Future Scenarios for Michigan's Bioeconomy: Planning Your Strategic Responses

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Michigan State University's Product Center for Agriculture and Natural Resources, under the direction of the MSU Bioeconomy Network, is offering a series entitled, "Status of Michigan's Bioeconomy: Progress & Evolving Potential." The purpose of the series is to better inform decision-makers and bioeconomy stakeholders about a range of issues and opportunities related to the still emerging bioeconomy, especially in Michigan.

The papers in the series include:

- *Advancing the Bioeconomy: Overview of Michigan's Progress*
- *Michigan's Position in the U.S. Biofuel and Bioenergy Market*
- *Potential Future Scenarios of Michigan's Bioeconomy*

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EXECUTIVE SUMMARY

"Future Scenarios for Michigan's Bioeconomy: Planning your Strategic Responses" is the third in the series of white paper reports prepared by the MSU Product Center for Agriculture and Natural Resources on the "Status of Michigan's Bioeconomy: Progress & Evolving Potential." This white paper presents the findings and analysis of an extensive scenario planning effort done by the Product Center and Shepherd Advisors that examines characteristics and potential outcomes of distinct scenarios for Michigan's bioeconomy future. The purpose of the paper is to paint a vivid story about a possible future state of the world that is both *believable* and *plausible* (though not necessarily *probable*). The scenarios provide a range of potential outcomes that arise from different resolutions of key uncertainties in the bioeconomy market. The analysis also describes approaches that decision-makers (public and private) could use to develop strategies that allow them to respond to and operate in each of the given scenarios. The analysis is not intended to suggest a particular scenario that is ideal or is more or less likely, but to present the range of possibilities to help decision-makers target desired outcomes – and prepare appropriately for all of them.

With extensive input from MSU and external bioeconomy stakeholders regarding key trends and forces in the bioeconomy, the Product Center and Shepherd Advisors created five plausible scenarios for the bioeconomy that can be described as follows:

> ***Scenario 1 – Thriving Bioeconomy:*** *Everything related to the bioeconomy works; technology saves the day; advances in the harvesting and processing of biomass; food vs. fuel resolved through improvements in land productivity and crop efficiency; biobased products are very cost-competitive with fossil fuel counterparts – buying bio is a natural choice economically.*
>
> ***Scenario 2 – Business as Usual:*** *No radical changes from the path we're on today; petroleum still the lifeblood; bioeconomy still exists with some marginal advancements; technology advances help both improve biomass harvesting and processing AND petroleum processing/use; policy and market support for bioeconomy is decentralized and not comprehensive; corn ethanol still primary biofuel, but dampened by continued food vs. fuel debate.*
>
> ***Scenario 3 – Climate-Driven Bioeconomy:*** *Climate change disrupts food production, and so in the food vs. fuel debate, food wins; public policy plays a large role in shaping this future; engine efficiency, electrification, and public transit drive down overall demand for fuel, yet the demand for biofuels is strong and makes up a larger share of the overall fuel demand; corn ethanol declines; dismissed as a viable alternative, but cellulosic biofuels grow in importance; renewable and nuclear energy play a larger role, with policy supports; biobased materials and chemicals find a strong niche market.*
>
> ***Scenario 4 – Strategic Biofuels Imperative:*** *Domestic home grown energy security is primary issue; anti petroleum view prevails; government policies against importing*

petroleum are driving the success of biofuels, forcing cost competitiveness of biofuels; little market activity in biomaterials and chemicals; food vs. fuel still an issue.

Scenario 5 – Deathanol: *Bioeconomy is dead; technology advances to make it competitive never materialized and policy supports are gone; advances in vehicle electrification, alternative energy allow us to wean off our use of foreign oil; chemicals and materials still predominately made from petroleum – sourced domestically; Overall carbon footprint is better*

Table 1 in the report summarizes the key implications for various sectors of the bioeconomy under each scenario. In order to better understand some of these implications for the state of Michigan, the Product Center and Shepherd created an Excel-based, regional biofuel model that provides a baseline comparison of Michigan's bioeconomy resources vs. surrounding Great Lakes states. The model is primarily biofuels-oriented, but provides insight into the strength and interplay of the various drivers that shape not only the biofuels market, but the broader bioeconomy as well.

The model outputs demonstrate that under the scenarios where the current corn-ethanol-dominated biofuels market continued to predominate, Michigan would benefit less compared to neighboring Great Lakes states because it has the lowest level of corn ethanol production in the Great Lakes. However, in scenarios that require significant future production of cellulosic biofuels, Michigan's significant forestry resources gives the state an opportunity to be a relatively strong bioeconomy leader among Great Lakes states. As cellulosic biofuels become a greater part of the market, and particularly under a scenario in which cellulosic biomaterials (chemicals, other products) also gain prominence, Michigan's substantial forestry resources provide opportunities for relatively greater bioeconomy success.

Using the bioeconomy scenarios and the modeling data that help illustrate some of the resource and sector implications for Michigan and its neighboring states, public and private decision-makers in Michigan can begin to develop appropriate strategies to lower risk and increase opportunity to thrive under different scenarios. With strategies in place, stakeholders can then monitor variables related to key drivers to better understand which scenario is actually unfolding over time. The key drivers for different bioeconomy scenarios identified in this analysis are broadly categorized as 1) technology breakthroughs, 2) level of investment, 3) policies, 4) consumer values and behavior, and 5) biomass availability. As decision-makers develop strategies to both encourage and respond to different scenarios, and then track which scenario is actually developing over time, they will be relatively better positioned to both survive and thrive as Michigan's bioeconomy unfolds.

INTRODUCTION

"Future Scenarios for Michigan's Bioeconomy: Planning your Strategic Responses" is the third in the series of white paper reports prepared by the MSU Product Center for Agriculture and Natural Resources on the "Status of Michigan's Bioeconomy: Progress & Evolving Potential." This white paper presents the findings and analysis of an extensive scenario planning[1] effort done by the Product Center and Shepherd Advisors that examines characteristics of distinct scenarios for Michigan's bioeconomy future. The purpose of the paper is to paint a vivid story about a possible future state of the world that is both believable and plausible (though not necessarily probable). The scenarios provide a range of potential outcomes that arise from different resolutions of key uncertainties in the bioeconomy market. The analysis also describes approaches that decision-makers (public and private) could use to develop strategies that allow them to respond to and operate in each of the given scenarios. The analysis is not intended to suggest a particular scenario that is ideal or is more or less likely, but to present the range of possibilities to help decision-makers target desired outcomes – and prepare appropriately for all of them.

To further facilitate the construction and evaluation of the potential scenarios, the Product Center and Shepherd refined an existing Shepherd/Product Center biofuel model for Michigan to reflect some of the relevant material aspects of the potential scenarios, and provide insights about how Michigan's future bioeconomy may compare with those of neighboring Great Lakes states. (For information about the current bioeconomy in these states, please see white paper 2: "*Michigan's Position in the U.S. Biofuel and Bioenergy Market.*")

More specifically, the expanded bioeconomy model and the potential scenarios describe (1) factors that shape various scenarios, (2) present a range of future bioeconomy inputs and products that are more likely under different scenarios, and (3) identify cross-cutting and unique strategies for increasing opportunities for Michigan to more fully realize its bioeconomy potential.

For the purposes of this report series, the Product Center defines the bioeconomy as "*any commercial or industrial effort that is based on the conversion of growing, renewable biomaterials into products that replace petrochemical or fossil fuel-based products."*

[1] The Product Center and Shepherd conducted a modified version of the scenario planning process developed by the Royal Dutch Shell Company. For more information on this type of scenario planning see: http://www.shell.com/home/content/aboutshell/our_strategy/shell_global_scenarios/

BIOECONOMY SCENARIO PLANNING – METHODOLOGY

The initial purpose of developing and modeling the five scenarios was to help MSU faculty members and leaders better understand the opportunities for and constraints in advancing the state's bioeconomy.

