Exploring the Potential for Biomass Power in Ontario

A Response to the OPA Supply Mix Advice Report

by

David B. Layzell, Jamie Stephen and Susan M. Wood

BIOCAP Canada Foundation,
156 Barrie Street,
Queen's University
Kingston, Ontario K7L 3V2
Tel: 613 542-0025 X 26
Fax: 613 542-0045
Email: info@biocap.ca

Capturing Canada's Green Advantage

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Executive Summary

On Dec. 9th, 2005, the Ontario Power Authority (OPA) released their Supply-Mix Report, and concluded that biomass should supply only 250 to 500 MW of additional power by 2025[1]. This was a surprising assessment given **the major opportunity that renewable biomass offers as a 'made-in-Ontario' energy resource for the province.** This document explores the biomass energy opportunity as a response to the OPA report.

Benefits of Biomass. Recent increases in energy prices make the large-scale use of biomass a credible alternative to more expensive oil and gas. During the last 10 years, wellhead prices for crude oil and natural gas have increased by 2.5 and 4.4 fold, to more than $10/GJ, whereas farm gate or forest road costs for biomass of $2.50 to $6/GJ make it more comparable to the price of coal ($1.50 to $2/GJ). However, biomass has far fewer emissions than coal and its production, harvesting and processing will greatly stimulate the provincial economy. **Biomass energy will keep energy dollars in the province and enable the transition to a sustainable bioeconomy.** Biomass also integrates well with the existing fossil energy infrastructure, especially in a province committed to phasing out coal-fired plants that could easily be converted to accept biomass.

Ontario has vast biomass resources. Ontario is rich in the resources and infrastructure necessary for the sustainable production and use of biomass energy. Two independent studies from the 1980's[2] are consistent with a more recent analysis[3] and estimates done here (Appendix C) that Canada and Ontario have huge renewable bioenergy potential: sufficient to support at least 27% of the total current energy needs of the province. Add to this Ontario's diverse and extensive transportation infrastructures (Great Lakes, roads, trains, pipelines) and the prospect to divert export energy dollars into local economic development, and the opportunity to develop biomass as a credible source of energy becomes too attractive to ignore.

Case Studies. Three case studies are presented here to expore the potential role for biomass energy to the production of base load electrical power. The results (see summary table) show that biomass is competitive with other alternative energy sources; however, minimizing both cost and environmental impact requires development and implementation of a strategy that integrates biomass with other socio-economic and infrastructure needs.

Summary of Case Studies exploring Ontario Biopower opportunities

Case Study	Target	Biomass	Power	
		Mt/y	Million KWh	$/MWh
1. Atikokan	Forest harvest	0.56 (dry)	900	$70.81
	Prairie residues	0.59 (dry)	900	$71.98
2. Municipal Solid Waste	70% of MSW by Anaerobic Digest'n	5.2 (wet)	1,544	$55 to $97
3. Nanticoke	15% cofire w/ coal	2.3 (dry)	3,439	$66.56
	100%	14.8 (dry)	22,927	$84.98

Recommendations:

1. **Move to Implement.** There are a number of biomass power initiatives (Atikokan, Nanticoke cofiring, MSW AD) that could be implemented now at reasonable cost and help in the learning process;
2. **Think beyond energy to economic development and innovation.** Biomass energy and a vibrant bioeconomy will stimulate innovation, revitalize the rural economy and the environment;
3. **Develop Vision and Strategy for an Ontario Bioeconomy.** The province should empower a multisector body to develop a strategy that will make Ontario a world bioeconomy leader.

[1] Advice and Recommendations, Ontario Power Authority - Supply Mix Advice (Dec 9, 2005) Table 1.2.8. http://www.powerauthority.on.ca/Report_Static/157.htm

[2] From Love, Peter. 1980. Biomass energy in Canada. Its potential contribution to future energy supply. Energy, Mines and Resources, Report ER 80-4E Mar 1980. AND Robinson, John 1987. An Embarrassment of Riches: Canada's Energy Supply Resources. **Energy** 12: 379-402.

[3] Hoogwijk, M, Faaij, A, Eickhout, B, deVries, B and Turkenburg, W. 2005. Potential for biomass energy out to 2100, for four IPCC SRES land-use scenarios. Biomass and Bioenergy 29: 225-257.

1. Introduction

Ontario's economy depends upon a stable and secure supply of energy. The province is currently an energy consumer, largely depending upon energy sources from western and eastern Canada, and from the USA. Concerns about air quality, climate change and energy supply and security have spurred interest in finding new and clean sources of energy for the citizens and industries of Ontario.

Ontario accounted for 3.3 EJ of the 10.5 EJ of energy consumed in Canada in 2003. Coal and natural gas accounted for 16% and 34%, respectively, of Ontario's 2003 energy consumption (see Appendices B & C).

Why Bioenergy for Ontario?

1. **Make Ontario an Energy Producer:** Complement, extend and replace expensive fossil energy imports with home-grown, renewable biomass;
2. **Care for the Environment:** Bioenergy use can address municipal waste disposal, reduce air pollution and lower the greenhouse gas (GHG) emissions linked to climate change;
3. **Spur Economic Development:** Huge opportunities exist for northern, rural and aboriginal development in the creation of a bioeconomy that will help keep Ontario industries competitive.

This report explores the potential of biomass[4] to provide a source of clean, climate-friendly energy for the province of Ontario, as an alternative to coal, oil and natural gas for providing heat and power. Although biomass can be used for the production of transportation fuels and industrial chemicals and materials, this study concentrates on its potential for heat production to generate electrical power or in the production of industrial products such as cement and steel. Given environmental concerns and a provincial commitment to close down the coal-fired power plants, this subject is the focus of major policy decisions in the province in early 2006.

