Minnesota Biomass -

Hydrogen and Electricity Generation Potential

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- System benefits charges or other rate-payer funded utility efficiency and renewable programs,
- Renewable or efficiency portfolio standards,
- Use of clean energy technologies to help states and localities address air emissions, or
- Use of renewable energy on state or local public lands.

These requests are for short-term assistance, with a maximum budget of $5,000 per request. States can access experts from the National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL) and Lawrence Berkeley National Lab (LBNL).

The National Renewable Energy Laboratory (NREL) is the nation's primary laboratory for renewable energy and energy efficiency R&D. Established in 1974, NREL began operating in 1977 as the Solar Energy Research Institute. It was designated a national laboratory of the U.S. Department of Energy (DOE) in September 1991 and its name changed to NREL. NREL's mission is to develop renewable energy and energy efficiency technologies and practices, advance related science and engineering, and transfer knowledge and innovations to address the nation's energy and environmental goals. More information on NREL's programs and capabilities can be found at www.nrel.gov.

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Today, renewable energy sources—solar, wind, biomass, and hydroelectric power—account for 9.4% of the total electricity generated in the United States. Biomass power is the second largest source of renewable electricity (after hydroelectric power), making up 19% of the total renewable electricity, or 76% of the non-hydro renewable electricity. (EIA, 2004). Most of this biomass power (62%) is produced from wood residues generated by the forestry industry, urban wood waste, and pulp and paper mills. While this power is largely generated by direct-fired combustion, which operates at about 20% efficiency, the same biomass can also be used in 37% efficient integrated gasification combined cycle (IGCC) technologies. In addition to this more efficient method to produce electricity from biomass, recent advances also provide the means to convert the biomass to hydrogen, which can be used safely as fuel or as a component in products such as ammonia-based fertilizers.

The need to address waste streams and environmental concerns about our current fossil-based energy system have provided new incentives for using biomass to produce energy. Mill residues and other wood residues are used to generate electricity, avoiding landfill disposal costs while generating power for on-site use. Agricultural residues are used as biomass power feedstocks as a waste control strategy and have been encouraged, in part, to reduce the air quality impacts of open-field burning. The pulp and paper industry has been using on-site power systems to recover valuable chemicals from the black liquor and generate steam and electricity for the plant. Landfill and manure methane projects utilize methane that would otherwise be vented or flared, while displacing the need for conventional electricity generation. Using biomass for energy generation also offers a number of other benefits such as greenhouse gas reduction and air-quality benefits compared to open burning and coal-fired power plants. Additionally, because many biomass feedstocks are concentrated in rural areas, biomass energy facilities can provide rural economic development benefits by creating jobs and tax revenues. Finally, biomass energy offsets fossil fuel consumption and helps to diversify the nation's energy supply mix.

As a State, Minnesota is rich in natural resources, a majority of which are in the agricultural and forestry sectors. As a consequence of these resources, significant quantities of residual biomass is available. A study was conducted by the National Renewable Energy Laboratory to determine the total amount of biomass-derived hydrogen and electricity that could be produced in the State of Minnesota from its energy crops and residual biomass. Additionally, the percents of today's gasoline consumption and electricity consumption were calculated, as well as the resulting reductions in greenhouse gas emissions.

Biomass resource estimates from three literature sources were obtained and used to estimate the total quantity of forest residue, mill residue, agricultural residue, energy crops, and urban wood residue. As in many biomass-related studies, the most significant area of uncertainty in this analysis is in the area of resource data inputs. As shown in Table 1, biomass resource quantities were not available for all biomass categories in any of the data sources. Only lignocellulosic (e.g., wood, grasses, agricultural residues) biomass was included in this assessment, although additional biomass in the form of animal excreta, municipal solid waste, and food processing residue may also be used to produce electricity and/or hydrogen. If data on the amounts of these additional waste streams become available, estimates for biomass-based electricity and hydrogen generation potential for the state would be revised upward.

1. Biomass Inventory

The data from three Minnesota biomass inventories were averaged to determine values for this analysis.

