Sector | Cash Receipts ($ thou) |
|---|---|
| Dairy | 1,020,380 |
| Greenhouse/nursery | 609,209 |
| Corn | 458,050 |
| Soybeans | 422,684 |
| Cattle/calves | 262,757 |
| Hogs | 234,992 |
| Vegetables | 229,055 |
| Wheat | 127,506 |
| Sugarbeets | 124,780 |
| Blueberries | 97,210 |
| Apples | 95,160 |

Table 2 displays the values of Michigan's top five agricultural exports for FY2004. The difference between farm cash receipts (Table 1) and the values in this table indicate that some of the products are consumed in the state, in addition to being processed into products not recorded in the export statistics.

**Table 2. Michigan's Top 5 Agriculture Exports, Estimates, FY 2004**

| | Rank Among States | Value (million $) |
|---|---|---|
| 1. Soybeans and products | 13 | 201.5 |
| 2. Feed grains and products | 12 | 191.4 |
| 3. Vegetables and preparations | 8 | 137.0 |
| 4. Fruits and preparations | 5 | 84.7 |
| 5. Other | 14 | 81.2 |
| Overall rank | 22 | 919.0 |

In addition to being a diverse industry, Michigan agriculture has proven to be flexible and adaptive. In 2004, there were ten different agricultural products (acreage for all vegetables is grouped together) produced on more than 50,000 acres. The balance of the crops was grown on smaller acreage totals. Other than for the crops grown on trees and in greenhouses, the acreage is fairly flexible regarding what crop is grown on it, given the local climatic and geographic constraints.




Source: USDA

**Figure 3. CRP Acres by County**

Another potential agriculture-related biomass source is Conservation Reserve Program (CRP) acres. As of February 2006, Michigan had almost 271,000 acres enrolled in CRP, contracted by 9,442 farms in 61 counties (73 percent of the counties)[2]. If this acreage were turned into crop land, it would increase total acres in farmland by 3 percent.

[2] Compared to the four surrounding states (Illinois, Wisconsin, Indiana and Ohio), Michigan ranks fifth in total enrolled CRP acres, but third in ratio of CRP to farmland acres (behind Wisconsin and Illinois, respectively).

According to the 2002 Census of Agriculture, there were 30,234 full-time equivalents of farmers and 53,315 farms in Michigan. In addition, firms representing 34 different food processing and manufacturing industries exist in Michigan (Peterson, Knudson and Abate). To keep these sectors productive and growing, it is estimated that almost $7 billion were invested in the farming sector from 2001 through 2005, and there were $1.6 billion identified as public and private investment in major agri-processing activities during the same time frame. The total private sector level of investment in the agri-processing sector is unknown, but expected to be much higher.

**Michigan Advantage**

*Does Michigan's diversity provide a unique competitive advantage? Perhaps, in many ways, the agricultural bio-economy is in its infant stage. It is not yet clear which particular crops will be ultimately used as biomass feedstocks. It may be a great advantage for companies to locate in an area where it is possible to experiment with a wide variety of different species within a relatively small geographic range.*

This population of farmers represents a diverse group of livestock producers, cash grain farmers, vegetable farmers, specialty or niche market producers, nurserymen, and fruit growers. These different types of producers require different support services (machinery, inputs, shipping, packaging, storing, etc.), and provide inputs to a wide range of agri-processors. As a result, the sector is well positioned to adapt to a changing market for evolving product needs.

### 2.2.2. Forest-derived Biomass

Forestry-based biomass can be used to create biopower such as co-firing; biofuels such as cellulosic ethanol and biooils for biodiesel; and bioproducts including cellulose fiber products and structural components. Experts believe that the next breakthrough in ethanol production will come from cellulosic production methods. The abundance of timber resources in Michigan (including the available timber, harvesting and handling infrastructure, and mills capable of at least initial processing) could provide a competitive advantage if this were to occur.

Michigan's forests are diverse, healthy and accessible[3]. Michigan's timberland acreage (18.6 million acres) has increased 7 percent since 1980, and is the fifth largest in the U.S., exceeded only by the states of Georgia, Oregon, Alabama, and North Carolina. In addition, Michigan has the greatest area of timberland and the greatest timber volume of any state in the North Central region of the U.S. Annual forest growth in Michigan currently exceeds harvest, thus providing an opportunity for greater harvest of fiber from the forests. Production opportunities stem from the Forest Service's revised Allowable Sale Quantity (ASQ) for Michigan's three national forests (representing 14 percent of Michigan's forests), effective timber inventory on the state's forests (21 percent of the state's forests), and policies and educational programs geared towards promoting sustainable management and harvest of privately owned forests (representing 65 percent of Michigan's forests).

**Michigan Challenge**

*Suggestions have been proposed to improve the fiber industry in the state – improved inventory practices and programs targeted to private owners to increase/ improve harvest practices and improve industry coordination. Many of the forest owners have small tracts of land and this makes timber harvesting and delivery to the mills complicated. Addressing this would be necessary to provide a reliable source of biomass from timber.*

Based on interviews with industry experts, there appears to be some disconnects in the forestry sector value chains. Pulp and paper mills have been struggling due to foreign competition. This has led to closure of a number of plants. In addition, the lumber industry also is challenged due to the high cost of timber and energy. So, even though experts suggest that sustainable forest production can be increased by as much as 50 percent, the downstream economics remain an impediment. More analysis is needed to determine the crux of this issue.

[3] More information about Michigan's forestry industry appears in Appendix B.7.

### 2.2.3. Water Resources

Many of the industrial bioprocessing activities require significant amounts of water. While water resources are a significant asset for Michigan, simply having a lot of water is not enough. It must be available for use without leading to negative consequences, and it must be of sufficient quality to support the economic activities. Availability is manifested in three dimensions: nature, legal access, and services to provide the resource. Michigan possesses those three dimensions. Through adequate rainfall, aquifers, and Lake Michigan, nature provides abundant water to the state. Water rights are a known entity in Michigan, and water services are in place to meet the state's water needs.

Michigan's surface water quality is generally very good, and while the quality of Michigan's ground water varies, it is mostly excellent. Lake Michigan's water quality, despite pollution problems in some inlets and bays, is considered excellent.

Although Michigan has a plentiful and available supply of high quality water, it is recognized that a sustainable management regime needs to be in place to ensure the survival of this natural resource in Michigan. The State has recently invested millions of dollars in programs designed specifically to restore and protect Great Lakes water. In addition, several large companies such as Dow Chemical and Ford have implemented more ecologically sustainable practices that are compatible with bottom-line business goals. Continuation of these efforts will sustain Michigan's ample water supply, and contribute to its position in the emerging bioeconomy.

**Michigan Advantage**

*Continued research and policy efforts will facilitate sustainable water utilization and an emerging bioeconomy. What is the current status of Governor Granholm's Clean Water Forever agenda?*

## 2.3. Michigan's Infrastructure to Support the Bioeconomy

### 2.3.1. Industrial Facilities

Michigan has an established manufacturing industry that has undergone a significant transformation in recent years due to shifting global markets. The most prominent of these have been related to the automobile and forest-related products industries. The existing manufacturing industry provides a framework and a set of skills that could facilitate the building of biorefineries in Michigan. This framework and skill set includes zoning and permit issues, construction companies with experience in building manufacturing facilities, and the infrastructure for such enterprises.

An established forest products industry exists in Michigan and is available for innovative uses of forestry resources with a workforce trained in harvesting, milling and manufacturing of forest products (including almost 1,900 logging companies, about 500 furniture and fixtures companies, and approximately 230 paper and allied products companies).

**Michigan Advantage**

*Maintaining a steady and reliable flow of biomass is key to the success of a bioprocessing facility. There is an existing infrastructure to handle forest products. This includes harvesting, hauling, storage, and processing equipment as well as a trained labor force. Can this infrastructure be efficiently converted to serve biomass production?*

In recent years, a number of manufacturing, pulp and paper mills, and lumber facilities have been closed and could be available for alternative uses such as biorefineries. These facilities are already located in areas zoned for industrial purposes, have ample support services, access to major transportation, available labor, etc. This capacity could provide a great opportunity to retrofit to biomass processing. For example, three forestry product facilities have closed in the last year, and the facilities are either in the process of being purchased for other uses or will be available for sale.

**Michigan Challenge**

*Lumber companies have not put much capital investment into their facilities for over two decades, leading to inefficient and outdated plants. Despite these challenges, the structures are in place. Does this provide an opportunity for remodeling and updating the plants for biotechnologies?*

According to the Informa report… "There is also significant support for the concept of utilizing existing biorefineries, specifically pulp and paper mills as test sites. Many of these facilities in North America are underutilized and possess infrastructure that may allow their economic conversion to initially grain-based ethanol production with a long run strategy to manufacture with cellulosic raw material." (Informa Economics)

### 2.3.2. Michigan's Budding Biofuel Industry

While behind states such as Iowa and Illinois where grain-based ethanol and biodiesel production have grown rapidly, Michigan's alternative fuel industry is growing relative to its production of corn and soybean feedstocks. There is one existing and four under-construction ethanol plants in Michigan. These plants are (or will be) utilizing the dry-grind ethanol process. If any future ethanol plants use corn fractionation – either using "raw starch hydrolysis technology" or "modified dry grind ethanol process" – then Michigan could have a competitive advantage by being home to the next generation ethanol plants. These "next generation ethanol plants" could become possible due to the technological expertise that exists in Michigan.

**Michigan Advantage**

*While the wet milling ethanol plants have the potential for more stable returns in the long run, largely as a result of producing multiple by-products, they require greater upfront capital investment than do the dry grind ethanol plants. This is a significant reason why the new ethanol plants are using the dry grind technology. However, there are alternative dry grind processes based on corn fractionation technology platforms. What advantages could be gained from being early adopters of these technologies?*

Biodiesel is another growing alternative fuel market. There is an existing biodiesel plant in the Upper Peninsula of Michigan and a proposed plant in Wayne County. There are currently around 106 biodiesel suppliers in Michigan, and approximately one billion gallons of diesel fuel are used in Michigan annually.

A key economic consideration in evaluating the feasibility of a biodiesel plant using primarily soybean oil as its feedstock is whether a crushing facility should be built in conjunction with the refinery or if one of the state's two processing facilities (Zeeland Farm Soya and Thumb Oilseed Producers Coop) should be considered for sourcing the feedstock. Economies of scale is a significant factor, and a crush plant must be large enough to be cost effective. However, a major portion of the meal production from such a plant would probably have to be exported out of the state.

Michigan cannot compete on scale with the large grain-producing states when it comes to grain-based ethanol and biodiesel production. That is not to say that they will not have a proportionate share of successful production facilities. However, a key question becomes what are the next generation bioenergy opportunities that can exploit Michigan's strengths?

### 2.3.3. Bioeconomy Support Services

Due to the long history of the forestry industry, agriculture and manufacturing in Michigan, there are well-established and existing supporting services for these industries. These support services include equipment, input suppliers (such as seed and chemical), insurance providers, technology advisors, and capital providers.

Again, an advantage could be realized from the fact that the agricultural production in Michigan is very diverse. Whether it be support for specialized planting, harvesting, and handling equipment or packaging and distribution, this diversity could serve the emergence of the bioeconomy well.

Capital providers are an important key in an emerging and successful industry. Capital to fund all stages of technological development and commercialization is needed, including pre-seed and seed funds and commercialization funding. The types of capital providers meeting these needs include angel investors, venture capital funds, and investment and commercial banks with the expertise to finance these types of projects. Michigan is home to capital sources in all these categories. Examples include Grand Angels, Apjohn Ventures, and the Technology Industry Group at the Bank of Ann Arbor.

### 2.3.4. Skilled Labor Force

Michigan has an excess supply of skilled labor originating from the auto, forestry and drug manufacturing industries. Michigan's Economic Development Corporation (MEDC) indicates that:

- Michigan's total labor force now exceeds 5.1 million.
- High tech professionals total over 560,000, ranking Michigan fourth nationally.
- Automotive R&D professionals total over 65,000.
- Michigan ranks third nationally in the number of Bachelor of Science engineering graduates with more than 4,100 degrees granted in 2004.
- In comparison to surrounding states, Michigan's younger population profile insures a balanced long term employee pool.

**Michigan Advantage**

*The recently unemployed mill workers are eager to work. Labor costs were not the driving forces behind the recent mill closures (three mills closed within twelve months); therefore, labor costs should not prevent Michigan from being economically competitive in the bioeconomy from the labor perspective. Labor costs are not usually the largest cost factor.*

While Michigan has an abundance of labor in the short term, the bioeconomy is not likely to generate a large number of jobs immediately. Even under the best case scenario, the creation of jobs will evolve over a number of years. Further, the early jobs will be in research and development followed by construction followed by plant and support workers. It will be important for policy makers to understand these time dynamics and set expectations accordingly.

### 2.3.5. Transportation and Logistics Infrastructure

Due to the longstanding history of Michigan's agriculture, forestry, and manufacturing industries, a robust and relevant transportation and logistics infrastructure exists. This includes roads, trucks, tractors, loading and unloading, and staging areas. In addition, the expertise to manage and maintain this infrastructure is in place.

This system is strong in three dimensions – highway, rail and waterborne shipments. Michigan ranked 4$^{th}$ in the nation in 2002 for value of all truck shipments originating in the state. These shipments are made possible by the state's almost 122,000 miles of roads with almost 40,000 miles in non-local roads.

Michigan also has a strong railway system:

- 12 railroads in 2004 (ranked 14th)
- Total rail miles in 2004 – 3,590 (ranked 13th)
- Tons originated in 2004 – 37.6 million (ranked 19th)
  - ✓ 8% or 3.1 million tons were farm products

The third leg to Michigan's strong transportation system is its deep water ports that provide access to Atlantic. In 2001, Michigan was ranked 13$^{th}$ for total waterborne commerce and 9$^{th}$ for domestic shipping tonnage.

#### 2.3.6. Overall Geographic Location and Access to Consumers

The above-mentioned transportation strengths position Michigan to deliver bioproducts to the customers in a timely and efficient manner. In addition to its transportation assets, Michigan is blessed with a location advantage:

- Proximity to major Midwestern population markets – Chicago, Milwaukee, Indianapolis, Cincinnati
- Proximity to diverse manufacturing markets – Illinois, Wisconsin, Indiana and Ohio in addition to Michigan itself
- Proximity to Canada and access to "NAFTA Highway"
- Shipping capabilities – 15 different ports with access to Atlantic through the St. Lawrence Seaway.

### 2.4. **Institutional Resources to Support the Bioeconomy**

#### 2.4.1. Intellectual Capital of the Universities

Michigan is the home to extensive and vibrant research capabilities in the plant and biological sciences across multiple universities. In FY2003, Michigan was ranked ninth in the nation for total university R&D expenditures ($1.39 billion) and for life science R&D expenditures ($831 million). MSU is a world-renowned university in multiple areas including the crop and biological sciences. MSU's commitment to advancing the bioeconomy is made evident by numerous research efforts and centers throughout the university:

- Plant Transformation Center
- Composite Materials & Structures Center
- Biomass Conversion Research Lab
- Advanced Technology Applications to Eastern Hardwood Utilization
- Product Center for Agriculture and Natural Resources
- Laboratory for Advanced Applications in GlycoChemistry

One outgrowth of MSU's leading researchers' efforts is commercial licenses and patents. For example, 42 patents were awarded in FY2005 at MSU.

#### 2.4.2. Intellectual Capital of Private Sector

The private sector works in tandem with the public sector in advancing technologies from conceptualization to commercialization. The growing bioeconomy and Michigan are no exceptions – both proving to be fertile grounds for these activities. Examples of three private sector efforts include:

- MBI International
- Diversified Natural Products
- NextEnergy

*MBI International*

Located in Lansing, MBI International has been committed to the application and commercialization of biotechnology approaches to creating renewable resources since 1981. Since that time, it has built a strong portfolio of leading-edge technologies. Key technologies relate to:

- Improved feedstocks
  - ✓ Biorefinery By-Product Processing – Ethanol production
  - ✓ Biomass Pretreatment – Production of fermentable sugars
  - ✓ BioFiber Production – Production of cellulose fibers
- Commodity and specialty chemicals
  - ✓ Energetic Materials
  - ✓ Antioxidants, Flavors and Fragrances
  - ✓ Liquid Crystal Polymers
  - ✓ Nylon-6
  - ✓ Polyamide Amines
  - ✓ Succinic Acid based C4 Platform
  - ✓ Nutraceuticals
- Structural materials and reinforcements
  - ✓ Cellulosic Macrofibers and Nanofibers – Fiberglass replacement
  - ✓ Exfoliated Graphite Nanoplatelets – Functional/Structural reinforcements
  - ✓ Structural Biocomposites – Lightweight, biodegradable structural components

MBI has important linkages locally as well as nationally. Locally, MBI has economic development responsibility for the Michigan Smart Zone program. At the same time, it has forged key linkages with both private and public research efforts throughout the country.

MBI has a strong track record of licensing and commercializing technologies as described in the following quote from their web site:

- The Business Development Phase began in 1992 and continues to the present (among the early success stories of MBI are Synthon Chiragenics, LacTech (Cargill Dow) and Emerald BioAgriculture). As of 2004, 11 new companies have been formed to commercialize technologies developed by MBI and five technologies have been out-licensed to various industrial sectors. To meet the unique requirements of start-up biotechnology firms, MBI created the Biobusiness Incubator of Michigan, the only incubator in Michigan specializing in the biotechnology sector.

Most recently, MBI provided a significant portion of the technical analysis for a national report on the state of the bioeconomy (Informa Report). MBI plans to release an update of this work each year in the future, positioning itself as the "go to" resource for technical information related to the bioeconomy.

*Diversified Natural Products (DNP)*

This company's technology makes succinic acid using patents developed by the research of MSU University Distinguished Professor Kris Berglund. DNP, along with MSU and Wayne County, recently announced the intention of developing a biotechnology park in Wayne County. DNP's biorefinery is expected to serve as the foundation for the park, and the vision is that the plant will offer improved economics over a traditional ethanol plant. This will be accomplished by producing a diverse array of fuels and chemicals with a broader set of replacement opportunities for petroleum (DNP is further described in Appendix A.3).

*NextEnergy*

NextEnergy is a non-profit corporation founded to enable the commercialization of energy technologies that positively contribute to economic competitiveness, energy security, and the environment. It was founded to advance the Alternative Energy Technology (AET) industry in Michigan. Major technology thrusts include portable power generation, renewable fuels and hydrogen production for use within commercial and military applications. The NextEnergy Alternative Fuel Infrastructure was partially funded by the U.S. Department of Energy to test and demonstrate emerging alternative fuel production and storage systems, including hydrogen, natural gas, bio/synthetic-fuel development platforms for vehicular and on-site power.