Changing Energy Economics Creates New Opportunities for Bioenergy. Recent increases in fossil energy prices make biomass a more cost-effective source of energy than it has been in recent decades. As shown in Fig. 1, 1995 prices for oil and natural gas were similar to or lower than the price for a similar amount of biomass energy, creating a disincentive for the large scale use of biomass energy in Canada.

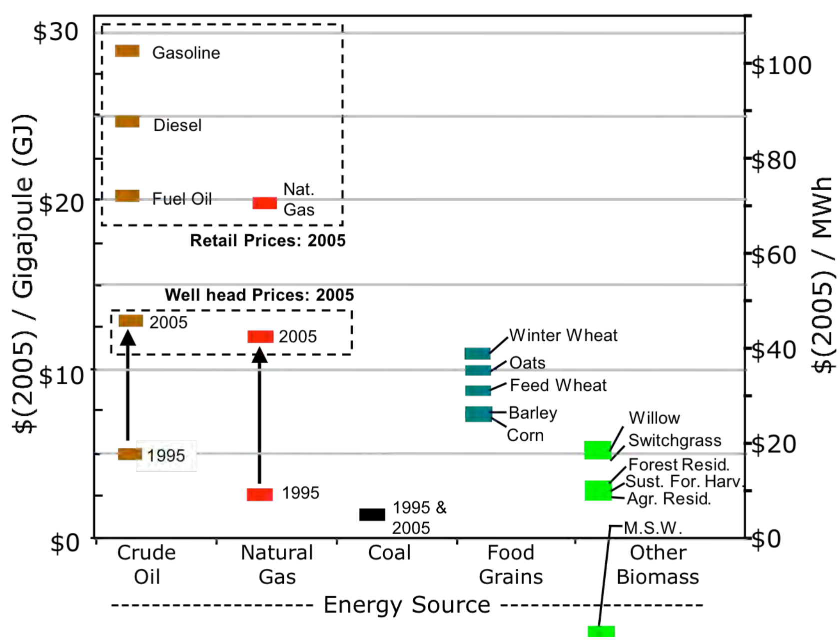


Figure 1. Comparison of fossil and biomass energy prices in Canada. All prices are in Canadian 2005 dollars, and are for year 2005 unless otherwise noted (some 1995 prices are included for comparison purposes). See Appendix A for the origin of these numbers. Energy Conversion Factor: 0.2777 Megawatt hour per Gigajoule (MWh/GJ).

[4] Biomass includes tree, crop and animal materials such as forest and crop residues, biomass crops, and the organic fraction of municipal solid waste, manure and human biosolids. While food, animal feed and fibre products are also biomass, the traditional uses for these products typically take precedence over their use as an energy resource.

However, in recent years, the wellhead costs for oil and gas have risen to the $C11 to $C13 per GJ range, whereas farm gate grain prices have remained between $C7 and $C11 per GJ, and lingo-cellulosic biomass production at the farm gate or logging road can be achieved at a price of $C2 to $C6 per GJ (Fig. 1).

The Bioenergy Opportunity

"The emergence of a differential between feedstock prices from fossil and biomass sources has opened up a huge potential market for agricultural and forest production, a market that could make Ontario a major energy producer in the Canadian and North American context."

The emergence of a differential between feedstock prices from fossil and biomass sources has opened up a huge potential market for agricultural and forest production, a market that could make Ontario a major energy producer in the Canadian and North American context. Biomass energy will be the foundation for a vibrant bioeconomy: an economic system where agricultural and forest resources – Ontario's 'Biological Capital' – provide environmental values, as well as the basic building blocks for industry and raw materials for energy.

The key challenge is to develop efficient transportation strategies and processing technologies to gather and convert the biomass in useable forms of energy that will ultimately retail for $C20 to $C30 per GJ ($C70 to $C110 per MWh).

This Document. This document will first explore the magnitude of the bioenergy opportunity in Canada (Section 2), then consider the technologies that are currently available for biomass energy conversion (Section 3) before exploring a few case studies (Section 4) and identifying three key recommendations (Section 4).