Table 1: Biomass Resources in Minnesota

Source of Biomass	Biomass Resources from ORNL database[1]	Biomass Resources from NREL GIS Group	Biomass Resource from 1997 ILSR Inventory	Average of all biomass resource data
	tons/year at <$50/ton	tons/year	tons/year	tons/year
Forest Residue	874,900	-	-	874,900
Mill Residue	1,121,000	1,017,688	571,960	903,549
Agricultural Residue	11,935,896	40,709,527	22,040,438	24,895,287
Energy Crops	5,783,002	-	-	5,783,002
Urban Wood Waste	1,532,529	-	-	1,532,529
Total	**21,247,327**	**41,727,215**	**22,612,398**	**33,989,267**

[1] ORNL 1999 database: http://bioenergy.ornl.gov/resourcedata/

[2]NREL GIS database, updated with new sources of data: mill residue data are from the 2002 Timber Products Output Database by the USDA Forest Service; agricultural residue data are from the National Agricultural Statistics Service at USDA (http://www.nass.usda.gov:81/ipedb/)

[3]ILSR 1997 database:
http://www.carbohydrateeconomy.org/library/admin/uploadedfiles/Survey_of_Minnesotas_Agricultural_Residues_and.html

2. Hydrogen from Biomass

Hydrogen can be produced from lignocellulosic biomass by combining gasification or pyrolysis, with steam reforming and the water-gas shift reaction ($CO + H_2O \Rightarrow CO_2 + H_2$). The technology to achieve this has been tested in systems equivalent to 10 kg of biomass per hour. Gasification technology has been tested at scales as large as approximately 15,000 kg of biomass per hour.

Biomass typically contains only about 6% (by weight) hydrogen. That leads many people to argue that it doesn't make sense to use biomass to produce hydrogen. However, the carbon in biomass is used as the chemical template for removing oxygen from water in the steam reforming process. By producing some hydrogen from steam in the reforming and water gas-shift reactors, approximately 50% more hydrogen can be produced than by using only the hydrogen in the biomass. If biomass is approximated as having the empirical formula of CH1.4O0.6, the full conversion of biomass to hydrogen can be represented as:

$$CH_{1.4}O_{0.6} + 1.4H_2O \rightarrow CO_2 + 2.1H_2$$

If all of the hydrogen were to come from the biomass, only 1.4 moles of hydrogen would be produced per "mole" of biomass. Because the carbon in the biomass is used to remove some hydrogen from water in reforming/shift, however, up to 2.1 moles of hydrogen per "mole" of biomass are possible.

Hydrogen can also be produced from manure using anaerobic digestion followed by reforming and shift. Biomass-derived sugars, which could be the waste products from food processing facilities (e.g., plants making beet sugar, corn syrup, cheese, cereals or baked goods) or the products of enzymatic breakdown of cellulose, can be converted to hydrogen via fermentation or anaerobic digestion followed by reforming.

Finally, low-temperature conversion of glucose to hydrogen is also being researched, but is not currently applicable to whole-biomass (lignocellulosic) streams.

To calculate the amount of hydrogen that could be produced from lignocellulosic biomass in Minnesota, a hydrogen yield of 0.725 kg/kg bone dry biomass (65.8 kg H2/ton bone dry biomass) was assumed (Spath and Mann, 2003). This corresponds to a 50% energy conversion efficiency and an assumption that the biomass has a heating value of 8,500 Btu/lb HHV, dry basis.

The amount of gasoline used in Minnesota in 2000 was approximately 2.5 billion gallons. On a lower heating value basis, the energy content of a gallon of gasoline is approximately equal to the energy content of a kilogram of hydrogen. From these parameters, the amount of gasoline that could be displaced by biomass-derived hydrogen was calculated using the following equation:

$$D = \frac{H2 * \eta}{G} * 100$$

Where:

D = percentage of gasoline displaced, gallons/year
H2 = amount of hydrogen used in transportation applications, kg/year
η = ratio of the efficiency of hydrogen use to gasoline use
G = amount of gasoline used in MN in 2000

Based on data from the GREET program http://www.transportation.anl.gov/software/GREET/index.html) at Argonne National Laboratory, the amount of CO_2 emitted from gasoline-burning automobiles is equal to 9,100 grams per gallon of gasoline consumed. Since no CO_2 is produced by using hydrogen in an internal combustion engine or fuel cell, the direct vehicle CO_2 emissions savings are equal to 9,100 grams per gallon of gasoline conserved.

