The Potential for Cogeneration from Manure, Crop Residues, and Food Processing Wastes in Michigan

By

Megan Falvey, Coordinator
Michigan Biomass EnergyProgram
Michigan Public Service Commission

March 1996

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INTRODUCTION

The purpose of this paper is to assess the potential for energy generation from a variety of biomass waste and residue sources in the state of Michigan. Such sources in the state of Michigan might include: timber and wood-waste; solid waste from municipal landfills; urban waste; residues from the food processing industries; and residues from wastewater treatment facilities. Some preliminary survey research on specific biomass sources potentially available for energy use in Michigan has already been completed (Stanton, 1995; Public Policy Associates, 1994; Goldberg, Laitner, and Holmes, 1994; Borwer et al, 1993). Therefore, in order to avoid duplicating existing research, this paper focuses specifically on assessing the potential for energy generation from agricultural wastes (both animal manure and crop residues) and food processing residues in the state of Michigan.

This paper is organized as follows: the first section briefly discusses what biomass energy is, and the advantages associated with biomass energy use. The next section then estimates the amounts of biomass potentially available from agricultural wastes and food processing residues in the state of Michigan. This section also includes a discussion of the alternative uses for and constraints on specific biomass feedstocks as well as any necessary treatments for energy conversion for each type of biomass. The final section of this paper provides a general description of the energy conversion processes for biomass, including a discussion on energy efficiency and the suitability of types of energy conversion systems to specific biomass feedstocks.

SECTION ONE:

Why Biomass Energy? Use Advantages

The term 'biomass" refers to organic matter produced by plants and animals. While this definition is broad enough to include agricultural crops, whole trees, and animal fats, biomass fuels from waste products (such as crop residues, manure, food processing wastes, municipal and wood wastes) are often the most economically viable. Since there is a negative, and often substantial cost associated with the disposal of these waste, biomass fuels derived from waste products offer a potentially low cost energy source with the added advantage of reducing the problems and environmental impacts associated with waste disposal.

The use of biomass feedstocks in energy generation has two significant advantages over traditional fossil fuels (such as oil, coal, and gas) that warrant a brief discussion. First, biomass energy often promotes the development of healthy, sustainable local economies (Stanton, 1995; Employment Research Associates, 1985). Stanton (1995) notes that there are three different paths to local economic development: (1) import substitution; (2) efficiency improvement; and (3) economic growth through new business recruitment (Stanton, 1995, p. 10). Unfortunately, local governments and community planners usually focus on the third of these options, recruitment of new business. The problem with this approach is that it pits communities against communities and states against states in a zero-sum, high-risk game competing against one another for few expanding industries (Stanton, 1995, p. 10). Even when successful, the recruitment of new businesses often has only a short term impact on local economies, as workers migrate in to fill job openings.

The development of biomass energy, on the other hand, usually involves both import substitution and efficiency improvement (Employment Research Associates, 1985). For energy importing states like Michigan, current energy consumption patterns essentially amount to supporting profits and jobs in energy industries out of state (or out of the country). The development of biomass energy reroutes those profits and jobs back into the state and local communities. In addition, biomass energy production tends to be much more labor intensive than that of traditional fossil fuels, resulting in more jobs: about 33% of the cost of biomass energy goes to labor, vs. about 7% for oil and gas production (Fulton & Grimes, 1988; Employment Associates, 1985). Over-all, statewide increases in jobs and corresponding consumer spending infuse markets and local economies throughout the state.

Besides rerouting Michigan dollars back to the state, biomass energy development can often offer a cheaper and more efficient alternative to fossil fuels. Reduced price and increased efficiency are the result of two factors in biomass energy production. First, several biomass feedstocks can simply supply energy at a lower cost than fossil fuels. For example, using existing technology, wood feedstocks can provide the same heating value at about 2/3 of the cost of fossil fuels (Stanton, 1995). Second, biomass energy conversion is often the most efficient disposal option of many types of wastes (such as manure, paper sludge, food processing wastes, wood wastes, and municipal sold wastes). Since these wastes often have a substantial negative values (i.e. there is a cost to properly dispose of them) using them in biomass energy conversion increases overall energy efficiency.