2. Biomass Resources in Canada and Ontario

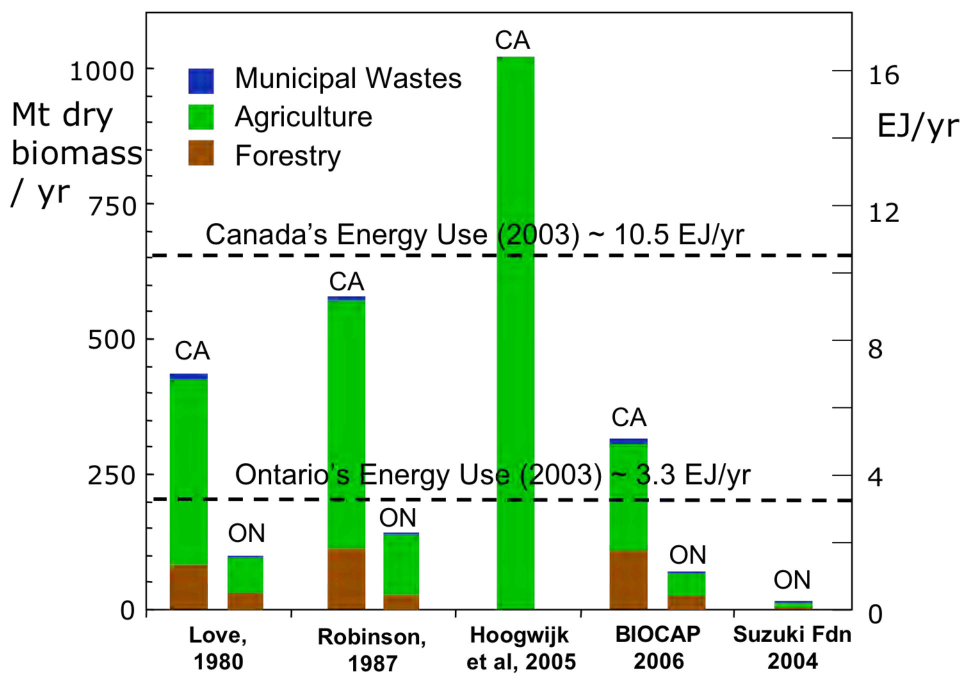
Comparing Energy in Forest and the Alberta Oil Sands. The development of technologies to access the vast oil sands in Alberta has transformed Canada into one of the world's energy superpowers, with 1.75 X 10^{11} barrels of Proven Recoverable Reserves in oil equivalent (boe); a resource with an energy content of 1068 EJ (Appendix C).

It is surprising for many to discover that Canada's vast biological resources are on a similar scale in energy terms to that of the Alberta Oil Sands. For example, the above-ground biomass in the Timber Productive Forest of Canada (about 25% of Canada's land area) has an energy content of about 535 EJ, or 50% of the proven reserves in the oil sands. In contrast to the oil sands, the forest biomass reserves are renewable, but careful management is critical to ensure sustainability. With careful management, the 'Biological Capital' in our forest and agricultural resources offers Canada great potential for a clean renewable energy resource that will benefit both the environment and the economy.

> ***Forest Energy = 50% Oil Sand Energy***
>
> *It is surprising for many to discover that Canada's vast forest resources are on a similar scale in energy terms to that of the Alberta Oil Sands (535 vs. 1068 EJ of energy). However, careful management of renewable resources is critical to ensure their long term sustainability.*

Previous Estimates of Sustainable Biomass Energy Potential in Canada and Ontario. Over the past 30 years, there have been a number of studies that have attempted to calculate the potential for sustainable biomass production in Canada and in the Province of Ontario (Fig 2). Those studies that have used a top-down estimation strategy all agree that the potential is very large, ranging from 66% to 152% of Canada's current energy demand (10.5 EJ), or from 52% to 73% of Ontario's current energy demand (3.3 EJ) (see Appendix C for details and references).

Fig. 2. Estimates of sustainable biomass energy potential in Canada and in Ontario compared to the total energy demand (all forms of energy) in Canada and Ontario.



A BIOCAP Estimate of Bioenergy Potential in Ontario. Compared to other studies presented in Fig. 2, the analysis recently carried out by BIOCAP is conservative. The results are summarized in Table 1, with details in Appendix C. This analysis estimated that the province could sustainably provide about 63 Mt/yr dry biomass for use as an energy resource, above and beyond the current and future (next 50-100 year) needs for agricultural production of food, feed and fibre. This biomass was estimated to have an energy content of about 0.87 EJ, sufficient to generate about 87 TWh of electrical power (Table 1 and Appendix C). To put these numbers in perspective, all the coal-fired power plants in Ontario generate about 31 TWh of electrical power.

Other studies offer a different perspective. In the 2004 Suzuki Foundation document "Smart Generation: Powering Ontario with Renewable Energy", biomass estimates total a very modest 15 Mt/yr[5]. Some restrictive principles limit the scope of biomass that is included in this study. For example, opportunities associated with the forest sector are limited to mill and pulp and paper production wastes and residual bark, while the opportunities to more effectively use insect or fire damaged wood are entirely overlooked. Similarly, diversion of agricultural land to new purposes is considered, but rejuvenation of abandoned farmland has not been included. This report is very important nevertheless, because it highlights the existence of a continuum from easily accessed resources whose use would have entirely positive environmental impacts, to much more aggressive biomass production and harvest, with potentially negative environmental effects.

Research, debate and policy directives are needed to ensure sustainability of biomass production, harvest and conversion. If transformative change to "energy from biomass" is to occur, then the environmental and economic costs and benefits must be determined, and the implications of forest harvest for a dedicated bioenergy market, the shift of agricultural lands to non-traditional crops, the rejuvenation of non-productive agricultural lands to support biomass crops and the public acceptability of use of municipal wastes and biosolids must all be examined.

Table 1: Summary Biomass Resources and Calculation of Potential for Power Generation

	Mt dry biomass/yr	*Energy Content (GJ/t dry)* [b]	*Thermal Energy (PJ/yr)*	*Power. (TWhr)*[c]
Forestry				
Residues from Existing Forestry	2.5	16.9	42.3	4.11
Accessing unused annual allowable cut	4.0	16.9	67.6	6.57
Harvesting forests after disturbance	3.8	16.9	64.2	6.24
Silviculture	13.8	16.9	233.2	22.67
Dedicated harvest for energy	3.0	16.9	50.7	4.93
TOTAL for Forestry:	**27.1**		**458.0**	**44.52**
Agriculture				
Crop Residues	4.0	16.0	64.0	6.22
Animal Manure[a]	7.7	16.0	21.0	3.10
Biomass Crops	20.0	16.0	320.0	31.1
TOTAL for Agriculture:	**31.7**		**405.0**	**40.4**
Municipal Waste				
Solid Waste[a]	3.7	16.0	10.2	1.48
Biosolids[a]	0.3	16.0	0.8	0.12
TOTAL for Municipal & Ind. waste:	**4.0**		**11.0**	**1.60**
GRAND TOTAL	**62.8**		**874.4**	**86.54**