Previous life cycle assessments by the National Renewable Energy Laboratory have shown that the total amount of greenhouse gases (CO2, methane, and N2O) that are produced by converting biomass to hydrogen depend on the type of biomass and the fate of the biomass if it were to have been disposed of rather than used for energy. If the biomass is grown as an energy crop, specifically for the purpose of energy production, the CO2 emitted from the hydrogen facility is balanced by the CO2 consumed by the biomass during its growth cycle. However, the process cannot be considered to be a zero-net emitter because of the fossil fuels used to grow and transport the biomass. Mann and Spath (1997) showed that the net greenhouse gas emissions are approximately 5% of the total carbon in the biomass. However, if the biomass is a residue that would have been sent to a landfill (e.g., urban wood waste), the net greenhouse gas emissions from the system are negative due to the avoidance of methane emissions during normal decomposition. Operations using biomass recovered from forest thinning would have a nearly zero net emissions profile because of the oxidation of nearly all of the carbon on the forest floor, less the carbon that may be stored underground. Emissions avoided by using agricultural residues would depend on how the residue was normally disposed of. Because of the wide variance in avoided greenhouse gas emissions profiles, it was assumed that the production of hydrogen from lignocellulosic biomass in MN would result in very little to zero greenhouse gas emissions.

Table 2 shows the amount of hydrogen that could be produced from the average of the resources identified in the three sources of literature cited in Table 1, assuming that the efficiency of the hydrogen vehicle is equal to the efficiency of today's fleet of gasoline vehicles. The major assumptions used to calculate Tables 2 are shown in the appendix.

Table 2: Hydrogen Potential Based on Average of Biomass Resource Data and Equal Fuel Efficiency Usage:
(assumes equal efficiency between hydrogen- and gasoline-fueled cars)

Source of Biomass	Average of all biomass resource data	Hydrogen potential	% of gasoline use that could be met with this H2	Direct CO2 reductions for hydrogen transportation fuel	Life-cycle GHG reductions for hydrogen transportation fuel
	tons/year	kg/year	%	tons C02/year	tons CO2-equiv/year
Forest Residue	874,900	57,543,023	2%	523,797	664,869
Mill Residue	903,549	59,427,318	2%	540,949	686,641
Agricultural Residue	24,895,287	1,637,387,220	65%	14,904,645	18,918,863
Energy Crops	5,783,002	380,353,662	15%	3,462,245	4,394,720
Urban Wood Waste	1,532,529	100,795,922	4%	917,515	1,164,626
Total	**33,989,267**	**2,235,507,144**	**89%**	**20,349,151**	**25,829,720**

Table 3 assumes that a future hydrogen fuel cell vehicle is twice as efficient as today's gasoline vehicles. Also shown in these tables are the amount of gasoline usage that could be displaced with this hydrogen and the accompanying reductions in CO_2 and life-cycle greenhouse gas emissions. The major assumptions used to calculate Tables 3 are shown in the appendix.

Table 3: Hydrogen Potential Based on Average of Biomass Resource Data and Double Fuel Efficiency Usage:
(assumes the efficiency of hydrogen-fueled cars is twice that of gasoline-fueled cars)

Source of Biomass	Average of all biomass resource data	Hydrogen potential	% of gasoline use that could be met with this H2	Direct CO2 reductions for hydrogen transportation fuel	Life-cycle GHG reductions for hydrogen transportation fuel
	tons/year	kg/year	%	tons C02/year	tons CO2-equiv/year
Forest Residue	874,900	57,543,023	5%	1,047,594	1,329,739
Mill Residue	903,549	59,427,318	5%	1,081,898	1,373,282
Agricultural Residue	24,895,287	1,637,387,220	130%	29,809,289	37,837,726
Energy Crops	5,783,002	380,353,662	30%	6,924,491	8,789,441
Urban Wood Waste	1,532,529	100,795,922	8%	1,835,030	2,329,253
Total	**33,989,267**	**2,235,507,144**	**177%**	**40,698,302**	**51,659,440**

