Informing the Debate

Michigan Applied Public Policy Brief

Developing a Cellulosic Biomass Supply Chain in Michigan

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Informing the Debate

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The IPPSR program, Michigan Applied Public Policy Research Program or MAPPR, generates research on current issues held in urban communities with special attention to Michigan. Policy researchers author summary briefs of their research outcomes and their implications. The funded research projects and related policy briefs focus on main headings of discussion being held in the policy arena.

When developing the paper series initiative in 1992, the topics of the papers were submitted following a two-day meeting with leaders from the business sector, nonprofit agencies, foundations, and university faculty and staff. That group evolved into the Urban Research Interest Group.

The Urban Research Interest Group recognized the pressure on urban core leaders to make critical decisions that continue to impact people long into the future. A commitment to generating background research to add to the core of debate on possible solutions to complex, urban problems was made.

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Informing the Debate

MAPPR Policy Research Brief

Developing a Cellulosic Biomass Supply Chain in Michigan

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EXECUTIVE STATEMENT

A nation-wide policy emphasis on the production of bio-based fuels and chemicals from biomass, namely agricultural waste (such as corn stalks) and dedicated grasslands, has been in place since 2007, but to date little progress has been made in actual commercialization. While low oil prices are a major contributor to this lack of commercialization, we believe that a comparative lack of emphasis on developing the biomass supply chain is also a problem. Thus, we suggest that the State of Michigan should focus on supporting and developing a biomass supply chain.

Our own research, as well as an exhaustive literature study, suggests that farmers would be willing to collect and sell biomass assuming there is a market for this material. The two key concerns, other than a market, are the loss of nutrients and the potential for erosion or nutrient runoff if the biomass is removed. Research at MSU and elsewhere indicates that erosion and nutrient runoff can be mitigated by leaving some portion of the biomass on the field. The exact amount to be left behind is dependent on the crop rotation, the slope of the field, and if any alternative conservation technologies are practiced. Up to two tons of biomass can be obtained per acre from low-yielding corn land, and up to four tons per acre can be removed from high-yielding land. Nutrient removal can be quantified and reflected in the price obtained for the biomass.

Of key concern to Michigan is the impact of nutrient runoff in the Great Lakes from agricultural fields. While there are other causes to algal blooms in the Great Lakes, experts agree that nutrient runoff from farmland is a critical concern. There are no easy answers to reducing this runoff. It is imperative, however, that any biomass collection approach is designed to integrate soil and water quality concerns with the economic incentive of removing biomass. Approaches such as planting cover crops and buffer strips can absorb excess nutrients, reducing runoff, while also having the added advantage of allowing more biomass to be economically harvested.

To date, conversion of biomass to biofuel is not economically competitive given low petroleum prices and the difficulty of storing and transporting biomass. We suggest focusing on developing a supply chain using near-term markets first rather than attempting to simultaneously develop a supply chain and cellulosic biofuels. These near term markets include heat and power production, anaerobic digestion, and animal feeds. Various physical and chemical treatments are available to enhance the value of the biomass for these near-term markets as well.

The impact of biomass collection in Michigan has the potential to collect over 3 million tons of corn stover alone, adding over $150 million to the rural economy and supporting hundreds of jobs. Adding wheat straw, perennial grasses, or residue from fruits and other specialty crops could further increase the value. Developing this biomass supply chain could well position Michigan if oil prices rise in the future or breakthroughs occur in research surrounding cellulosic biofuel production. It would also well-position Michigan to deal with the environmental burden of reducing runoff into the Great Lakes in a manner that can be economically beneficial to farmers as well.

INTRODUCTION

In 2007, President George Bush signed the Energy Independence and Security Act, which was intended in part to reduce dependence on foreign oil by developing alternative fuels. A key component of this act was to mandate 36 billion gallons of biofuels by 2022, of which 16 billion gallons would be cellulosic ethanol. At the time, it was believed that cellulosic biofuels – fuels made from the non-food portion of plants such as corn stalks, wheat straws, trees, or grasses such as switchgrass and miscanthus – was ready to be commercialized and thus all that was needed to incentivize production was to guarantee a market. However, since then, no commercial cellulosic ethanol plant has been in continuous production, and the targets for cellulosic biofuels mandated in the ESIA 2007 act have not been reached (see Figure 1). Of the six commercial projects that were announced (with US Department of Energy funding) in 2007, only two are still present (both are in commissioning their plants at this time). These two facilities – POET-DSM's plant in Emmetsburg, IA and DuPont's plant in Nevada, IA – are both heavily funded by the state and national government, and both are too small to likely be profitable on their own. At this time, no other commercial facilities are being constructed in the United States. This lack of commercial success is not due to a lack of scientific investment; there has also been a great deal of support for academic research in the field, including three bioenergy research centers funded at ~$25 million per year for nearly 10 years.

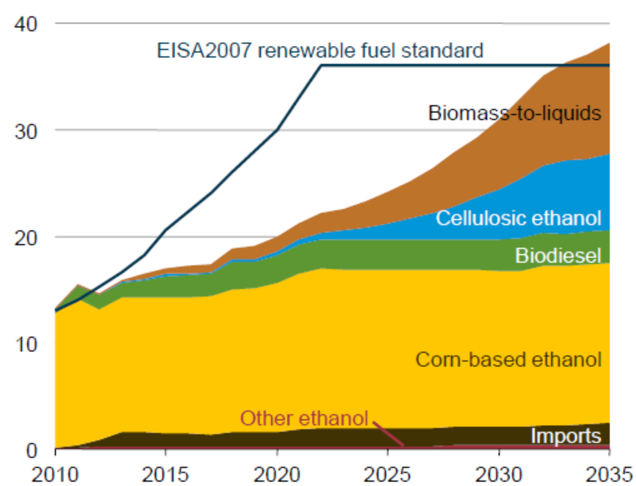

Figure 1: Current and projected biofuel use in the United States compared to mandated value. Source: Energy Information Administration Annual Energy Outlook 2012.

Thus, to date the cellulosic biofuel mandate has not been successful. Petroleum prices are currently low, which was not expected when the Act was signed, as prices remained high for several years before. In addition to the price of oil and the relative expense of cellulosic biofuels, industry leaders have pointed to three specific areas that have hindered commercial progress. The first is the inherent heterogeneity of the feedstock, making process control difficult. The second is the corrosiveness and fouling present when using acidic treatments in order to pump slurries of materials. And the last, and likely most significant, is the cost and difficulty of the feedstock and logistics of obtaining the feedstock.

The corn ethanol industry is a mature industry, and requires obtaining steady supply of corn grain. This grain is a commodity, and the transportation and storage infrastructure for this commodity is already in place. Trucks and rail cars can easily be loaded, measured, and unloaded, silos and grain elevators are prevalent throughout the corn belt, and negotiating the price for corn grain is simple given the homogeneity of the product. In contrast, bales of corn stover are difficult to load and unload, difficult to store, have a low density, and no set price. Moreover, the biorefinery owner would need to contract with hundreds if not thousands of farmers and build massive storage areas before being ready to construct and operate a refinery. Despite these barriers, there was relatively little funding or policy support to address these problems. For example, of the three bioenergy centers created by the US Government, virtually no funding was specified for feedstock logistics. It appeared that policy experts believed the biomass supply chain would be built up naturally as the industry matured, although clearly that is not the case.