- Multi-use hydrogen fueling system (vehicles, stationary power)
- Renewable and synthetic fuel collaborative research program
- On-site hydrogen generation test bed

### 2.4.3. Effective Distribution Mechanism for Innovations

As a land grant institution, part of MSU's charter is to disseminate the agricultural knowledge gained at the university to the state's agriculture industry participants. Traditionally this has been performed through MSU's strong and visible Agricultural Experiment Station and Extension Service. As the agricultural industry evolves, so does the delivery of the acquired knowledge. MSU continues to disseminate this knowledge through its traditional means to expanded audiences but also through new and innovative mechanisms such as the newly created Office of Biobased Technologies.

Licensing, patenting and commercialization of MSU technologies is done through the Office of Intellectual Property. This office also directs university inventors to various resources for further developing and commercializing inventions. These resources include the University Corporate Research Park, and several incubators such as Rational Siting/Push-Pull Accelerator project (RSPPA). This is a collaboration between MSU, Dow Chemical, Dow Corning, North Coast Technology Ventures, MBI International, Michigan Molecular Institute, and Midland Tomorrow.

Another example of Michigan's efforts to commercialize its innovations is Michigan Universities Commercialization Initiative (MUCI). This group provides a commonly managed pool for pre-commercialization research on technologies emerging from every research university in the state and the Val Andel Institute.

**Michigan Challenge**

*In recent years, MSU has not been in the lead in terms of number of disclosures, patents, and licenses when compared to other Midwestern universities. Having an efficient and effective process to move technologies from MSU to the private sector will be essential to attract the attention of businesses as well as to attract researchers with ambitions to have their work commercialized.*

### 2.4.4. Key Leaders Committed to the Bioeconomy

There is a widespread understanding among leaders in Michigan of how important the bioeconomy will be in the future. Further, there is a strong commitment to making Michigan a bioeconomy leader. This support comes at many levels including:

- Governor and state government efforts
  - ✓ Michigan Biomass Energy Program
  - ✓ Michigan Department of Agriculture (MDA)
  - ✓ Michigan Economic Development Corporation (MEDC)
  - ✓ Agricultural Renaissance Zones
  - ✓ 21st Century Jobs Fund
  - ✓ $15 million federal Workforce Innovation in Regional Economic Development (Wired) grant awarded to the Mid-Michigan Innovation Alliance
  - ✓ Proposed alternative energy bills before the Michigan State Legislature
  - ✓ Statewide partnership being formed among the alternative energy research and development institutions according to Governor Granholm. The alliance could build off a new $1 billion investment fund that encourages business growth in four areas, including alternative energy.
  - ✓ Michigan Food Policy Council
- MSU
  - ✓ President Lou Anna Simon has made a public commitment to the bioeconomy
  - ✓ An Office of Biobased Technologies located within the Office of the Vice President for Research and Graduate Studies has recently been established
  - ✓ MSU Product Center for Agriculture and Natural Resources
  - ✓ MSU Plant Transformation Center
  - ✓ Biomaterial Division of the Composite Materials & Structures Center
  - ✓ Biomass Conversion Research Lab
  - ✓ Advanced Technology Applications to Eastern Hardwood Utilization
  - ✓ MSU Office of Intellectual Property

### 2.4.5. Presence of Support and Industry Organizations

There are multiple support and industry organizations already in place to support and aid the development of Michigan's bioeconomy. Examples of these organizations include:

- Michigan Agribusiness Association (MABA)
- Great Lakes Entrepreneur Quest
- Michigan Bio (Michigan Biosciences Industry Association
- Michigan SmallTech Association
- Biosciences Research and Development Center
- Michigan Technology Leaders 2006 Conference
- Corn Marketing Board of Michigan
- Michigan Soybean Promotion Committee

**Michigan Advantage**

*There is a feeling that the various producer groups tend to work together more effectively in Michigan than in other states. There is no tangible evidence of this, but positive comments came from individuals who should have some perspective on this issue. What can be done to further engage these groups into the bioeconomy process?*

## 3. **Stakeholder Feedback**

As mentioned earlier, a key element of this project was a series of interviews with stakeholders who will play a part in or be impacted by the emergence of the bioeconomy. The list of stakeholders was generated by the Product Center for Agriculture and Natural Resources. This included over 30 individuals from the research institutions, political groups, and industry. A listing of the individuals and organizations they represent is included in Appendix B.

Following is a brief summary of the takeaways and common themes from those interviews.

- A uniform vision of a future bioeconomy in Michigan does not exist. This leads to differing expectations about what the future bioeconomy will provide to the state in terms of employment, investment, and economic impact.
- It is difficult for some to grasp the length of time that it will take for a bioeconomy to mature. Related to this, the short-term needs of elected officials to show progress in developing the bioeconomy are at odds with what is needed to truly grow this sector.
- MSU researchers tend to know little about what others are doing across campus. This is certainly not uncommon in the typical university setting, but improving communication and awareness across disciplines could create a competitive advantage over other institutions.
- There is a feeling that the various producer groups tend to work together more effectively in Michigan than in other states. There is no tangible evidence of this, but positive comments did come from people who should have some perspective on this.
- There is a strong perception that the technology transfer process at MSU is not as efficient and effective as it needs to be.
- MBI International is a very important entity that is broadly respected. However, it is sensed that the linkages to MSU researchers are not strong and that relations with MSU could be enhanced.
- It is broadly believed that being a first mover in getting a biorefinery located in the state (preferably near MSU) would have tremendous value in accelerating research around processing methods.
- NextEnergy is a very relevant organization to the development of the bioeconomy. Ways to link them into future strategies should definitely be considered.
- The auto manufacturers interviewed (GM and Ford) took a very pragmatic view of biobased products. While they welcome the opportunity to use the products because they would provide a valuable marketing angle, the manufacturers did not express a strong desire to invest in developing these products. However, they did feel that the products would become available in due time.

In addition to these observations, there was a general sense that key research universities, such as MSU, have tremendous potential to support the development of Michigan's bioeconomy. However, there also is a widespread perception that the major portion of that potential is unrealized today.

Michigan's large research universities are appreciated for their educational contributions and for their ability to attract substantial amounts of funding to support their research efforts. It is also widely perceived that inventions from basic and applied research are critical to determining the pace and extent to which the bioeconomy expands within the global economy. However, it also is commonly understood that a wide gap exists between invention in the lab and innovation in the marketplace. Therefore, a challenge emerged from the stakeholder interviews. That challenge focuses on identifying mechanisms and approaches by which large research universities, and specifically MSU, can close the gap between invention and innovation within Michigan's emerging bioeconomy.

## 4. **Knowledge Creation Archetypes**

MSU aspires to be a research and development hub (R&D hub) within the knowledge-creating community necessary to support the emerging bioeconomy. This aspiration explicitly includes the goal of enhancing economic growth, investment, and employment within Michigan. In this context, research success is necessary but not sufficient. Research success, as measured by journal articles and even patents, does not necessarily translate into economic growth within Michigan. Knowledge, in these forms, is highly mobile. The innovations that emerge from research and the economic impact associated with exploiting that knowledge, can occur in any locale. Therefore, it is important to address knowledge creation from the broad perspective of marketplace innovation, extending from the lab to its impact in society.

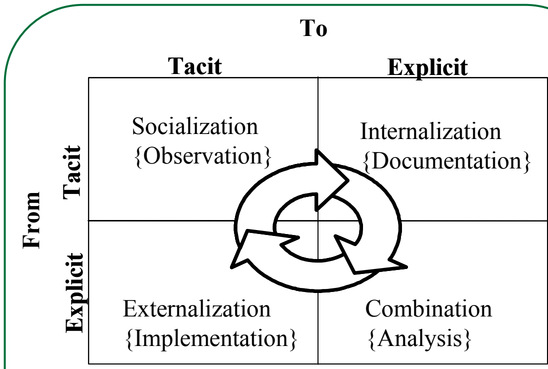
Nonaka and Takeuichi (1995) provide a particularly useful description of the process by which firms employ systems to generate knowledge resulting in innovation. They advance two key concepts within this framework. One of these is the recognition that there are two types of knowledge: tacit and explicit. The second concept focuses on the necessary interaction within those knowledge types – to create the knowledge spiral that leads to innovation. Both of these concepts will be briefly described here.

**Definitions**

*Explicit knowledge is transmitted through formal mechanisms such as journal articles. Tacit knowledge is gained through experience and exposure to the "real world".*

Explicit knowledge refers to knowledge that is transmittable in formal, systematic language. Definitions, equations and theories in journal articles are examples of explicit knowledge. Structured educational experiences typically emphasize the value of explicit knowledge. Nonaka and Takeuichi (NT) make an important contribution by stressing the key role of tacit knowledge within innovation processes. Tacit knowledge refers to the "mental models" that all decision makers possess of "how the world works". Tacit knowledge can be thought of as know-how, experience, and skill that all individuals use routinely.

NT emphasize the interactive role of both explicit and tacit knowledge, stressing that managers can implement systems and processes that intensify the effectiveness of these interactions. When effective in fueling innovation, these systems lead to the knowledge spiral depicted in Figure 4. Although ideally a continual process, it is necessary to describe the knowledge spiral sequentially. The upper left-hand quadrant, labeled **socialization** by NT, deals with observation focused on recognizing problems and opportunities. This recognition often occurs through subtle non-verbal cues and conversation. The experienced plant manager who can sense when performance problems exist, even when not apparent to others, exemplifies the socialization phase. The **internalization** quadrant (upper right-hand quadrant) exists because tacit knowledge by itself often is not sufficient. The process of making tacit knowledge explicit is necessary for effective communication but also can clarify dimensions of the issue furthering the innovation process. The lower right-hand quadrant, **combination**, refers to the type of intensive study and investigation typically associated with the formal research process. The final, lower left-hand, section of Figure 4 is labeled **externalization**. Formal research results typically need to be adapted to specific contexts, requiring and fueling the development of tacit knowledge.




*(Adapted from Nonaka and Takeuichi. The words within the brackets are interpretations of the NT terms)*

**Figure 4. The Knowledge Spiral**

Figure 4's circular set of arrows emphasizes the active, dynamic component of the knowledge spiral. It highlights the notion that effective knowledge creation is a continual process, incorporating both tacit and explicit knowledge. NT conduct their analysis in the context of the individual firm. However, this framework is relevant across a value chain as well. Indeed, the knowledge spiral of Figure 4 appears to be highly consistent with the historic effectiveness of the Land Grant University system in fostering innovation in U.S. agriculture.

The NT concepts provide an informative vehicle by which to contrast knowledge creation processes and expectations of the historic Land Grant University/agriculture system with those of today's research university. Within today's research university, research faculty excel at the combination phase of the knowledge spiral, where the emphasis is creation of explicit knowledge. The internalization phase also works well when the conversion of tacit to explicit knowledge is performed by a research expert such as program managers within government research institutes and/or corporate researchers. Success in this context is measured in terms of explicit knowledge artifacts such as journal articles, patents, and success in securing funds to support research. The externalization and socialization phases of the knowledge spiral typically are considered to be outside the purview and responsibility of research faculty.

The domain of the historic Land Grant system extended well further than that of the today's research university. During the rapid transformation of U.S. agriculture in the early segments of the 20th Century, the state Land Grant University had active responsibility that extended beyond the conduct of explicit research. Success of the system occurred through productivity advances and economic development within the state's production agriculture and the rural communities that supported the ag sector. Through the Agricultural Extension Service, the Land Grant University had a tangible presence within the community, providing a communication channel to and from the university. Indeed, this communication channel performed the socialization and externalization phases of NT's knowledge spiral across public and private sector boundaries.

The historic Land Grant system operated as the R&D hub for production agriculture through a critical period of its growth and development. This perspective can be illustrative in the context of a potential role for MSU as an R&D hub for the bioeconomy and the value chains that will emerge as the bioeconomy expands. Excellence in the combination phase (where advances in explicit knowledge occur) is essential within an R&D hub. Discovery, however, is not sufficient to fuel innovation over time within a value chain. Mechanisms which can effectively accomplish the roles of the socialization and externalization phases of the knowledge spiral will be required for an R&D hub to support value chains within tomorrow's bioeconomy.

**Successful R&D Hubs of the Future**

*A role of successful R&D hubs will be to facilitate the movement of inventions from the labs to innovations in the marketplace. This will occur through successful implementation of the socialization and externalization phases of the knowledge spiral.*

## 5. **Achieving the Goal**

MSU as a significant R&D hub for the bioeconomy is a desirable goal and an outcome worth pursuing. It would enhance the potential for value chains to emerge in Michigan as the bioeconomy expands. The prior discussion of the knowledge spiral as it applies to moving invention to innovation suggests two types of impediments that need to be overcome by any research university striving to fulfill such an aspiration. One impediment arises from the complexity of today's global economy. The second relates to organizational behavior within today's large, research university. Each impediment will be addressed in this section.

## 5.1. **Innovation within "Long" Value Chains**

Applying the knowledge spiral to the invention to innovation concept highlights the need for a university's focus to extend beyond campus boundaries if it expects to fulfill effectively a mission of stimulating economic growth locally. In addition, it is important to consider this concept within the context of today's economy, where innovation typically occurs within a network of suppliers, customers, and stakeholders. This network is commonly referred to as a value chain, referring to how the value enjoyed by a satisfied consumer is created by a series of entities linked through market and contract relationships.

The example of the effective knowledge spiral by which a Land Grant University supported and fostered economic growth within production agriculture in the early 1900s is highly illustrative, partially because production agriculture's value chain at that time was relatively short. The farmer delivered commodity output to the marketplace. Quantity of output was the primary determinant of marketplace value so the Land Grant University knowledge spiral was highly focused. Essentially one step existed between the commodity producer and the relevant customer. This was a short value chain. Today's value chains often are long because several firms are linked as suppliers and customers. In addition, the global nature of the marketplace means that the firms may be geographically dispersed, even across continents. The notion of longer value chains refers both to the number of entities and the complexity of information and product flows between those firms.

**Redefining Roles**

*Moving from short to long value chains significantly increases the complexity of innovation and redefines the role of the university.*

Today, short, one-step supply chains are relatively rare. Innovations, therefore, typically don't occur within short value chains. In longer value chains, quantity is only one of several attributes of marketplace importance. Even within Midwestern commodity agriculture, longer, more complex value chains are becoming the norm. For example, a major fast food chain may prescribe that the eggs it serves will be raised in an "animal welfare-friendly fashion"; therefore, the firms supplying the fast food chain's eggs must follow the quality standards and protocols dictated by the fast food chain. Innovations inconsistent with that parameter are no longer relevant to that value chain.

Therefore, the notion of being an R&D hub that supports value chains emerging within the bioeconomy can be depicted by a series of knowledge spirals rather than a single spiral. For example, a generic description of a bioeconomy value chain contains three components:

- The source of the feedstock,
- The processing stage where feedstock is converted to a useful commodity, and
- The manufacturing stage where products for industrial or consumer use are produced.

As shown in Figure 5, the notion of the knowledge spiral in this context can be portrayed as five interacting spirals - three knowledge spirals within the entities, and two between them. (In reality, this depiction significantly understates the actual level of complexity associated with innovation today.)

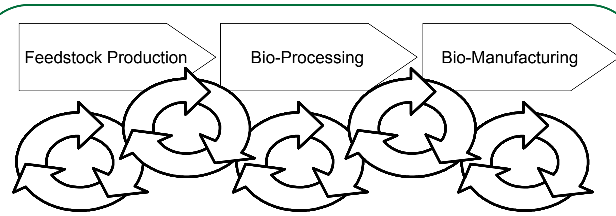



**Figure 5. Knowledge Spirals across a Bioeconomy Value Chain**

An important message of the interconnecting nature of the value chains shown in Figure 5 is that an innovation which affects any one step can have material impact on the effectiveness of several other stages in the chain. This interaction is illustrated by the example of marketplace adoption of ethanol. While low levels of ethanol can be blended with gasoline with minimal impact on engine performance, a product with a high proportion of ethanol requires considerable adaptation. The 85 percent ethanol product, E85, requires major adaptation by gasoline blenders, distributors and retailers, and by auto manufacturers.

A common perspective is that the nature of today's interconnected value chains tends to impede innovation. As in the E85 example, implementation of a marketplace development desired by some is being delayed as the other components of the value chain adapt slowly or not at all. Indeed the blunt force of government mandates may be required before E85 is widely available.

In the context of a university focused on being an R&D hub, an effective effort which understood and accommodated the needs of relevant value chains could be a distinguishing advantage. As depicted in Figure 6, that highly effective R&D hub would interact with knowledge spiral linkages across the targeted value chains, therefore fueling adoption of innovation from the feedstock to the product levels.

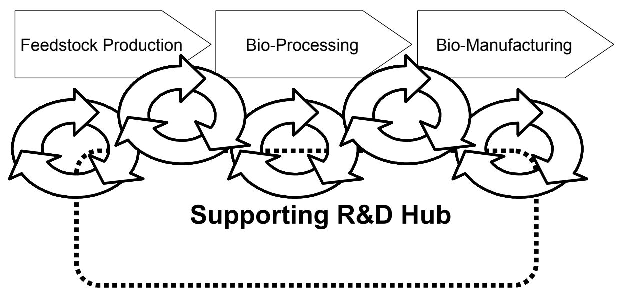



**Figure 6. Knowledge Spirals across a Bioeconomy Value Chain**

## 5.2. Organizational Dynamics within the Large Research University

As noted in the discussion of Figure 4's knowledge spiral, research universities have evolved to be highly effective in the combination and internalization phases of the process. Interpretation and further development of explicit knowledge are the key success factors at these points of the spiral. In contrast, the segment of the Land Grant University supporting production agriculture in the 1900s had a much stronger capability than today to operate within the socialization and externalization phases of the innovation knowledge spiral. The dynamics maintaining the research university's emphasis on the explicit knowledge-oriented phases of the knowledge spiral are powerful and well entrenched. Without proactive organizational changes to enhance the tacit knowledge-oriented phases, a university cannot operate as an R&D hub supporting bioeconomy innovation in Michigan. Identification of those dynamics and potential mechanisms to respond to them are discussed in the following paragraphs.[4]

[4] As a first step, it is important to recognize that knowledge spirals exist within different contexts. The focus of the discussions here has been on knowledge spirals to foster marketplace innovation. However, one also can identify the knowledge spiral which exists for the purpose of advancing the base of explicit knowledge. In this context, the socialization and externalization phases occur between the university researcher and research program managers of public and private institutions. Being effective within this knowledge spiral is critically important to the success of the research faculty member. However, the purpose of advancing the base of explicit knowledge in a field differs from that of fueling marketplace innovation from those advances.

Although there are many factors that could be (and have been) cited relative to the changing behaviors of the research university, this discussion focuses on only four. One deals with changes in societal needs and the other three deal with organization responses within the university.