[5] Smart Generation: Powering Ontario with Renewable Energy. 2004, David Suzuki Foundation http://www.davidsuzuki.org/files/Climate/Ontario/Smart_Generation_full_report.pdf

[a] **Assumed to be processed by Anaerobic digestion, therefore the thermal production only is achieved by burning the biogas, which captures 17% of the energy in the biomass.**
[b] Lower heat value expressed as Gigajoules (GJ) per tonne dry biomass. These values have been discounted to allow for the fact that the biomass typically has significant water content, which must be removed for thermal processing. These values assume about 45% water in forest biomass and 25% in crops and agricultural residues.
[c] Calculated as 3.6 GJ/MWhr at 35% efficiency for biomass combustion energy, or 52% efficiency for biogas combined cycle generation.

3. Getting the Energy out of Biomass

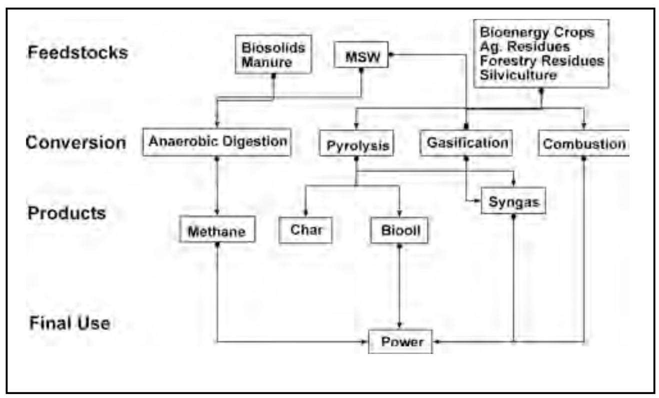
Biomass is a highly flexible feedstock that comes in a variety of forms and is readily converted to energy. Power can be produced from biomass by either thermo-chemical or bio-chemical means. The method of conversion is typically chosen based upon feedstock characteristics such as moisture content, particle size and homogeneity.

Electrical power production from biomass (biopower) has the following key features:

- May be used as base load power for the electrical grid;
- Complements existing fossil fuel power generation, such as cofiring with coal within the existing infrastructure;
- Can be used in centralized or distributed power systems.

<u>Biomass Conversion Technologies:</u>

Combustion has been the traditional method of extracting energy from biomass and involves thermal breakdown of biomass from high temperature. Combustion is one option for co-firing with coal, thereby utilizing existing power plants while effectively reducing net greenhouse gas and SOx emissions. This is a proven option that may meet Ontario's short-term needs.



Gasification uses high pressure and temperature to convert solid biomass into gaseous and liquid forms. Gasification produces syngas (CO and H_2) and can reach efficiencies over 50% in integrated combined cycle (IGCC) systems.[6] Gasification benefits from very low particulate, NOx, and SOx emissions.

Pyrolysis is the breakdown of biomass in the absence of air and produces liquid and solid products, which can then be used as feedstocks for power generation in combustion or gasification applications. A key role for pyrolysis is as a densification pretreatment to reduce transportation costs, an important consideration for large-scale operations with a distributed feedstock.

Anaerobic digestion uses microorganisms to digest biological materials and produce methane, the major constituent of natural gas. As with natural gas, biomass-sourced methane can be used in a turbine to produce power. Anaerobic digestion is particularly valuable for treatment of heterogeneous and high-moisture feedstocks, such as municipal solid waste, biosolids, and manure.

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[6] Swithenbank, J.; Shabangu, S.; Chang, B.F.; Johari, A.; Russel, N.V.; Sharifi, V.N.; Warner, N. and F.M. Lewis. (2003) Biomass/Coal Gasification for Efficient Embedded Power Generation. Pyrolysis and Gasification of Biomass and Waste. Edited by A.V. Bridgwater.

Table 2: A Summary of Biomass Conversion Technologies

Technology	Conversion Efficiency	Suited Feedstock	Note and Niche Applications
Combustion	25–30% (1–100MW); 30 – 35% (>100 MW)[7]	Dry agricultural or forestry biomass	Utilize in existing coal plants up to 15% without retrofit
Gasification	30 – 40% (simple); 40 – 55% (combined cycle)[6]	Dry agricultural or forestry biomass; sorted municipal waste	Can add units to existing plants; low emissions; uses same premise as clean coal technology
Pyrolysis	20 – 25% overall (70 – 80% for biooil and char production)[8]	Very distributed feedstocks such as forestry residues/slash	Primarily as a pretreatment technology for long distance transport and in conjunction with chemical extraction
Anaerobic Digestion	15 – 20%[9] to biogas; ~9% to power by combined cycle.	High moisture and heterogenous; biosolids, manure and MSW	Can complement natural gas energy streams; negative value feedstock

<u>Successful Applications of Technologies:</u>

Power production from biomass has numerous proven operations around the world, particularly in Finland and the United States. The majority of these are combustion operations, although gasification is becoming increasingly popular due to the substantially reduced air pollutant emissions. Of the combustion facilities, many in the United States are cofiring biomass with coal or are being converted from coal to biomass plants. Most of the technologies are now commercial and can be implemented in the short-term. However there is still room for improvements in the technologies or the development of novel approaches through targeted research and development.