POLICY STATEMENT

It has long been a goal for the State of Michigan to promote alternate energy, including biofuels. In 2006, Michigan provided funding to construct alternative fuel stations, including E-85 stations, through the Michigan Strategic Fund Act. In 2008, Michigan developed a renewal fuel standard with the goal of using 10% of its transportation fuel as renewables in Clean, Renewable and Efficient Energy Act. While no new recent legislation has been developed, a cellulosic bioeconomy would still be valuable for Michigan given its large corn production. However, as stated above, such an economy is difficult if not impossible to develop given the lack of a supply chain, as stated above. **Thus, our policy statement is that the State of Michigan should instead focus on supporting and developing a biomass supply chain.**

This emphasis is particularly true for Michigan relative to other areas of the corn belt such as Iowa, as Michigan has several challenges to developing this supply chain. Michigan has a shorter growing season than Iowa, which results in lower grain yields (147 vs 170 bu/acre) and thus decreased stover yields as well. Michigan also has a lower density of corn cropland compared to Iowa, increasing transportation costs. Contracting costs would also be higher in Michigan compared to Iowa given the preference for smaller farms in this state (for example, 8% of Michigan farmers growing corn grow 500 or more acres of corn, compared to 17% in Iowa). Finally, Michigan has more precipitation than Iowa, thus making it more difficult to store the biomass without absorbing too much moisture.

While drawbacks are present, Michigan has several advantages that make developing a biomass supply chain a desirable prospect for the state. Michigan produces large quantities of both corn and wheat, the residues of which are both possible biomass feedstocks. By obtaining two separate crops at two separate times of the year (corn in

October, wheat in July), storage costs are mitigated. Furthermore, Michigan's ample precipitation allows for the development of cover crops, which can increase the amount of material removed from a field. Developing a cellulosic biomass supply chain may be critical in Michigan for environmental reasons as well, as increasing biomass production on the field can potentially reduce soil and nutrient runoff into the Great Lakes.

While the focus should be on developing a cellulosic supply chain, there are several barriers to success that must be overcome. ***In particular, the cellulosic supply chain must be sustainable on its own; not only environmentally but also economically and socially***. A biomass supply chain must not be harmful to the ecology of the farmland or the surrounding area, in terms of both soil and water quality. It must also be profitable to all parties involved in order to survive without government intervention. Finally, it must also be desirable for the farmer involved to invest in the time and resources to harvest and sell the biomass, which includes evidence of environmental and economic payoff. In this paper, we describe these barriers and the likely impact of biomass collection. We also describe a case study – AFEX treatment in biomass depots – that may be an approach to creating a biomass supply chain.

Farmer Acceptance

Farmers' willingness to participate in suppling cellulosic biomass is directly related to their ability to make a profit, which starts with access to a market. Profit may sound self-serving but most businesses exist to make money. Farmers will need to make large capital investments in equipment and infrastructure in order to enter the biomass supply chain. This means they will need some level of guarantee that a market will develop and exist long enough to earn back their investment. Farmers are also interested in long term environmental stability because they rely on the land to produce crops for a living. Many growers want to leave the land in better condition for their children and grandchildren, thus, sustainable biomass production will be critical.

Corn stover (residue) is likely the best alternative for cellulosic biomass since we already have 2.5 million acres of corn being produced in MI. Researchers at Purdue and Michigan State University found that on average, about 2.5 tons of stover residue can sustainably be removed each year (Seamon 2013, Thompson and Tyner 2014). This equates to a potential of 6.25 million tons (2.5 million acres x 2.5 tons per acre = 6.25 million tons) of stover available in MI (USDA NASS, 2016). Farmers may very well be willing to remove this stover due to recent difficulties with managing increasing residue amounts. Improved hybrids are more resilient and resistant to disease, causing them to break down (decompose) more slowly than in the past. As a result, farmers have had to increase tillage or chop the biomass in order to get it to break down in time to plant the next crop. Removing a portion of the biomass would be one alternative that would address the abundance of residue and slow decomposition rates while at the same time supplying biomass for biofuels.

Harvesting stover requires haying equipment (mower, rake, baler, loader with spears) that many corn growers do not have. It is expected that some farmers will invest in their own equipment to harvest their own biomass. However, custom harvesters will probably become an important part of the supply chain. The DuPont Pioneer (Nevada, IA) and Poet (Emmetsburg, IA) cellulosic ethanol plants use custom harvesters at least in part. Custom harvesters purchase their own line of equipment and hire their own operators to harvest and deliver biomass. This helps with availability of labor as farmers generally are very busy just harvesting grain in the fall.

Research at Michigan State University and other institutions across the corn belt is underway to examine the impacts of removing biomass on soil quality and nutrient status. Organic matter comes from dead and decaying plant material (stover) and serves as a "glue" to hold soil particles together which increases soil health and longevity. When farmers remove stover, they are also removing organic matter and nutrients contained in the plant material. Keeping organic matter contributions back to the soil in balance is on the mind of every farmer. The nutrients that are removed are also valuable because farmers have to replace them via fertilizer for the next crop. Models have been developed to help farmers predict the impact of removing stover at different rates on soil organic matter and nutrient removal (Campbell et al, 2014; Tan and Liu 2015). It can be done sustainably, but farmers will need to pay attention to the details to make sure their stover removal rates are tied to existing soil types and management practices.

In order for a cellulosic biomass supply chain to develop, stover biomass needs to be priced high enough to account for all of the issues stated above. Capital investment, nutrient removal, labor availability or custom operator hire are all factors that drive the price that farmers are willing to accept. If the price is too low, farmers will keep the stover, return the organic matter and nutrients to the soil and continue farming as they have in the past. If there is enough financial incentive to remove a portion of the stover they produce, farmers will figure out the best way to do that in an economical and environmentally sound way. Farmers will also factor in risk. As with any new market, there needs to be some level of assurance that the market will be there long term so that they will be willing to make the capital investments.

1. Increased corn residue has created logistical challenges for farmers
2. Likely custom harvesters, as many corn growers are not set up to harvest stover
3. Concerns for soil quality in regards to removal of organic matter and nutrients
4. Value of stover removed may not be in line with actual costs (intrinsic and real)
5. Equipment is available to perform harvest, transportation and storage, but economics may not be feasible.

Environmental Considerations

Soil quality

The single largest environmental concern regarding stover removal is soil quality. It is generally accepted that the corn stalks must be returned to the soil in order to preserve nutrients for later plantings, particularly the soil organic carbon (SOC) content of the soil. In addition, the corn stover contains nitrogen (N), phosphorus (P), and potassium (K), which are all vital ingredients in fertilizers. If the stover is removed from the field, then these nutrients would need to be replaced, which is not only an additional cost but also include the additional environmental burden of obtaining the nutrients.