3. Electricity from Biomass

Two important technologies for converting lignocellulosic biomass to electricity are direct combustion and integrated gasification/combined cycle (IGCC). Technical information on how these technologies work can be found at NREL's Biopower web site: http://www.nrel.gov/clean_energy/biopower.html. Most of the biopower plants in the world use direct-fired systems. They burn bioenergy feedstocks directly to produce steam. This steam is usually captured by a turbine, and a generator then converts it into electricity. Gasification systems use high temperatures and an oxygen-starved environment to convert biomass into a gas (a mixture of hydrogen, carbon monoxide, and methane). The gas fuels what's called a gas turbine, which is very much like a jet engine, only it turns an electric generator instead of propelling a jet. For the calculations presented here, conversion efficiencies of 1.41 and 1.76 MWh/ton of bone dry biomass were assumed for the direct-fired and IGCC cases, respectively. The other major assumptions used to calculate power potential are shown in the appendix. **Table 4** shows electricity generation potential and greenhouse gas savings that could result by using the average amount of biomass in Minnesota in direct-fired power plants.

Table 4: Power Potential from the Use of Direct-Fired Biomass Power Plants in MN (Based on Average of Biomass Resource Data)

Source of Biomass	Electricity potential	% of MN electricity use that could be met with biomass power	Equivalent capacity	Direct CO2 reductions for this biomass power	Life-cycle GHG reductions for biomass power
	MWh/year	%	MW	tons CO2/year	tons CO2-equiv/year
Forest Residue	1,233,609	2%	176	935,138	965,030
Mill Residue	1,274,005	2%	182	965,760	996,631
Agricultural Residue	35,102,355	58%	5,009	26,609,365	27,459,935
Energy Crops	8,154,033	14%	1,164	6,181,170	6,378,752
Urban Wood Waste	2,160,866	4%	308	1,638,046	1,690,406
Total	47,924,867	80%	6,839	36,329,479	37,490,754

Table 5 shows electricity generation potential and greenhouse gas savings that could result by using the average amount of biomass in Minnesota in for IGCC plants.

Table 5: Power Potential from the use of Biomass IGCC in MN (Based on Average of Biomass Resource Data)

Source of Biomass	Electricity potential	% of MN electricity use that could be met with biomass power	Equivalent capacity	Direct CO2 reductions for this biomass power	Life-cycle GHG reductions for biomass power
	MWh/year	%	MW	tons CO2/year	tons CO2-equiv/year
Forest Residue	1,539,824	3%	220	1,167,265	1,204,576
Mill Residue	1,590,247	3%	227	1,205,488	1,244,021
Agricultural Residue	43,815,705	73%	6,252	33,214,526	34,276,231
Energy Crops	10,178,084	17%	1,452	7,715,503	7,962,130
Urban Wood Waste	2,697,251	4%	385	2,044,653	2,110,011
Total	**59,821,110**	**99%**	**8,536**	**45,347,435**	**46,796,969**

4. Generic Results Due to Resource Uncertainty

Because of the large variability in biomass resource data, calculations of the hydrogen and electricity potential were also carried out for functional amounts of biomass. Tables 6 and 7 show hydrogen results parallel to those shown above. Tables 8 and 9 show electricity results. It is important to note that the impact of using biomass to produce hydrogen for the transportation sector or power for the electric sector is directly related to how much biomass is available. To displace just 3% of gasoline use in Minnesota, at least one-million tons per year of biomass will be required for hydrogen production and use in vehicles that match today's internal combustion engine efficiencies. Two-percent of the traditional power generation in Minnesota can be replaced with this much biomass used in direct-fired power plants. Greater displacements of both gasoline and power can be achieved by using more efficient conversion systems such as fuel cells and IGCC power plants.