- **Growth of private sector capabilities**: As knowledge and innovation became more important to economic success in the last 50 years, the private sector's knowledge spiral capabilities also expanded. These capabilities included development of internal research and development capabilities which have allowed the private sector to conduct explicit knowledge creation activities internally. In addition, private sector firms have developed mechanisms to monitor and acquire advances in explicit knowledge created in the public sector. As the economy has become more global and as explicit knowledge has become more mobile, the spiral of knowledge has accelerated its pace. However, geographic linkages between the location of knowledge creation and the location of its application, which existed in the past, have been greatly diminished.
- **Sources of funding**: Much has been written about the decline over the last decade of state support for institutions of higher education. The decline in public support for socialization and externalization activities has occurred over a much longer timeframe. Especially when compared to public and private support for the knowledge spiral's internalization and combination functions, the research university's capacity to engage in socialization and externalization is only a fraction of the capability available to the Land Grant University supporting production agriculture in the early 1900s. Research universities have developed improved capabilities to attract funding for explicit knowledge creation while the capabilities to link to tacit knowledge have atrophied.
- **Specialization within disciplines**: As explicit knowledge creation advanced across the academic disciplines, researchers were driven to excel through specialization. This tactic was necessary to compete for research funds, particularly as both public and private sources of funds were controlled by disciplinarily-oriented program administrators. Increasing specialization in explicit knowledge creation, however, typically comes at the expense of the understanding of the tacit knowledge dynamics that stand between invention and innovation.
- **Organizational incentive mechanisms**: Faculty in large research universities guard with passion the historic self-governance mechanisms of the academy. Mechanisms such as the promotion and tenure process, salary increases, and peer recognition are driven by the collective understanding of peers in the researcher's discipline.

Over time, the four forces noted above have acted as a powerful positive feedback loop to materially enhance the research university's ability to advance explicit knowledge – typically along narrow disciplinary dimensions. Conversely, efforts to enhance the institutional capability to link invention to marketplace innovation were not emphasized and did not develop at a similar pace.

The preceding discussion has focused on the forces that enhanced the explicit knowledge creation efforts for invention within the research university without a commensurate development of tacit knowledge capabilities for innovation. For a research university that aspires to become an R&D hub to fuel local innovation, explicit knowledge creation capabilities are necessary to serve as an effective R&D hub. Enhancement of tacit knowledge capabilities, therefore, can't come at the expense of the key explicit knowledge creating capabilities.

Earlier it was noted that powerful positive feedback loops acted to accelerate the research university's focus on explicit knowledge creation. A strategy to advance a research university's ability to serve as a focused R&D hub needs to augment those feedback loops rather than trying to eliminate those linkages. Effective activities within the socialization and externalization phases of the knowledge spiral are time consuming. The time and attention of the most productive researchers are typically the limiting factors within the research university. However, participation in socialization and externalization activities can enhance the sense of professional accomplishment for many researchers as well as increasing the capability to engage in the creation of explicit knowledge more effectively. Such participation can lead to a sense of achieving impact which advances society more directly than does publication of disciplinary journal articles. Further awareness of the factors that impede the transfer of invention to innovation provides perceptive clues as to where the most pressing areas are for future research.

In academic settings, the mechanisms to advance explicit knowledge for invention are well understood and are conducted within the normal course of events. Participating in seminars, serving on graduate committees, and attending academic conferences are the norm. However, the mechanisms to acquire tacit knowledge necessary for innovation are not well known and the needed support structures tend to be insufficient or do not exist. Two key precepts do seem critically important to bridge that gap:

- Being effective at socialization and externalization requires sustained interaction over time between researchers and staff in the academy and practioners in the private sector.
- While researcher involvement is essential, it is not efficient for individuals who are most proficient at explicit knowledge creation to conduct the entirety of the socialization and externalization functions. Professionals who can serve to link the languages and cultures of the academy and of the market need to be available within the university setting.

## 6. **Concluding Comments**

Michigan is not alone in its quest to build a strong bioeconomy sector. Every state or region has their unique blend of resources that will define their competitive position. The question is "where does Michigan stack up relative to other states?" In this analysis, that question was raised relative to the following four asset categories:

- Natural resource-based,
- Industrial infrastructure,
- Intellectual capabilities, and
- Leadership commitment.

Michigan has an attractive mix of the natural resources which could foster growth in the bioeconomy. Relative to feedstock sources, Michigan will struggle to compete solely on volume and scale in the production of agriculturally-based feedstock. However, Michigan's forestry resources are large enough to achieve levels of sufficient critical mass if cellulosic ethanol technologies become viable. Available water resources are a potential strength relative to economic activities across the value chain.

The industrial infrastructure in Michigan is both well developed and exhibits excess capacity currently. Human and physical resources to handle biomass feedstocks from forests and from agricultural production are readily available. Supplies of labor, manufacturing capacity and transportation capabilities are abundant. However, there is the potential for timing mismatches between today's availability and the likely need for those resources some time in the intermediate future.

Significant intellectual capabilities focused on the bioeconomy exist within Michigan's universities; however, that same statement would be true for several Midwestern states. The human capital for private sector design, development, and logistic efforts is probably unusually strong within Michigan because of the historic presence of the auto sector. Research entities such as MBI and NextEnergy are potentially distinctive and important assets.

Relative to leadership commitment, the strong support of the MSU President and her administration are particularly noteworthy. Many of the nation's large public research universities have significant research capabilities relative to the biosciences. However, MSU has proven strength relative to plant biology and chemical sciences necessary to advance bioprocessing and biomanufacturing. These strengths have potentially important links to MSU's aspiration to be a research and development hub for Michigan's emerging bioeconomy.

A key factor likely to affect MSU's future success in this aspiration significantly is the administration's ability to construct an organizational structure that will enhance MSU's performance, not just in creating new explicit knowledge, but in linking those advances to the needs of new and established firms within Michigan. Marketplace innovation often results from research-based invention. Typically, however, a knowledge spiral (or set of knowledge spirals) is necessary to transform invention to innovation.

Crafting an innovative organizational structure within MSU, which is as effective relative to tacit knowledge identification and communication as it is in explicit knowledge creation, is critically important to MSU's aspiration to contribute to Michigan's emerging bioeconomy. In the 19th Century, MSU led the nation in establishment and definition of the Land Grant University. Success in its bioeconomy aspiration will provide MSU the opportunity to lead in redefining the 21st Century Land Grant University.

## MSU Bioeconomy
## Case Vignette Details

Seven vignettes describing opportunities for Michigan's participation in the bioeconomy were developed. These sketches were based on interviews Centrec conducted with stakeholders around the state during February and March 2006. Two versions of these vignettes were developed. The first is a longer version containing detailed background information. The second is a condensed "glossy" version prepared for the Bio 2006 Conference in Chicago on April 9-12. Appendices A.1 through A.7 contain the longer versions of the vignettes, while the "glossy" versions appear in Appendix C.

## 1. Introduction

*Michigan understands that significant opportunities exist for firms to profit from targeting the high value new uses for bioproducts which exist beyond, but in some cases rely upon, the development of the capacity to effectively produce biofuels.*

In the future, as much value will come from by-products of biofuel production as from the fuel itself. Realizing this will come from:

- Enhancing ways to capture value from by-products from existing processes – DDGs from ethanol or glycerin from biodiesel
- Employing different approaches to biofuel production in order to enhance the value of by-products from existing feedstocks – i.e., raw starch hydrolosis or modified dry grind for ethanol production
- Utilizing by-products from the production of biofuels from new feedstocks – cellulosic ethanol or biodiesel from novel oilseeds or forest products

Michigan is a leader in the research that will make these new methods possible.

The volume of by-products from the production of biofuels is and will generally continue to increase proportionally to total production. Turning these by-products into something useful will be essential in order to make the production of biofuels economical. Common examples of by-products from existing processes include Dried Distillers Grains (DDGs) from dry mill ethanol production, and glycerin from biodiesel production.

However, effectively dealing with these by-products are only the beginning; as the range of feasible feedstocks expands in the future, new uses for new by-products will need to be found. For example, as cellulosic ethanol production enters the picture, a whole new set of by-products will emerge. A cellulose-based biorefinery producing 100 million gallons per year from corn stover and grasses will also generate:

- 23,000 tons of CA, K, Mg, and P
- 22,000 tons of lipids, fats, and waxes
- 57,000 tons of protein (not including cell biomass)
- And lots of lignin that can be combusted for energy

Michigan has successful examples of maximizing the value from existing by-products, has promising research for new uses, and is poised to tackle challenges of dealing with future by-products.

## 2. Polylactic Acid (PLA) from Corn

There is no reason that biorefineraries should not take advantage of all molecules of the biomass. One example is production of polylactic acid (corn dextrose lactic acid is fermented, and then polymerized) which is produced at a very large scale in the United States, Europe and Japan. Polylactic acid is used in food packaging and apparel industry. This crop by-product product competes well with its synthetic production. Another example is 1,3-propanediol made from fermentation of carbohydrates. Crop sugars can also be processed into three carbon and six carbon carboxylic acid such as hydropropanoic acid and glucaric acid, and into non-ethanol alcohols such as glycerol and sorbitol.

MBI International (http://www.mbi.org/index.html) has demonstrated a solid success story in the development of Polylactic Acid (PLA) in conjunction with Cargill and Dow. Polylactic acid is a biobased polymer that can be used to make a broad range of biodegradable plastic products. This is a key ingredient in the 74 billion pounds per year plastic resin market (Dale, 2005).

And the demand for biodegradable plastics is immense. According to the Informa Report, U.S. degradable plastic demand will grow 13.7 percent annually through 2008 as prices and properties become more competitive with conventional polymers. Biodegradable/compostable types will lead gains, especially polylactic acid. Film and ring carriers will dominate packaging uses while degradable foodservice items grow the fastest (Informa Economics). At the same time, the U.S. demand for all plastic containers will grow 5.3 percent annually through 2008 (Informa Economics), providing a solid foundation of demand growth.

**MBI International**

*Since 1981, MBI has been committed to the application of biotechnology to renewable resources. They provide an important linkage to private and public research organizations across the country.*

The U.S. supplies approximately 45 percent of the world's carpet. More than 2.5 million tons of carpets are discarded each year and landfill capacity is declining. The carpet industry has a history of innovation to reduce the environmental impact of its products. Cargill projects a possible market for PLA of 8 billion pounds by 2020. The industry-wide goal of diverting 40 percent of landfill waste by 2012 and increasing the biodegradability of carpet will both promote the use of biobased products as these are more easily returned to nature.

**Michigan Advantage**

*Technical knowledge base, patents, supporting laboratory and development resources, underutilized manufacturing infrastructure.*

## 3. Biodegradable Solvents from Ethanol

The U.S. solvents market will reach $3.4 billion in 2007, with biobased solvents growing six percent annually to nearly 25 percent of the overall market. Since most solvents are currently petroleum-based, they also pose environmental challenges for disposal (Miller).

The global demand for solvents is forecast to increase 2.3 percent per year through 2007 to 19.7 million metric tons. The market growth is due to faster growth for higher value products, and the ongoing replacement of traditional solvents with alternatives that are less damaging to the environment.

Ethyl lactate is a high performance solvent which, unlike its petroleum-derived counterparts is nontoxic and biodegradable.

A large demand for a product with these characteristics exists in Michigan and surrounding states where a significant amount of the country's manufacturing takes place.

MSU's Dr. Dennis Miller is leading researcher in the Department of Chemical Engineering on economical ways to produce ethyl lactate as a co-product of ethanol.

One of the key inputs in the production of ethyl lactate is ethanol. And, as an added bonus, a good portion of the ethanol used can be recovered and put back into the ethanol stream. The production process involved fits nicely along side of an existing ethanol plant as the recovery process can utilize the same ethanol purification processes already in place.

Thus, ethyl lactate can be produced as a very high value co-product of ethanol, providing added value and diversification to the ethanol producer as well as an environmentally friendly product for downstream industries.

This technology is ready for licensing. A plant adjacent to an ethanol facility would cost about $10 million to build.

**Michigan Advantage**

*Technology exists and is ready for licensing and commercialization, technical knowledge base, available ethanol plants, development grants, tax incentives.*

## 4. Products from Glycerin

The conventional transesterification process used to make biodiesel generates a glycerin as a byproduct. While glycerin has many uses and is an important ingredient in many products, the demand is such that even modest increases in supply will significantly reducing its market price. The opportunity here is to discover new uses for glycerin to take advantage of its anticipated abundance as well as to provide additional economic value to the biodiesel producer.

**Michigan Advantage**

*Can work with auto manufacturers to gain acceptance for new types of antifreeze and fuels.*

MSU researchers are on the forefront of exploring new possibilities for converting glycerin to chemical products that could ultimately be used to produce non-toxic antifreeze or even as fuel additives.

## 1. Introduction

*Michigan understands that significant opportunities exist for firms who can adopt the next generation of biofuel production technologies.*

There are significant short and long-term drivers to find more economical and environmentally sound ways to produce biofuels from un-utilized biomass resources. While many are focused on building more traditional production facilities, Michigan is focused on the next generations of production and committed to supporting their development.

## 2. Cellulosic Ethanol

Cellulosic ethanol production has long been identified as an opportunity to expand overall ethanol production. However, there are significant economic barriers to producing ethanol from cellulose matter using current processing techniques. Clearing this hurdle will be essential if we are to achieve the DOE's goal to replace 30 percent of the total transportation petroleum fuel with biofuels by 2025.

Presently in the U.S., ethanol is mainly produced from corn seeds or corn starch. Starch is made of a chain of glucose connected together with relatively weak chemical bonds which are broken by heat and/or amylase enzyme, and then the glucose is fermented into ethanol alcohol.

The current supply of sustainable global biomass energy potential is at about $10^{30}$ joules per year, in which 60 percent is not presently used.

Considering that biomass is mostly composed of cellulose and hemicellulose which are both made of chains of fermentable sugars almost similar to the sugar chains that are in starch, there are plenty of fermentable sugars from biomass going to waste every year at the global level. Researchers in Michigan are focused on discovering new ways to economically break down the plant biomass into fermentable sugars and then ferment these sugars into alcohol fuels such as ethanol (Sticklen).

These are four major steps associated with this technology.

1. Harvest and transport biomass fresh or dry to the biorefineries.
2. Grind the biomass and depolymerize through a process called "pretreatment" to break down the biomass further and to get rid of lignin so one could get cellulose (and in some pretreatment methods), hemicellulose accessible to polysaccharides breaking enzymes or hydrolysis (see #3 below) for conversion into fermentable sugars.
3. Produce cellulase enzymes in deep microbial tanks and use these enzymes to convert the cellulose and hemicellulose into fermentable sugars.
4. Ferment sugars into ethanol.

Every one of the above steps is expensive, especially steps 2 and 3. Michigan researchers are achieving success in developing technologies which will reduce costs related to all of the above.

For step 2, currently, pretreatment methods are all expensive and different solutions will be needed for different types of feedstocks.  Michigan-based researchers are addressing this challenge from different angles:

- Dr. Mariam Sticklen in the Department of Crop and Soil Sciences is looking at how modifications to the plant can solve the problem. To cut costs of pretreatments of crop (corn stover, switchgrass, etc.) biomass, one can decrease the amount of lignin in plants while increasing the plant cellulose through crop genetic engineering at a level that the change would not harm plant growth and developments. This would cut the pretreatment costs because there will be an easier access of enzymes to the cellulose and hemicellulose and therefore less need for very expensive pretreatments, and also there will be more cellulose for conversion into more fermentable sugars.
- Dr. Bruce Dale in the Department of Chemical Engineering & Material Science is working on novel pretreatment approaches that can be applied to a broad range of feedstocks.  A particularly promising process is called ammonia fiber explosion (AFEX). This process employs the use of liquid ammonia under moderate heat to explosively separate lignin, cellulose, hemicellulose and other biomass components.  Once treated, the sugars can be released using cellulase and xylanase enzymes.  Research continues into ways to scale this up for commercial application (Dale, 2006).
- MBI International has been working on the conversion of corn fiber to ethanol for a number of years using FIBEX (fiber extrusion) methods (MBI).

The challenge in step 3 here is that, at present, microbes are genetically engineered to produce cellulose enzymes, and then these recombinant microbes are grown in deep tanks using energy (sugar, and other nutrients that are added to the tanks). Dr. Sticklen's laboratory has produced cellulase enzymes within the cells of plant biomass through molecular farming, so there would be no need to produce these enzymes in recombinant microbes and then expensively grow these microbes in deep tanks.

Biomass crops get their energy directly from the sun through photosynthesis. Thus, these enzymes can be produced cheaply within the biomass crops (both corn and switchgrass) using the free energy of sun in the farms. In fact, these enzymes could be produced only in green tissues of biomass crops such as in leaves and stems, and not in the seeds or pollen grains. This is called tissue specific gene expression technology. A better method is to transfer the genes for these enzymes in the chloroplast genome instead of nuclear genome of crops. In this case, the male cells or the pollen grains are free from the transgenes.

In addition to having a solid technological base for jumping to the next generation plants, Michigan has access to plant locations that are currently underutilized as a result of declining production of pulp and paper mills.  This is supported by the recent findings in the Informa report which stated:

There is significant support for the concept of utilizing existing biorefineries, specifically pulp and paper mills as test sites. Many of these facilities in North America are underutilized and possess infrastructure that may allow their economic conversion to initially grain based ethanol production with a long run strategy to manufacture with cellulosic raw material.

**Michigan Advantage**

*Technical and research base, demonstration sites, access to and knowledge about producing a variety of feedstocks from corn to various types of timber, potential refinery sites and supporting infrastructure.*

## 3. **Next Generation Vegetable Oil Production**

The increased demand for vegetable oils needed to expand the production of biodiesel in the U.S. and other countries could quickly drive the prices of these feedstocks up beyond economical limits. Further, it could raise difficult ethical questions about trading off food for energy. While others are looking at ways to incrementally increase vegetable oil production, MSU is looking for exponential leaps in production from a fixed set of resources.

Dr. Christoph Benning has isolated the gene within the Arabidopsis plant that controls lipid production within the cells (Benning). Managed experiments have been able to demonstrate methods to achieve oil yields that are as much as 20 times greater than possible from the unmodified plant. This is an exciting development because Arabidopsis is a close relative to canola, which is already a relatively high producer of oil. It is also in the same family as the rutabaga…which could open a whole new set of opportunities and challenges.

**Michigan Advantage**

*Diverse range of microclimates that can support crops ranging from canola to rutabagas, producers who are currently raising a highly diverse range of crops, the infrastructure to handle many different kinds of crop products.*

## 1. Introduction

*Michigan understands that significant opportunities exist for firms to profit from employing biobased resources to offer new food and new industrial products.*

Science and its application in commerce offer the potential for new environmentally-friendly products that can substitute for petrochemicals. Such innovations are a key component of the promise of tomorrow's bioeconomy. However, these developments don't have to come at the expense of advances in the variety and quality of food.