That wastes and residues can be used as biomass energy feedstocks brings us to the second major advantage of biomass energy: it is often more environmentally friendly than fossil fuels (Brower et al, 1993). This is the case because energy conversion from waste streams uses (and can significantly reduce) the amount of waste that currently ends up in the state's landfills, groundwater, and air. For example, excess wood waste (which, until very recently was often disposed of through the highly polluting process of open-burning in the state of Michigan), can be used in a variety of energy applications, that both extract a profitable energy value from the wood and significantly reduce the total amount of wood waste which must be treated and disposed of. Many materials -- such as railroad ties, discarded tires, sewage sludge, and animal manure, just to name a few -- can similarly be converted to energy significantly reducing Michigan's total waste stream.

In addition to reducing waste, biomass feedstocks and biomass energy conversion technologies are often simply less polluting compared to fossil fuels systems (Brower, et al, 1993; Stanton, 1995). The environmental impacts associated with fossil fuels use are well documented: the use of fossil fuels in existing energy applications results in air pollution from sulfur dioxide, carbon monoxide, nitrogen oxides, lead, ash and soot; water pollution from mercury and other contaminants, and potential global warming from carbon dioxide emissions (Brower, et al, 1993). Pollution emissions depend on the energy conversion process employed as well as the feedstock used. In general, however, wood and plant feedstocks emit less sulfur dioxide, chlorine, and ash/particulates during combustion than fossil fuels; wood, plant, and food-processing residues can be used to produce liquid fuels that reduce air pollutants through significantly lower carbon monoxide emissions than gasoline, and animal manure and plant feedstocks can generate methane gas for electric power generation with reduced levels of sulfur dioxide.

The advantages to energy conversion from biomass feedstocks are clear: biomass energy can provide a cheaper and more environmentally friendly fuel source than traditional fossil fuels while at the same time promoting the sustainable development of local economies. The first step in considering the potential for biomass energy in the state of Michigan is assessing what types and how much biomass is available. The next section of this paper will focus on estimating potential energy generation in the state of Michigan from agricultural wastes and food processing residues.

SECTION TWO:
Agricultural and Food Processing Wastes

Michigan has an ample supply of crop, animal manure, and food processing wastes suitable for energy conversion. However, the amounts of these wastes actually available for energy conversion depends on several factors. Specifically, the amount of crop residue, animal manure, and food processing wastes actually available for energy recovery in Michigan will depend on its value in alternative uses; the price of energy; current farming/industry practices; and collection, transportation, and treatment costs.

Animal Manure:

The livestock industry in Michigan generates large amounts of manure at animal holding areas, dairies, feed lots, and pasturelands. Manure from Michigan's confined (non-grazing animals)[1], such as swine, poultry and non-grazing cattle, must be collected and treated or disposed of. Typically, manure from confined animals is spread directly on fields, stored in earthen pits, or treated in manure lagoons. Although improvements have been made in storage and manure treatment facilities, significant amounts of manure eventually leach back into the soil, which can both contaminate ground and surface water and destroy soil nutrient balance[2].

This waste stream, which in many areas of the state has become problematic, can be used and significantly reduced via energy generation applications. Michigan's poultry, cattle, and swine farming operations offer a large potential source of biomass for energy generation. The Michigan Department of Agricultural estimates a statewide population of 1,200,000 hogs and pigs and 5,555,000 laying chickens (Michigan Agricultural Statistics, 1994). A study conducted by Michigan State Department of Agricultural Engineering estimates that there are 571,000 head of non-grazing cattle and at least 42,300 broilers. Unfortunately, no estimate of the number of farm-raised turkeys in the state of Michigan is available.

There are no direct data available on the volume of manure generated by cattle, swine, and chickens in the state of Michigan. However, manure generation can be estimated, using a coefficient of manure production based on animal type and weight category (Midwest Plan

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[1]Manure generated by grazing animals, such as horses and sheep, is usually collected only seasonally (for example during lambing and foaling when animals are confined), and therefore will not be included in this study.