Scenario planning is a strategic planning method intended to describe future scenarios that are possible and plausible. Primarily developed for business applications by Royal Dutch Shell in the 1970s, scenario planning is a process for generating and evaluating strategic options. It is not intended to predict the future. When a company or organization employs scenario planning, the company can create flexible long-term plans adapted for the various plausible future scenarios. Figure 1 below outlines the scenario planning process the Product Center and Shepherd Advisors adapted for this effort.

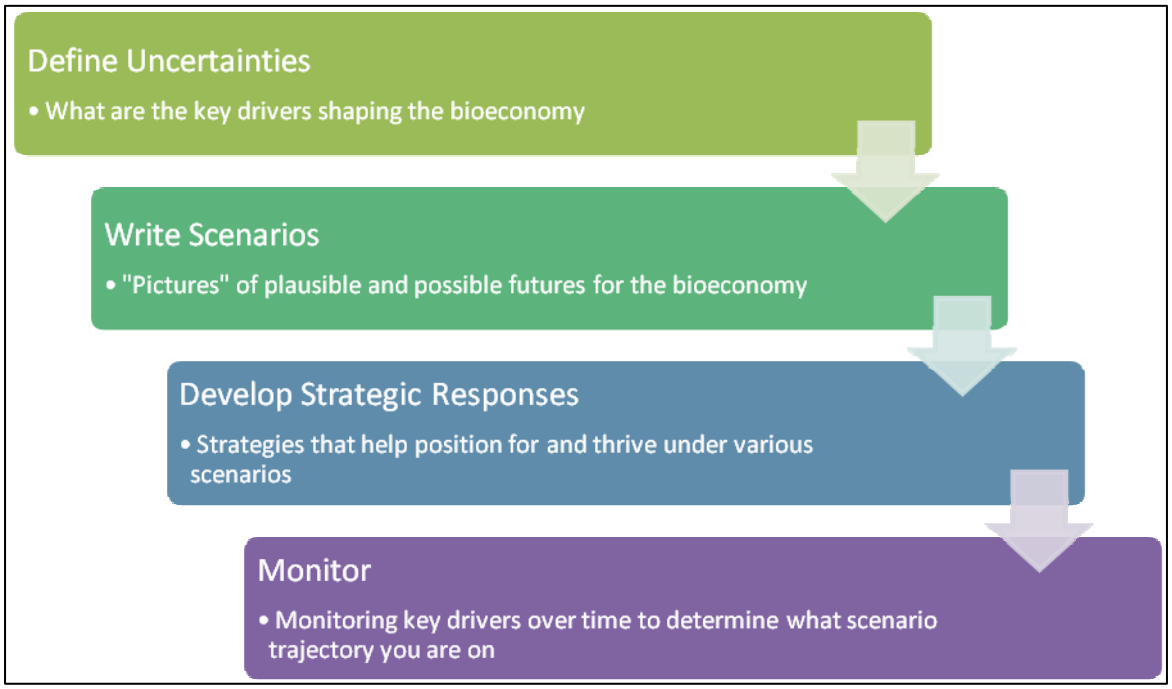

FIGURE 1: BIOECONOMY SCENARIO PLANNING PROCESS

The scenario planning effort first gathered input from MSU internal and external bioeconomy stakeholders to help identify key drivers that would shape the bioeconomy scenarios and to develop and verify data points for the bioeconomy planning model. Shepherd Advisors interviewed nine MSU faculty members and external stakeholders regarding their views on the evolving potential of the bioeconomy in general, and in Michigan specifically. The interviews were structured to solicit information regarding:

- how stakeholders defined the bioeconomy
- the two or three fundamental forces shaping Michigan's bioeconomy over the next 15 years
- the direction of those key forces

- the role of some specific drivers such as the macroeconomy, consumer preferences for green products, and technology advancements

A summary of key observations from the interviews is attached in Appendix A.

Initial input from the discovery stage and significant internal discussions with the Shepherd/Product Center team were then used to develop a set of five distinct bioeconomy scenarios for the national bioeconomy. In order to further refine and evaluate the plausibility and believability of the scenarios, they were given to a group of more than 30 faculty members associated with MSU's Bioeconomy Network. The faculty members were given a chance to review the scenarios and then they were used as the focal point for a workshop discussion regarding MSU's role in engaging with industry to advance Michigan's bioeconomy.

These scenarios are described in detail in the next section of the paper. In addition, for each of the scenarios the Shepherd/Product Center team developed a price schedule for several variables, including petroleum, a potential carbon or gas tax, corn bushels, and gasoline and ethanol costs to produce. The price schedule was used to verify and validate the scenarios, and identify key variables that would interplay to create certain aspects of the scenarios. The price schedule is included in Appendix B.

The faculty participants all agreed that each of the distinct scenarios were both believable and plausible, and the participants agreed that there were conditions under which each of the scenarios, or a combination of scenarios, could be more likely. There were also minor changes made to the scenarios to reflect the workshop discussion, including a fuller recognition of the role of abundant coal.

BIOECONOMY SCENARIOS 2029

The scenarios begin with a short introduction of the Baseline Future that lays out the relative certainties (vs. those things that are truly *uncertain*) related to the five variables that cut across all five scenarios, derived from interviews of numerous experts in the field. This is followed by summaries of the individual scenarios of the future being considered, and a description of how each future scenario affects the various aspects of the bio-economy.

Baseline Future

The price of oil has been steadily rising, albeit with considerable volatility, since the early 2000s and continues to do so through 2030. The magnitude of this rise is unclear and the jury is still out on the peak oil debate as worldwide supplies have only barely begun to flatten out. Technology advances have been steady across many sectors of the bioeconomy, alternative energy, and automotive sectors. A U.S. carbon cap-and-trade program has been in effect for a number of years, although the greatest emissions reduction standards are just beginning to be phased in. Consumer awareness has also moved markets towards more sustainable goods, as people chose to buy more environmentally-friendly items. Despite this movement, however, price is still paramount.

SCENARIO 1 – THRIVING BIOECONOMY

The West Texas landscape is dotted with withered specters of a bygone era. Towering rigs that were once a symbol of the wealth and power of America will eventually be reclaimed by the land, consumed in a field of energy crops. This is the dawn of the Age of the Bioeconomy. Humans can now look back on the Age of Oil as a period of history, beginning with the first drop taken from the mountains of Titusville, Pennsylvania in 1859 and ending with a whimper through the 2010s with the rise of plant and animal-based transportation fuels, electricity, materials and chemicals farmed and processed in the United States. The bioeconomy solutions were welcomed with open arms by consumers who were unwilling to put up with the volatility of the market after drastic spikes in the price of oil, as well as the adverse consequences of burning fossil fuels. While the human pursuit of technology in the previous century sought to shelter us from nature, to guard against its effects, this new age sees a move back to nature. We have finally developed the technologies to provide sustenance to people not by seeking dominion over natural processes, but by mimicking them.

In this future, technology has saved us. While policy prescriptions and changing consumer values have helped to a certain degree to make these bioproducts more attractive in the market, this future mainly owes its existence to great breakthroughs in technology that have allowed bioproducts to compete very effectively on the open market with petroleum-based products. Due to the sustained high price of oil in the early years and, more recently, a policy-driven price floor and environmental policies limiting the use of other fossil fuels such as coal, the effective price of petroleum-based products causes them to lose out to bioproducts. These bioproducts, derived from renewable biomass, are being produced and deployed throughout the U.S. and indeed much of the globe.

On a deeper level, all aspects of the bioeconomy supply chain experience success as industries formerly involved in the petroleum industry now supply the bioeconomy. Companies that once separated high-value chemicals and materials from petroleum now do the same for biobased feedstock. New entrants also have been steadily entering the market for years as the technology progresses and financing has become more available due to a stronger national and international macroeconomy.

One key obstacle, the seemingly intractable food vs. fuel debate, has also been resolved. Population growth is slowing. Arable land area increases or at least remains constant and agricultural efficiency rises, ensuring long-term availability of feedstocks for both food and bioproducts. Additionally, the biofuel supply chain has inherent sustainability across all metrics (energy, water, carbon, toxics etc.). Technology plays a large role here as the continued development of more productive land and nutrient-efficient feedstocks, as well as feedstocks that do not require arable land, allow both the food and fuel industries to thrive. There is also heightened support as private landowners cooperate on a large scale to open up vast new tracts of arable land, partnering with local companies to supply biomass. This trend presages a move towards more regionally sustainable economies. Biofuels are no longer shipped across the country, but rather are produced on a more regional scale, with local farming interests supplying local biorefineries, which in turn supply local fuel distributors. This regional sustainability is not complete by any stretch, but there is a clear movement in this direction.