Table 6: Hydrogen Results Based on Functional Amounts of Biomass Resources (assumes equal efficiency between hydrogen- and gasoline-fueled cars)

Biomass resource base	Hydrogen potential	% of gasoline use that could be met with this H2	Direct CO2 reductions for hydrogen transportation fuel	Life-cycle GHG reductions for hydrogen transportation fuel
tons/year	kg/year	%	tons C02/year	tons CO2-equiv/year
1	66	0%	1	1
100	6,577	0%	65	83
1,000	65,771	0%	651	826
100,000	6,577,097	0%	65,094	82,593
1,000,000	65,770,972	3%	650,935	825,934
10,000,000	657,709,719	26%	6,509,351	8,259,340

Table 7: Hydrogen Results Based on Functional Amounts of Biomass Resources (assumes the efficiency of hydrogen-fueled cars is twice that of gasoline-fueled cars)

Biomass resource base	Hydrogen potential	% of gasoline use that could be met with this H2	Direct CO2 reductions for hydrogen transportation fuel	Life-cycle GHG reductions for hydrogen transportation fuel
tons/year	kg/year	%	tons C02/year	tons CO2-equiv/year
1	66	0%	1	2
100	6,577	0%	130	165
1,000	65,771	0%	1,302	1,652
100,000	6,577,097	1%	130,187	165,187
1,000,000	65,770,972	5%	1,301,870	1,651,868
10,000,000	657,709,719	52%	13,018,703	16,518,680

Table 8: Electricity Results Based on Functional Amounts of Biomass Resources used in Direct-fired Biomass Power Plants

Biomass resource base	Electricity potential	% of MN electricity use that could be met with biomass power	Equivalent capacity	Direct CO2 reductions for this biomass power	Life-cycle GHG reductions for biomass power
tons/year	MWh/year	%	MW	tons CO2/year	tons CO2-equiv/year
1	1	0%	0	1	1
100	141	0%	0	107	110
1,000	1,410	0%	0	1,069	1,103
100,000	141,000	0%	20	106,885	110,302
1,000,000	1,410,000	2%	201	1,068,852	1,103,017
10,000,000	14,100,000	23%	2,012	10,688,515	11,030,174

Table 9: Electricity Results Based on Functional Amounts of Biomass Resources used in IGCC Power Plants

Biomass resource base	Electricity potential	% of MN electricity use that could be met with biomass power	Equivalent capacity	Direct CO2 reductions for this biomass power	Life-cycle GHG reductions for biomass power
tons/year	MWh/year	%	MW	tons CO2/year	tons CO2-equiv/year
1	2	0%	0	1	1
100	176	0%	0	133	138
1,000	1,760	0%	0	1,334	1,377
100,000	176,000	0%	25	133,417	137,682
1,000,000	1,760,000	3%	251	1,334,169	1,376,816
10,000,000	17,600,000	29%	2,511	13,341,692	13,768,161

5. Summary

The analysis projects that there is enough residual biomass and energy crops in the State that, if collected and fed to the most efficient conversion technologies available, it could produce up to 99% of the total electricity currently used in Minnesota. Exclusively using agriculture residue has the potential to produce up to73% of the electricity currently used.

In regard to hydrogen, the analysis projects that there is enough residual biomass and energy crops in the state, that if collected and fed to the most efficient conversion technologies available (assuming equal fuel efficiency) that the hydrogen produced could replace up to 89% of the total gasoline currently used in Minnesota. Exclusively using agriculture residue could replace 65% of the gasoline currently used.

However, this potential cannot be realized unless economically viable collection, hauling, energy conversion and energy distribution systems are in place. There is substantial research and increasing numbers of demonstration projects occurring nationally to determine which system components are most functional and cost effective for given locations. Results of the data analysis performed for this report provides convincing evidence that Minnesota should further participate in such research and demonstration projects. This course of action would help ensure that the state maximizes value while benefiting from its significant renewable biomass resources.

6. References

Energy Information Administration (July 2004). Renewable Energy Trends 2003 with Preliminary Data for 2003. Table C-3, p 24. http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea.pdf

Mann, M.K., Spath, P.L. (1997). Life Cycle Assessment of a Biomass Gasification Combined-Cycle System. NREL/TP-430-23076. National Renewable Energy Laboratory. Golden, CO.