[2]A study conducted by the Agricultural Engineering department at Michigan State University found that approximately 1/3 of counties in Michigan had excess amounts of nitrogen, phosphate and/or potash (Salthouse, 1995).

Service Handbook , 1985). The Midwest Plan Services Handbook also provides estimated ratios of wet manure to total solids and total volatile solids for each animal type.

animal type	total animal weight in MI (tons)	manure coefficient lbs./per day	wet manure generated, annual tons	total solids generated, annual tons	total volatile solids, annual tons
non-grazing cattle	385,666	.082	11,542990	1,465458	1,204,486
swine	81,000	.0653	1,931,579	177,380	141,912
chickens	11,653	.0525	213,710	53,936	37,654
turkeys	not available	not available	72,800	18,373	12,826

Applying the coefficients , Michigan's non-grazing cattle generate approximately 11,500,000 tons of manure a year; swine almost 2,000,000 tons per year, and chickens and broilers approximately 210,000 tons of manure per year. A feasibility study conducted by Michigan Biomass Energy program in 1994 estimates total turkey litter[3] production in the state of Michigan at approximately 72,800 tons per year.   Adding total annual generated turkey liter to the estimated cattle, swine, and chicken manure, we arrive at a manure biomass potential of 12,0780,00 tons annually in Michigan.

This estimated annual biomass generation can in turn be converted to Btu, using conversion factors for each manure type (Western Regional Biomass Energy Program, 1993). For these estimates, dry manure weight (or total solids) and total volatile solids are used, since the water value of the manure has no energy conversion value.

animal type	total volatile solids, annual tons	estimated energy coefficient	MM* Btu/year
non-grazing cattle	1,204,486	5.85	7,046,241
swine	141,912	5.19	736,523
chickens	37,654	6.3	237,218
turkeys	12,826	6.3	80,806

*MM refers to millions of Btu.

[3]turkey litter is approximately 50% turkey manure and 50% wood-chip turkey bedding. Because of its high wood content, it has an even greater energy generation potential than animal manure.

Combined, the manure generated from confined farm animals in Michigan could supply roughly 8.1 trillion Btu s each year, or approximately 5% of current nuclear energy generation in the state of Michigan.

Alternative Manure Applications

There is concern that increasing manure-to-energy applications might reduce the amount of manure used as a soil supplement (fertilizer), and thereby threaten soil nutrient balance. Although there are no data on the amounts of manure currently used as a soil supplement, the study by Salthouse (1995) found that a statewide soil nutrient deficit exists equaling 243,664 tons of nitrogen, 56,982 tons of phosphate and 97,735 tons of potash. The study concludes that approximately one half of these nutrient deficits could be met by applying the existing animal manure in the state (Salthouse, 1995). While the statewide nutrient deficits could also be met by using commercial fertilizer, manure application seems the obvious choice since it both provides farmers with a low cost substitute for commercial fertilizer products and recycles manure that would otherwise have to be treated as waste and disposed of.

The manure as fertilizer/biomass energy source dilemma is not be an either/or proposition, however. With certain types of energy conversion (namely anaerobic digester systems, discussed in detail under section two), the energy value is extracted from the biomass feedstock (in this case manure) while leaving valuable "fertilizer components" (phosphate, nitrogen, and potash) intact. With anaerobic digester systems, the manure end product actually has an improved value as a soil supplement because the moisture, acidity, and the risk of bacterial spread is reduced (Sampt, 1995).

Collection and Pre-treatment of Manure:

State law requires that manure generated by confined farm animals be collected and properly treated or disposed of. Therefore, no additional collection techniques for manure -to- energy conversion processes are required. Instead of farmers collecting waste and transporting it to a storage facility, treatment lagoon, or spreading it on crop land, collected waste would be brought to an on or off farm energy facility. Manure does need to be treated, however, depending on the particular type of energy conversion process employed. Specifically, manure will need to be dried for use in both combustion and gasification systems, and "mixed" to a consistent thickness and PH level for anaerobic digester systems (see section two for more details).