Future Research and Development priorities for Canada should include the development of technologies for large scale movement of biomass or the energy from biomass, including:

- Remote conversion of biomass into pyrolysis oil for easier shipping and handling;
- Conversion of biomass into a gas that can be upgraded and distributed with natural gas in pipelines;
- The potential to create dedicated bioenergy pipelines;
- The potential to use 'clean coal" gasification technology with biomass and then geologically sequester the CO_2 with pipelines for biooil and distributed systems for reduced transportation costs and impacts.

It is important to remember that bioenergy is not a new phenomenon; however research and development is required to develop highly efficient technologies that maximize energy extraction and capitalize on waste biomass and existing infrastructure utilization opportunities.

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[7] Wiltsee, G. (2000) Lessons Learned from Existing Biomass Power Plants. Prepared under contract no. DE-AC36-99-GO10337 for the National Renewable Energy Laboratory, United States Department of Energy.
[8] Toft, A.J. and A.V. Bridgwater (1997) How Fast Pyrolysis Competes in the Electricity Generation Market. Biomass Gasification and Pyrolysis: State of the Art and Future Prospects. Edited by M. Kaltschmitt and A.V. Bridgwater.
[9] A. Kani Associates and Enviros Ris. 2001. WDO Study: Implications of Different Waste Feed Streams (Source- Separated Organics and Mixed Waste) On Collection Options and Anaerobic Digestion Processing Facility Design, Equipment and Costs. Waste Diversion Organization Ontario. http://www.csr.org/wdo/iwdo_reports/ORGANICS/ORG%20R3-21.pdf

4. Case Studies on Economic and Logistical Feasibility

As noted previously, rising fossil energy prices and environmental concerns have opened up new opportunities for producing and using biomass as a source of renewable and sustainable energy. Technological advances in recent years have also helped to reduce harvest and processing costs, and low prices for agricultural and forest products have individuals, communities and companies looking for new opportunities.

This section attempts to bring these realities together around a series of case studies that explore the economic and logistical feasibility associated with large scale use of biomass energy in Ontario. The following case studies (see summary at right) have been developed and are described in brief, 2-page documents following this report.

Summary of Case Studies exploring Ont. Biopower opportunities

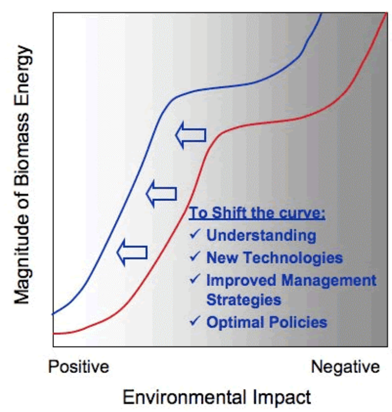
Case Study	Target	Biomass	Power	
		Mt/y	Million KWh	$/MWh
1. Atikokan	Forest harvest	0.56 (dry)	900	$70.81
	Prairie residues	0.59 (dry)	900	$71.98
2. Municipal Solid Waste	70% of MSW by Anaerobic Digest'n	5.2 (wet)	1,544	$55 to $97
3. Nanticoke	15% cofire w/ coal	2.3 (dry)	3,439	$66.56
	100%	14.8 (dry)	22,927	$84.98

- Case Study 1. Replace Coal at Atikokan Power Generating Station
- Case Study 2. Power from Anaerobic Digestion of Ontario's MSW
- Case Study 3. Cofire with Biomass or Replace Coal at Nanticoke Power Generating Station

5. Conclusions and Recommendations

Renewable biomass provides Ontario with a major opportunity to develop a "made-in-Ontario" energy resource for the province. Many bioenergy opportunities have obvious benefits to the environment (GHG, clean water and air) in addition to providing renewable energy. Others will carry more of an impact (see figure to right).

Bioenergy & the Environment



We need to understand the costs and benefits of each opportunity and then develop new management and processing technologies and implement policies that will shift the 'impact curve' to the left. Embracing this opportunity will require strategic partnerships and transformative thinking among government policy makers, industry investors, researchers and environmental organizations.

Ontario is strategically poised to capitalize on the bioenergy opportunity and become a world leader in the emerging bioeconomy. To capture this opportunity, we recommend that the province should:

- **Move to Implement.** There are a number of biomass power initiatives (Atikokan, Nanticoke cofiring, MSW AD) that could be implemented now at reasonable cost. Doing so would provide invaluable insights in the setting the stage for a longer term strategy;
- **Think beyond energy to economic development, innovation and the environment.** Biomass energy and a vibrant bioeconomy will stimulate innovation, revitalize the rural economy and provide environmental benefits for all Ontarians;
- **Develop Vision and Strategy for an Ontario Bioeconomy.** The province should empower a multisector body to develop a strategy that will make Ontario a world bioeconomy leader.

Case Study #1:

Replace Coal at Atikokan Power Generating Station

The Atikokan Power Generating Station is a 215 MW, coal-fired facility that produces 900 million KWh/yr of electrical energy from lignite coal shipped from Western Canada by rail (see http://www.opg.com/ops/Atikokanbrochure.asp).

This case study explores two options for replacing coal with biomass:

- sustainable forest harvest, in which biomass is delivered by truck, or
- The use of residual agricultural production from the prairies and delivery by truck and then rail.

The Biomass Energy Requirement: At the present time, the Atikokan Power plant uses about 500 Mt lignite coal to generate 900 million KWh of power. Assuming 34% efficiency, the thermal energy input into the plant was calculated to be **9.53 million GJ per year**. A similar energy requirement was assumed for biomass as a feedstock.