SCENARIO 2 – BUSINESS AS USUAL

The business-as-usual future, as belies the name, looks a lot like the world of today. While pockets of bioeconomic innovation persist in certain parts of the country and the world, we still live in the Age of Oil. Petroleum is still the lifeblood of the world economy and its abundance continues to defy all experts who portended a catastrophic decline in world reserves. Indeed, as the bioeconomy has continued to find ways to use technology to harness the power and efficiency of natural processes, so too have technological advancements given us the tools to access previously unrecoverable and new oil reserves, to continue to generate electricity from coal in an ever cleaner manner, and to increase production of liquid fuels from coal. Technology is at once our savior and our nemesis, providing fuel to both sides of the fire.

Bioproducts occupy niche markets and maintain price competitiveness in most areas due to policy-driven price supports. The steady, if unremarkable, expansion of flex fuel vehicle markets has allowed for some growth in the biofuels markets, although the success of the electrified car has impeded that modest growth even more. The use of biobased materials and biobased chemicals is driven mostly by environmental and vague national security concerns, not price, limiting their growth. Modest amounts of electricity from biomass persist as a result of renewable portfolio standards (RPSs) and a moderately implemented carbon price.

Oil reserves and supplies have kept up with rising global demand due to steady technological advancement in the extraction of oil from tar sands, improved methods of deep sea recovery, and better recovery rates from current fields. Softening demand due to increases in the fuel efficiency of the vehicle fleet also relieves pressure on existing reserves. While these do not prevent oil prices from increasing, they have suppressed catastrophic price increases and have allowed oil to remain the lifeblood of the economy.

The bioeconomy picture under this scenario is not dire, just somewhat slow and unremarkable. Environmental and international strategic concerns have still provided steady support to policies aimed at helping the bioeconomy to succeed. While lawmakers have gradually accepted that global warming is a rising threat and have responded with research and development subsidies, RPSs, and even a carbon pricing system, these policies have not been comprehensive, and are not rigorously supported or enforced. Each year, the United States struggles to produce enough biofuel to meet the renewable fuel standard targets passed in 2007. Corn ethanol still dominates the biofuels space due to lobbying by Midwestern farming interests, despite conflicts regarding food supply and environmental effects. Strategically, the support that oil gives to rogue regimes around the world has prompted lawmakers to continue to encourage expanded use of biofuels. Concerns about the prices that their constituents pay for energy, however, have made lawmakers loathe implementing policies with real teeth.

One major issue that has kept the bioeconomy from truly succeeding is the negative effect that the production of biomass, as an energy feedstock, has had on the food industry. Without truly revolutionary technological innovations in agricultural processes and feedstock processing, the use of ever larger tracts of public and private land to create bioproducts has an inflating effect on food prices, and vice versa, due to land competition. This has the perverse environmental consequence of encouraging land-use change at home and abroad, as forests that act as carbon sinks are cut down to make room for more agricultural land. This has suppressed support for policies that encourage too much expansion in the bioproduct markets.

In this future, the bioeconomy is complicated and many issues surrounding the continued production of bioproducts have not been resolved. There is continued public support for environmentally-friendly energy and materials, but other renewable sources of energy such as wind and solar dominate the electricity production sector and recycling improvements are viewed as a better option for material sustainability than biobased materials. There is still hope for the bioeconomy here, but technology will need to provide a silver bullet if it is to truly succeed further down the road.

SCENARIO 3 – CLIMATE-DRIVEN BIOECONOMY

The nay-sayers have quieted. The world has become increasingly warm. Our climate is in peril and policy makers (with the support of their constituents) no longer want to wait and see. Global warming has proceeded at a faster pace than most anticipated and public opinion has shifted in favor of making significant sacrifices to quell this threat. Public policy has been strongly supporting a variety of new technologies to wean the country off fossil fuels – for both transportation fuels and electricity production.

While the overall consumption of fuel is down under this scenario, the ratio of ethanol to fossil fuels is much higher. Corn ethanol, however, has been dismissed as a green fuel alternative. Despite the corn lobbyists' best efforts, corn ethanol has not been endorsed under the climate change policies because of the energy intensity required to produce corn ethanol and the displacement of rainforests as a result of corn ethanol crops. In addition, climate change has reduced the amount of traditionally arable land, significantly increasing the competition for and expense of food crops, making corn ethanol far too expensive to produce. In short, food wins in this scenario.

Fortunately, in part because of large and targeted research and development investment, significant processing and yield advancements have been made with cellulosic biofuels, greatly increasing their market share compared to petroleum-based fuels. Furthermore, a comprehensive approach to public transit, batteries, and electrification has drastically reduced overall fuel consumption. The United States also followed the European example for electricity production, paving the way for both renewable and nuclear energy to produce more of its electricity.

Underneath the surface, however, corn is thriving in other areas of the bioeconomy. While most consumers never really see the chemicals and materials industries, these help support the backbone of the American economy. As costs for fossil fuels have steadily risen, biobased chemicals and materials have begun to replace petroleum-based products. While corn prices are high due to food-driven demand, relatively higher value corn-based biomaterials and biochemicals have become a solid, growing niche market. In this scenario, agricultural and woody cellulosic based fuel is steadily replacing petroleum as the liquid transportation fuel of choice, growing rural economies and significantly accelerating the overall reduction of green house gas emissions from the transportation sector.

SCENARIO 4 – STRATEGIC BIOFUELS IMPERATIVE

There is one primary driver in the strategic biofuels imperative scenario: energy security. Nuclear proliferation has worsened, the Middle East has once again descended into violence, and the developing world is churning out rogue dictators as if they were cars on an assembly line.

Despite the best efforts of the developed world to engage in diplomacy and peacemaking, the world is becoming an increasingly unsafe place.

After finally coming to the full realization that relying on oil drove up its price and enriched the very countries that were located at the epicenter of the destabilized developing world, the United States and other major international players decided to launch attacks against wallets instead of armies. Consumer values also shifted drastically, making petroleum use as revolting as advertising cigarettes to minors and the American people forced their politicians to act. The U.S. government enacted policies stipulating that the country become foreign oil neutral as quickly as possible. The cost to the country of engaging in conflicts abroad was far greater than the increased cost of using more expensive alternatives to oil. So we began to wage a war of attrition against these petro-authoritarian regimes by starving them of oil revenues.

As demand has fallen, so have international oil prices. But the determination to switch fuels has emboldened U.S. policies to place hard limits on the amount of oil that can be imported. Abundant coal resources were initially viewed as a primary energy substitute, but the lack of technology advances and consumers' environmental concerns about converting coal to liquid fuel have limited their viability as an alternative to oil. As such, government policies have mandated that remaining fuel demand be met primarily by biofuels. While impressive technological advances have been made in the biofuels arena, resulting in lower costs for biofuels, they have still not reached price parity with oil, which has fallen in cost as demand has shrunk. As such, the government imposes a large tax on oil and uses the tax revenues to invest further in biofuels and keep a ceiling on biofuel prices so that U.S. taxpayers do not pay too high a price for this strategic policy.

This has a perverse affect on other areas of the bioeconomy, specifically the biobased materials and biobased chemicals sectors. Policy and research and development funding has been so focused on reducing the use of foreign fuels that there has been little attention on or investment in developing improved biobased chemicals and materials. Since feedstock costs are still high, these bioproducts cannot survive on price alone and when they are produced as biofuel byproducts, they cannot be sold at a low margin since price controls depress the margins of biofuels themselves. This means that while biofuels thrive through artificial markets, biobased materials and biobased chemicals remain a small fraction of the petroleum-based market. This has not caused great public outcry because the United States can manufacture petroleum-based materials and chemicals with nationally-sourced oil.