Advances in our scientific understanding, coupled with entrepreneurship and an environment conducive to public/private collaboration, can fuel economic growth. The evolving dynamics of Diversified Natural Products (DNP) of Scottville, Michigan, illustrate the potential for serving food and petrochemical substitute markets. DNP has embarked on a path which, on the one hand, explores providing succinic acid as a valuable industrial input, replacing petrochemical-based sources of the input, while on the other hand, produces specialty mushrooms to fill market niches and create jobs in a particularly vulnerable rural area. Beyond its specific products, these developments illustrate the opportunity associated with the application of scientific advances to foster small firm establishment and growth in Michigan.

## 2. Biopotentials in Environmentally Friendly Chemistry

Succinic acid, a four-carbon dicarboxylic acid, has the potential to become an important commodity chemical which could form the basis for supplying numerous intermediate and specialty chemicals employed in a range of consumer product industries. Succinic acid and its salts, therefore, form a platform from which many chemicals and resulting products can be supported. The potential applications include plastics, surfactants and detergents, clothing fibers, food and pharmaceutical products, and biodegradable solvents.

Government agencies, such as the U.S. Department of Energy, and research institutions, such as Michigan State University, have conducted considerable research focused on enhancing the effectiveness of succinic acid as an input in numerous applications. For example, as deicing components, succinic acid could substitute for the environmentally detrimental inputs now used in the more than 10 million pounds of deicers used on airport runways. Those petrochemical based inputs range in cost from $0.46 to $0.88 cents per pound. Succinic acid also could serve as a replacement for solvents such as tetrahydrofuran and 1,4-Butanediol. Millions of pounds of these inputs are used annually in adhesives, printing inks, coating resins, and as intermediates for producing other solvents and chemicals.

Research advances also have reduced the cost to produce biobased succinic acid by 75 percent over the last decade. Further cost reductions are anticipated, especially as larger-scale manufacturing methods can be employed. It is estimated that the domestic demand for the chemicals for which succinic acid can substitute currently is $1.3 billion annually. Energy savings from substitution of succinic acid is estimated to exceed 9.8 trillion Btu.

## 3. In the Marketplace Today

Based upon scientific advances originating at Michigan State University, DNP is leading in the development of methods by which succinic acid can replace petrochemical-based chemicals. Fifteen of DNP's key patents have sprung from the research of MSU Distinguished Professor

Kris Berglund. These technologies are “green” as they are made from natural sugars from crops such as corn or wheat. They serve as the starting point for chemicals that can:

- Lower the freezing point of water, enabling the manufacture of safer engine coolants and runway deicers,
- Be employed as biodegradable solvents, or
- Be incorporated into biodegradable polymers for use plastics.

DNP origins illustrate the power of public collaboration with entrepreneurial application of science. Its current site, in Scottsville, Michigan, was developed with the assistance of State of Michigan credits for brownfield development. Its location in rural Michigan allows access to a high quality labor force with experience in manufacturing methods.

DNP’s interactions and collaborations, however, are global. Research collaborations leading to the technologies employed include efforts with scientists at MSU, the U.S. Department of Energy and in academia in Sweden. Strategic partners in the development effort include the Toyota Tsusho Corporation, emphasizing biodegradable coolants, deicers and plastics, and Agro-industrie Recherches e.t., Developments in France, to advance the manufacture of succinic acid and its derivatives.

### 3.1. **Mushrooms**

Marketed under the Midsummer Exotics brand, DNP also produces five types of gourmet mushrooms. Produced indoors with patented methods, DNP is providing these exotic mushroom types on a year round basis. Current marketing efforts focus on Midwest retailers such as Whole Foods, D&W Food Centers, and Meijers, Inc. Expanding production capacity to respond to demand is the current primary focus.

Mushrooms are fungi, a natural product that have no leaves, roots, flowers or seeds. They attach themselves to naturally decaying barks and soils. Located in the heart of Michigan’s hardwood lumber lands, DNP employs clean, freshly cut sawdust to grow varieties of wood-degrading specialty mushrooms. In addition to the highly desired morel mushroom, DNP produces shitake, cinnamon nameko, oyster, and black poplar varieties of mushrooms.

## 1. Introduction

*Significant opportunities exist for firms located in Michigan to profit from leveraging the region's existing industrial production strengths to provide innovative new products and industries. Michigan has long been a leader in manufacturing that utilizes huge quantities of plastic and other structural inputs that could be provided through biobased products.*

In recent years, significant strides have been made in the development and production of biobased polymers[5]. These bioplastics are directly useful in many applications and, with the addition of reinforcing fibers, can achieve desirable levels of performance with respect to thermal, moisture, and mechanical durability across a wide range of uses.

Interest is growing in the use of plant-based fibers for a wide range of industrial purposes, including the use of natural fibers in the automobile industry. These fibers have a number of applications in both the interior and exterior of the vehicle, including a potentially large volume use in the replacement of glass fibers. The interest in biomaterials is being stimulated by several factors, including (1) the desire to recycle automobiles, (2) recent rises in the cost of petroleum-based inputs, and (3) production factors, such as worker safety and environmentally friendly manufacturing techniques. The first of these factors is especially true for European automakers, which are required by European Union (EU) regulations to improve the ability to recycle automobiles.

The feedstocks for such biomaterials are of special interest to U.S. agriculture because they have the potential to become valuable new crops. Native switchgrass is one example given the potential to create value from land otherwise of less use for major field crops. In addition to native switchgrass, other fiber sources such as industrial hemp, flax and sisal are already in use to produce automobile components. The experience with these other commodities can shed light on the potential for native switchgrass.

**Why Michigan?**

*Proximity to auto manufacturing and suppliers, research base focused on plastics and structural components.*

## 2. Uses of Biobased Fibers and Bio Based Nano-Fibers in the Auto Industry

Europe has led the way in the use of biobased fibers in the auto industry. For example, up to 50 components of the Mercedes-Benz A,C,E and S class models are biobased, and each BMW 7 series automobile uses over 52 pounds of natural fibers (Elliot-Sink) Table 1 shows the range of manufacturers and uses for biofibers in automobiles, including models that are not available in North America. The table clearly shows that European manufacturers are leading the way in adopting biofibers for automobile applications, although domestic firms are also involved in the industry, often through European subsidiaries.

Currently, biobased fiber composites are being used in Europe for door panels, door cladding, seat bottoms, seat back headliners, package trays, dashboards, and trunk liners (Elliot-Sink; Sherman). FlexForm Technologies LLC, of Elkhart Indiana, provides molded seat backs for the 2005 Ford Freestyle SEL, the door armrests and upper panels on the front and rear doors of the 2005 Jeep Grand Cherokee and the front and rear panels on the 2005 Mercedes M-Class vehicles. These products are produced from a combination of kenaf, hemp, flax, jute and sisal, and thermoplastic polymers such as polypropylene and polyester (*www.compositesworld.com).*

[5] Much of the material is this section is drawn from a working paper by Knudson and Peterson evaluating the market potential of biobased fibers and nano-fibers in the auto industry.

**Table 1. Manufacturers, Models and Components Using Natural Fibers**

| Manufacturer | Model | Components (if known) |
|---|---|---|
| Audi | A2, A3, A4, A4 Advant, A6, A8, Roadster, Coupe | Seat backs, side and back door panel, boot lining, hat rack, spare tire lining |
| BMW | 3, 5, 7 series and others | Door panels, headliner panel, boot lining, seat backs |
| Daimler/Chrysler | A, C, E, M and S series Mercedes, Jeep Grand Cherokee | Door panels, windshield/dashboard, business table, pillar cover panel, door armrest, front and rear panels |
| Fiat | Punto, Brava, Marea, Alfa Romeo 146, 156 | |
| Ford | Mondeo CD 162, Focus, Freestyle, Volvo C70, V70 | Door panels, B-pillar, boot liner, seat backs |
| Peugeot | 406 | |
| Ranault | Clio | |
| Rover | 2000 and othrs | Insulation, rear storage shelf/panel |
| Saab | Various | Door panels |
| SEAT | Various | Door panels, seat backs |
| Vauxhall | Astra, Vectra, Zafira | Headliners panel, door panels, pillar cover panel, instrument panel |
| Volkswagen | Golf A4, Passat, Bora | Door panel, seat back, boot lid finish panel, boot liner |

Figure 1 shows the auto component parts with the most potential for biofibers. However, it should be noted that the fibers used are primarily kenaf (a relative of cotton), flax, and industrial hemp, although jute and sisal are also used. Native switchgrass is lagging behind in terms of adoption. The length of native switchgrass fibers is shorter than other natural fibers making it less desirable. Many of these other products are produced in Europe or are already widely available in international markets.

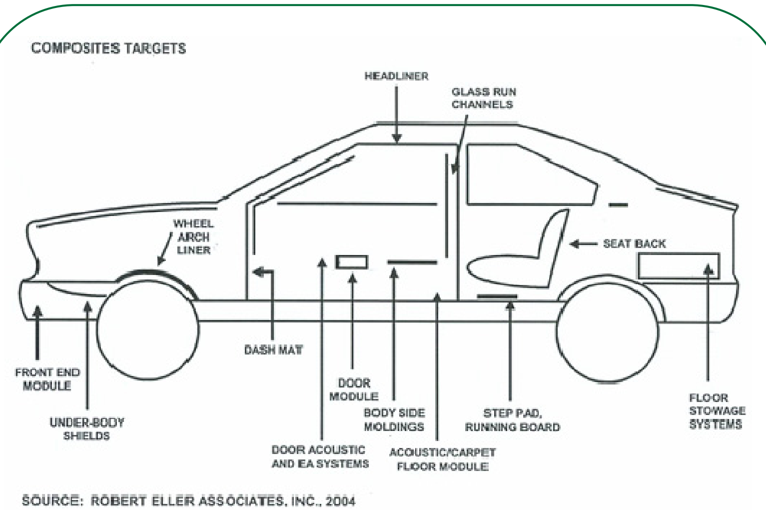



**Figure 1. Possible Uses for Biofibers**

## 3. **Size of the Market**

The level of biofiber utilization in the North American automobile industry is estimated to be 91 million pounds in 2005 (Suddell and Evans). In North America, the emphasis in the automobile industry has been on compression molding or thermoforming using polypropylene, polyvinylchloride, and high-density polyethylene, although phenolic and polyester resins are also used (Lackey, et al.). These materials are used for door panels, seat backs, insulating, and other applications.

One potential use for biobased fibers is as a replacement for fiberglass. It is forecast that there will be 16.7 million cars and light trucks (pickups and SUVs) produced in North America in 2005 (State of Michigan). The typical vehicle has more than 100 pounds of fiberglass reinforced plastics (Institute for Local Self Reliance). Therefore, the maximum conceivable size of the market for biobased fibers or biobased nano-fibers as a replacement for fiberglass would be 1.67 billion pounds. Assuming a price of 60 cents a pound for fiberglass gives the potential value of the market of $1.0 billion. However, there are some applications that are not suitable for biobased fibers given their flammability and problems with the product uniformity of biofibers. These drawbacks mean that the real potential for biofibers as a replacement for fiberglass is less (and perhaps considerably less) than $1 billion. The state of the production technology does not allow for a precise estimate of how much less because the technology in biomaterials is evolving and may resolve many of these drawbacks thus opening additional market potential.

To successfully compete in this market, biofibers need to possess the following characteristics: low cost, low weight, high quality, capability to improve safety, and production in a fully automatic operation at an extremely low failure rate. Other desirable characteristics are low waste or emissions with a minimum consumption of energy (Fries, et al.).

# 4. **Biobased Fibers**

## 4.1. **Sources**

Biobased fibers can come from a number of sources. In the U.S. the primary interest has been on developing industrial markets for native switchgrass. In Europe, which is leading utilization of biofibers, flax, kenaf, hemp, jute and sisal are often used in automobile components as are coconut fibers.

## 4.2. **Desirable Characteristics of Biofibers**

### 4.2.1. Environmental Benefits

One of the most desirable characteristics of biobased fibers is their ability to be recycled. This is a particular issue in the European Union which currently requires 80 percent of a car to be recycled. This requirement will be increased to 90 percent by 2015 with only 5 percent of the vehicle being placed in landfills (Powell). Toyota is attempting to meet these criteria for its North American Operations (Toyota). While environmental sustainability has not traditionally been a marketing tool used by manufacturers, biobased fibers could be used to appeal to environmentally conscious consumers. Another major environmental advantage to biofibers is the fact that they sequester carbon dioxide while the plant is growing (Mohanty, et al.). Carbon sequestration reduces greenhouse gas emissions and may curb global warming. It should be noted, that according to Toyota, the world’s number-two auto manufacturer, it appears that most consumers will not substitute environmental benefits for performance, nor are they likely to pay a premium for an environmentally sensitive vehicle (Toyota).

Another advantage of biofibers is the relatively low energy cost of production. Studies have shown that the energy cost of biofiber mat production can be as much as 83 percent less than glass fiber mats (Bismarck, Mishra and Lampke). If the price of petroleum, natural gas, and other forms of energy continue to increase, biofiber products become increasingly cost competitive.

### 4.2.2. Performance and Cost Attributes

There are attributes of biofiber based products that enhance the performance of certain automobile parts. Biofiber reinforced polymers show high tensile strength and stiffness and also act as a coating (Riedel and Nickel). They can provide the same level of performance as glass composites for a lower weight for some applications (Wibowo, et al.; Mohanty, et al.). This in turn, creates the potential for reduced fuel consumption for the vehicle. Joshi et al. believe that the reduction in weight and the resultant reduction in gasoline consumption and emissions would be the primary environmental benefit of biofibers in automobiles (Joshi, et al.). Improved fuel efficiency could also increase consumer interest in components made with biofibers. Biofibers are also effective noise reducers, provide good insulation, are more shatter resistant and have better energy management characteristics than glass based composites (Wibowo, et al.; Suddell and Evans). Biobased composites also provide stiffness enhancement compared to glass fibers and mineral fillers for some applications (Sherman).

A major possible desirable attribute of biofibers is their potential cost advantage. The rising cost of petroleum based products improves the price advantage of biobased fibers. In 2003, glass fibers cost between 59 and 91 cents a pound while flax fiber cost between 10 and 50 cents a pound (Joshi, et al.). Other types of cellulose fibers may be even less expensive; however, markets for these fibers have not been developed. In addition, the total cost of biofiber use (not just its raw material cost) is not yet price competitive for some applications.

Another cost advantage is the fact that some biobased automobile components require less energy to produce, are less destructive to machinery and are less toxic to workers (Elliot-Sink; Joseph, Jacob and Thomas). Producing glass fibers is very energy intensive, and as energy prices increase the cost of fiberglass relative to biofibers also increases. Traditional glass fibers have the potential to be allergens and a source of skin irritation (Schuh). However, most production processes are geared toward glass production and the costs of retooling and establishing a different supply chain may offset the lower raw product (biofiber) input costs.

## 4.3. Undesirable Characteristics of Biobased Fibers

Unlike glass and other industrial based fibers, biofibers are a result of a biological process. This means that obtaining consistent quality may be difficult. This is the single biggest disadvantage to the adoption of biofibers. The automobile industry demands both high quality and consistent automotive parts. Unless the issue of consistency is addressed, it will be difficult for biofibers to get widespread acceptance in the industry. For example, flax from Canada has less reinforcing effect than flax from Sweden (Sherman). Yields, moisture content, etc. will also vary from year to year as a result of disease, weather and other factors outside of a particular farmer’s control. Production and processing may also cause variability in quality. One approach to addressing these quality concerns is by mixing batches of fibers from different sources (Schuh). Another way to address this issue is through the use of grading or classifying the plant materials. Cotton fibers are already graded by the USDA (Dodd and Akin). The development of standards that would ensure consistency would aid in the development of a biofiber industry.

An additional weakness of biofibers is the fact that they generally have lower inherent (as opposed to tensile) strength and stiffness than glass fibers. This is less of a consideration for applications where weight is important, but it is an issue in applications where strength and load bearing is the overriding concern (Suddell and Evans).

Another possible disadvantage to the use of biofibers is their odor. Some products have a definite plant odor that consumers may find objectionable (Elliot-Sink). Natural fibers also have a tendency to absorb moisture. This is a major drawback in the performance of biofibers in that moisture absorption adversely affects the strength and consistency of biofibers (Bismark, Mishra and Lampke; Herrera Franco and Valadez-Gonzalez). However, it is believed that these shortcomings can be addressed through the use of fiber surface treatments that repel water, and utilization of other technologies and manufacturing methods, such as the proper selection of resins and additives (Lackey, et al.); this includes the use of nano technology (Ratner and Ratner).

An added drawback that deserves attention is the comparatively high flammability of biofibers Lackey, et al.). Biofibers can only be processed at temperatures below 230 degrees Celsius; this precludes the use of biofibers for some manufacturing processes (Schuh).

One more challenge facing the biofiber industry is the ability to produce biofiber products that meet the performance standards during the lifetime of the product yet remain recyclable or biodegradable at the end of the product lifetime (Mohanty, et al.). Consumers are likely to resist products that break down before the expected end of the life of the product. Finding the right combination of durability and recyclability or biodegrability may be difficult.

Some costs are also a major issue. While the cost of the raw material for plant matter is low, the cost of separating the plant matter into usable fibers is high and labor intensive. For example, European grown flax is not cost competitive with fiberglass (Bismark, MIshra and Lampke). In order to minimize the cost, the initial processing should probably take place near the location of agricultural production (Munder, Furll and Hempel). For some applications, it appears that the overall cost of biofiber based automobile parts currently exceeds fiberglass.

## 5. **Conclusion**

For a number of reasons, including environmental concerns, the desire to save weight, and EU regulations that might affect the North American market, automotive OEMs are becoming increasingly interested in the use of biofibers as a raw material source of automobile components. Biofibers have several desirable characteristics, the most important being lower weight and biodegradability as well as other positive environmental attributes. As a result, there are a number of possible applications in the automobile industry. With the passage of time, biofibers may also be cost competitive with glass fibers. Fiber glass production is very energy intensive, and the rising cost of energy improves the relative cost of biobased fibers. The cost of the raw material is already lower, and improved separation and other processing techniques could reduce the cost further. Cost is an important consideration given the level of competition at both the OEM and supplier levels.

Biofibers have the potential to be a large market. Currently, the North American auto industry uses approximately 1.7 billion pounds of glass fibers with a value of $1 billion annually. If biofibers can resolve production and distribution issues, they could potentially capture a significant share of this billion dollar market. Additional markets are also possible, but this appears to be one of the markets with the highest potential.

A natural source of biofiber in the U.S. is native switchgrass. However, industrial hemp and other natural fibers seem to have a higher level of acceptability in the market. This is a barrier that switchgrass producers will need to overcome. It should be noted that this market is a commodity market, and as such, price and cost is the major concern for buyers of these raw materials. Environmental benefits and other non-economic benefits will not be enough on their own for biofibers to replace glass fibers.