Option 1: Meeting the Biomass Requirement through Sustainable Forest Harvest:

The Atikokan Power plant is surrounded by forest which could be harvested on a sustainable basis to provide the energy needs of the plant in perpetuity. To calculate the forest biomass requirement, an assumption was made that the wood would have a moisture content of 45%, resulting in a lower heat value of 16.9 GJ/t dry biomass. Therefore, the plant would require 0.56 Mt dry biomass or **1.02 Mt wet biomass per year.**

Assuming that only 0.3% of the forested land area (excluding parkland) around Atikokan could be harvested in any given year and that each harvested hectare yields 175 t(wet) biomass (including roundwood and that slash not needed to preserve nutrients), the land area requirement would be within a **96 km radius** of the town of Atikokan (Fig. 1). Assuming a road tortuosity of 2.4, the average haul distance for the biomass was calculated to be 154 km.

The cost of the biomass at the side of a logging road was calculated as **$20.92/t(wet)**, including the provincial government stumpage free, and the cost for felling, creating composite logs from the slash, forwarding, chipping and an overhead charge. Transportation to the plant by truck was estimated to cost $27.29 /t(wet) for a total delivered biomass cost of $48.21/t(wet), equivalent to $54.81/MWh of electrical power at 34% conversion efficiency.

Assuming, a capital cost for retrofitting the plant of $10/MWh (equivalent to $100M amortized over 20 year at 6.6% return on investment), an operations cost of $16/MWh, and a Renewable Energy Credit (federal government) of $10/MWh, power could be put on the grid for about $70.81/MWh. The total net annual cost under this scenario would be about **$64M/yr** to provide 900 million KWhr to the grid.

The calculations used here for estimating the cost for harvesting and transporting forest biomass to the power plant have been discussed at some length with experts in the Ontario Ministry of Natural Resources (OMNR) and within a pulp and paper company that operates in Northern Ontario. The values presented here were considered to be realistic estimates of likely costs, especially given the top-down nature of this initiative.

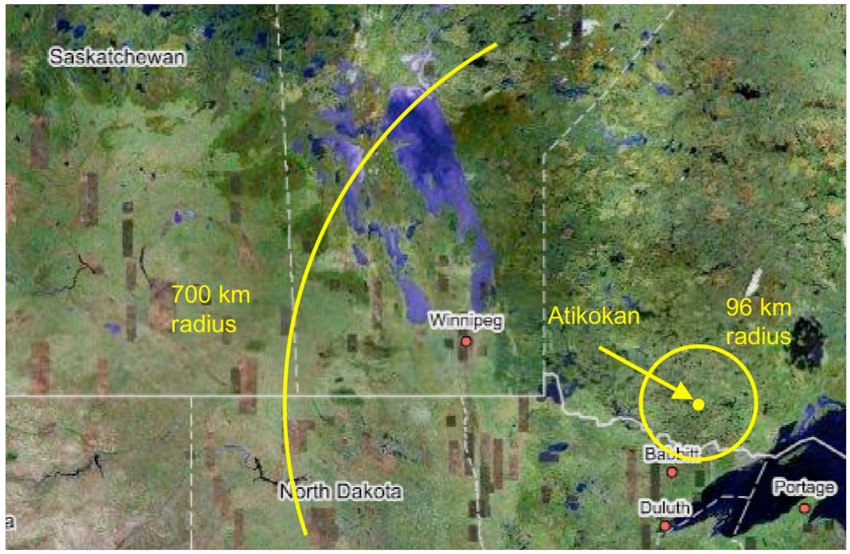
BIOCAP has also contributed to the development of OMNR's Biomass Spatial Analysis Tool (BSAT) model, and preliminary results from that model indicated that there is more than 2 Mt(wet) biomass that could be harvested sustainably within 200 km of Atikokan. Even though this biomass exists, key issues that need to be addressed relate to licensing rights to the biomass, policy barriers, etc.

Option 1: Sustainable forest harvest

Cost Element	Biomass $/t(wet)	Power $/MWh	Total cost $M/yr
Harvest, forwarding, chipping	$20.92	$23.78	$21.40
Loading /shipping/unloading	$27.29	$31.03	$27.93
Capital cost (retrofit)	-	$10.00	$ 9.00
Maintenance and Operations	-	$16.00	$14.40
SUB-TOTAL	**$48.21**	**$80.81**	**$72.73**
Renewable Energy Credit		$(10.00)	$(9.00)
NET COST		**$70.81**	**$63.73**

Option 2: Meeting the Biomass Requirement through Prairie Agricultural Residues:

A second option for accessing the necessary biomass is to bring agricultural residues (straw) in by train from the prairies. Western Canada typically has millions of tonnes of crop residues (especially wheat and flax) that currently have few markets.



Since agricultural residues have a lower water content (estimated at 20%) than fresh woody biomass and therefore an energy content of 16.2 GJ/t(dry), the Atikokan Power Plant should require only about 0.59 Mt(dry) biomass or **0.73 Mt(wet) biomass per year** to meet its energy needs**.**

Assuming a biomass cost at the farm gate of $30/t(wet) and an average distance of 100 km to bring the biomass to loading sites adjacent to the train tracks, the delivered cost to the train was calculated as $47.50/t(wet). Loading the train, transporting the biomass an average of 700 km and unloading it at the power plant was estimated to add another $21.10/t(wet) to the supply cost, bringing the total delivered cost of biomass to $68.60/t(wet).