Agricultural Residues:

Agriculture is a vital and important part of Michigan's economy. The agricultural residues -- cobs, stems, stalks, straws, and other plant matter that are left in the field after crop harvest can be used for energy generation. The most important of these wastes are wheat straw, corn stalks, and soybean field wastes, which make up about 85% of total crop residue stream annually (U.S. Department of Energy, 1990). Currently, most residues are returned to the soil for fertilizer and to prevent soil erosion. There are no direct data available on the volume of agricultural wastes generated in Michigan. However, we can get a partial estimate of this waste stream, by applying ratios[4] of crop yield/agricultural residue (see: University of Nebraska-Lincoln study, 1990; Larson et al, 1978). Unfortunately, these ratios are not available for all Michigan crops. However, using the available ratios, we can estimate annual agricultural residues generated from corn, soybeans, wheat, oats, barely, and rye crops.

We begin this process by first assessing total crop production in Michigan. During 1993, the Michigan Agricultural Statistics service estimates that 2.5 million acres of corn (at approximately 110 bushels per acre), 1.45 million acres of soybeans (at approximately 38 bushels per acre), .58 million acres of wheat (at approximately 41 bushels per acre), .15 million acres of oats (at approximately 55 bushels per acre), .03 million acres of barley (at approximately 54 bushels per acre), and .08 million acres of rye (at approximately 28 bushels per acre) were planted in Michigan (Michigan Agricultural Statistics, 1994). From these figures we can estimate total tons of agricultural output for each of the five crops by using the following estimated weight per bushel figures: corn: 56 lbs. of grain per bushel; soybeans: 60 lbs. of grain per bushel; wheat: 60 lbs. of grain per bushel; oats: 32 lbs. of grain per bushel; barley: 48 lbs. of grain per bushel; and rye: 56 lbs. of grain per bushel. Subtracting an estimated 11.5% water from each of these totals then gives us an estimated crop output for Michigan in dry tons.

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[4]the amount of crop residues generated by a specific crop can vary, depending on the geographic region, and the soil preparation and harvesting techniques employed. Therefore, these ratios should be considered rough estimates.

crop	1993 total crop output (million dry tons)	residue to crop output ration	in-field residue (millions dry tons)	heating value (trillion Btu)	deliverable residue (million dry tons)	heating value (trillion Btu)
corn	6.545	1.0	6.545	104.72	1.309	20.94
soy	1.463	.75	1.097	17.552	.219	3.5
wheat	.6314	1.67	.1.054	16.864	.211	3.37
oats	.219	2.0	.438	7	.0876	1.402
barely	.03434	1.5	.0515	.824	.0103	.165
rye	.0555	1.5	.0833	1.333	.0166	.267

Next, applying the crop production/crop residue rations, an we arrive at an estimated 8.95 million dry tons of agricultural residue generated annually in Michigan from corn, soybean, wheat, oat, barely and rye crops.

As with manure, an energy value for this waste residue can be calculated by using conversion factors for each residue type. However, unlike manure, crop residue-to-energy conversions would require substantial changes in current farming practices. Realistically speaking, because of various alternative uses for crop residues and collection constraints, not all crop residues can be used for energy conversion. Therefore, before finding energy values for agricultural residues, we should consider some of the current alternative uses for crop residues.

Alternative Crop Residue Applications:
In order to assess the amount of crop residues potentially available for energy conversion, two alternative uses of agricultural wastes must be considered. The first of these uses, as mentioned earlier, is applying crop residue to the field for its erosion prevention and fertilizing qualities. The national soil conservation plan recommends that approximately 30%[5] of all crop wastes should be returned to the field in order to ensure proper soil nutrient balance and erosion prevention. However, as was the case with manure, certain types of crop residue-to-energy applications (namely anaerobic digestors) can extract the energy value of the residue, while leaving the fertilizing and erosion preventing qualities intact (see section two for more details).

[5] the ideal amount of agricultural residues that should be left in the field depends on current soil characteristics, slope, crop type, and planting and harvesting practices. Therefore, the national soil conservation plan figure of 30% should be considered a rough estimate.