## 1. Introduction

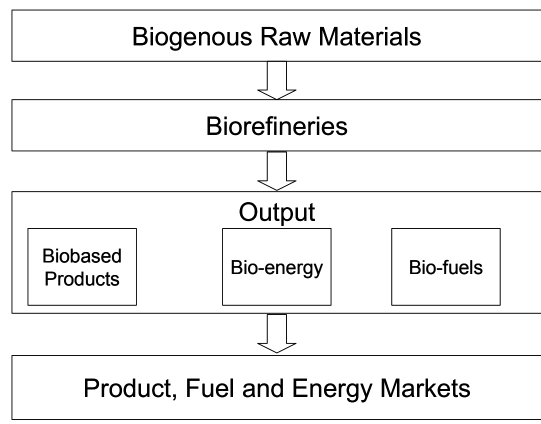
*Michigan understands the important role that biorefineries will play in the future bioeconomy infrastructure and is committed to building the service sector needed to support the growth of biorefineries.*

The opportunity exists to utilize renewable resources to replace petroleum in many petroleum-based products. Renewable resources are either utilized raw (e.g., wind and sun) or converted from biomass into biofuels, bioenergy and/or bioproducts. The conversion process occurs in a similar manner to how petroleum is converted to products – via a biorefinery.

## 2. Biorefineries are the Cornerstone to an Economically Viable Bioeconomy

Biorefineries are the mechanism for transforming raw biomass into various products, thus extracting as much value out of the biomass as possible by creating many products.

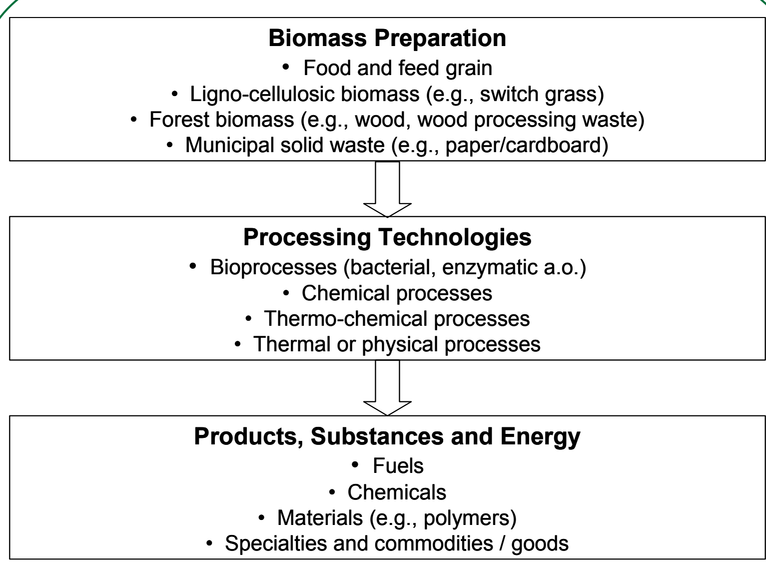
Biorefineries can take one of many different forms, depending on the biomass used as feedstocks and the desired output whether the output is biobased products, bioenergy and/or biofuels. However, the basic framework is the same across all biorefinery variations – the ability to prepare the biomass for conversion; convert the biomass via a technology (or number of technologies) such as bioprocesses, chemical processes and thermal processes; and creation of the various products resulting from the processing technologies.




Adapted from *Biorefineries – Industrial Processes and Products. Status Quo and Future Directions. Vol. 1*

**Figure 7. Biorefinery Concept**

Capital investment in biorefineries varies widely depending on the technology platforms used in the biorefineries, and production size of the plants. However, the capital costs are significant and can begin at $250 million and go up to $700 million.




Adapted from *Biorefineries – Industrial Processes and Products. Status Quo and Future Directions. Vol. 1*

**Figure 8. Biorefinery Concept**

## 3. **Why Michigan?**

Michigan is uniquely positioned to cultivate, build and support on an ongoing basis a bioeconomy with a strong biorefinery infrastructure. There are many factors crucial to economically successful biorefineries, including:

- **Existing Infrastructure** – Michigan has experience with similar types of operations. The biorefinery concept has long been in place in the pulp and paper industry, where wood is converted into pulp for papermaking, and various byproducts used to produce chemicals, fibers, and plastics. Black Liquor, a byproduct of the pulping process, is used in onsite cogeneration systems to meet a large share of electricity and steam requirements for the plant (Industrial Bioproducts: Today and Tomorrow p8).
- **Location** – There are several vital factors relating to location for biorefineries – availability of biomass; availability of capital resources; availability of an infrastructure and support services, and availability of labor (discussed below).
  - ✓ Michigan has a large and diverse supply of forest and agriculture-derived biomass located throughout the state. This diversity of both biomass types provides the strategic opportunity for biorefineries to locate in an area where they have access to a diversity of potential biomass inputs.
  - ✓ At this time, there are existing manufacturing facilities that are appropriately zoned, and have supporting infrastructure for a biorefinery. These opportunities can lower the capital costs required to open a biorefinery and expedite the permitting process.
  - ✓ Due to the existing agriculture, forestry and manufacturing industries in Michigan, a strong infrastructure and supporting services are already in place to facilitate the efficient transporting of biomass inputs and biorefinery products. In addition, the services needed to support the bioeconomy have a strong foothold in Michigan due to the related pre-existing industries.
- **Labor** – Michigan possesses a skilled and diverse labor force due to the strong manufacturing, forestry, and agricultural industries located within the state. This breadth of skills and depth of labor availability create a strong asset for supplying the biorefineries with the necessary labor for efficient and economical biobased products.
- **Bioeconomy-skilled professionals** – Michigan's globally recognized universities and colleges and the diverse private sector (including agriculture, forestry, and manufacturing) provide a rich resource of educated skilled lab technicians, chemists, engineers, managers, and biotechnology specialists, among others. This skilled knowledge base will serve as both a pool for candidates for direct employment and intellectual capital for developing the bioeconomy.
- **Water** – Water is a key input for various biorefining processes, and Michigan is well served with readily-available reserves of water, in addition to adequate annual precipitation. This natural resource eliminates a constraint present in other areas of the country that might be candidates for biorefineries.
- **Investment** – The financial resources needed for innovative, cutting-edge technologies and enterprises include angel investors, venture capital funds, federal and state financial support and grants, and investment and commercial banks. Michigan has numerous financial resources to meet the financing needs of biorefinery entrepreneurs across the above mentioned spectrum. Examples include:

- ✓ WIRED grant – shows state's commitment to supporting this new industry. A $15 million federal Workforce Innovation in Regional Economic Development (WIRED) grant has been awarded to the Mid-Michigan Innovation Alliance. The grant program will be used, in part, to jump-start a biomanufacturing industry in mid-Michigan.
- ✓ Technology Industry Group at the Bank of Ann Arbor
- ✓ Grand Angels
- ✓ DaVinci Capital

- **New technology and intellectual property** – Access to cutting edge technological platforms and intellectual property are mandatory to maximize biorefineries' productive and economic potential.
  - ✓ **MSU** – A leading research and educational land-grant university, MSU is a committed leader in the agriculture and forestry industries. In addition to faculty member in the Chemical Engineering and Material Science, Crop and Soil Sciences, Forestry, Chemistry, Biochemistry and Molecular Biology Departments, there are several centers focusing on topics relevant to the bioeconomy. These centers include:
    - MSU Product Center for Agriculture and Natural Resources
    - MSU Plant Transformation Center
    - Biomaterial Division of the Composite Materials & Structures Center
    - Biomass Conversion Research Lab
    - Advanced Technology Applications to Eastern Hardwood Utilization
    - MSU Office of Intellectual Property
  - ✓ **University of Michigan** – Michigan Nanotechnology Institute for Medicine and Biological Sciences (UM)
  - ✓ **Michigan Technological University**
  - ✓ **MBI International**, based in Lansing, works with individuals, industry and government to develop and commercialize biobased technologies.
  - ✓ **MichBio** (Michigan Biosciences Industry Association) is a non-profit organization dedicated to driving the growth of the life sciences industry in Michigan.
- **Responsive government and public sector** – Local and state governments and a public sector committed to the philosophy and the economic well-being of a bioeconomy are crucial. There are numerous entities and efforts in the public sector, including Michigan's Department of Agriculture (MDA), that provide that role, including:
  - ✓ Being available to help companies needing assistance in locating a plant.
  - ✓ There are 20 **Agricultural Processing Renaissance Zones** (APRZ) in Michigan. These APRZ are administered by the Michigan Economic Development Corporation (MEDC), and are company-specific with developmental agreements. The APRZs are exempt from all state and local taxes for "qualified agriculture processors" who want to expand or begin processing operations in Michigan. They are designed to help utilize and transform Michigan's raw commodities in the state into processed and value-added agriculture products and improve markets and profitability for Michigan growers.
  - ✓ **Michigan Economic Development Corporation** is geared towards assisting and promoting economic development in the state.

## 1. Introduction

*Significant opportunities exist for firms located in Michigan to profit from creating, supplying and utilizing new high value biobased products. Science and technology (biotech) are opening important opportunities to employ currently under or un-utilized biologically based resources to serve high value needs of society. This will emerge from a combination of market needs, science and technology, and cheap underutilized resources.*

In addition to fuels and energy, a wide variety of useful products are based upon petrochemicals. High priced fossil fuels and growing environmental sensitivities, coupled with advances in science and technology, offer exciting opportunities across a range of product applications for growth in the use of biobased materials to replace petrochemical-based inputs. An interesting example of these possibilities is the development of specialty chemicals for use in pharmaceuticals. Such applications are characterized by markets which have high per unit value and low unit volume (relative to fuel uses). Although the eventual final products require stringent manufacturing systems, the biomass that serves as the original feedstock often can be relatively low value components and residues from food and agricultural operations. For example, in Michigan it has been demonstrated that the pulp left over from sugar beet production and processing, combined with scientific innovation and entrepreneurship, can serve as the basic input for production of high value inputs to the drug manufacturing industry.

The world's pharmaceutical industry is a major economic sector with sales nearing $600 billion in 2003. North America itself accounts for approximately 50 percent of those revenues. The two trends of continued aging of populations that characterize developed nations and income increases in developing nations both support the notion that spending on medical drugs will continue to increase. This market is expected to see a 50 percent increase by 2008 (Informa Economics).

**Michigan Advantage**

*A strong history and an active current portfolio of research and development focused on chemicals from biomaterials, experience with public-private partnerships with both entrepreneurial and corporate entities, and access to a wide variety of sources of biomass.*

## 2. Biopotentials in Pharma Manufacturing

The science of biotechnology already is a major factor in pharmaceutical manufacturing, with 20 to 30 percent of the industry employing fermentation or enzyme catalysis in the manufacturing process. Since 1997 about 16 percent of new drugs have been based on biotechnology. Further, some estimate that up to 40 percent of new drugs will be biotechnology based in 10 years. And currently 30 percent of new drugs in development are biological, indicating that biological manufacturing capabilities will increase in scale by a comparable amount (MoRST).

The drive to discover and advance new drugs is important to the continued well-being of aging populations in the developed countries of the world. At the same time that leading pharmaceutical companies search for new compounds, pressure from generic manufacturers requires that additional attention be devoted to how existing products are produced. Increased efficiency in manufacturing processes through the use of improved micro-organisms and enzymes could serve to reduce drug manufacturing costs. For example, the use of chirally pure compounds based on enzymes can halve the amount of input needed and increase the efficacy of drugs relative to chemical catalysts.

## 3. In the Marketplace Today

While the eventual marketing of widely used products is typically accomplished by large-scale organizations, innovation in the United States has a history of being fueled by small-scale, entrepreneurial start up ventures. Commercialization of biobased chemicals to aid human health is likely to see a similar pattern.

Michigan presents a fertile environment for creation and growth of such initiatives. One example is AFID Therapeutics (http://afidtherapeutics.com) located in Lansing, Michigan. The AFID Therapeutics technology base uses the structural richness of carbohydrates to allow intervention and therapies across a wide span of the disease spectrum. Started within the last five years, the company combines its proprietary drug delivery technology with its proprietary and non-proprietary therapeutic compositions. The result is both totally new therapeutic offerings as well as new formulations that extend the use of established drugs or removes barriers to the use of others. Aggressively employing a significant biomaterials platform, AFID Therapeutics has a comprehensive portfolio of chemical technologies and proprietary compounds for use in drug design, discovery, and development processes.

An immediate focus of the company's efforts is the area of anti-infectives (antibacterial, antifungal, and antiviral programs). The company has exclusive access to over 20 issued US patents. Research discoveries at Michigan State University, under the direction of Professor Rawle Hollingsworth, Professor of Chemistry and Biochemistry and Molecular Biology, and licensed to AFID Therapeutics by MSU, provide an exceptional intellectual foundational for the company. Collaboration such as this provides tangible evidence of the enthusiasm of Michigan's leading research institutions not just to conduct research aimed at scientific discovery but to fully support entrepreneurial and commercial efforts by which discoveries can be used to foster economic development and improve human well-being. As the first recipient of a cash grant from Michigan's Technology Tri-Corridor, AFID Therapuetics further illustrates the potential for targeted public-private collaboration to support the advance of the bioeconomy in Michigan (AFID Therapeutics).

## 4. Research Capabilities

The existence of a stream of commercial innovations over time, whether through entrepreneurial or corporate entities, requires continued innovation in research and development. Michigan State University continues to lead in the application of science to better understanding the vast potentials locked within carbohydrates to replace petrochemicals in the production of products of commercial and societal benefit.

One example of this capability is illustrated by MSU's Laboratory for Advanced Applications in GlycoChemistry (LAAGC). Informed by an extensive history of discovery, LAAGC's mission is to provide a national and international resource to academia and industry in the chemistries and applications of carbohydrates and materials (www.laage.bch.msu.edu).

The lab is driven by the recognition that carbohydrates both are the most abundant organic materials on earth and are materials whose full potential as a renewable resource to better human well-being has not been achieved. They are superior to all other compounds, including petrochemical-based compounds, in their structural complexity and richness. Historically, however, that sheer structural complexity has limited the utilization of carbohydrates. Building upon a rich intellectual heritage at MSU, LAAGC has led in the drive to unlock these potentials to better serve society through medicine and materials.

Yesterday, chemistry was driven by the use of small molecular fragments derived from the cracking of petroleum. This chemistry is responsible for shaping the world around us in terms of the chemicals, drugs, plastics, dyes and resins society routinely employs. But chemical intermediaries derived from petrochemical feedstocks have relatively limited scope in the design and fabrication of biomaterials. LAAGC's primary strategic intent is to open pathways into exciting new worlds of chemistry using renewable resources based upon the carbohydrates provided by agriculturally derived raw materials.

Chemistry developed at Michigan State University is being used on a daily basis around the world in the discovery, development and manufacture of drugs used across the entire spectrum of diseases. LAAGC exists to provide a more effective means to disseminate this knowledge and expertise through collaborative research, advising and consulting, strategic alliances and industrial liaisons, out-licensing, as well as education and instruction (LAACG).

## 1. Introduction

*Michigan understands that significant opportunities exist for firms to profit from better utilizing the abundant forest resources of the state, while maintaining the environmental and recreational services now provided by those resources.*

This theme highlights the growing capability to better utilize a biobased resource, one that is particularly abundant and available in Michigan.

## 2. Opportunities within Michigan

The U.S. Government, through its Biomass R&D Technical Advisory Committee, has established an aggressive goal for increasing biomass utilization by 2030 by five times the country's current use of biomass feedstock. This goal encompasses biomass contributing to increased supply of power, transportation fuels, and chemicals.

More than 50 percent of the currently used biomass comes from wood residues and pulping liquors generated by the forest products industry (DOE, 2005). Forests are a particularly attractive source of biomass because they are highly productive, available year-round, and less subject to year to year variations in growing conditions than agricultural crops. In addition to the direct benefit of sourcing biomass from forests, wise use of forest resources can enhance the environmental and ecological services they provide, including carbon credits. Forests provide an opportunity for carbon sequestration, and well-managed forests do a better job of this process.

Forest-derived biomass can be used for a wide range of uses: biopower (direct combustion of biomass feedstock to produce electric power or heat), biofuels (cellulosic ethanol and biooils for biodiesel) and bioproducts (cellulose fiber products and structural components such as wood-plastic composites and wood substitute products). The technology for producing cellulosic ethanol is still in the development phase (including technologies being developed by a Michigan-based company, MBI International). However, it is expected that the new technologies for lignocellulose-based biorefineries will make cellulosic ethanol more economical. Examples of developing bioproducts include the possibility of pyrolytic production of biodiesel from wood, wood composites, and cellulose nanofibers (MBI is also developing technologies for cellulose nanofibers). Wood-plastic composites comprise the largest share of the North American composite and plastic-lumber market. The market for wood substitute products is growing rapidly, by as much as 20 percent or more per year, and this trend is expected to continue for many years (Informa Economics).

Michigan is well-positioned to contribute to meeting the biomass as a feedstock goal due to its many forestry-based assets. Michigan's forestry-based assets span the spectrum from research and development of innovative products and technologies of fiber-based products to production and delivery of revolutionary biofuels and bioproducts sourced from the forest. These assets include:

- Diverse, healthy and accessible forests with growth exceeding harvest rates.
- An established forest products industry with excess facilities potentially available for alternative uses and existing infrastructure positioned to facilitate the utilization of biomass for a variety of uses.
- Private and public sectors committed to preserving the state's natural resources and the economic health of the forest products industry.
- A diverse and strong technology and research base.

## 2.1. Michigan's Forests

Michigan's forests cover more than half of its land base. Forestland acreage totals 19.3 million acres, and its timberland (18.6 million acres) has increased 7 percent since 1980 and is the fifth largest in the United States. Because Michigan has a higher than average forest coverage, the state has an opportunity to capture a disproportionate share of biomass from forest products.

Forest growth in Michigan is currently exceeding harvest, thus providing an opportunity for greater harvest of fiber from the forests. Opportunities for increased production come from the Forest Service's revised Allowable Sale Quantity (ASQ) for Michigan's three national forests (representing 14 percent of Michigan's forests), effective timber inventory on the state's forests (21 percent of the state's forests), and policies and educational programs geared towards promoting sustainable management and harvest of the privately owned forests (representing 65 percent of Michigan's forests).

The state's forests provide a wide variety of tree species accessible for active and sustainable management, including harvest of trees and removal of biomass. The diverse forests provide the opportunity for a wide-spectrum of fiber utilization including biomass. Key sources of unexploited forest resources for biomass are logging residue and other removal residue, and fuel treatments for timberland and other forestland.