Spath, P.L., Mann, M.K., Amos, W.A. (2003). Update of Hydrogen from Biomass – Determination of the Delivered Cost of Hydrogen. National Renewable Energy Laboratory. Golden, CO. http://www.nrel.gov/docs/fy04osti/33112.pdf

Appendix: Calculations and Assumptions

Hydrogen Calculations & Assumptions (assuming equal efficiency)

Hydrogen yield (kg/kg BDW)	0.0725	Source: Spath and Mann, 2000
Hydrogen yield (kg/ton BDW)	65.8	
Gallons of gasoline consumed in 2000 in MN	2,523,108,000	
Ratio of the efficiency of hydrogen use to gasoline use	1	
GHG emissions from gasoline combustion in today's ICE (g/mile) (not LCA)	400.83	Source: GREET
Mileage on car (miles/gallon)	22.4	Assumption in GREET
GHG emissions from gasoline combustion in today's ICE (g/gallon gasoline) (not LCA)	8,978.56	
Direct g CO2-equiv/kg H2 offset	8,978.56	
Direct tons CO2-equiv/kg H2 offset	0.0099	
Life-cycle GHG emissions from gasoline combustion in today's ICE (g/mile)	508.59	Source: GREET
Life-cycle GHG emissions from gasoline combustion in today's ICE (g/gallon)	11,392.37	
Life-cycle g CO2-equiv/kg H2 offset	11,392.37	Source: GREET
Life-cycle tons CO2-equiv/kg H2 offset	0.0126	

Hydrogen Calculations & Assumptions (assuming double efficiency)

Hydrogen yield (kg/kg BDW)	0.0725	Source: Spath and Mann, 2000
Hydrogen yield (kg/ton BDW)	65.8	
Gallons of gasoline consumed in 2000 in MN	2,523,108,000	
Ratio of the efficiency of hydrogen use to gasoline use	2	
GHG emissions from gasoline combustion in today's ICE (g/mile) (not LCA)	400.83	Source: GREET
Mileage on car (miles/gallon)	22.4	Assumption in GREET
GHG emissions from gasoline combustion in today's ICE (g/ gallon gasoline) (not LCA)	8,978.56	
Direct g CO2-equiv/kg H2 offset	17,957.11	
Direct tons CO2-equiv/kg H2 offset	0.0198	
Life-cycle GHG emissions from gasoline combustion in today's ICE (g/mile)	508.59	Source: GREET
Life-cycle GHG emissions from gasoline combustion in today's ICE (g/gallon)	11,392.37	
Life-cycle g CO2-equiv/kg H2 offset	22,784.74	Source: GREET
Life-cycle tons CO2-equiv/kg H2 offset	0.0251	

Power Calculations & Assumptions (direct-fired plant)

IGCC or Direct Combustion?	Direct	Specify "IGCC" or "Direct"
Electricity yield (MWh/ton BDW)	1.41	IGCC assumes a 37% HHV efficiency; Direct assumes a 27.7% HHV efficiency
Assumed power plant capacity factor	80%	
MWh of electricity consumed in MN in 2002	60,169,575	Source: EIA, State Electricity Profiles, 2002
Direct emissions, g CO2/kWh offset	687.7	
Net generation in MN, MWh	52,777,966	Source: EIA, State Electricity Profiles, 2002
CO2 emissions from electricity in MN, thousand short tons	40,009	Source: EIA, State Electricity Profiles, 2002
Direct emissions, tons CO2/MWh offset	0.76	
LC emissions, g CO2-equiv/kWh offset	709.7	
LC emissions, tons CO2-equiv/MWh offset	0.78	

Power Calculations & Assumptions (IGCC plant)

IGCC or Direct Combustion?	IGCC	Specify "IGCC" or "Direct"
Electricity yield (MWh/ton BDW)	1.76	IGCC assumes a 37% HHV efficiency; Direct assumes a 27.7% HHV efficiency
Assumed power plant capacity factor	80%	
MWh of electricity consumed in MN in 2002	60,169,575	Source: EIA, State Electricity Profiles, 2002
Direct emissions, g CO2/kWh offset	687.7	
Net generation in MN, MWh	52,777,966	Source: EIA, State Electricity Profiles, 2002
CO2 emissions from electricity in MN, thousand short tons	40,009	Source: EIA, State Electricity Profiles, 2002
Direct emissions, tons CO2/MWh offset	0.76	
LC emissions, g CO2-equiv/kWh offset	-	
LC emissions, tons CO2-equiv/MWh offset	-	

[redacted]