Biomass production is steadily ramped up nationwide, which has an inflating effect on food prices, and the cost of feedstocks is fairly high as a result. While incremental technological advances have been made in advanced feedstocks and production methods, no major breakthroughs have been made to fully address the food-versus-fuel and land-use change debates. However, our social and political drive to rid foreign oil from our shores is a higher priority.

It is through this convoluted process that biofuels have won and biobased materials and chemicals have lost, despite the latter being higher value-added products from the same feedstock. Is this fair? Does it matter?

SCENARIO 5 – DEATHANOL

The ethanol refiners lower their heads in defeat; the bioeconomy is dead. This does not mean that environmentalism has followed suit, however. Electric cars dot the highways in ever-

increasing numbers. In addition to an augmented use of coal, electricity is increasingly produced through wind, solar, and nuclear energy. While photovoltaics are the rage, we were never quite able to harness the power of photosynthesis in a way that could significantly benefit us in our production of energy, materials and chemicals. The biorefineries that had once been a symbol of our return to nature have been torn down, replaced with advanced technology coal generators, wind turbines, solar panels, and nuclear reactors, and visions of buildings and cars made from corn starch-based plastics seem quaint now.

Technology is a main driver of change in this future, but advances happen outside of the bioeconomy. Wind and solar energy have produced breakthroughs that put them even further down the cost curve; coal remains cheap and technology advances allow generation facilities to burn it with fewer environmental impacts; and even the petroleum industry finds less expensive ways to extract oil from shale, tar sands, and the deep seabed. Battery technology continues to hold more power in smaller packages and the expansive vehicle market has made the technology affordable.

Because of a lack of technological advances in the bioeconomy, both on the agricultural and processing sides, experts have come to the conclusion that the scale simply does not work to accommodate both food and energy feedstocks. As such, there is a major push to make electricity the transport fuel of choice and policies are enacted that put us on the brink of this reality. Major investments in the smart grid and electric vehicles are encouraged with tax incentives and other market distorting policies, and a large expansion in renewable, clean coal, and nuclear energy, excluding biomass electricity, is pursued to make up the extra demand created by these electric vehicles. As consumers and policymakers wait for the electric car to dominate the market and its required parallel infrastructure to come on-line, major improvements in the fuel efficiency of internal combustion engines have allowed the transportation sector to significantly reduce its environmental impact.

On the materials and chemicals side, petroleum also has kept its preeminence. Environmentalists do not protest the use of petroleum in these processes since the carbon embedded in the oil is not released into the atmosphere, but is tied up in the materials. The price of oil had been rising throughout the 2010s and 2020s, but the extreme softening in demand caused by the push for electric vehicles depressed its price considerably in the last couple of years and it has settled into a relatively stable market providing raw materials and chemicals cheaply to American industry using existing infrastructure.

To some, the death of the bioeconomy might be cause for alarm, but in some sense, this future has some sustainability advantages. Even though technology has failed to provide breakthroughs that allow us to tap the immense potential of natural processes such as photosynthesis, we are still able to wean ourselves off of oil by moving towards electrifying the drivetrains of our vehicles and powering them with increasing amounts of renewable and nuclear energy, and cleaner coal technology. This also has required us to find complex solutions to land-use change both at home and abroad, which was significantly retarding the environmental advantages of biofuels and creating distorting price effects on food products. As such, our carbon footprint is reduced and we no longer funnel money to petro-authoritarian states. We are still able to manufacture chemicals and materials from nationally-sourced oil with minimal environmental impact, but this is the limit of the oil market aside from jet fuel. This future is not an objective failure; it just picks different winners.

IMPLICATIONS

There are differences in the relative role of the drivers and how the uncertainties resolve themselves across each of the scenarios; as a result, the potential outcomes for various bioeconomy products are quite different as well. Table 1 below provides some sense of the impacts that we might see on the key bioeconomy products under each of the potential scenarios. Appendix B: Scenario Price Schedules gives a further picture of variations among the drivers under each scenario.

TABLE 1: POTENTIAL BIOECONOMY IMPACTS UNDER EACH SCENARIO

		SCENARIOS				
		1: Thriving Bioeconomy	**2: Business as Usual**	**3: Climate-Driven Bioeconomy**	**4: Strategic Biofuels Imperative**	**5: Deathanol**
BIO ECONOMY PRODUCTS	**Biofuels**	Biofuels beat out petroleum-based fuels on price, performance and environmental sustainability, and have essentially replaced gasoline and diesel. The electric car has made inroads, but liquid biofuels are the primary transportation choice.	Biofuels occupy a similar or slightly larger market share as the present day. They are still significantly supported by subsidies.	Biofuels have largely replaced fossil fuels as a liquid transportation fuel. At the same time, drivetrain electrification and advanced battery technologies have reduced overall liquid transportation fuel needs.	Biofuels are artificially supported in this market for strategic and environmental reasons, irregardless of the price of oil. Electrified vehicles are a growing share of the auto market, but large amounts of biofuels are still necessary	Biofuels are phased out of the U.S. economy. Technology never gives them the breakthroughs to compete with oil on price, and the government is not willing to prop up the markets for strategic or environmental purposes
	- Corn Ethanol	*Corn-based biofuels are not dominant in this market due to rising food pressures*	*Still dominates the market despite advances in other feedstocks due to extensive lobbying and ample domestic feedstock supply*	*Corn-based biofuels are not dominant in this market due to their climate footprint and rising food pressures*	*Still dominates the market despite advances in other feedstocks due to expanded subsidies, extensive lobbying and ample domestic feedstock supply*	*Ceases to matter*
	- Cellulosic Ethanol	*Agricultural and woody cellulosic feedstocks, however, have become a major new source of biofuel supplies*	*Still plays minor role due to lack of technology breakthroughs in cellulosic and algae based feedstocks*	*Agricultural and woody cellulosic feedstocks, however, have become a major new source of biofuel supplies*	*Agricultural and woody cellulosic feedstocks, however, have become a major new source of biofuel supplies to augment corn and meet demand*	*Ceases to matter*
	Biomass Electricity	Mixed success as other alternative sources like wind, solar and nuclear power become more dominant, as well as continued use of coal. Growing market in off-grid production, particularly in rural areas	Enjoys a niche market share due to RPS policies, a carbon price and co-located, off-grid generation. Coal remains very competitive, however, and biomass feedstock is relatively expensive	Biomass electricity hasn't fully reached grid parity on price, but enjoys a moderate market share due to targeted RPS policies in various states. Fossil fuel electricity is limited due to new environmental regulations, and electricity is increasingly supplied by nuclear and many renewable energy sources including biomass.	In a somewhat similar position as the present. The push for biofuels has caused the price of biomass feedstocks to rise considerably, making biomass electricity less attractive on price. Survives because of RPS policies	Biomass electricity loses market share to other forms of energy as other sources of energy fall in price faster than biomass electricity.
	Bio-Based Products	Plastics, rubbers, adhesives and other raw materials from renewable biomass are cheaper and more durable than petroleum-based products due to technology advances and rising price of oil	Bio-based materials have made strides towards price equality with petroleum-based materials, but they do not have a large slice of the raw materials market.	Major breakthroughs have been made in the production of bio-based materials, and the decreasing corn prices make bio-based material products increasingly marketable.	Bio-based products make very minor gains in this scenario as the artificial demand given to biofuels is not extended to bio-based materials. Petroleum-based and other non-renewable materials still dominate.	Bio-based materials lose in this scenario as they are deemed inferior on price and quality as compared to petroleum-based materials. No policies are instituted to prop up this market.
	Bio-Based Chemical	Bio-chemicals gain greater share of the chemicals industry. Although they cannot replace all petroleum or non-renewable products.	Traditional bio-based chemicals markets continue to enjoy success, but no major inroads made into the petroleum-based chemicals markets	High-value bio-chemicals have made steady inroads into the traditional chemical markets. Significant R&D is devoted to this, and technological breakthroughs allow chemical extraction from biomass cheaper than many petro-chemicals	Similar to bio-based materials, the economics of bio-based chemicals are hurt by a lack of technology and high feedstock prices	The economics of bio-based chemicals are hurt by a lack of technology and high feedstock prices, so these markets never emerge

MODELING THE BIOECONOMY SCENARIOS TO BETTER UNDERSTAND THE IMPLICATIONS

A key tool to visualize the relative role of the drivers and understand the implications for the bioeconomy under each scenario is a Great Lakes bioeconomy model developed by Shepherd Advisors and the Product Center. The model provides a baseline comparison of Michigan's bioeconomy resources vs. surrounding Great Lakes states. It illustrates biofuel production in each of the scenarios and is primarily biofuels-oriented, but provides insight into the strength and interplay of the various drivers that shape not only the biofuels market, but the broader bioeconomy as well.