## 2.2. Michigan's Forest Products Industry

Due to its natural resources and the history and extent of the forest products industry in Michigan, the state has a strong existing fiber supply chain. The infrastructure includes almost 1,900 logging companies, about 500 furniture and fixtures companies, and around 230 paper and allied products companies. These companies are surrounded by the services necessary for an efficient and competitive forest products industry. As a result, Michigan's forest products industry is well-positioned to support new uses of forestry resources with:

- A workforce trained in harvesting and milling of forest products;
- Supporting services to the forest products industry (equipment, supplies, insurance, policies, etc.);
- Physical infrastructure (roads, trucks, tractors, loading and unloading, staging areas); and
- Paper mills that can be converted to plants that could provide alternative forest-based products.

The forest products industry in Michigan is undergoing a transformation with the closure of some mills, resulting in the availability of resources including an excess fiber supply, skilled workers, and unused capital structures. The availability of these resources creates a unique opportunity for innovative biomass production. These opportunities include taking advantage of readily available fiber and converting paper mills to biorefineries.

## 2.3. Michigan's Commitment to the Forest Products Industry

Recognizing the importance of the forest products industry to the state, the private and public sectors are committed to preserving the state's natural resources and the economic health of the forest products industry. Private sector examples include the efforts of the **Michigan Forest Products Council** and of companies and individuals to utilize the recently closed mills in Michigan in some capacity.

State efforts include:

- **Michigan's Forest Legacy Program** (FLP), a partnership with the USDA Forest Service. Its goal is to protect privately owned and environmentally significant forest lands from being converted to non-forest uses.
- The **Forest Finance Authority** which has been given the task of bringing Michigan fiber to market through numerous efforts including promoting infrastructure development and timberstand improvement. It also has money set aside for biomass research.
- The **Commercial Forest** program that provides a property tax reduction to private landowners as an incentive to retain and manage forestland for long-term timber production. Landowners participating in this program pay a reduced property tax of $1.10 per acre listed in the program. Additionally, the State of Michigan pays $1.20 per acre annually to each county where land is listed in the program.
- Current proposed **forest industry development legislation** before the Michigan State legislature. The legislation comprises eight bills. These bills would, among other things, add renaissance zones for forestry product facilities; provide a tax incentive to private land owners so they would allow timber harvests on their lands, and also open them to the public; and require the Department of Agriculture to review and approve private landowners' forest management plans.

## 2.4. Michigan Technology and Research Base

Technology developments in the private and public sectors offer the potential for economic use of forest resources for the production of fuels, chemicals, and enhanced structural materials. These developments occur through dedicated research and resource centers across the state, in addition to focused research areas by individual faculty members. Examples of dedicated research centers are:

**MSU's Advanced Technology Applications to Eastern Hardwood Utilization Center** – This center has several areas of research focus, including the Engineered Wood Composites Manufacturing Laboratory. Examples of their research related to forestry and biomass are:

- Wood-plastic composites and their foams – A current project is to develop a process to utilize eastern hardwood species and wood sawdust from hardwood waste of furniture industry as raw materials in the manufacture of commercially viable and value-added products such as wood-plastic composites and their foams. This project is led by Dr. Laurent Matuana.
- Wood fiber thermoplastic and wood cement particleboards – Another existing project is the investigation of viable methods to dispose of preservative treated wood that is retired from service with limited sign of degradation. The goal is to recycle this valuable source of wood fibers and to use them as raw materials for wood fiber composites. Thermoplastic and cement will be used to manufacture wood fiber thermoplastic and wood cement particleboards, and the properties compared to that of commercial sources to evaluate the commercial feasibility of such project. This project is led by Dr. Donatien Pascal Kamdem.

**MSU's Biomaterials Division of the Composite Materials and Structures Center** – Three faculty members are on staff, and current research projects include:

- Composite prepreg production using powder processing techniques.
- Interphase structure-composite property relationships in thermostat and thermoplastic systems.

- Quantification of fiber-matrix interphase structure in thermoset and thermoplastic composites.
- Analysis and comparison of methods for measurement of fiber-matrix adhesion.
- Green Composites and Biocomposites
- Green Nanocomposites
- Reactive Extrusion Blendings
- Biodegradable Thermoplastic Polymers
- High Impact PLA & Bacterial Polyesters
- Emerging Applications of Cellulose Esters Bioplastics
- Biobased Polyesters/Epoxies/Polyurethanes
- Life Cycle Assessment of Biobased Materials

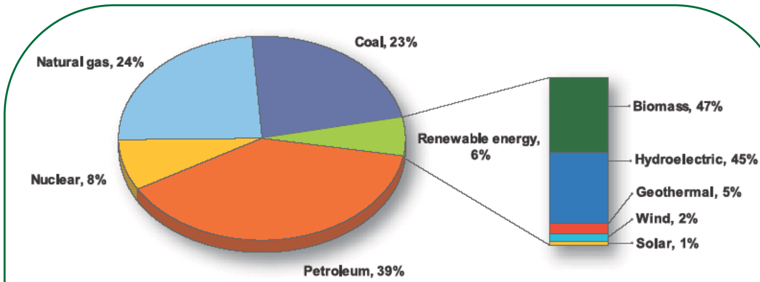
**MSU Department of Forestry** – An example of MSU's adaptive educational component is the Department of Forestry's efforts to address the broadening scope of forestry. A new curriculum is being offered featuring concentrations in Forest Conservation and Environmental Studies, Forest Resource Management, Forest Sciences, Urban and Community Forestry, and Wood Products Manufacturing and Marketing.

## 3. Additional Background Information

### 3.1. Biomass Opportunities for Forest Products

Biomass has been recognized as a viable alternative to petroleum-based products for energy, chemicals and materials. This is evidenced by the Biomass Research and Development Act of 2000's creation of the Biomass R&D Technical Advisory Committee. This committee established a national vision for bioenergy and biobased products, and this vision encompasses the challenging goal of biomass supplying 5 percent of the nation's power, 20 percent of its transportation fuels, and 25 percent of its chemicals by 2030. The goal is equivalent to 30 percent of current petroleum consumption and will require more than approximately one billion dry tons of biomass feedstock annually – a fivefold increase over current consumption (DOE, 2003).

In 2003, renewable energy contributed 6 percent of total U.S. energy consumption, and 47 percent of the nation's renewable energy consumption came from biomass (Figure 9). More than 50 percent of this biomass comes from wood residues and pulping liquors generated by the forest products industry (44 and 52 million dry tons/year, respectively).



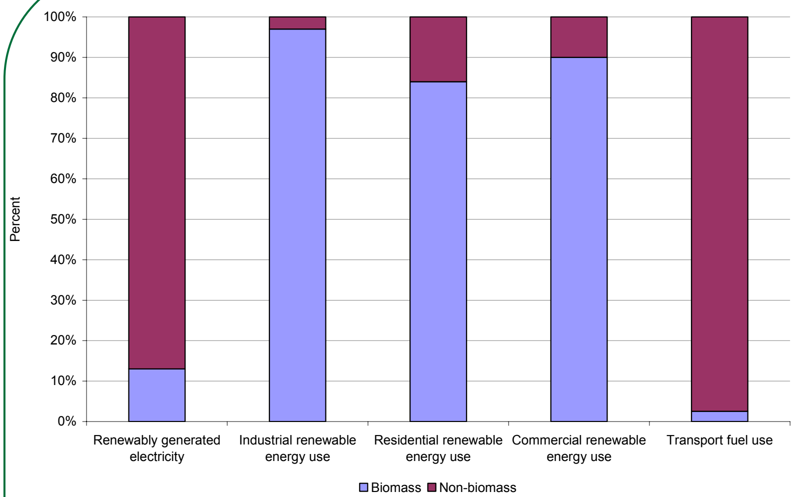

| Biomass Consumption | Million dry tons/year |
|---|---|
| Forest products industry | |
| Wood residues | 44 |
| Pulping liquors | 52 |
| Urban wood and food & other process residues | 35 |
| Fuelwood (residential/commercial & electric utilities) | 35 |
| Biofuels | 18 |
| Bioproducts | 6 |
| Total | 190 |

- Forestlands and agricultural lands contribute 190 million dry tons of biomass – 3% of America's current energy consumption.

Source: *Biomass as Feedtock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*

**Figure 9. Summary of Biomass Resource Consumption**

Currently, biomass accounts for approximately 13 percent of renewably generated electricity, nearly all of the industrial renewable energy use (97 percent), nearly all of the residential and commercial renewable energy consumption (84 and 90 percent, respectively), and 2.5 percent of transport fuel use (Figure 10). Approximately 6 to 9 million dry tons are being used for a variety of industrial and consumer bioproducts that directly displace petroleum-based feedstocks (DOE, 2005).



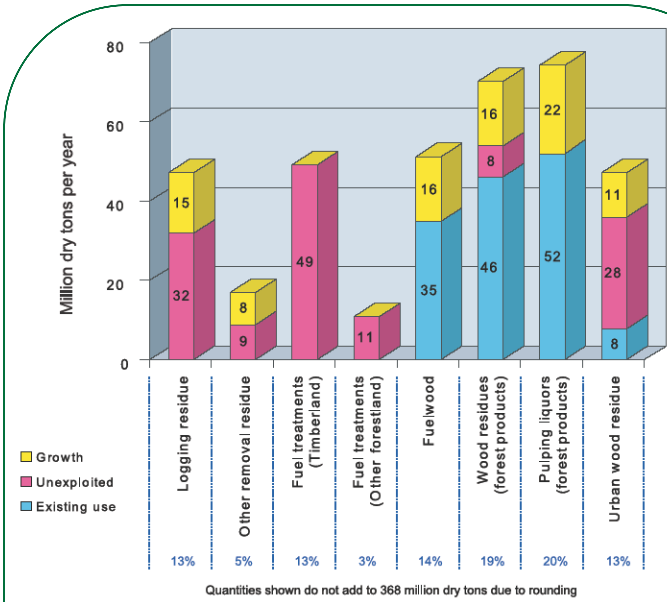

*Source: Biomass as Feedtock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*

**Figure 10. Energy Sources**

The primary forest resources for biomass are logging residues from conventional harvest operations and residues from forest management and land clearing operations; removal of excess biomass from timberlands and other forestlands, and fuelwood extracted from forestlands (DOE, 2005).

Biomass derived from forestlands currently contributes about 142 million dry tons to the total annual consumption in the U.S. of 190 million dry tons. Based on DOE's 2005 analysis, the amount of forestland-derived biomass that can be sustainably produced is about 368 million dry tons annually – more than 2.5 times the current consumption. Key sources of unexploited forest resources are logging residue and other removal residue, and fuel treatments for timberland and other forestland. These four resources total an additional 101 million dry tons per year (DOE, 2005). The logging and other removal residues can easily be recovered following commercial harvest and land clearing operations. Fuel treatment thinnings can also be recovered concomitantly with efforts to reduce forest fire hazards and otherwise improve the health of the nation's forests.

Forests are a particularly attractive source of biomass as they are highly productive, available year-round and less subject to year to year variations in growing conditions than agricultural crops.




*Source: Biomass as Feedtock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*

**Figure 11. Summary of Potentially Available Forest Resources**

Wise use can enhance the environmental and ecological services also provided by forest resources, including carbon credits. Forests provide an opportunity for carbon sequestration, and well-managed forests do a better job of this process.

Various opportunities exist for wood-sourced biofuels and bioproducts. Examples include the possibility of pyrolytic production of biodiesel from wood, wood composites, and cellulose micro-fibers.

Keys to successful utilization of forestry-sourced feedstocks for biomass include efficient use of capital and transportation. Transportation costs, usually in the range of $0.20 to $0.60 per dry ton-mile, could severely limit haul distances, if based solely on bioenergy and biobased product values. As a result, the availability of markets within viable transport distances may limit the practicality of removing fuel treatment biomass for bioenergy and biobased products. The capital costs required for forestry-sourced feedstocks will require innovative utilization of existing structures and implementation of efficient and innovative technologies.

The portfolio of products that could utilize forestry-based biomass include:

- Bioenergy
  - ✓ Biopower such as co-firing;
  - ✓ Biofuels such cellulosic ethanol and biooils for biodiesel; and
- Bioproducts including cellulose fiber products and structural components.

The timber industry has been using wood residues from primary wood processing mills for decades for fuel, pulpwood and feedstock for products such as particleboard (Informa Economics). However, the economics have prevented the wood residues to be a viable energy source for other end-users.

It is well known that corn-derived ethanol has a perceived bright future, but, it is less well known how cellulosic-derived ethanol will compete in the marketplace. Cellulosic ethanol is produced from lignocellulose-based biorefineries, and the economics of biorefineries are dependent upon the production of co-products to provide revenue streams to offset the processing costs. Therefore, new technologies are being developed to make lignocellulose-based biorefineries more economical (Informa Economics).

Lignin, a by-product of industrial conversion of cellulose, has numerous uses such as resins, dispersants and gasoline additives, in addition to co-firing. The stage of lignin participation in a specific product market, market awareness, and potential market growth depends on the product market and varies from well-established markets to the research/conceptual stage. The overall market attractiveness of these lignin-based products varies from very attractive (on-site energy) to questionable (animal health, resin, cosmetics and gasoline additive) (Informa Economics).

Wood-plastic composites comprise the largest share of the North American 2004 composite and plastic-lumber 2.26 billion pound market. Wood substitute products are growing rapidly, by as much as 20 percent or more per year, and this trend is expected to continue for many years (Informa Economics). Sales in 2006 are expected to be $1.95 billion.

The wood waste market is considered to be moderately attractive with a moderately fast expected rate of growth (Informa Economics). According to Informa Economics, the wood substitute and wood waste product sectors are in the initial commercialization stage of development. Given the market potential for these products, the technological stages provide sufficient opportunities for innovation and market growth.

# 4. The Case for Michigan

## 4.1. Michigan's Basic Landscape

Michigan's forests cover more than half of its land base, and are located predominately in the northern two thirds of the state. Forestland acreage totals 19.3 million acres, a 5 percent increase since 1980. Michigan's timberland acreage (18.6 million acres) has increased 7 percent since 1980, and is the fifth largest in the United States, exceeded only by the states of Georgia, Oregon, Alabama, and North Carolina (Michigan Department of Natural Resources). In addition, Michigan has the greatest area of timberland and the greatest timber volume of any state in the North Central region (Smith, et al.).

Michigan has a maturing forest resource, increasing in both tree size and age. Sawtimber sized tree stands now comprise 46 percent of the timberland acreage; poletimber and seedling/sapling tree stands comprise 30 percent and 24 percent respectively of the timberland acreage (Michigan Department of Natural Resources).

The temperate forests of Michigan contain a rich and diverse mix of tree species in an equally diverse forest type mix. The hardwood (broadleaf deciduous) forest types that comprise 75 percent of the total timberland acreage base include maple-beech-birch, aspen-birch, oak-hickory, and elm-ash-soft maple. Principal softwood (coniferous) forest types include red-white-jack pine, spruce-fir, and northern white cedar (Michigan Department of Natural Resources). The three timber production zones in Michigan are:

- Lower MI – high value hardwoods
- Mid MI – mixed conifers
- Upper MI – hardwoods

Michigan's forest resource is owned predominately by the private sector (65 percent), spread among 312,500 individuals (Smith et al.). The non-industrial private owner and farmer categories collectively control 57 percent of the total timberland acres, while forest industry has 8% of the ownership. The remaining 35 percent is controlled by the public sector (21 percent state owned; 14 percent federally owned).

Michigan has excess annual growth of its timber, implying that its forests are growing at a greater rate than are being harvested. This is attributed to several factors including timber harvesting policies on the National and State Forests, and small tracts of land owned by the private individuals.

The timber industry has become a global enterprise, and with the globalization, tremendous price competition and efficiencies have permeated the industry. As a result, production of some product categories (e.g., pulp and paper products) have moved outside the U.S., and the existing U.S. producers are either closing facilities or looking to reinvent their product lines and the manner in which the products are delivered. Due to the history and extent of the timber industry in Michigan, the state has a strong existing supply chain. The infrastructure includes almost 1,900 logging companies, about 500 furniture and fixtures companies, and around 230 paper and allied products companies. These companies are surrounded by the services necessary for an efficient and competitive timber industry. As a result, Michigan's timber industry is well-positioned to support new uses of forestry resources with:

- Workforce that is trained in harvesting
- Supporting services to the timber industry (equipment, supplies, insurance, policies, etc.).

- Physical infrastructure (roads, trucks, tractors, loading and unloading, staging areas).
- Paper mills that can be converted to plants that could do pre-processing.

The changing timber industry and Michigan's existing timber infrastructure can provide the impetus for taking advantage of the opportunities biomass production can provide to the state. The USDA Forest Service reported in 2002 that Michigan was 11$^{th}$ in the U.S. in dry tons of total biomass (live and dead) on timberland overall (817 million dry tons), but by far first in the north central region. Wisconsin was the closest with 588 million dry tons (USDA Forest Service). Michigan ranked 16$^{th}$ in sound dead biomass across the nation. In 2001, Michigan ranked eighth in the U.S. in the contribution of non-hydro renewable energy to electric power (this includes biomass, wind, geothermal, and solar energy) (EERE).

Forest production in MI has the potential to be increased by 50 percent without adverse impacts. This production increase can come from the upcoming Forest Service's updated Allowable Sale Quantity (ASQ) for Michigan's three national forests, effective timber inventory on the state's forests, and policies and educational programs geared towards promoting sustainable management and harvest of the privately owned forests. Increased supply of fiber in Michigan due to these changes could be realized as soon as 2006 with respect to the revised ASQ for the national forests and within five years for the state and privately owned forests.