The academic literature is clear that complete removal of stover from the fields is not advisable from a soil health perspective. However, the prevailing view of the scientific community is that in most fields, a portion of the stover can be harvested sustainably. A variety of organizations and academic groups have devoted significant resources to determining the factors involved in sustainable stover harvest practices.

There is widespread understanding that various factors govern stover harvest besides soil organic carbon, which includes wind and water erosion, soil, water, temperature dynamics, and soil compaction (Wilhelm et al., 2007; English et al., 2013; Thompson and Tyner, 2011). In general, flat land is less susceptible to soil erosion, and thus more stover is available for harvest. There is also widespread appreciation that the factors governing sustainable stover removal must be applied at the field and local landscape levels. The extension stations of major land grant institutions, as well as National government laboratories, have active research initiatives in progress to address guidelines for sustainable practices.

Given the variance in cropland, it is impossible to give a broad recommendation for the amount of stover that can be removed from any given field. Table 1 below gives examples of recommendations for the Great Lakes region found in the academic literature. A general rule of thumb is that at least 2-2.5 tons stover per acre should remain on the field (Wilhelm et al, 2007), while the rest may be removed. For Michigan, this corresponds to 1-2 tons per acre of stover that can be collected.

Table 1: Stover available for harvest

Grain Yield	Stover Production[1]	Continuous Corn[2]	Corn-Soybean[3]	Corn-Soybean w/cover crop[4]
bu/acre	dry matter tons/acre			
150	3.5	1.2	0.0	2.0
160	3.8	1.5	0.3	2.3
170	4.0	1.7	0.5	2.5
180	4.3	2.0	0.8	2.8
190	4.5	2.2	1.0	3.0
200	4.7	2.4	1.2	3.2
210	5.0	2.7	1.5	3.5
220	5.2	2.9	1.7	3.7
230	5.4	3.1	1.9	3.9
240	5.7	3.4	2.2	4.2
250	5.9	3.6	2.4	4.4

[1] Based on a harvest index of 0.5

The statement above assumes that there is no drawback to leaving biomass on the field, and thus the only balance is between the economic value of the biomass and the environmental value of leaving the material on the field. However, there are two possible advantages to removing stover:

1) In areas of high corn yields, a portion of the stover should be harvested to maintain yields (Birrell et al., 2014; Kenney et al., 2014). As corn yields increase, so do stover yields, and too much stover can prevent the field from warming in the spring, can compete with the new crop for nutrients as it decomposes, and decreases soil at the top layers. This leads to a decreased nutrient efficiency, requiring more nitrogen and phosphorus per bushel of corn grain produced.

2) It should be noted that while corn stover does contribute to soil fertility, it is also true that a significant amount of the corn stover carbon is lost to the atmosphere as carbon dioxide during the decomposition process in the field. Furthermore, decaying corn stover is also linked to nitrogen losses (as nitrogen is tied up in the decomposing stover) and to harmful N_2O emissions (Kim et al., 2009).

Addition of a cover crop significantly increases the amount of biomass stover that can be removed. Cover crops are crops planted at the end of the season that grow up quickly in fall, cover the ground in winter, and can be harvested or plowed under in spring in time for the next crop. Variability in weather can cause problems in establishing cover crops, especially after corn. Average ryegrass cover crops range from 2-4 tons per acre. Since the carbon degradation between ryegrass and corn stover is similar, one can substitute stover removal with cover crop production on a one to one basis, meaning that for every ton of cover crop produced, you can remove another ton of stover and still maintain soil carbon.

Assuming a conservative yield of 2 tons per acre cover crop yield significantly increases the amount of stover that can be removed (see column 4 of the table). In addition to increasing the amount of stover removed, cover crops protect the soil from erosion and cycles nutrients for the next crop. Adding cover crops into the system can be challenging but should be encouraged, even where stover will not be removed.

Water quality

With soil quality, the primary concern is the tradeoffs between collecting biomass and maintaining soil organic carbon and fertilizer nutrients. In contrast, there appears to be a synergy between promoting the quality of rivers and lakes with biomass removal. This is because methods to improve water quality are not universally practiced due to the costs associated with them. If profitable, biomass collection would be an approach to offset these costs.

One of the key environmental concerns in the Great Lakes region is eutrophication, which generally appears as algae blooms (Scavia et al., 2014). Eutrophication occurs when there is an excess of nutrients (namely phosphorous and nitrogen) in a lake or reservoir, which allows for rapid biomass growth within the lake. The bloom of algae that appears not only absorbs all of the excess nutrients, but all of the natural resources in the water as well. In particular, it absorbs all the oxygen in the reservoir, choking out other plant and animal life. In addition to being harmful for the native lake environment, the algae blooms can be toxic for human development along the Great Lakes. While not specific to Michigan, the large algae blooms in Lake Erie due to the Maumee river basin has threatened Toledo's water supply in recent years. Smaller blooms and sediment runoff are concerns in the Saginaw Bay watershed as well.

While there are several causes of excess phosphorous and nitrogen (which in turn cause algae blooms), experts agree that farming is likely the largest source of these nutrients. Nitrogen and phosphorous are two key components in fertilizer, and can be washed off the farmland and enter rivers and streams, where they eventually make their way into the Great Lakes. Interestingly enough, the size of a summer algae bloom can be predicted based on the amount of rain received in the spring (see Figure 2). This is because spring is the most dangerous time for fertilizer being washed off the field and into springs (Lindsey, 2014). Farmers apply significant amounts of fertilizer in the spring as they plant the next crop of corn. However, there isn't much plant growth to immediately absorb the nutrients, nor is there sufficient ground cover to trap the nutrients on the field. Thus, in years with heavy spring rainfalls, more nutrients end up in the lake, and larger algae blooms occur.

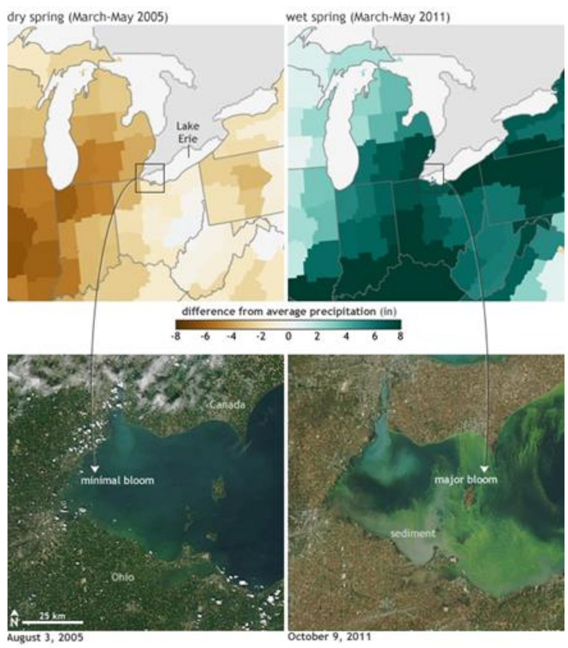

Figure 2: Comparison of spring rainfall in Great Lakes Watershed to Lake Erie algae bloom in summer and autumn. Source: Climate.gov.