Figure 2 is a graph of the current ethanol capacity in each of the six states analyzed in the model. All production capacity is currently from corn, as there are no commercially viable cellulosic plants in the Great Lakes states.

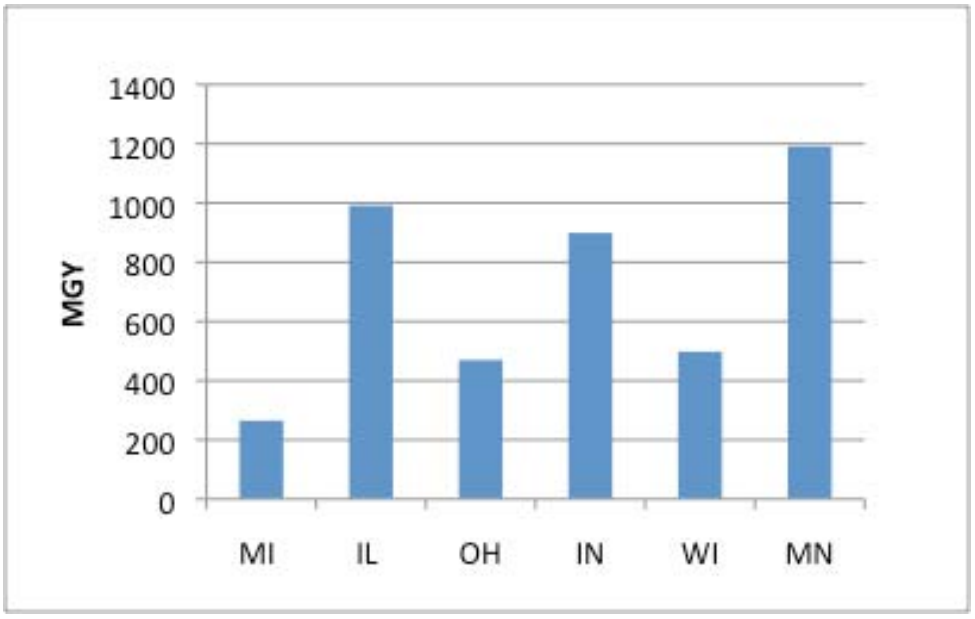

FIGURE 2: 2009 GREAT LAKES CORN ETHANOL CAPACITY: 4.3 BILLIONS OF GALLONS PER YEAR (BGY)

Currently, the Great Lakes region has capacity to produce 4.3 BGY of ethanol, which represents about 25 percent of the nation's 12.3 BGY capacity.

Figure 3 shows total projected ethanol output – by state and type of feedstock under a best-case scenario (thriving bioeconomy) in 20 years. As the graph illustrates, as long as corn is still a viable ethanol feedstock, the largest corn-producing states continue to dominate ethanol production.

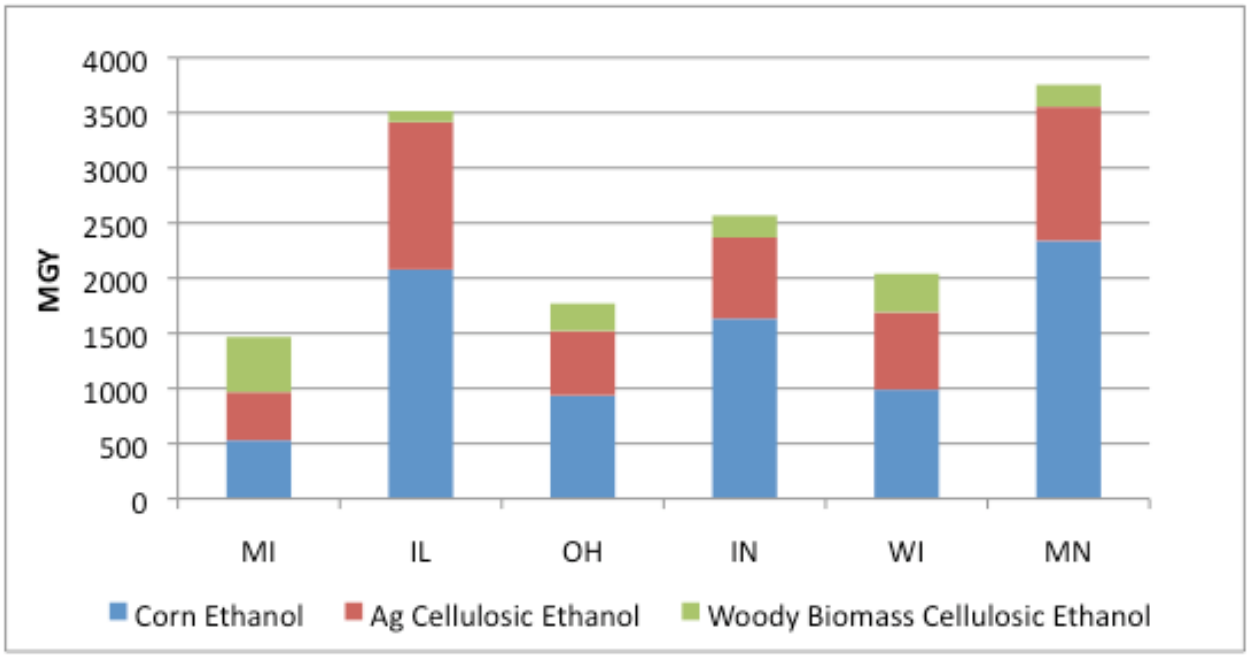

FIGURE 3: 2029 GREAT LAKES ETHANOL PRODUCTION: 15.2 BGY (THRIVING BIOECONOMY - BASELINE SCENARIO)

With the baseline model in place and the key scenarios developed, Shepherd applied toggles to three variables to help illustrate the changes that would likely take place under each set of circumstances. The three toggles that changed in each scenario are cropland area allocations, crop yield improvements, and ethanol yield improvements based on the various scenarios. These toggles were applied to the baseline scenario to predict biofuel production under each scenario.

For example, in the thriving bioeconomy scenario, the percentage of corn going to ethanol stays consistent at 2008 levels (approximately 30 percent of each state's corn goes to ethanol). However, in the climate-driven bioeconomy, the percentage of the corn crop going to ethanol drops to around 10 percent because of concerns regarding corn ethanol's climate footprint.

Figure 4 is a graph of aggregate ethanol production in the Great Lakes under each scenario. As the graph shows, the various policies and market support vastly change how much and which type of ethanol is produced.