During February and March 2006, Centrec conducted a series of interviews with stakeholders around the state of Michigan who have an interest in, or will be impacted directly by, the emerging bio-economy. The findings from these interviews are reflected in the white paper and vignettes. Following is a list of those individuals who participated in these interviews.

| Interviewee's Name | Organization | Interviewer | Comments |
|---|---|---|---|
| Ingmar Ackerman | Ford Motors | Chris Schroeder | Telephone Interview |
| Jon Bartholic | MSU Crop and Soil Sciences | Steve Sonka | |
| Christoph Benning | MSU Biochemistry & Molecular Biology | Chris Schroeder | |
| Bioeconomy Project Team | MSU Product Center | Chris Schroeder<br>Steve Sonka | |
| Bob Boehm<br>Wayne Wood | MI Farm Bureau | Chris Schroeder<br>Steve Sonka | |
| Jim Byrum | MI Agri-business Assoc. (MABA) | Chris Schroeder<br>Steve Sonka | |
| Jim Croce | Next Energy | Chris Schroeder | |
| Bruce Dale | MSU Chemical Engineering | Chris Schroeder | |
| Larry Drzal | MSU Chemical Engineering | Chris Schroeder | |
| Rawle I. Hollingsworth | MSU Biochemistry & Molecular Biology | Steve Sonka | |
| Paul M. Hunt | MSU Associate Vice President For Research | Chris Schroeder<br>Steve Sonka | |
| Mitch Irwin et al. | MI Department of Agriculture | Chris Schroeder | |
| Satish Joshi | MSU Agricultural Economics | Steve Sonka | |
| Dan Keathley | MSU Department of Forestry | Chris Schroeder<br>Steve Sonka | |
| Kevin Korpi | MI Forest Products Council | Chris Schroeder<br>Steve Sonka | |
| Dennis John Miller | MSU Chemical Engineering | Chris Schroeder | Telephone Interview |
| Suzanne G. Nichols | MSU Public Relations | Steve Sonka | |
| Judy Pollock | MI Corn Growers | Chris Schroeder<br>Steve Sonka | |
| Steven Pueppke | MSU Office of Biobased Technologies | Chris Schroeder<br>Steve Sonka | |
| Rich Schroeder<br>Dave Armstrong | Greenstone Farm Credit | Chris Schroeder<br>Steve Sonka | |
| Lou Anna Simon | MSU President | Chris Schroeder<br>Steve Sonka | |
| James Spearot | General Motors R&D | Chris Schroeder | |
| Agit Srivastava | MSU Biosystems & Agricultural Engineering | Chris Schroeder | |
| Masomeh B. Sticklen | MSU Crop & Soil Sciences | Chris Schroeder | |
| Mark D. Stowers | MBI International | Chris Schroeder | |
| Steven M. Webster | MSU Governmental Affairs | Steve Sonka | |

## MSU Bioeconomy
## Materials Distributed at the Bio 2006 Conference

Concise, “glossy” versions of the seven vignettes highlighting Michigan bioeconomy opportunities were developed for the Bio 2006 Conference. This appendix contains these materials.

The following individuals played a significant role in the development of these materials:

Sandra Conn, Assistant Vice President, Division of University Relations, Michigan State University

Marguerite A. Halversen, Editor and Project Manager, Marketing and Creative Services, Division of University Relations, Michigan State University

Kirk L. Heinze, Director, Communication & Technology Services, Michigan State University

Alex Parsons, Designer, Marketing and Creative Services, Division of University Relations, Michigan State University

Brenda Sanborn, Designer, Marketing and Creative Services, Division of University Relations, Michigan State University

# Tomorrow's Bioeconomy

## Institutional Commitment

At MSU, research, development, and entrepreneurship for the bioeconomy are fundamental to who we are and what we do.

– President Lou Anna Simon

## Intellectual Assets

Office of Biotechnology
Michigan Biotechnology Institute
Michigan Agricultural Experiment Station
MSU Extension
Product Center for Agriculture and Natural Resources
Research Centers

# Today's Bioeconomy

**Learning • Discovery • Engagement**

within firms • across supply chain • throughout network

MICHIGAN STATE UNIVERSITY

# Questions and Answers on the Bioeconomy

MICHIGAN STATE UNIVERSITY

bioeconomy.msu.edu

### How does the new bioeconomy relate to traditional agricultural production?

The new bioeconomy, which will yield the next generation of materials, chemicals, and energy, builds upon the foundation of traditional agriculture which focused on the cultivation of plants to produce food and fiber. The new bioeconomy will tap not only the primary outputs of traditional agriculture, such as grain and forest products, but also the waste and residues derived from processing those outputs for established consumer markets. In addition, the bioeconomy will tap the potential of new feedstock developed from currently unused plant material, such as grasses.

Michigan State University (MSU) has been a world leader in advancing agriculture in Michigan and around the world for more than 150 years. MSU has led Michigan's progress into one of the nation's most successful and diverse agriculture-producing states. Today, MSU is home to some of the most renowned plant scientists in the world. Working in interdisciplinary collaborations with engineering and biotechnology researchers in more than five dedicated laboratories on campus, these scientists are developing the plants and processes required to establish the foundation for a strong bioeconomy.

### How rapidly can public awareness, infrastructure development, and workforce education be disseminated about the bioeconomy?

Enthusiasm about the bioeconomy is currently high, but it must become more than a passing media interest or trendy policy story. To achieve a working bioeconomy, both Michigan and the nation must make a concerted effort to advance and disseminate knowledge about the benefits of the new bioeconomy while investing in developing infrastructure and worker training for this emerging industry.

In addition to Michigan State University's research machine dedicated to the bioeconomy, MSU is also home to the Michigan Agricultural Experiment Station (MAES), where MSU researchers refine the outcomes of plant research and speed them toward production. As a land-grant university, MSU also has the asset of the Michigan State University Extension, which provides education and training opportunities to Michigan residents in every county. Working with other land-grant universities and extension systems throughout the nation, MSU will contribute its expertise to expanding awareness of the new bioeconomy—leading to both workforce preparation and business-to-business and consumer market development.

### Who are the current prospective market leaders of the new bioeconomy?

Because the new bioeconomy will present new opportunities in a variety of industries—automobile, energy, pharmaceutical, chemicals, materials, packaging, and more—it is unlikely that one or even a few entities will emerge to dominate the market. This is also unlikely because biomass sources are so diverse, including food crops, woody crops, crop residue, grasses, and more. Further, a strong processing sector needs to emerge to develop the conversion processes, technologies, and facilities to make adopting the bioproducts and new feedstock viable. Leadership of the new bioeconomy will require partnerships that bring together plant, chemical, and materials researchers with government and business interests to build and manage the processing facilities and then develop relationships with industrial companies to bring the products to the consumer market.

Michigan State University has a strong record of bringing together and working in partnerships to advance emerging industries. One goal of MSU partnerships is always to bring benefits to Michigan while developing a firm national and international market share for Michigan raw materials, products, and intellectual assets. As one of the top 100 research universities in the world and a leading U.S. land-grant university, MSU wants to advance science while protecting the environment and creating products needed by people and societies worldwide.

## Where will the dominant markets be?

If the United States is successful in developing a strong market for renewable biobased resources, it holds the potential to become a dominant market. The market for renewable sources is worldwide and already growing rapidly in Europe, with strong potential for rapid growth emerging in Asia and other parts of the world.

Michigan State University is uniquely positioned as one of the most internationally engaged universities in the world to lead in the development of international research partnerships and to assist other nations and cultures in transitioning to capitalize on the market and environmental benefits of the new bioeconomy.

## What does Michigan State University have ready now to contribute to the development of the new bioeconomy?

Michigan State University's contribution begins with commitment. From our research—plant, chemical, engineering, economic, packaging, and social—we are convinced that the vision of a strong bioeconomy can be achieved. We have made the commitment to pursue research with intended outcomes to build the bioeconomy in Michigan, the nation, and the world.

Research, development, and entrepreneurship for the bioeconomy are fundamental to who we are and what we do. As a result of our long-standing commitment to the bioeconomy—traditional and new—MSU has a portfolio of patents and intellectual assets as well as capacity, international connections, national stature as home of one of the top three plant science programs in the world, and research programs in this field that extend beyond agriculture and plant science to include all disciplines: chemistry, biochemistry, physics, engineering, entrepreneurship, logistics, packaging, and more.

We also have a number of economic structures in place and have partnered with state government (Michigan's) to develop incentives and facilities to support entrepreneurs in bioeconomy-related and other ventures. Our faculty members have dozens of approved patents based on biotechnology-related research that are already being used in small companies throughout Michigan and many more are available for licensing. As an example, 15 patents resulting from the research of University Distinguished Professor Kris Berglund are at the heart of Diversified Natural Products (DNP) of Scottville, Michigan, an entrepreneural company in which Dr. Berglund is a principal. DNP is leading the development of methods by which succinic acid can replace petrochemical-based chemicals using MSU-developed research and technology.

Other MSU research under development in new business ventures involves more efficient and cost-effective ways of producing cellulosic ethanol, increasing the yield of oil producing plants (to use in biomass conversion), converting the byproduct glycerin to chemicals, and creating environmentally friendly packaging materials from corn starch blown-foam. These companies, working with MSU, now have international branches in France and Sweden.

[1] The Biomass Conversion Research Lab, the Biomaterial Division of the Composite Materials and Structures Center, the MSU Plant Transformation Center, the MSU Product Center for Agriculture and Natural Resources, the Advanced Technology Applications to Eastern Hardwood Utilization, and the MSU Office of Intellectual Property, among others

*Michigan State University (MSU) has been advancing knowledge and transforming lives through innovative teaching, research, and outreach since it was founded as the pioneer land-grant university in 1855. As a land-grant, MSU's mission has been to embrace practical knowledge as well as traditional scientific and classical studies to apply the rewards of higher education to the benefit of society and the public good. From research-based agricultural innovations in the nineteenth century to biobased research today, MSU has remained true to its mission—taking ready advantage of the kaleidoscope of research findings to move the world forward with practical advances. As the nation and world move from an industrial to a knowledge-based economy, MSU stands ready to find the knowledge necessary to meet today's needs—and has the experience to apply that knowledge to real-world challenges.*

# Michigan Advantages

Michigan understands that it will take a long-term commitment to nurture the bioeconomy through its infancy.

In some ways, the bioeconomy is no different than other types of commerce – it needs a supply of inputs, a demand for the outputs, and a supportive environment in which it can grow.

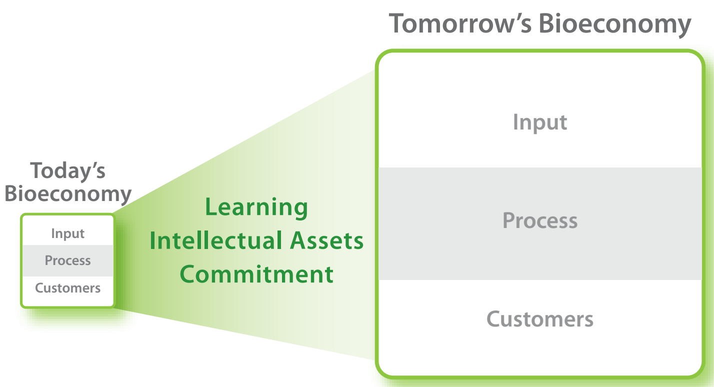
**On the supply side, Michigan stacks up very well:**

- Broad range of biomass sources including a diversified agricultural sector and abundant forest resources
- Well managed and available water resources
- Industrial infrastructure
- Excellent transportation and logistics resources

**On the demand side, Michigan is also very strong:**

- Proximity to major Midwestern population markets
- Proximity to diverse manufacturing markets
- Excellent transportation and logistics resources
- Access to “NAFTA Highway”

But what really sets Michigan apart is what is “in the middle” — the intellectual and educational foundation to propel growth.




**PATHWAY TO GROWTH**

Michigan understands that in an emerging sector, the needs of the organizations making up the sector will evolve rapidly as experience is gained with the new bioeconomy products and services being developed. Recognizing this, Michigan is committed to building the supportive environment that will enable these organizations to grow and evolve.

The components of this include:

- Commitment to the bioeconomy at all levels
  - State government
  - Grant programs and startup capital
  - Higher education
- A strong community of leading bioeconomy research organizations is already in place and growing
  - Michigan State University
  - MBI International
  - NextEnergy
- A network of industry participants with a history of working together is ready to support bioeconomy growth.
  - Michigan Economic Development Corporation
  - Michigan Department of Agriculture
  - Michigan Agri-Business Association
  - Michigan Farm Bureau
  - Michigan Forest Products Council
  - Michigan Biotechnology Institute (MBI)
  - MSU Product Center for Agriculture and Natural Resources
  - Michigan Agricultural Experiment Station
  - Michigan State University Extension

# Michigan Partners for a Bioeconomy

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# Biofuels and Higher Value Byproducts

MICHIGAN STATE UNIVERSITY

## The Opportunity

Converting biobased resources into biofuels produces not only the energy desired but secondary products. These secondary products, or byproducts, of biofuel production will potentially be as valuable as the biofuel itself, making the future production of biofuels even more economical and profitable. Further, unlike petroleum-based products, these byproducts hold the promise of safe applicability, increasing their "green" appeal—and the volume will continue to increase as a renewable resource with the production of biofuel.

MSU Plant Biology Professor Michael Thomashow and his colleagues work to develop cellular structure to increase oil production in Arabidopsis plants.

## Advantages

- The volume of co-products from the production of biofuels is and will generally continue to increase proportionally to total production.
- Biorefineries are seeing the value in using all biomass molecules.
- Demand for biodegradable plastics is immense.
- Biobased products are recyclable.

## Products

- Polylactic acid
  - › Food packaging
  - › Apparel industry
- 1, 3-propanediol (made from the fermentation of carbohydrates)
- Crop sugars that can be processed into three-carbon and six-carbon carboxylic acid:
  - › Hydropropanoic acid
  - › Glucaric acid
- Nonethanol alcohols:
  - › Glycerol
  - › Sorbitol
- Biodegradable plastics
- Components in carpeting
- Glycerin

## Challenges

Current demand for biobased byproducts is limited. Specific challenges include:

- Developing new uses and products from byproducts to create and sustain financially viable bioeconomy firms
- Creating byproducts to meet market needs
- Enhancing ways to produce byproducts in a cost-effective manner

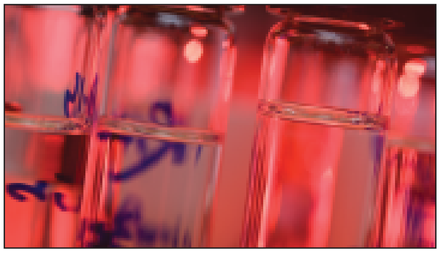
## Meeting the Challenges in Michigan

Michigan strengths:

- Patents
- Technical knowledge base
- Supporting laboratory and development resources
- Underutilized manufacturing infrastructure

### Research strengths

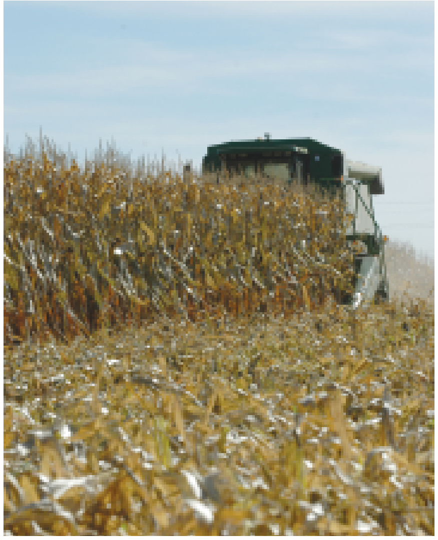
Researchers at Michigan State University (MSU), a leader in biobased products research and development, envision a future where markets will value the byproducts from biobased fuels as much as the biofuel itself, so they're investing energy and resources in developing them concurrently, ultimately creating multiple markets instead of just one.



MAES researcher and MSU Professor of Chemical Engineering Dennis Miller works towards developing a continuous production process for biodiesel fuel.

## Current research at MSU

- MSU's Dr. Dennis Miller of the Department of Chemical Engineering is leading research on economical ways to produce ethyl lactate as a byproduct of ethanol. Ethyl lactate is a high-performance solvent, which, unlike its petroleum-derived counterparts, is nontoxic and biodegradable.
- MSU researchers are on the forefront of exploring new possibilities for converting glycerin to chemical products that could ultimately be used to produce nontoxic antifreeze or even as fuel additives.



Corn grown on MSU land is harvested and used in research and development

## Biobased innovations at MSU

- The production of caprolactam and succinic acid and their conversion to a variety of materials
- The synthesis of shikimic acid (the precursor of Tamiflu™)
- Commodity chemicals from sugar beets
- Novel composite materials for avionics and construction
- Corn starch blown-foam packaging materials

Professor Ramani Narayan's Magic Nuudles, eco-friendly arts and crafts construction materials derived from an eco-friendly packaging development

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# Biobased Chemicals

MICHIGAN STATE UNIVERSITY

## The Opportunity

For the past 100 years, chemistry has been driven by the use of small molecular fragments derived from petroleum. This chemistry is responsible for producing much of the world's chemicals, drugs, plastics, dyes, and resins used throughout industry and day-to-day life. But petroleum's days as the be-all, end-all of production and innovation are numbered due to its cost, its negative impact on the environment, and the political concerns surrounding its sources. Indeed, the very fact that it is a nonrenewable resource whose supplies cannot meet the needs of a developed world that now includes China and India renders it a resource ripe for replacement.

Soybean and corn fields on the MSU campus

One of the biobased chemicals proving its value as a petrochemical substitute is succinic acid. Michigan State University (MSU) has conducted considerable research focused on enhancing the effectiveness of succinic acid as an input in numerous applications, with promising results. Succinic acid, a four-carbon dicarboxylic acid, has the potential to become an important commodity chemical that could form the basis for supplying numerous intermediate and specialty chemicals employed in a range of consumer product industries. Succinic acid and its salts, therefore, form a platform from which many chemicals and resulting products can be supported.

## Products and Advantages

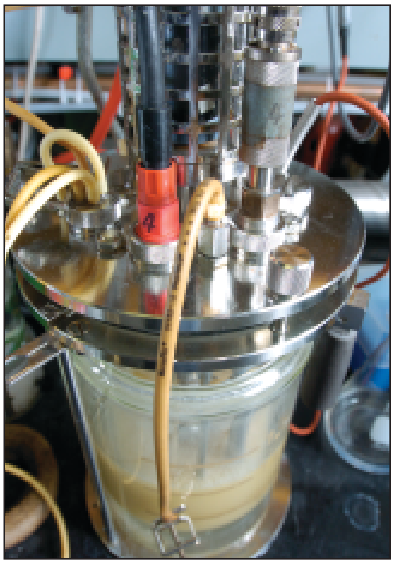
- An industrial input to replace petrochemical-based sources
- Energy savings (of succinic acid over petro-based equivalent) estimated to exceed 9.8 trillion Btu annually
- Environmentally friendly technology—based on natural sugars derived from corn and wheat
- $1.3 billion market
- Plastics
- Surfactants and detergents
- Chemical-free cosmetics
- Clothing fibers
- Food
- Pharmaceuticals
- Biodegradeable solvents
  - Used in adhesives, printing inks, and coating resins, and as intermediates for producing other solvents and chemicals
  - A green replacement for tetrahydrofuran and 1, 4-Butanediol
- Environmentally friendly inputs for deicers (for airport runways)
  - Current inputs are environmentally detrimental.
  - Current inputs cost $0.46 to $0.88 per pound.