Option 2: Prairie Agricultural Residues

Cost Element	Biomass $/t(wet)	Power $/MWh	Total cost $M/yr
Biomass cost at farm gate	$30.00	$24.48	$22.03
Road transport to train	$17.50	$14.28	$12.85
Train transport to plant	$21.10	$17.22	$15.50
Capital cost (retrofit)	-	$10.00	$ 9.00
Maintenance * Operations	-	$16.00	$14.40
SUB-TOTAL	**$68.60**	**$81.98**	**$73.78**
Renewable Energy Credit		$(10.00)	$(9.00)
NET COST		**$71.98**	**$64.78**

Given the energy content of the biomass, this delivery cost was calculated to contribute $55.98 to the cost of each MWh of power production. Assuming, a capital cost for retrofitting the plant of $10/MWh (equivalent to $100M amortized over 20 years at 6.6% return on investment), an operations cost of $16/MWh, and a federal renewable energy credit of $10/MWh, power could be put on the grid for about $71.98/MWh. The total annual investment under this scenario would be about **$65M/yr** to provide 900 million KWhr to the grid.

Conclusion. The Atikokan power plant could be converted to run on biomass energy at a reasonable cost of about $71 to $72 per MW, and result in significant benefits to the regional economy. As long as sustainable management practices are used to grow and harvest the biomass, there could also be large environment benefits. There is more than one source for the biomass needed to fuel the plant, a fact that may be helpful in controlling costs.

The analysis and cost estimates provided here do not take into account the greater tax revenues that the province will realize by investing in an Ontario workforce to grow and harvest the biomass feedstock rather than importing fossil energy from other jurisdictions. Such analyses need to be carried out.

For Further information, contact:
BIOCAP Canada Foundation
156 Barrie St., Kingston, Ont. K7L: 3N6
Tel: 613 542-0025 Fax: 613 542 -0045 Email: info@biocap.ca
Web: www.biocap.ca

Case Study #2:

Power from Anaerobic Digestion of Ontario's MSW

The expense and environmental impacts associated with the disposal of Municipal Solid Waste (MSW[1]) has stimulated a search for alternative solutions. In Europe, organic materials cannot be landfilled and this has encouraged a vibrant industry in the Anaerobic Digestion (AD) of MSW where the resulting biogas is either used for heat and power generation or the methane concentrated and mixed with natural gas for pipeline distribution. Anaerobic digestion uses microbes in a controlled, oxygen-free environment to convert biomass into biogas (methane and carbon dioxide) and a rich organic residue that may be used as nutrient-rich soil amendment. Unless otherwise noted, this analysis is based on a 2001 study by Kani and Associates[2], but all dollar values have been converted into $(2005).

AD towers (www.o-r-a.co.uk/ images/ad_towers2.jpg)

Available Biomass from Municipal Waste:

Ontario residents generate approximately 1 tonne MSW per person per year, resulting in around 12,000,000 tonnes MSW each year[3]. About 77% of this, or 9.3 Mt is destined for landfill, but it contains an estimated 7.4 Mt of usable biomass that could be converted to energy. A UK study[4] has reported that MSW has an energy content of 9-11 gigajoule (GJ)/t; in this report we have used a conservative estimate of 9.5 GJ/t.

Diverting to AD, 70% of MSW now Destined for Landfill

If 70% of the 9.3 Mt MSW currently being landfilled were to be diverted for processing by AD, the 6.5 Mt MSW would have 5.2 Mt wet biomass and an energy content of about 61.7 million GJ. Assuming that each tonne of MSW yields 108 m^3 of biogas having 55% methane (both conservative values), the 6.5 MT MSW would generate 702 million m^3 of biogas or 386 million m^3 of methane. The energy content of the methane would be about 13.6 million GJ, or about 22% of the energy in the original biomass.

Kani and Associates[2] estimate that 20% of the biogas must be consumed to maintain the AD process, leaving about 309 million m^3 of methane (equivalent to 10.7 million GJ for power production). Assuming power generation through a combined cycle plant yielding 5 KWh per m^3 methane, a total of 1,544 million KWh of electrical power would be generated. Assuming an 80% capacity factor, The MSW feedstock would provide sufficient energy to support a number of MSW power plants totaling **220 MW**. On the basis of these calculations, approximately 9% of the bioenergy potential in the MSW ends up as electrical power.

These calculations are very conservative and it is likely that more power could be generated from the MSW feedstock than what has been estimated here, especially if large centralized MSW processing facilities were used. European experience has shown that large AD facilities capable of processing up to 300,000 t (wet) MSW / yr or more are optimal. With these large MSW processing facilities, 22 plants would be required across the province, each having a capacity of about 10 MW.

Cost of Power: Since MSW has a negative value, municipalities will pay to remove and process the material. Our calculations have indicated that the size of this payment is critical to the economics of power generation from MSW. We have provided calculations for two scenarios, one for a tipping fee of $50/t(wet) MSW (equivalent to a credit of $5.26/GJ thermal energy) and one at $60/t(wet) MSW (equivalent to a credit of $6.32/GJ thermal energy).

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[1] MSW: solid, non-hazardous waste material from households, industries, institutions & construction activities.