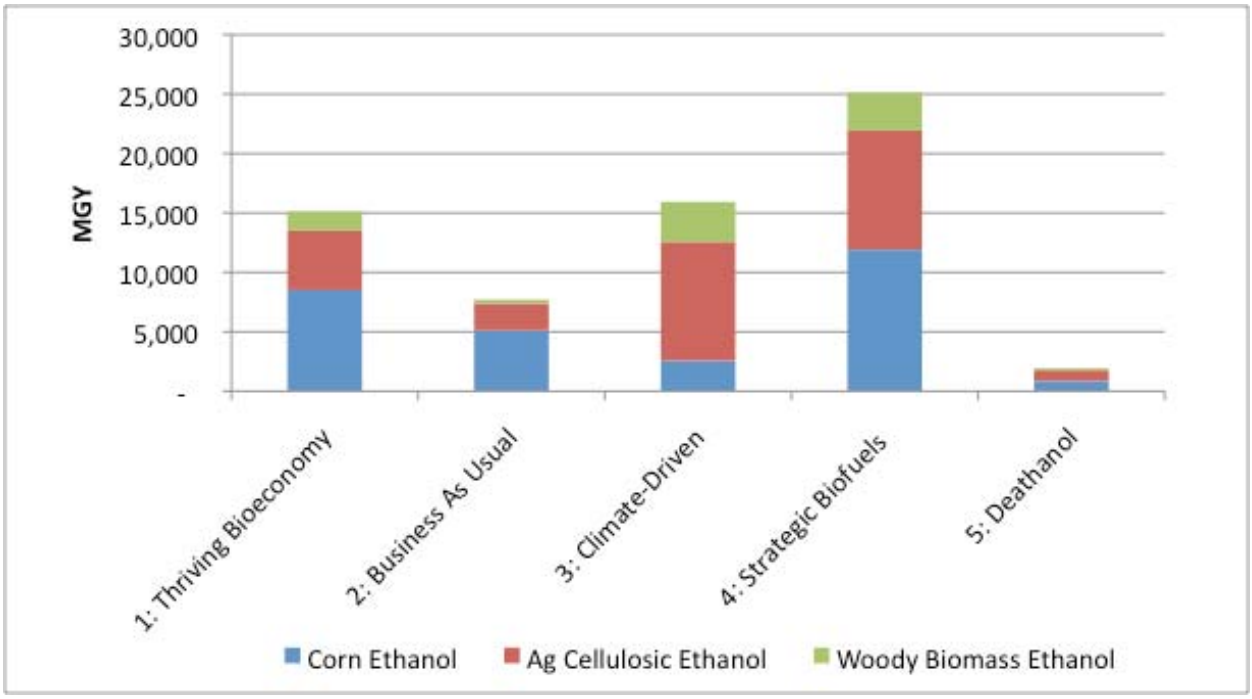

FIGURE 4: 2029 GREATLAKES ETHANOL PRODUCTION SCENARIOS

The graph below shows only Michigan's ethanol production under each scenario. Similar to the Great Lakes as a whole, Michigan's best opportunities for excelling in the bioeconomy are under the strategic biofuels imperative and the climate-driven bioeconomy scenario.

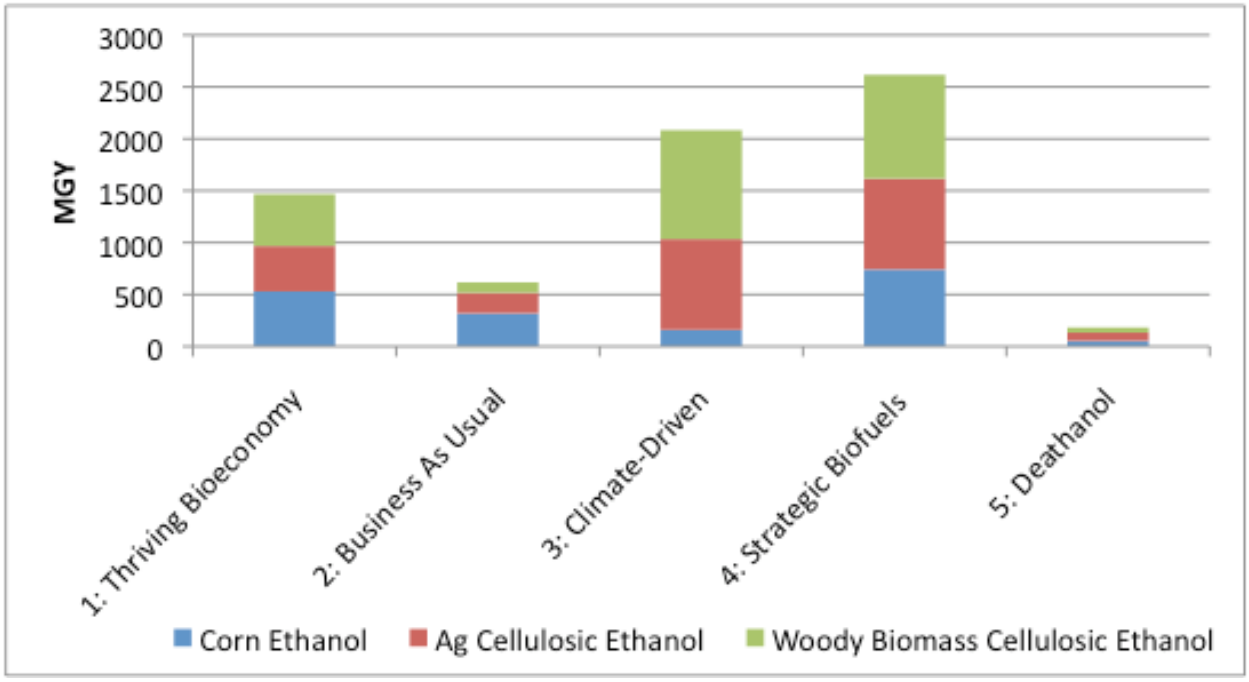

FIGURE 5: 2029 MICHIGAN ETHANOL PRODUCTION SCENARIOS

These model outputs demonstrate that under a scenario where the current corn-dominated biofuels market continued to predominate, Michigan, which has the smallest corn harvest and the

lowest level of corn ethanol production in the Great Lakes, would be at a strategic disadvantage in the bioeconomy.

However, as the bioeconomy continues to expand and next-generation cellulosic biofuels start being produced in larger amounts, Michigan has an opportunity to be a more significant leader in the bioeconomy. If cellulosic biofuels become a greater part of the market, particularly under a scenario in which cellulosic-based biomaterials (chemicals, other products) also gain prominence, Michigan's relative success in the bioeconomy would significantly increase based on the state's substantial forestry resources. As Figure 4 illustrates, Michigan would produce significantly more ethanol from woody biomass than the other Great Lakes states.

To do this would require ramping up production of woody biomass crops over the next 20 years, including woody energy plantations, energy crops, corn stover, and wheat straw (while not exceeding any more than 30 percent harvest rate for any given crop for ethanol production). Achieving this increase in production and building a competitive advantage within the Great Lakes region over the next two decades would require policy decisions and investments in cellulosic ethanol to become an immediate priority for the state.

DEVELOPING STRATEGIC RESPONSES

The five bioeconomy scenarios paint the range of possible futures. The future or combination of futures that actually happen ultimately will be determined by how the uncertainties underlying the scenarios are resolved over the trajectory of the next 15 to 20 years. But how can decision-makers use these scenarios today to plan for their organizations' futures? Without some consideration of strategic response, the scenarios are useful to provoke discussion and understanding but not action.

Decision-makers can use the scenarios to guide their strategic (action) choices today so they are ready as the future unfolds. Based on the characteristics of each organization (private or public), each decision-maker must decide how to respond to the scenarios. In principle, there are three ways to use the scenarios in individual organization planning.

First, if one scenario is particularly desired by an organization, its decision-makers can develop and implement strategies designed to create that future and not merely respond to it. For example, an organization could pursue public policy advocacy or consumer marketing consistent with creating the desired outcomes rather than wait for the government or consumers to change.

Second, an organization could choose distinct strategies that position the organization for each of the more probable scenarios. Then as the future unfolds, the organization can narrow its efforts to strategies most likely to achieve success based on the scenario that actually happens. For example, a decision-maker chooses a set of strategies to respond to scenario one and a separate set for scenario three. Based on key indicators of how the uncertainties are resolved over time, the organization shifts from the scenario one strategies to the scenario three strategies if scenario three emerges as the likely outcome. Pursuing distinct strategies for distinct futures can be expensive, so it is important to lay out strategy implementation as a set of options that are exercised as key indicators or milestones in the resolution of uncertainty are reached.

Third, the scenarios can have common elements across all of them or the vast majority of them. To the extent this is true, strategies based on these common elements may be developed and implemented so that organization is successful no matter which scenario actually unfolds. These

are obviously highly valuable strategies if they exist. Without the scenarios, such robust strategies might merely be chosen by accident rather than chosen with intent.