Naturally, then, one way to prevent these algae blooms is to prevent the fertilizer from running off the field. Several alternative farming practices have been suggested to keep the fertilizer on the field.

1) The simplest approach is to reduce tillage operations. Maintaining cover on the soil surface helps to prevent soil erosion, thereby keeping nutrients in place in farm

fields. Many farms are experimenting and practicing minimum, reduced and no-tillage on their farms. Thus, the previous stover remains on the top of the soil, reducing runoff.

2) A potentially more impactful approach is to use winter cover crops. After harvesting the corn or soy from the previous year, a farmer would quickly seed a rapidly growing grass or legume into the field. This cover crop would grow partially before winter, but quickly shoot up once the snow melts. The fresh growth would be killed when the new crop is planted to prevent competition of resources, but the dead grass or legume would remain on the surface of the field to prevent runoff.

3) The strongest approach to reducing runoff is to use buffer strips. In this approach, farmers would sacrifice a portion of their farmland to produce perennial grasses rather than corn or soy. These would be in the form of strips of land (up to 50 ft wide) that would surround the corn land or be present at the bottom of a slope. Because the buffer strip is a perennial grass, it can absorb nutrients year round, including in the spring during the time of fertilizer runoff. Thus, it acts as a buffer between the corn fields and the streams and rivers, absorbing soil and fertilizer before it reaches the rivers. In 2015, Michigan had 166,662 acres enrolled in the federal Conservation Reserve program, which encourages conservation practices like buffer strips.

It should be noted that these are not three alternative scenarios. All three can be practiced simultaneously, thus enhancing the benefits of fertilizer reduction. If all farmland practiced these three conservation techniques, the algae bloom problem could potentially be reduced. The impact on nitrogen, phosphorus, and sediment runoff is highly dependent on location, the slope of the farmland, amount of precipitation, etc. Thus, the values cited in Table 2 below should be considered as examples only and not necessarily representative of results that might be obtained in Michigan. However, given the strong potential of these three technologies, full implementation could significantly reduce runoff into the Great Lakes.

Table 2: Reduction in nitrogen, phosphorus, and sediment runoff in various locations due to implementation of conservation practices (relative to fields that do not perform the practices).

Practice	**Location**	**Nitrogen**	**Phosphorus**	**Sediment**	**Source**
No-till	Missouri	-	-	85%	Wendt 1985
No-till	Ohio	-	-	55%	Shipitalo 1998
No-till	Quebec	0%	93%	92%	Pesant 1987
No-till	Mississippi	70%	79%	95%	Mcdowell 1984
No-till	Maryland	87%	90%	-	Angle 1984
Buffer strips	Italy	-	75%	-	Borin 2004
Buffer strips	Missouri	-	-	42%	Udawatta 2005

Buffer strips	Kansas	95%	95%	99%	Mankin 2007
Buffer strips	Iowa	79%	85%	-	Lee 2003
Cover crops	Missouri	-	-	77%	Wendt 1985
Cover crops	New York	-	74%	-	Kleinman 2005
Cover crops	Alabama	-	54%	-	Yoo 1988
Cover crops	Georgia	-	66%	-	Langdale 1985

Despite this potential, only approximately 35% of Michigan corn farmers practice no till, and only about 2% plant cover crops (although this number is increasing). If buffer strips are present, they tend to be too small to have the desired effect. The primary concern is one of cost. No-till agriculture is actually less expensive than conventional tillage, but there is a concern that too much biomass on the field will reduce next year's crops. This is particularly true for colder climates such as Michigan, as the additional biomass can insulate the ground and prevent it from warming in the Spring, delaying planting times. Buffer strips require taking land out of productive corn and placing it in non-productive grasses, and thus has no immediate economic benefit to the farmer. And cover crops must be planted after harvesting corn and killed prior to planting new corn, which requires both time and money (~$30 per acre).

The question then becomes, is it possible for farmers to actually make money (or at least break even) by performing these conservation practices? There is a key element that all three practice have in common: they allow more cellulosic biomass to be removed from the field.

1) The concern with no-till farming is that too much stover is left on the surface of the field. If the farmer removes more of the stover off of the field, this concern is eliminated. Combine this with the fact that no-till farming is less expensive than conventional tillage, and it becomes clear that farmers can make a significant profit by switching to no-till farming as long as there is a market for the removed corn stover.

2) Because cover crops act as additional plant matter, a farmer can remove much more stover than even a no-till field can. The cover crop produces all the field cover and soil organic matter needed to sustain the field, allowing an additional 1-2 tons of stover per acre to be removed. If the farmer can obtain a modest profit from the stover, this can cover the cost of the cover crop (Pratt et al, 2014). In addition, there are additional benefits of cover crops that a farmer would consider, including an increase in soil organic matter, potential additional nitrogen if the cover crop is a legume, and reduction in soil compaction. Thus, even if a farmer breaks even on

cover crops, the non-monetary benefits may make it worthwhile to the farmer to produce these crops. If one attempts to assign monetary value to these additional benefits, then producing cover crops becomes significantly profitable.

3) While buffer strips remove some land from food or feed crop production, there is no reason that the buffer strips themselves cannot be harvested. It is possible that as much as 5-10 tons of grass per acre can be harvested. These buffer strips alone are unlikely to produce enough biomass to supply a processing facility, but could supplement traditional corn stover and wheat straw removal. In addition, these buffer strips may have low input costs, as the fertilizer runoff they absorb could supply all of their nutrient needs.

Economics of Biomass Collection and Use

Cost of harvesting biomass

Corn Stover Pricer

Ag Decision Maker -- Iowa State University Extension
Estimate a price for corn stover standing in the field or harvested and stored.
Ag Decision Maker information file A1-70 "Estimating a Price for Corn Stover" has more details.
Please enter your input values into the yellow shaded cells.
Place the cursor over cells with red triangles to read comments.