A second primary alternative use for agricultural residues (from straw and corn stalks in particular) is as a supplement in livestock feed. Unfortunately, no estimates are available for the amount of agricultural residues currently processed as animal feed in the state of Michigan. However, the Congressional Office of Technology Assessment (OTA) estimates that about 20% of the crop residues generated annually could be used for energy conversion without adversely affecting livestock feed supplies or soil quality.

Applying the OTA's estimate of 20% to our original annual total of agricultural residues for corn, soy, wheat, oats, barley and rye crops in Michigan (totaling 8.95 million tons), we find that approximately 1.9 million dry tons of agricultural waste could be used for energy conversion in Michigan, without adversely affecting livestock feed supplies or soil quality. Because this study does not consider fruit, vegetable, legume, or even all grain agricultural crops in Michigan, and because certain types of energy conversion do not reduce the erosion prevention and fertilizing qualities of agricultural waste, this figure underestimates the total crop residue potentially available for energy generation in Michigan.

Crop Residue to Btu Conversion:
Using this figure of 1.9 million dry tons of agricultural residue available for energy conversion, we can now assess the estimated Btu value of this agricultural waste by using conversion factors for each type of agricultural residue. Using only 20% of crop residue from Michigan's wheat, corn, soy, oat, barley and rye crops could supply Michigan with approximately 30 trillion Btu of energy annually, approximately 15% of current nuclear energy generation in the state of Michigan.

Collection and Pre-treatment of Agricultural Residues:
Collection methods of agricultural residues will vary depending on the crop type, and on whether the crop is being harvested solely for energy uses, or if the residue only will be used for energy conversion[6]. The most basic method of crop residue collection, however, is to collect residue discharged from a combine using a bailer (Lindley et al., 1994). This technique is employed when only the crop residue will be used for energy conversion and it requires that the farmer the make a separate, additional pass with the combine after the primary crop product has been harvested. The costs of collection, along with concerns about the timing of harvesting and

[6]For a more in-depth discussion of crop residue collection methods, see "A Review of Agricultural Crop Harvest and Collection Technology" Lindely et al., 1994.

planting must be weighed against the energy value of the residue.[7] The Lindley study estimates that the collection cost of agricultural crops is approximately $12.88/ton, not including any additional transport charges to an energy facility (Lindely et al., 1994).

As with manure, crop residues require some pre-treatment, specifically, residues will need to be dried for combustion and gasification applications and "mixed" to a consistent thickness and PH level for anaerobic digestors (see section two for more detail). Water will need to be added to crop residue for use in anaerobic digestors.

Food Processing Wastes:

There is good potential for energy conversion from food processing wastes in Michigan. Michigan is home to over 600 food processing plants, including a number of food processing giants such as Kellog, Bil-Mar, Country Fresh, Bristol-Myers, Murco, Coca-Cola Foods, Cherry Central, Michigan Sugar, Faygo, Thorn Apple Valley, Ralston Foods, Kraft General Foods, Butternut Bread, Oven-Fresh, Sarah Lee Bakery, Lifesavers, Stroh Brewery, Frito-Lay, Swift-Ekrich, and Gerber (Michigan Harris Directory, 1995).

While estimated conversion factors exist for calculating some types of food processing wastes, unfortunately, data on the quantities of various types of processed foods (let alone wastes!) in Michigan are sorely lacking. Obviously, assessing energy potential from food processing residues must consider the value of these residues in alternative uses; several types of food processing residues have significant positive values as feed supplements. However, many types of food residues have negative values, and given Michigan s huge turkey, cherry, and blueberry processing facilities, and large cereal and baby food industries, food processing residues could play an important role in supplying biomass power in Michigan. Future research needs to be done to assess the amounts, types, and locations of food processing residues in Michigan, as well as values in non-energy applications.

[7]The time frame for crop residue collection is fairly short: it must be doe after primary crop harvesting, but fairly quickly after, as residues left in the field tend to rot quickly.