Typically, there are three types of strategic response developed for scenario planning exercises:

- optimal strategy(ies) to lead to a desired scenario
- optimal strategy(ies) given a particular scenario(s)
- robust strategy(ies) relevant across multiple scenarios

Using the bioeconomy scenarios developed for this effort as an example, Figure 6 highlights the different types of strategies an organization might pursue depending on which scenarios it decides need strategies that are desired, more probable, or robust. These are just examples to illustrate the process, not what the Product Center deems as actual desired or probable scenarios.

Strategy Type:	Thriving Bioeconomy Scenario	Business as Usual Scenario	Climate Driven Scenario	Strategic Biofuels Imperative Scenario	Deathanol Scenario
Optimal to Lead to Desired Scenario	Desired				
Optimal Given a Particular Scenario		More Probable		More Probable	
Robust over Multiple Scenarios	Robust	Robust	Robust	Robust	

FIGURE 6: TYPES OF STRATEGIES FOR SCENARIO PLANNING (FOR ILLUSTRATION PURPOSES ONLY – NOT ACTUAL STRATEGIES)

Optimal strategy(ies) to lead to a desired scenario

While gaining a better understanding of some of the plausible scenarios that may affect their organizations, state and corporate decision-makers may want to focus their strategies on moving toward a particular desired scenario. In this case, leaders must clearly define the key management decisions they will likely face during the scenario-planning period – what will literally or figuratively be on their agendas. Evaluating how these key management issues look under each scenario will allow decision-makers to focus on which scenario may be the most desired and then plan particular strategies that will help them shape the future for maximum impact on creating a particular scenario.

For example, in Figure 5 above, an organization might determine that the thriving bioeconomy scenario is most desired given the specific management or policy issues it will be addressing in the next 15 years. Decision-makers might consider strategies that:

- Lead to increased investment in cellulosic ethanol, including expanded research and development, feedstock development, and investment in scale-up of cellulosic fuel plants.

- Increase price/cost parity between biofuel and fossil fuel production, such as altering the subsidy structure, or improving the costs of production for biofuels.

- Increase consumer acceptance of biobased products through outreach, education, or incentives to try bioproducts.

Optimal strategy(ies) given a particular scenario(s)
By better understanding the decisions they will need to make during the scenario-planning period, decision-makers also may focus on creating a strategy(ies) that will optimize their ability to respond to and succeed under one or more particular scenarios they feel confident could occur. This approach requires identifying the scenario(s) that are most likely and then determining what various organizational decisions should be under those strategies. Decision-makers must then identify the strategies that will allow them to optimize outcomes of those decisions under that particular scenario.

Again in the example in Figure 6, an organization may evaluate the scenarios and determine that the strategic biofuels imperative and the business as usual scenarios are the most likely to happen. Subsequently, leaders may focus on creating strategies that:

- Expand the state's corn ethanol industry, such as investments to increase corn yield, improve efficiencies of corn ethanol plants, or improve the supply chain infrastructure.

- Capitalize on niche opportunities for biomass electricity production, such as co-generation opportunities, or smaller, community-owned biomass power facilities.

- Continue or expand subsidies for ethanol production.

Robust strategy(ies), relevant across multiple scenarios
Finally, decision-makers also can look across multiple scenarios and develop strategies that are robust across scenarios. The intent is to minimize risk by developing strategies that will allow the organization to safely and effectively cope with all the alternative outcomes rather than aiming to optimize performance (profits or sales, for example) by gambling on one particular scenario.

For example, an organization might determine that it needs to have strategies that are robust across all of the bioeconomy scenarios (except deathanol) in order to minimize its risk. In that case, decision-makers might pursue strategies that:

- Increase the level of investment in cellulosic ethanol.

- Improve the efficiencies of the biofuel supply chain to reduce production costs.

- Allow them to pursue production of higher value biobased products used by the chemical industry

The examples provided here are not exhaustive, but provide some illustration of the different types of strategies that a company, community, or the state might pursue under the various scenarios. Each entity must evaluate its own needs and goals in determining the specific strategies to pursue. Because these scenario futures are inherently uncertain, the goal of developing the strategies is not

to ensure the outcome of particular scenarios. Rather, it is intended to help organizations develop plans for positioning themselves to thrive under a given scenario or scenarios.

MONITORING KEY DRIVERS OF THE SCENARIOS

In developing the five scenarios, the Product Center and Shepherd identified and evaluated the key driving forces for shaping bioeconomy futures, including:

- technology breakthroughs
- level of investment
- policies
- consumer values and behavior
- biomass availability

Each of the bioeconomy scenarios is defined in part by these driving forces and there are significant uncertainties related to them in terms of the direction and magnitude of their role in shaping the future scenarios. In scenario planning, it is imperative that decision-makers monitor what is happening with the various drivers in order to understand which scenario path they are on and make any corrections to the strategic responses.

For example, some of the bioeconomy scenarios, particularly the climate-driven bioeconomy and the thriving bioeconomy, are more favorable for Michigan based on the state's diverse resource base, substantial amount of woody biomass, and access to other relevant resources, such as water. If Michigan hopes to advance its bioeconomy, it makes sense to move toward these scenarios, both in terms of its own bioeconomy and its impact in shaping the national and global bioeconomy. To do this requires leaders to understand and monitor the trajectory of the bioeconomy.

Given the uncertainties surrounding these drivers, it is important to identify measures for each of these uncertainties. While the specific monitoring measures will depend on what decision-makers' strategic responses are, the Product Center and Shepherd have identified some potential variables or signals to watch that can help identify which track the bioeconomy is taking so decision-makers can continue to accelerate toward that path or make corrections.

Variables to monitor for each of the drivers are summarized below.

<u>Technology breakthroughs</u>
Two potential measures of innovation and technological breakthrough include:

- number of bioeconomy related patents (tracking if going up or down)
- number of new commercial-scale biofuel and biomaterials facilities using non-food feedstocks

The current bioeconomy, particularly corn-based ethanol and biodiesel, does not require substantial technological innovation. A higher number of patents would likely indicate technological breakthroughs in non-food feedstock products and/or facility and system innovations that reduce the production costs for biofuels and biomaterials. More commercial-scale facilities also would be indicative of technology breakthroughs that allow for increased efficiencies and cost competitiveness of biobased products.

Level of investment
Ideally, level of investment would be tracked by:

- corporate research and development expenditures on bioeconomy-related science and engineering
- capital flow to bioeconomy-related facilities or other ventures

The federal government tracks private sector research and development expenditures, but with very little granularity. As data are reported now, it would be difficult to track bioeconomy-specific research and development by the private sector. Similarly, there are organizations that track venture capital flows, but the leading groups do not specifically monitor bioeconomy related investment.

Given the importance of both public and private sector investment in advancing the science of developing and refining bioeconomy products, as well as supplying necessary funding for start-up operations and facility expansions, it will be important to develop mechanisms to track bioeconomy-related investment data to resolve some of the scenario uncertainties.

Policies
There are numerous policies that could affect the pace and progress of bioeconomy growth. Policies can have an impact by offering incentives for bioeconomy research and development, technology advances, and infrastructure development. They also can significantly affect the bioeconomy market through regulations that limit bioeconomy-related activities or competitor technologies and efforts. While many of these policies could play a strong role in advancing the bioeconomy, the best way to monitor policies is to create an index of government support for the bioeconomy that compares states in terms of policy supports. For example, the index could include:

- mandated renewable energy standard size
- amount of support for renewable fuels, such as fleet mandates and renewable fuel standards
- state or federal policies that encourage the siting and development of bioenergy facilities (digesters, wood-fired boilers)

Consumer behavior
The rate of adoption of biofuels, bioenergy, and bioproducts is largely driven by the price of these items compared to fossil-fuel counterparts, as well as consumers' perceptions of the products' quality and sustainability. Variables that could provide proxy measurements for consumer behavior include:

- relative price index of gasoline/diesel versus biobased counterparts per British thermal unit (BTU) to determine oil price
- percentage of ethanol/biodiesel capacity in production (capacity utilization)
- amount of biofuels sold annually at commercial pumps
- amount of electricity produced (in megawatts) from biomass fuel

Another option would be to develop a consumer behavior survey (similar to a Nielson survey) to collect annual data on consumer behavior. Results would show both trends in consumer behavior as well as any major, discontinuous jumps or changes.