Feed value and nutrient costs for corn stover			*Nutrient removal rates, lb. / T dry matter (optional)*	
Hay price for medium quality mixed grass/legume hay, $ per ton	$	95	Nitrogen, lb.	13.4
Price of dried distillers grains (DDGS), $ per ton	$	125	Phosphorus, lb.	2.6
Price of anhydrous ammonia, $ per ton	$	400	Potassium, lb.	29.0
Price of MAP (11-52-0), $ per ton	$	310	*Estimated weight of a large round bale (optional)*	
Price of potash (0-0-60), $ per ton	$	235	Bale diameter, inches	66
Estimated moisture percent of stover, %		25%	Bale width, inches	48
Estimated weight of a large round bale of corn stover		1,000	Est. bale weight, lb.	1,045
Harvesting costs for corn stover				
Chopping stalks, $ per acre	$	3.00	See current Iowa Farm Custom Rate Survey	
Raking, $ per acre	$	-		
Baling, $ per bale	$	14.00	*Estimated bales harvested per acre (optional)*	
Cost for plastic wrap (if used), $ per bale	$	-	Corn yield, bu./acre	175
Moving or transporting bales, $ per bale	$	5.00	% of stover harvested	33%
Bales harvested per acre		3.4	Est. bales harvested per acre	3.4

Value for large round bales of corn stover						
Value based on costs to seller (minimum price to accept)		Per Bale		Per Wet Ton		Per Acre
Pounds of nitrogen removed		5.0		10.1		17.1
Pounds of phosphate removed		1.0		2.0		3.3
Pounds of potash removed		10.9		21.8		37.0
Value of extra nutrients removed	$	3.60	$	7.19	$	12.23
Total harvesting costs	$	19.88	$	39.76	$	67.60
Equals cost of corn stover (at the farm)	$	23.48	$	46.96	$	79.83
Value based on the cost of alternative feed sources (maximum price to offer)						
Market value of 1.16 tons of hay minus .22 ton of DDGS	$	41.35	$	82.70	$	140.59

Value for standing corn stover that will be harvested		$ / bale		$ / ton		$ / acre
Value based on costs to seller (minimum price to accept)	$	3.60	$	7.19	$	12.23
Value based on the cost of alternative feed sources (maximum price to offer)	$	21.47	$	42.94	$	72.99

Value for standing corn stover that will be grazed		$ / acre
Value based on costs to seller (minimum price to accept)	$	1.35
Value based on the cost of alternative feed sources (maximum price to offer)	$	17.81

Figure 3: Snapshot of Iowa State University decision-making tool to assist farmers in determining a price for corn stover harvest.

The cost of harvesting biomass includes (1) the costs to raise the crop, (2) the machinery operations to get the biomass collected and moved off the field and (3) the value of nutrients removed in the biomass. In the case of corn stover, we do not associate any costs to raise the crop, since the costs were incurred to produce and sell the grain crop.

The residue is what is left over and usually returned to the soil. The machinery operations can vary from farm to farm, depending on what equipment they have access to, but generally includes a stalk chopper to chop and windrow the stover, a baler and equipment to pick up and move bales off the field. The stover contains nutrients that, if removed, have to be replaced with fertilizer. These costs are figured based on the amount of nutrients removed per acre multiplied by the current cost of fertilizer replacement nutrients. Iowa State University Extension developed a nice spreadsheet which we have used here to estimate the costs of stover removal for Michigan farmers (Figure 3).

Current machinery operation costs were used from previous experience, MSU Custom Work Rates publication and current fertilizer prices were plugged into the spreadsheet to calculate the cost to harvest corn stover biomass. Based on the prices entered above in the example, a price of $46.96 per wet ton ($62.61 per dry ton) would be paid to the farmer. Note that this cost includes $17/ton to return the nitrogen present in the stover to the field. However, current research suggests that most of this nitrogen is instead lost to the atmosphere if the stover is left on the field, and would thus need to be replaced regardless. Thus, the true cost of the stover may be closer to $45/ton. This would just cover their costs to collect the biomass stover. They would need some kind of incentive (additional dollars) to pay for their time and efforts in order to convince them to remove their corn stover.

Cost of transporting biomass

It is common and relatively simple to transport grains long distances, but biomass generally is only consumed in local markets. There are two main advantages of transporting grain compared to biomass bales: density and handling. Corn grain is approximately 700 kg/m3 density, while bales are approximately 200 kg/m3 and loose, unbaled biomass can be as low as 50 kg/m3. Thus, the same volume will contain less biomass than corn grain. If a truck or rail car is loaded with biomass and does not reach its weight limit, than the cost of transportation per ton would be higher for the biomass than for grain. Secondly, grain can flow readily, and thus can be easily poured into and out of rail cars or trucks. Bales, however, must be loaded individually, a more time consuming process. Unbaled biomass will bridge, preventing it from flowing easily, and thus is even less suitable for handling.

Because of these factors, estimates for the cost of transporting biomass are higher than for transporting grain. Transportation costs generally have three elements: the cost of labor, the cost of renting the truck, and the cost of diesel fuel. These are often simplified to a fixed cost plus an additional cost per mile. Grain costs are approximately $3.44 per truckload ($0.14/mile/ton) in the corn belt in 2016 (USDA AMS). This is for short haul (<25 miles) trips; the price significantly decreases for long haul trips. In contrast, Lu et al. (2016) estimated a 25-mile distance cost for switchgrass bales (which should be similar in cost to corn stover) was $0.38/mile/ton.

Thus, it is difficult to transport biomass long distances to support a biorefinery. Instead, the refinery must be supported by local biomass. This becomes more difficult in regions where corn fields are relatively rare or conditions are such that very little stover can be harvested. The cost of production of biofuels tends to decrease as the size of a refinery increases due to reduced cost of capital and other fixed costs (for example, the labor cost is the same per year for a small and large refinery, but spread out over more gallons of biofuel in the latter example). Thus, a balance must be had between increasing the size of the refinery to reduce production costs, but keeping the refinery size low enough that transportation costs are not a serious concern. Most studies have placed this size between 2000 and 5000 tons per day (Argo et al., 2013; Sendich et al., 2008).

Note that this size considers only the cost of transporting biomass, but no other considerations. As the biorefinery size increases, the number of trucks required to supply the refinery increases. Assuming outside storage, a 2000 ton per day refinery requires 100 trucks per day, and thus would require a road system capable of supporting that heavy load. Furthermore, permitting for a space must take into account this heavy traffic. This problem is only exacerbated if the size of the refinery increases.

An alternative to these concerns is to densify the biomass prior to transport to the refinery. Pelletization of agricultural residues is a well-understood technology, and several studies have proven its feasibility (Kaliyan and Morey, 2009; Sokhansanj et al., 2005). These pellets are high density (500-600 kg/m3, compared to 700 kg/m3 for corn grain), can flow easily (and thus be transported in and out of trucks or rail cars), and can be stored for long periods of time. Thus, they can be transported long distances in a manner similar to corn grain, thus eliminating the constraints described above. This would add additional cost to the process, however.

Cost of storing biomass

A key concern with biomass collection and logistics is that biomass must be stored year-round. Biomass is generally only harvested once per year, yet must be processed throughout the year. Given the amount of material involved, this is a staggering challenge. A single biorefinery may require 2000 tons per day to operate for 350 days, meaning 700,000 tons of biomass or 1.4 million bales. Even by packing square bales five bales high, this would require over 140 acres of storage space, not including alleyways. This also can increase the transportation cost, as the bales must be moved first to the storage facility, and then to the final processing facility.