## Challenges

- Still under research
- Lowering the current cost of producing succinic acid

## Meeting the Challenges in Michigan

Research and applicable advances at Diversified Natural Products (DNP) of Scottville, Michigan, illustrate the power of public collaboration with entrepreneurial applications of science. DNP's chief science officer is Michigan State University Distinguished Professor Kris Berglund of the Department of Chemical Engineering and Materials Science. Indeed, 15 of DNP's patents have sprung from his research at MSU. Built at a site developed with the assistance of State of Michigan credits for brownfield development,



Microbes are created in this fermentation chamber in the lab of chemistry professor John Frost

DNP is leading in the development of methods by which succinic acid can replace petrochemical-based chemicals. These technologies serve as the starting point for chemicals that can:

- Lower the freezing point of water, enabling the manufacture of safer engine coolants and runway deicers
- Serve as biodegradeable solvents
- Provide biodegradeable polymers for use in plastics

### Lower production costs

- Research advances have reduced the cost to produce biobased succinic acid by 75 percent over the last decade.
- Further cost reductions are anticipated as larger-scale manufacturing methods can be employed—an area of expertise in Michigan.

### Related innovations

- DNP's Natural Health Division grows and develops numerous natural products for consumers:
  - › Gourmet mushrooms—grown year-round based on scientific methods
  - › Health supplements
  - › Food ingredients that reduce unpleasant aftertaste in salt-substitutes
  - › Pharmaceuticals
- A natural cholesterol-reducing compound
- Products to inhibit oxidants
- Pain and inflammation relievers
- Immune system boosters
- DNP produces environmentally friendly products for large-scale industry:
  - › Runway deicers and engine coolants for reducing toxic substances
  - › Biobased solvents for replacing chlorinated and volatile solvents
  - › Diesel fuel additives for reducing particulate emissions
  - › Specialty chemicals for biodegradable chelators and detergent builders

Professor Ramani Narayan's Magic Nuudles are poured into crates as they are made at KTM.

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# Plastics and Biofiber Composites for the Auto Industry

MICHIGAN STATE UNIVERSITY

## The Opportunity

In recent years, significant strides have been made in developing and producing biobased polymers. These polymers, or bioplastics, are useful in many applications and, with the addition of reinforcing fibers, can achieve desirable levels of performance with respect to thermal, moisture, and mechanical durability across a wide range of applications. Michigan's success in conducting biobased research resulting in biobased products—combined with its history in high-tech manufacturing, particularly in the auto industry—make it the perfect place for these two technologies to come together to advance the production of biobased products for cars to enhance profits for industry and benefits for the environment.

A detail of biocomposite material at an early stage

## Advantages

- Biofibers are developed from native switchgrass, flax, kenaf, hemp, jute, coconut fibers, and sisal—all easily grown and renewable resources.
- Plant-based fibers used as input for interior and exterior parts of vehicles can be recycled.
  - Currently, Europe requires that 80 percent of its automobiles be recycleable.
  - This percentage will rise to 90 percent by 2015.
  - Successfully producing such products ensures a market in Europe.
- Producing biofibers requires 83 percent less production energy used than that expended for glass fiber
- Biofibers are cost competitive with petroleum, natural gas, and other forms of energy.
- Some biofiber-based products enhance the performance of certain automobile parts.
  - Biofiber reinforced polymers show high tensile strength and stiffness and also act as a coating.
  - Some biofiber-based fibers provide the same level of performance as glass composites at a lower weight.
- Biofibers are also effective noise reducers, provide good insulation, are more shatter resistant, and have better energy management characteristics than glass-based composites.
- Some biobased automobile components are less destructive to machinery and less toxic to workers.

## Products

The variety of products developed from bioplastics and biofiber composites is extensive and increasing:

- Seat backs
- Side and back door panels
- Trunk/Boot lining
- Spare tire lining
- Windshields
- Dashboards
- Door armrests
- Insulation
- Body side moldings

In addition to products for the automobile sector, opportunities to use these same materials in other products are immense.

## Challenges

- Consistent quality of fiber materials
- Less strength than glass fibers
- Moisture-absorbing qualities of natural fibers can produce unpleasant odors
- Requires reconfiguration of the supply chain

Dr. Lawrence Drzal, professor of chemical engineering and materials science and mechanics, in his laboratory

## Meeting the Challenges in Michigan

Research on bioplastics and biofiber composites is extensive at Michigan State University (MSU). The Composite Materials and Structures Center (http://www.egr.msu.edu/cmsc/biomaterials/index.html), led by Dr. Lawrence Drzal, is already investigating how to counter the challenges of biofibers to assure their consistent quality and safety for the automobile industry. Through partnering with Ford and General Motors along with plastic technology companies, the center and others at the university are working to address the following types of challenges:

- Consistent quality is being sought through grading and genetic engineering of particular plants.
- Increased strength in biobased fibers is being pursued through genetic engineering.
- Research on decreasing moisture absorption in biobased fibers focuses on:
  - Fiber surface treatments that repel water
  - Use of resins and other additives
  - Nanotechnology

Michigan State University is already steeped in research on biobased products and works with the automobile industry to increase its productiveness. Applying MSU's biobased research to further auto industry needs is a natural extension of MSU's research and its commitment to growing the economy of Michigan. Collaboration between the auto industry and MSU is good business, good research, and good sense.

Dr. Lawrence Drzal's biocomposites group in the laboratory

Biopolyomer base material in Dr. Ramni Narayan's lab

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# Biorefineries

## The Opportunity

As the bioeconomy continues to expand, biorefineries designed to convert biomass into biofuels, bioenergy, and/or bioproducts will need to be built to meet the growing use of renewable resources in place of many petroleum-based inputs and products. Michigan, a leader in biotechnology innovations, is eager to add this component to its bioeconomy investment to complete the production cycle of converting biomass to usable, renewable products.


Soybean and corn fields on the MSU campus

## Advantage

- A biorefinery located near the source of biomass saves on transportation costs.

## Michigan Advantages

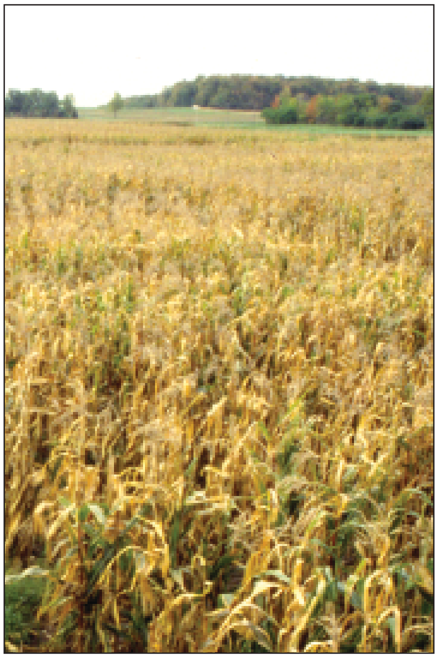
Michigan is uniquely positioned to cultivate, build, and support a bioeconomy with a strong biorefinery infrastructure.

- Existing infrastructure – The biorefinery concept has long been in place in the pulp and paper industry, where wood is converted into pulp for papermaking and various byproducts used to produce chemicals, fibers, and plastics.
- Location – Availability of biomass, availability of capital resources, and availability of an infrastructure and support services:
    - › Michigan has a large and diverse supply of forest and agriculture-derived biomass located throughout the state.
    - › Michigan has existing manufacturing facilities that are appropriately zoned.
    - › Michigan has a strong infrastructure and supporting services already in place to facilitate the efficient transporting of biomass inputs and biorefinery products.
- Labor – Michigan possesses a skilled and diverse labor force due to the strong manufacturing, forestry, and agricultural industries located within the state.
- Bioeconomy-skilled professionals – Michigan's globally recognized universities and colleges and the diverse private sector (including agriculture, forestry, and manufacturing) provide a rich resource of educated and skilled lab technicians, chemists, engineers, managers, and biotechnology specialists.
- Water – Michigan has readily available reserves of water in addition to adequate annual precipitation.
- Investment – Michigan's financial resources include angel investors, venture capital funds, federal and state financial support and grants, and investment and commercial banks. Specific sources include:
    - › WIRED (Workforce Innovation in Regional Economic Development) grant – A $15 million federal grant has been awarded to the Mid-Michigan Innovation Alliance. It will be used, in part, to jump-start a biomanufacturing industry in mid-Michigan.
    - › Technology Industry Group at the Bank of Ann Arbor
    - › Grand Angels
    - › DaVinci Capital


Great Lakes freighter Black Bay loads her hull with corn in Ohio from Michigan

- New technology and intellectual property – Access to cutting-edge technological platforms and intellectual property is mandatory to maximize the productive and economic potential of biorefineries.
  - › MSU – A leading research and land-grant university, MSU is a committed leader in the agriculture and forestry industries and home to several centers focusing on topics relevant to the bioeconomy.
    - –MSU Product Center for Agriculture and Natural Resources, www.aec.msu.edu/product
    - –MSU Plant Transformation Center, www.ptc.msu.edu
    - –Biomaterial Division of the Composite Materials & Structures Center, www.egr.msu.edu/cmsc/biomaterials
    - –Biomass Conversion Research Lab, www.everythingbiomass.org
    - –Advanced Technology Applications to Eastern Hardwood Utilization, http://forestry.msu.edu/hardwood/
    - –MSU Office of Intellectual Property, http://oip.msu.edu/
    - –University of Michigan
    - –Michigan Technological University
    - –MBI International, based in Lansing, Michigan, works with individuals, industry, and government to develop and commercialize biobased technologies.
    - –MichBio (Michigan Biosciences Industry Association), is a nonprofit organization dedicated to driving the growth of the life sciences industry in Michigan.
- Responsive government and public sectors – Local and state governments and the public sector are committed to the philosophy and the economic well-being of a bioeconomy.
  - › Twenty Agricultural Processing Renaissance Zones in Michigan are administered by the Michigan Economic Development Corporation (MEDC) and exempt from all state and local taxes for "qualified agriculture processors" who want to expand or begin processing operations in Michigan.
  - › MEDC is geared toward assisting and promoting economic development in the state.

Michigan understands the important role that biorefineries will play in the future bioeconomy infrastructure and is committed to building the refineries and service sector needed to support the growth of biorefineries and, ultimately, the bioeconomy.

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# Pharmaceuticals from Crop Residue



## The Opportunity

Pharmaceuticals are nearing a $1 trillion annual market. Aging populations and developing nations insure that the demand for medicines will continue to increase. Biotechnology is already a major factor in pharmaceutical manufacturing, with 20 percent to 30 percent of the industry employing fermentation or enzyme catalysis in the manufacturing process. High-priced fossil fuels and growing environmental sensitivities coupled with advances in science and technology offer exciting opportunities for growth in the use of biobased materials to replace petrochemical-based inputs. With a 150-year history of innovation in chemistry and agricultural innovations, Michigan State University (MSU) is well equipped to further the development and production of biobased chemicals for pharmaceutical use.

Winter wheat looking healthy in May

## Advantages

- Low environmental impact, particularly versus petrochemicals
- Renewable resources, such as agricultural residues
    - For example, scientific innovation and entrepreneurship in Michigan has demonstrated that the pulp left over from sugar beet processing can serve as the basic input for the production of high-value inputs to the drug manufacturing industry.
- Biobased components for chemicals that can be far less expensive than petrochemicals
- Specialty chemicals for use in pharmaceuticals
- Drugs from biobased chemicals that have high per-unit value and low unit volume

## Products

A broad range of biobased pharmaceutical products are possible, including:

- Cardiovascular drugs
- Anticancer drugs
- Antibiotics, antifungals, and antivirals

## Challenges

- Developing under- or un-utilized biologically based resources
- Access to underutilized resources
- Increasing the efficiency in manufacturing processes through the use of improved micro-organisms and enzymes to reduce drug manufacturing costs
- Reconfiguring the value chain to accommodate the new products and production processes

## Meeting the Challenges in Michigan

Providing a stream of commercial innovations over time, whether through entrepreneurial or corporate entities, requires continual innovation, research, and development. Michigan State University is a leader in the application of science to unleash the vast potentials locked within carbohydrates. MSU is committed to advancing the replacement of petrochemicals with biobased products of commercial and societal benefit.

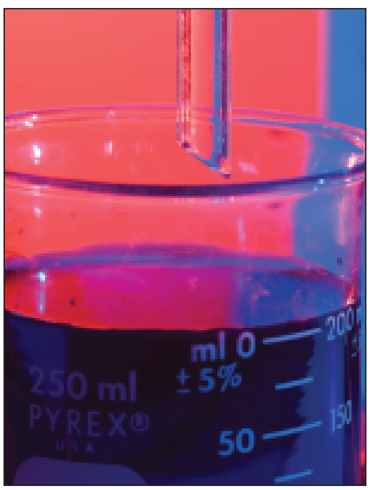
Chemistry developed at Michigan State University is being used on a daily basis around the world in the discovery, development, and manufacture of drugs addressing the entire spectrum of diseases. Resources include:

- MSU's Laboratory for Advanced Applications in GlycoChemistry (LAAGC), http://laagc.bch.msu.edu
    - LAAGC provides a more effective means to disseminate knowledge and expertise in glycochemistry through collaborative research, advising and consulting, strategic alliances and industrial liaisons, out-licensing, and education and instruction.

- LAAGC's mission is to provide a national and international resource to academia and industry in the chemistries and applications of carbohydrates and materials provided by agriculturally derived raw materials.
    - The lab is driven by the recognition that carbohydrates both are the most abundant organic materials on earth and are materials whose full potential as a renewable resource to better human well-being has not been achieved.
- LAAGC serves as a consulting service for research projects and develops collaborations and strategic alliances and liaisons with industries.

• AFID Therapeutics (advances frontiers in drug design, discovery, development, and delivery) located in Lansing, Michigan.

- Based on licensed discoveries made by MSU's Dr. Rawle Hollingsworth of the departments of Chemistry and Biochemistry and Molecular Biology




MAES researcher and Professor of Chemical Engineering Mark Worden studies how to turn what is now considered waste into high-value chemical products.

- Uses chemical technology that allows the rapid synthesis of compound libraries
- Received cash grant from Michigan's Technology Tri-Corridor, illustrating Michigan's commitment to public-private collaboration to support the advance of the bioeconomy
- Possesses chemistries for the preparation of chiral amides, esters, lactones, pyrrolidinones, epoxides, oxazolidinones, pyrrolidines, iminopentitols, iminohexitols, and other classes of compounds.

Microbes are created in this fermentation chamber in the lab of Chemistry Professor John Frost.

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# Forestry and Forest Products

MICHIGAN STATE UNIVERSITY

## The Opportunity

Forests are a predominant feature of the Michigan landscape. Covering more than 52 percent of the state, nearly 19 million acres of forest land representing nine major forest types contribute directly to Michigan's economy through timber production and forest products industries. Only four other states can boast of more acres of commercial forest land than Michigan. Already a leader in forest management, Michigan understands firms can profit from better utilizing the state's abundant forest resources as biomass and still maintain the environmental and recreational services now provided by these resources.

Wood processing in Presque Isle Co., Michigan, is a major part of the economy.

## Advantages of Forests as a Biomass Source

- Forests are available year-round, highly productive, and less subject to year-to-year variations in growing conditions than agricultural crops.
- More than 50 percent of the currently used biomass comes from wood residues and pulping liquors generated by the forest products industry.
- Sourcing biomass from forests and the wise use of forest resources can enhance the environmental and ecological services they provide, including carbon credits.
- The amount of forestland-derived biomass that can be sustainably produced is about 368 million dry tons annually—more than 2.5 times the current consumption.
- Logging and other removal residues can easily be recovered following commercial harvest and land-clearing operations.
- Fuel treatment thinnings can be recovered with efforts to reduce forest fire hazards and improve forest health.
- Forests provide an opportunity for carbon sequestration, and well-managed forests do a better job of this process.

## Potential Products

Forest-derived biomass can be applied to a range of uses:

- Biopower (direct combustion of biomass feedstock to produce electric power or heat)
- Biofuels
  - Cellulosic ethanol
  - Bio-oils for biodiesel
- Bioproducts
  - Cellulose fiber products
  - Structural components such as wood-plastic composites and wood-substitute products
- Chemicals

## Challenge

- The technology for producing cellulosic ethanol is still in the development phase.

## Meeting the Challenges in Michigan

### Natural assets

Michigan is well-positioned to meet the biomass feedstock goal because of its many forestry-based assets, which span the spectrum from research and development of innovative products and technologies of fiber-based products to production and delivery of revolutionary biofuels and bioproducts sourced from the forest. These assets include:

- Diverse, healthy, and accessible forests with growth exceeding harvest rates
- An established forest products industry with excess facilities and existing infrastructure available for alternative uses

Due to Michigan's natural resources and the history and extent of its forest products industry, the state has a strong existing fiber supply chain, including almost 1,900 logging companies, about 500 furniture and fixtures companies, and approximately 230 paper and allied products companies. As a result, Michigan's forest products industry is well-positioned to support new uses of forestry resources with:

- A workforce trained in harvesting and milling of forest products

- Supporting services to the forest products industry (equipment, supplies, insurance, policies, etc.)
- Physical infrastructure (roads, trucks, tractors, loading and unloading, staging areas)

### A diverse and strong technology and research base

- MSU's Advanced Technology Applications to Eastern Hardwood Utilization Center.
  Examples of research related to forestry and biomass are:
  - MSU's Dr. Laurent Matuana, Department of Forestry, is researching how to utilize Eastern hardwood species and wood sawdust from hardwood waste in the manufacture of wood-plastic composites and their foams.
  - MSU's Dr. Donatien-Pascal Kamdem, Department of Forestry, is investigating methods to recycle preservative-treated wood to raw materials for wood fiber composites. Specifically, thermoplastic and cement will be used to manufacture wood fiber thermoplastic and wood cement particle-boards. Their properties will then be compared to that of commercial sources to test their commercial feasibility.
- MSU's Biomaterials Division of the Composite Materials and Structures Center.
  Three faculty members are on staff:
  - Dr. Lawrence Drzal, University Distinguished Professor and director, researches surface and interphase phenomena, adhesion, fiber-matrix bonding, surface modification of polymers, and biomaterials.
  - Dr. Manjusri Misra, associate professor, conducts research activities in the area of biobased composites and "green" nanocomposite materials.
  - Dr. Amar K. Mohanty, associate professor, researches "green" and applicable biobased product development.
- MBI International, a Michigan-based company, targets practical innovations in biotechnology:
  - Lignocellulose-based biorefineries for making cellulosic ethanol more economical
  - Pyrolytic production of biodiesel from wood, wood composites, and cellulose nanofibers
- MBI is also developing technologies for cellulose nanofibers.

### Extensive state incentives and efforts to sustain forests

- Michigan's Forest Legacy Program (FLP) is a partnership with the U.S. Department of Agriculture Forest Service to protect privately owned and environmentally significant forest lands from being converted to nonforest uses.
- The Forest Finance Authority has been given the task of bringing Michigan fiber to market through numerous efforts, including promoting infrastructure development and timberstand improvement. It also has money set aside for biomass research.
- The Commercial Forest program provides a property tax reduction to private landowners to retain and manage forestland for long-term timber production.

Fifty-two percent of Michigan land is forest.


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