Biomass availability

Biomass availability depends on not only biomass resources, but also the infrastructure to extract and transport biomass so it is available for use in biofuels, bioenergy, and biomaterials. Again, there are many indices that could be used to monitor biomass availability, but those that are most focused on driving the scenarios (versus being affected by a driver) will provide the most insight into the bioeconomy trajectory. Some potential indicators include:

- acres of new plantings of short rotation woody crops (indicating an emergence of true energy cropping)
- acres of forestry resources
- bushels of corn converted to ethanol annually

Whichever variables are monitored, they must help track the trajectory of the bioeconomy so that leaders know the steps to take to support or shift that trajectory.

CONCLUSIONS

The scenarios presented in this paper represent five plausible future scenarios for the bioeconomy. They describe potential pictures of what the bioeconomy in Michigan and elsewhere might look like in the next 20 years so public and private decision-makers might improve the state's ability to succeed and even thrive under any of the scenarios. The analysis is not intended to suggest a particular scenario that is ideal or is more or less likely, but to present the range of possibilities to help decision-makers target desired outcomes – and prepare appropriately for all of them.

Using these five scenarios, the state can now better evaluate the importance of decisions relating to Michigan's bioeconomy in the coming years and develop appropriate strategies for optimizing those decisions under different scenarios. The MSU Product Center/Shepherd Advisors bioeconomy model demonstrates that Michigan's bioeconomy will expand under all of the contemplated scenarios expect for deathanol. It also suggests that Michigan's bioeconomy does relatively better in future scenarios where cellulosic biofuels have a larger share of the market. This implies that scenarios that accommodate and promote future cellulosic biofuel production will be relatively more beneficial to the state and strategies that encourage such scenarios will be materially more beneficial. Of course, identifying and assessing strategies that strengthen Michigan's bioeconomy under other future bioeconomy scenarios is equally important, especially strategies that are more robust across scenarios.

As Michigan's strategic response is created, state government can track variables of key technology, investment, policy, consumer behavior, and biomass supply drivers to monitor and better understand the actual evolving trajectory of the bioeconomy. With strategies in hand, public and private sector decision-makers will then be well positioned to implement the strategies that most favor Michigan's bioeconomy success.

APPENDIX A: SUMMARY OF STAKEHOLDER INTERVIEWS

In March and April 2009, Shepherd Advisors interviewed nine internal and external stakeholders who are involved in bioeconomy research and industry to get input on key bioeconomy trends and drivers. Stakeholders interviewed were:

Bryan Ritchie	MSU – MSU Bioeconomy Network
Bobbi Bringi	MBI
Brett Smith	Center for Automotive Research
Donna LaCourt	Michigan Economic Development Corporation
Doug Gage	MSU – Office of the Vice President for Research and Graduate Studies, and MSU Bioeconomy Network
Ray Miller	MSU – Department of Forestry
Steve Pueppke	MSU – Michigan Agricultural Experiment Station, and Office of the Vice President for Research and Graduate Studies
Steve Rapundalo	MichBio
Wally Tyner	Purdue University

Questions posed to stakeholders were:

1. What does bioeconomy mean to you? What is included in your definition?
2. What do you see as the top three fundamental forces shaping Michigan's bioeconomy in the next 15 years?
    a. What are the trends associated with those fundamental forces?
    b. In which direction are those trends moving?
    c. How certain do you think they are?
3. To what extent does the state of the world's macroeconomy act as a driving force in shaping the bioeconomy?
4. What is the relationship between the price/availability of oil and the advancement of the bioeconomy?
5. What role do you think consumer preferences towards sustainability/desire for green products and energy will play in the future state of the bioeconomy?

6. What do you see as the most likely role that technology plays in shaping the bioeconomy?

7. Based on your view of the above driving forces/trends, what implication does this have specifically for Michigan's ability to excel in the bioeconomy?

Key observations from the stakeholder interviews:

Trend/Force	Direction	Certainty
Consumer preference	increasing interest and public understanding. Upward trend, but slope is unclear.	Uncertain - cost will always be a big factor.
Cost of biofuels/materials: relative to oil/fossil fuels	Continued volatility. Price of fossils fuels trending up; biofuels/ biomaterials likely trending down.	Certain that it will be a primary force re: biofuels; uncertain about actual oil prices.
Economy: transitioning to knowledge-based	Continue to move toward more knowledge-based economy.	Uncertain.
Economy: urgency to diversity our economy	increasing urgency and interest in expanding and diversifying our economy	Confident.
Improved efficiency of bioproducts: integration of products/processes to improve efficiency and economics	Increased integration has to happen in order to achieve efficiency and price parity.	Uncertain - dependent on policy changes that reward efficiencies.
Natural resource availability: MI's strengths in natural resource availability	Increasing understanding and ability to sustainably use our natural resources for the bioeconomy.	Uncertain - will depend on whether and how we can utilize resources sustainably.
Political support/action: for biofuels	Probably increasing, but direction of political support can go both ways.	Uncertain - a lot of fractionation within the agriculture community. Probably will have political support and action.
Political support/action: GHg/carbon and renewable energy policies	Increasing regulation and government political intervention.	Confident.
Strong base of assets/talent in Michigan	Flat now, or declining, but could reverse the brain drain that has been happening by promoting ourselves and creating vibrant communities where people want to live.	Uncertain - some people get this, many don't.
Technology advancements	increasing advancements, complexity, and efficiency gains - there has to be some technology breakthroughs that improve efficiencies/costs.	Confident that technology advancements will impact bioeconomy, but could also see a technology leapfrog that negates our need for biofuels. Technology will also play a role in advancing markets for bio-pharmaceuticals and therapeutics
Venture capital availability	Increasing.	Uncertain - in the short term, more certain in the long term.

APPENDIX B: SCENARIO PRICE SCHEDULE

For each of the scenarios, the Shepherd/Product Center team developed a price schedule for several variables, including petroleum, a potential carbon or gas tax, corn bushels, and gasoline and ethanol costs to produce. The price schedule was used to verify and validate the scenarios and identify key variables that would interplay to create certain aspects of the scenarios.

	Scenario									
	1		2		3		4		5	
	Thriving Bio-Economy		Business-as-Usual		Climate-Driven BioEconomy		Strategic Biofuels Imperative		Deathanol	
DRIVERS										
Petroleum ($/barrel)	High	$150	Med	$ 100	Med	$ 100	Low	$ 50	Low	$ 50
Carbon/Policy ($/ton)	Med	$ 13	Med	$ 13	High	$ 26	High	$ 26	Low	$ -
Subsidy ($/gal)	Low	$ -	Med	$0.45	High	$0.90	High	$0.90	Low	$ -
Fossil Fuel Gas Tax ($/gal)	NA	$ -	NA	$ -	NA	$ -	High	$4.00	NA	$ -
Corn ($/bushel)	Med	$ 4	Med	$ 4	High	$ 8	Med	$ 4	Med	$ 4
Cellulosic Feedstock ($/bushel)	Med		Med		High		Med		Med	
Yield Production (gal/bushel)	High	3.4	Med	3.1	Low	2.8	High	3.4	Low	2.8
Bio-Based Chemical Penitration	High	25%	Low	1%	Med	12%	High	25%	Low	1%
RESULTS										
Retail Gasoline + Carbon + Gas Tax	$	5.64	$	4.00	$	4.12	$	6.38	$	2.14
Wholesale Gasoline	$	4.80	$	3.23	$	3.23	$	1.67	$	1.67
Corn Ethanol Cost to Produce	$	1.83	$	1.83	$	2.87	$	1.83	$	1.83
Cellulosic Ethanol Cost to Produce	$	1.78	$	1.78	$	2.25	$	1.78	$	1.78
OTHER CRITICAL ASSUMPTIONS:	Market forces favor ethanol		No major technological breakthroughs; no major political/social incentives		Subsidy does not apply to corn; only on cellulosic		High fossil fuel gas tax to eliminate demand		As the name suggests	
Check: Price 67% of wholesale	$	3.21	$	2.17	$	2.17	$	1.12	$	1.12
Check: cost - subsidy	$	1.83	$	1.38	$	1.97	$	0.93	$	1.83