One key risk of storage is the risk of loss. Spontaneous combustion of bales can occasionally occur if the moisture is too high. This occurs with wet bales, as microbial activity inside the bales dramatically increases the temperature of the interior of the bale while simultaneously reducing the water content inside the bale. As the temperature increases, oxidation of plant material can begin to occur, which is an exothermic reaction that raises the temperature to its autoignition point. Even without considering spontaneous combustion, lightning strikes can also start fires. Given the high flammability of biomass, a small fire can quickly spread to the entire area, destroying the entire storage facility.

Besides fire, shrinkage is the other primary concern. Moisture in the bales allows for microbial growth, which not only can reduce the quality of the biomass but also reduce the total mass of biomass. Erosion and pests can also reduce the amount of material present. Bales stored in an unprotected environment can lose 5-20% of their mass by these factors, meaning that additional bales must be collected to support a facility.

There are approaches to mitigating these losses, but all are costly (Hess et al, 2009; Petrolia 2008; Morey et al., 2010). Bales can be wrapped, which prevents moisture from entering the bales, preventing temperature increases or spoilage. However, individually wrapping bales is expensive (~$5/ton) and would require the end user to be able to unwrap the bales, adding more costs. Covering the bales to reduce penetration by rain, whether through tarps, open-sided barns, or enclosed spaces, is cheaper ($3-5/ton), but also may not be practical for large quantities. Tarps are the least expensive of these options, but carry the risk of being blown away with high wind or allowing rain through a hole. Elevating the biomass or placing the bales on gravel can reduce the amount of water absorbed from the ground, providing further protection. While building elevated platforms for 700,000 tons of biomass is prohibitively expensive, gravel is relatively inexpensive (~$6/ton).

Whether or not biomass must be protected depends on the climate. Michigan is a state with a great deal of precipitation, and thus it is more likely that protection from moisture would be required in Michigan than in the Great Plains states. This is particularly true in the winter, as snow accumulates both above tarps (potentially allowing it to seep through holes over a long period of time) and on the ground (increasing the area of bales contacting water, particularly for round bales). Thus, storage will be a significant factor for Michigan.

While mitigating strategies may exist, the key problem is the fact that crops are only harvested once per year. If a biorefinery only uses corn stover, then it must store a 12 month supply of corn stover. An alternative mitigation strategy is to use multiple biomass types in the same location. Corn is harvested in October, but wheat is harvested in July. If both wheat and corn straw are used in a biorefinery, then corn stover would only need to be stored from October to July, which would mean ~25% reduction in the amount of material needed to be stored. This would reduce the land required to be stored, and if mitigating strategies that can be reused such as barns or gravel are used, then it would reduce the cost of storage. Likewise, dedicated energy crops, particularly miscanthus (Lewandowski and Heinz, 2003), can be left standing over winter and harvested in early spring (February-April). Thus, a corn-miscanthus-wheat biorefinery would substantially reduce the amount of storage required.

Potential revenue from biorefinery

The costs of collecting, densifying, and storing biomass are only part of the overall cost of finding value for the biomass. The biomass itself remains heavily resistant to conversion to biofuels or biochemicals, and multiple processing steps that require either expensive pieces of equipment or significant raw material cost. In the traditional fermentation process, only approximately 25% of the weight of the biomass is actually converted to the final biofuel. Thus, the cost and the nature of the process is highly critical to whether or not a supply chain will develop.

Biofuels and chemicals are usually produced via fermentation. Micro-organisms such as bacteria or yeast consume sugars obtained from the biomass and convert the sugars into a valuable product such as ethanol or butanol. However, sugars in biomass are locked up into long fiber chains of cellulose and hemicellulose, and are not consumable by the microbes in this form. Thus, these fibers must first be broken down into their component sugars (a process called hydrolysis), which requires mixing with water and cellulase enzymes. Yields of free sugars from this process are very low, however, as the fiber is tightly packed and surrounded by a water-resistant polymer called lignin. Thus, this tightly packed cell wall must first be opened up prior to adding enzymes. This operation, called pretreatment, generally requires high temperatures and pressures as well as an alkaline or acidic catalyst. After these three steps – pretreatment, hydrolysis, and fermentation – the biofuel or chemical has been produced, but then must be separated from the water and the rest of the chemicals in the broth. Likewise, the residual water must be recycled while the other components of the biomass (such as lignin) either converted into co-products or disposed of. A diagram of the generic process is shown in Figure 4 (Humbird et al., 2011).

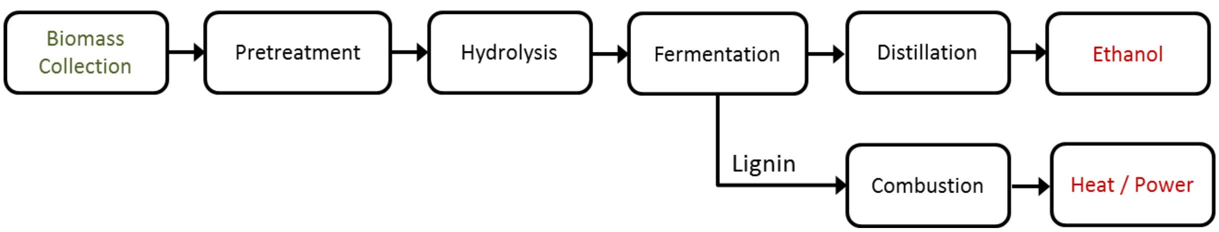

Figure 4: Simplified diagram of fermentation route to biofuel (ethanol). The carbohydrates in the plant are converted to biofuel while the remainder of the plant (primarily lignin) is burned for heat and power.

The most important cost factors of this process are the cost of the biomass itself, the enzymes used to break down the biomass, and the capital cost of the facility. Energy costs are generally not a large concern, as it is expected that the residual biomass can be burned for heat and power. Capital costs are dependent in large part on the type of pretreatment performed, if biomass is burned for heat and power, the number of tanks required for hydrolysis and fermentation, and the complexity of downstream purification. Estimates for the enzyme cost vary widely and thus represent a large unknown in the cost of the overall process. A reasonable estimate is approximately $4/kg protein (Humbird et al., 2011), which is equal to ~$0.50/gal gasoline-equivalent fuel. Other costs, such as labor and other raw materials, are relatively minor.

Based on this information, the most important concerns in processing are the yield of biofuel (and therefore also the yield of sugar), the enzyme loading, the rate and titer of biofuel production (how concentrated the product is as well as how fast it can be produced), the type of biofuel being produced, and the potential for co-products. Ethanol is the simplest and cheapest material to produce, as ethanol fermentation is rapid with high yield, and the process of separating ethanol is well established and requires only distillation and molecular sieving. However, ethanol is a low-value fuel, particularly since its market as a fuel oxygenate is already saturated in the United States. In contrast, larger hydrocarbons that can directly replace gasoline often require more difficult fermentation conditions (such as requiring specialized aerobic fermenters rather than simple anaerobic ones that ethanol uses) and may require more equipment and energy to purify. Likewise, simply burning all other organic residue for heat and power is the easiest way to dispose of the material, but is also low value. If some lignin can be recovered in a highly purified form, however, then it has great value in a variety of products (Upton and Kasko, 2016).