SECTION THREE :

Biomass Energy Conversion Processes:

The following section of this paper will provide a brief overview of biomass-to-energy conversion processes commonly used for manure, agricultural waste, and food processing residues. For more detailed information on these processes see: Energy Conversion of Animal Manure, 1993; Bioenergy '94 Technical Papers, 1994.

Combustion Systems: Combustion systems tap the energy stored in biomass by burning it. If the biomass feedstock is very wet, then before combustion, it will need to be dried, so that the moisture content is no higher than roughly 50%. Next the biomass is heated, releasing volatile substances into the air, which combust at a set temperature. The remaining biomass material oxidizes and generates additional heat.

Combustion systems produce power at a relatively low rate of efficiency and conventional combustion systems have reported fuel handling problems with various biomass feedstocks, namely crop residues and some manures (where dirt and sand are inadvertently collected with the manure, as is common with dairy cattle manure). Finally, the fertilizing qualities of plant and manure biomass are significantly reduced in the combustion process (discuss ash applications here). Direct combustion systems are not ideal for most biomass feedstocks.

Gasification Systems: Gasification systems generate energy by super heating the biomass feedstock in an air-free environment, which changes it into energy-rich gases and burnable solids. As with the combustion processes, gasification requires that the biomass material be dried; however, the drying process occurs in an oxygen-free environment. Next, the dried biomass is super heated to 1,400-1,600 F (pyrolysis), in an air-free environment. Gasses and volatiles are released from the biomass material. If allowed to cool, some of these gases condense into liquid tars and oils, which can further be converted into a "biocrude" oil. If these gasses are not allowed to cool, they can be burned with oxygen to generate a steam turbine or cleaned and burned directly to generate electricity. A solid material called char (mostly carbon) which is left over after gasification can be burned to supply heat for the gasification process *(discuss chemistry of losing nitrogen up the stalk).

Gasification systems can handle a wide variety of biomass stocks and have a fairly high energy efficiency rating. As with combustion systems, the nitrogen left in the final plant or manure biomass stock residues is reduced because of the burning processes.

Anaerobic Digestors: The anaerobic digestion process takes place in a tank or vessel containing bacteria that decompose manure in an oxygen free environment. During the decomposition process, these bacteria release methane gas. This process takes place in three steps. First, bacteria break the matter down into simple sugars, which are in turn broken into organic acids. Finally, methane bacteria digest these acids, and release methane gas in the process.

Anaerobic digestors are low in cost and are well suited on small and large scale farming operations. In addition, biomass digestors can handle a wide variety of biomass feedstocks, although each "batch" needs to be mixed to consistency. The final end product of anaerobic digestion is a dry, light weight slurry, which is an excellent fertilizer with reduced acidity and risk of bacterial contamination. It also can be used to prevent soil erosion. However, since the bacteria are living organisms, temperature of the tank must be kept at an ambient temperature above 4O F. Digestors require feed almost daily and can take up to 60 days to complete the digestion process.

CONCLUSION

Biomass feedstocks currently supply approximately 3% of Michigan's total energy consumption. Currently, most biomass energy feedstocks in Michigan come from wood and wood waste, however, there is great potential within the state for energy generation from "alternative" biomass feedstocks, such as manure, crop residues, and food processing wastes. These "waste" feedstocks have good potential, both because there is an ample supply within the state and because their low or negative value makes them a cheap potential source of energy.

The purpose of this paper is to help provide an estimate of just how much manure, agricultural and food processing wastes can realistically be used in energy generation in Michigan. Biomass energy offers the state many potential benefits, including infusing local economies, and providing a cheap, renewable, and less polluting source of energy. There is much that can be done to encourage the development of biomass energy in the state. Specifically, while there is good information on the amounts and locations of wood waste, manure, crop residues, and municipal solid waste, research to determine the potential for energy generation from waste water treatment plants, and food processing wastes is needed. In addition, while other studies have identified market and legislative barriers to biomass energy (Goldberg, et al, 1994; Stanton, 1995), the development of a state-wide action plan with appropriate incentives to overcome barriers to biomass energy development is critical.

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