Because of these variables, one cannot directly determine the potential revenues of biofuel production without knowing the specifics of a process. While newer products have more value than ethanol, their yield may be lower and require a higher cost to produce. However, the potential for high value co-products from lignin can have great potential in increasing the overall revenue from a refinery. Given current petroleum prices, it is unlikely that a pure biofuel-only facility could be profitable, but one focusing on more chemicals, particularly if it includes chemicals produced from both sugars and the lignin, would be more likely.

Potential for dual use

One particular concern regarding a biomass industry is the risk involved. While a biorefinery could potentially demand thousands of tons of biomass per day, there is great risk of the refinery idling or shutting down, whether due to shifting economic conditions, a disaster, or so forth. If so, the farmers may have no other market to sell the biomass to. To combat this, a secondary use for the biomass is preferred, one that can be entered and exited easily. Unless transportation costs are very low, the other markets may not be other refineries further away. One particular alternative market may be the animal feed industry.

Agricultural residues are currently occasionally used for feed or bedding, but the market is local and sporadic rather than a true commodity. Generally, the biomass is sold at hay auctions or informally bartered. Prices are dependent on the local supply and demand. Furthermore, the quality of the residues can vary widely, as differing storage conditions may lead to increased moisture, causing mold, leeching, etc. This lack of a commodity market means price and supply uncertainty, increasing the risk on local farmers. Furthermore, its value as a feed is limited due to its low nutritional value, being low in nitrogen (protein) and having highly indigestible fiber.

While one might expect that biomass collection for biofuels might hurt the animal feed industry by increasing competition, there is also the possibility that improved technology for feedstock logistics could benefit the agricultural sector. Densification is required to transport biomass long distances, but also makes biomass easier to store. Thus, storing biomass as pellets could reduce storage variability as well as supply variability by making biomass available year-round. Furthermore, densification can increase the digestibility of the fiber of the biomass, as the sheer stresses in the pelletizer partially break open the cell walls. For example, Ray et al (2014) found approximately 25% higher ethanol yields from pelleted stover than from nonpelleted corn stover. In contrast, however, the biomass will lose some of its value as a fiber source. Ruminant animals need a small portion of long fibrous material in their diet, but the pelletization process decreases the size of the fibers. Alternative densification methods, such as cubing, could preserve the fiber size, although it would not likely increase its digestibility.

Currently, there are approximately 22 million head of cattle in the United States' corn belt (USDA NASS). While these residues could be a feedstock for smaller markets (such as sheep or goats), this represents the majority of the potential animal feed market for agricultural residue pellets. Approximately 25-30 lb of dry feed are consumed per day by a finishing (nearly at full body weight) steer. It is highly likely that only a portion of the diet can be agricultural residues or grasses. Assuming a 25% inclusion rate in diets, the total demand for residues by cattle in the United States is 23 million tons per year. In contrast, the total potential recoverable corn stover is approximately 104 million tons per year.

Thus, a synergistic effect could exist between the bioenergy market, cattle feeding operations, and biomass logistics. Currently, there is no incentive to produce a biomass logistics industry for cattle feed, as the investment is not worth the market risk and uncertainty. However, the risk of developing, simultaneously, a bioenergy market and a biomass logistics industry is too high for both to likely occur. Allowing access to the secondary market of animal feed would reduce this risk significantly. Because of the relative amount of feed required compared to the potential amount of recoverable biomass is small, there is less concern that competition will raise the price of biomass outside the margin that is viable for biofuels. Given that animal feed prices are correlated with corn grain price, and the corn grain price is correlated with oil prices, it is likely that biomass prices will remain viable for both markets.

Besides animal feed, other uses are possible as well. The pellet industry for combustion for heat and power has increased rapidly in the last decade, mostly for export to Europe. These pellets are primarily wood pellets, which are denser, have more energy, and less ash than agricultural residues. This makes them less valuable as a combustion feedstock. It remains to be seen if agricultural residues can be competitive with wood pellets. A second option is use in anaerobic digestion, which converts animal manure to biogas for heat or power. Agricultural residues can be combined with the manure to improve efficiency and increase total biogas output (Li et al., 2013). However, the additional energy from the agricultural pellets may not offset the costs of producing the pellets. Furthermore, many animal farms also produce corn and other crops, and thus already have agricultural waste to mix with manure. Thus, this market, if it does exist, is likely to be small. However, such a market could develop in site-specific areas with large animal farms.

Potential for upgrading

While finding an alternative market for biomass would be a considerable benefit for starting a cellulosic bioeconomy, a key concern is that the biomass, even as a densified form, has such low value. Thus, it would be preferable to upgrade its value prior to sale. Currently, there are no commercial activities to upgrade densified biomass, although research is being performed in this area. Two primary areas of research are present: leaching out salts and other inorganic material to improve properties for fuel combustion, and performing an alkaline treatment to improve its digestibility for cattle feed, anaerobic digestion, or biofuel production.

Co-firing biomass with coal requires the biomass to be low in ash content, as the minerals do not contribute to energy production can also cause corrosion and other maintenance problems. However, corn stover, wheat straw, and other agricultural residues are generally 5-10% ash. Leeching with water or a mild acidic solution involves contacting the biomass with water to allow these minerals to dissolve. Experiments show that between 10-50% of minerals can be removed with this approach (Tonn et al., 2012; Yu et al., 2014). While effective, the key concern is the cost of the process. This process creates a great deal of wastewater to be treated (approximately 20 tons of water used per ton of biomass), and also requires the biomass to be dried afterwards. Because of these costs, leeching is not yet performed commercially. Leeching provides very little benefit for a traditional fermentation approach to biofuel production, and thus a facility that focuses on leeching and densifying biomass would likely not be a potential supplier to these biorefineries.

Ammonia treatment has been studied to improve low quality biomass for cattle feed for (Waiss et al., 1972; Huber and Santana, 1972; Knapp et al., 1974). In brief, anhydrous ammonia, concentrated alkaline ammonia, or urea (which breaks down into ammonia) is added to a pile of biomass at a ratio of approximately 10-30 kg ammonia per ton of biomass. The biomass is left to react under a tarp for several weeks, during which time a portion of the ammonia reacts with the cell wall. This reacted ammonia can be digested in the cattle stomach and converted to protein, and thus serves as a protein source for the cattle. Furthermore, the digestibility of the fiber within the biomass is increased slightly.

Widespread use of anhydrous ammonia to improve the nutritive value of low quality forages such as corn stover, wheat straw and grass hay began in the late 1970s (Saenger et al, 1982). This technology is still used in modern times to some extent on small holder farms in developing countries (Schiere and Nell, 1993; Mehra et al., 2004).
An alternative to this mild ammonia treatment is to use calcium oxide or calcium hydroxide. This lime treatment is performed in a similar manner as the ammonia treatment, although since the calcium is not volatile a tarp is not required. Studies at the University of Nebraska have found that the lime treated corn stover can be combined with distiller's grains (the byproduct of corn ethanol production) to replace corn grain (Peterson et al., 2014).

While ammoniation and lime treatment can improve the value of the agricultural biomass as feed for animals, it has little impact on biofuel production. Thus, it is unlikely that material treated in this matter would be sold to biorefineries. In contrast, AFEX treatment has been shown to be effective as a treatment for both cattle feed and biofuel production. AFEX (ammonia fiber expansion) pretreatment reacts biomass with ammonia under moderate temperatures (100-150°C) and pressures (~20 atm) to decrystallize cellulose, partially solubilize hemicellulose, and redistribute lignin (Chundawat et al., 2010;

Balan et al., 2009). Unlike all other leading pretreatments, this reaction takes place at low water loading (0.5 – 1 g water/g biomass), and so the resulting product has no liquid streams (a "dry-to-dry process") and only a small amount of water needs to be removed.

The lignin that was redistributed during the pretreatment acts as a binding agent, allowing for pelletization to occur with modest energy input and without the need for an added binder. Based on laboratory-scale studies, the resulting AFEX pellets are denser and more durable than traditional pellets (from untreated biomass) due to the redistributed lignin (Campbell et al., 2013). The dense, durable AFEX pellets can be economically handled, stored, and shipped using current corn grain infrastructure.

The AFEX pellets are ready to be converted to sugar as-is; no further processing is required prior to enzymatic hydrolysis into component sugars at the biorefinery (Bals et al., 2014). AFEX pellets do not need to be crushed prior to enzymatic hydrolysis, nor do they require being washed or detoxified. Thus, the front-end portion of a cellulosic biorefinery can be similar to a corn-grain ethanol refinery, dramatically simplifying the biorefinery design. MBI has made considerable progress developing the AFEX process over the past decade. The critical barrier to AFEX depots was the design of a robust, low cost reactor that could be scaled down to the depot scale (Campbell et al., 2013). This barrier was overcome with the design of a novel packed-bed reactor in which ammonia is cycled between a pair of these reactors operating in tandem. In 2011, this design was scaled up from a laboratory prototype to pilot scale, consisting of two 3-m tall reactors capable of treating ~30 kg dry weight of biomass per batch. To date, over 600 runs have been successfully completed in this pilot plant using corn stover and wheat straw.

In a pilot-scale test, over 90% of the glucan was converted to glucose using commercially available enzymes, and completely consumed by *Zymomonas mobilis 8b* after just 36 hours of fermentation (Sarks et al., 2016). An ethanol titer of 60 g/L was obtained at a yield of 80 gallons/US ton of biomass. No sterilization, detoxification, or crushing of the pellets was required to obtain these results. For the cattle feed market, preliminary feeding trials have been performed on sheep, goats, and both beef and dairy cattle, demonstrating that AFEX pellets are palatable to these animals and support weight gain and dairy production.

Potential Impact on Michigan

There is great potential to developing a biomass economy in Michigan based around decentralized processing centers. While the corn yields obtained in Michigan - as well as the extent of farmland – are less than in states such as Iowa, it is sufficient to allow for the collection of some corn stover while leaving enough on the field for erosion control and nutrient replacement. Planting cover crops, a growing practice in Michigan, would allow for further biomass collection and use. Table 3 below shows the average acreage of corn planted and the yield in Michigan over a 3-year period (2013-2015). In total, Michigan could support 3 million tons of biomass from corn stover alone. If wheat straw and dedicated energy grasses were included, the figure would be much greater.

Table 3: Potential corn stover supply in Michigan if conservation practices are observed.

Agricultural Region	Corn Acreage	Average Yield	Removable Stover
Central	242,000	150	484,000
Southeast	322,000	161	740,000
Southwest	363,000	161	835,000
East Central	418,000	171	1,045,000
South Central	693,000	161	1,594,000
Total	2,038,000		4,698,000

Assuming 4.7 million tons of corn stover collected and $60/ton paid to the farmer, this would represent an additional $280 million in revenue directly for farmers. Harvesting this biomass would likely produce approximately 1,000 seasonal jobs in Michigan. Furthermore, assuming these were processed in pellet producing depots throughout Michigan, this would represent an additional 70 processing centers in the state. Each depot would likely include ~20 employees, representing an additional 1,400 jobs for Michigan, which does not include equipment providers, transporters, or additional harvesters. If used to produce biofuels, then approximately 280 million gallons of gasoline equivalent biofuel could be produced, potentially producing $700 million in additional revenue and producing an additional ~150 jobs.

As the biomass economy in Michigan grows, it can be used to further enhance agricultural farmland to provide further economic and environmental benefits. If a proven market for biomass is developed, there would be incentive to grow dedicated grasses in the future. Early adoption of this approach might be to grow and harvest grasses as buffer strips on the edges of fields and riparian zones along streams and rivers. Other land in the conservation reserve program could also be used for biomass collection. Policy directives are needed to ensure that environmental benefits are maintained while allowing farmers to gain some revenue from this land. Dedicated fields of grasses are less likely due to the opportunity costs compared with traditional crops, but may also be produced.

Depending on the technology used for processing the biomass, residues from Michigan's extensive fruit and other human-use crops may also be collected. These crop residues generally are not suitable for ammonia-based treatments, but may be suitable for anaerobic digestion or other treatments. It remains to be seen if these residues can be mixed with grasses and grain residues or if separate processing centers are necessary.

Table 4: Advantages and disadvantages to a large-scale biomass industry in the state of Michigan

Advantages	Disadvantages
- Large areas of corn and wheat land, creating sufficient biomass for recovery - Conditions acceptable for growing cover crops - Relatively flat landscape in corn regions reducing need to leave stover on field for erosion control - Possible synergistic value with combating nutrient runoff into Great Lakes - Potential for significant increase in rural economy	- Requires developing lower value markets first prior to cellulosic biofuels - Heavy winter precipitation creates challenges for storage - If performed without sustainability in mind, could exacerbate nutrient runoff concerns

Government policy must be aligned with economic and environmental sustainability in order to obtain the potential benefits of a biomass collection economy. Notably, we do not recommend specific funding or development of specific final products for the biomass. Given the price fluctuations in oil and the difficulty in predicting which technologies will ultimately be successful, mandating specific biofuel production or funding specific products is likely to be counterproductive. Instead, we recommend focusing on developing the supply chain to support final products when and if they arise. In particular, we recommend the following:

1) Continue farmer education and outreach on the benefits and environmental impact of stover collection, cover crop production, and buffer strips.
2) Develop incentives to allow harvesting of buffer strips and conservation grasses. This may require more research to ensure that this is performed in an environmentally sustainable manner.
3) Encourage near-term usage of corn stover, such as anaerobic digestion or cattle feed.

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Informing the Debate

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