[2] Allen Kani Associates with Enviros RIS Ltd 2001 WDO Study: Implications of Different Waste Feed Streams (Source-Separated Organics and Mixed Waste) on Collection Options and Anaerobic-DigestioDesign, Equipment and Costs. (Table 6.1)

[3] Statistics Canada. 2004. Waste Management Industry Survey, Business and Government Sectors 2002. Catalogue no. 16F0023XIE http://epe.lacbac.gc.ca/100/201/301/statcan/waste_manage_business_govt/16F0023XIE2002001.pdf

[4] Dept for Environment, Food and Rural Affairs, UK; Department for Environment, Food and Rural Affairs, UK; www.defra.gov.uk/environment/waste/research/health/pdf/health-report10.pdf

Due to the relatively low efficiency in biomass conversion to the methane that can be used in power generation (17.3%), and significant capital and operating expenses, the net cost of electrical power generation rises to $34.50 per GJ or **$124.24 per MWh** when a tipping fee of $50 per t MSW is payable, but to $22.81 per GJ or **$82.15 per KWh** when a tipping fee of $60 is payable (Table 1 and 2). In other words, each $10 per tonne that is paid for a tipping fee reduces the cost of power generation from AD of MSW by about $42 per MWh. This illustrates the importance of the tipping fee in determining the economics of power generation from MSW.

Table 1. Anaerobic Digestion of 70% of Ontario MSW with a $50/t tipping fee.

Cost Component	Processing Cost	Power Cost		Total Cost
	$/t(wet)MSW	$/GJ	$/MWh	$M/y
Tipping Fee	$(50.00)	$(58.44)	$(210.44)	$(325)
Capital Cost	$33.60	$39.27	$141.41	$218
Maintenance & Ops	$45.92	$53.67	$193.27	$299
Sub Total	**$29.52**	**$34.50**	**$124.24**	**$192**
GHG Credit	$(6.44)	$(7.52)	$(27.09)	$(42)
Total	**$23.08**	**$26.98**	**$97.15**	**$150**

Greenhouse Gas (GHG) Credits. One of the key drivers for keeping organic wastes out of landfill sites is to reduce the emissions of methane, a potent (21 times CO_2) GHG linked to climate change. Landfill emissions from Ontario account for emissions of 7.97 Mt of CO_2 equivalents (CO_2e) per year[5], or about 0.86 t CO_2e per t(wet) MSW. While there are GHG emissions associated with AD of MSW, these are likely to be considerably lower than those from landfill sites.

We have used a conservative estimate in suggesting that the net GHG emissions associated with AD of MSW is **50%** of that from landfill sites, or about 0.43 t CO_2e per t (wet) MSW. Assuming an emission reduction value of $15 per t CO_2e, processing MSW via AD instead of landfilling would have a value of $6.44 / t (wet) MSW (Table 1 and 2). This calculation does not include the emission reductions associated with displacing a fossil fuel source.

Even so, the impact of this greenhouse gas credit on the economics of power generation is significant, reducing the cost per MWh by $27.09 (Table 1 and 2). Consequently, electrical power costs from MSW could be as low as **$55.07 to $97.15 per MWh** for tipping fees of $60 and $50, respectively. This calculation does not include the greenhouse gas credit associated with using MSW as a source of power instead of a fossil fuel feedstock like coal. If this were to be included, the cost of power could be reduced by another $10/MWh (e.g. federal renewable energy credit).

Table 2. Anaerobic Digestion of 70% Ontario MSW with a $60/t tipping fee.

Cost Component	Processing Cost	Power Cost		Total Cost
	$/t(wet)MSW	$/GJ	$/MWh	$M/y
Tipping Fee	$(60.00)	$(70.13)	$(252.53)	$(390)
Capital Cost	$33.60	$39.27	$141.41	$218
Maintenance & Ops	$45.92	$53.67	$193.27	$299
Sub Total	**$19.52**	**$22.81**	**$82.15**	**$127**
GHG Credit	$(6.44)	$(7.52)	$(27.09)	$(42)
Total	**$13.08**	**$15.29**	**$55.07**	**$85**

Conclusion. Anaerobic Digestion of MSW was originally developed as an alternative to the high costs and environmental concerns associated with landfilling, whereas power generation was a beneficial byproduct. With rising energy prices, the contribution of power generation to AD economics can be significant, creating the necessary economic driver to encourage widespread use of this well-established technology in Canada, as is now the case in Europe. With a reasonable tipping fee, and credit for greenhouse gas emission reductions, the cost of power could be competitive with other sources of conventional or alternative energy sources. By creating the necessary policies and incentives in this area, Ontario could add 220 MW of base load of power to the grid in the province.

For Further information, contact:
BIOCAP Canada Foundation, 156 Barrie St., Kingston, Ont. K7L: 3N6
Tel: 613 542-0025 Fax: 613 542-0045 Email: info@biocap.ca Web: www.biocap.ca

[5] Canada's Greenhouse Gas Inventory, 1990-2001. Greenhouse Gas Division, Environment Canada (August 2003).

Case Study #3:

Cofire with Biomass or Replace Coal at Nanticoke PGS

The Nanticoke Power Generating Station is a large, eight unit coal-fired facility capable of generating 3920 MW of power. Each year, it produces about 22,900 million KWh/yr of electrical energy from coal shipped from USA (http://www.opg.com/ops/Stations/Nanticoke.pdf).

This case study explores two biomass energy options for Nanticoke:

- Cofiring with agriculturally generated biomass to provide 15% of power output, or
- Replacement of 100% of the coal with agricultural and forest biomass.

The Biomass Energy Requirement: At the present time, the Nanticoke Power plant generates about 22,900 million KWh of power with approximately 9 Mt coal. Assuming 34% efficiency, the thermal energy input into the plant was calculated to be **243 million GJ per year**. If biomass is used to cofire with coal at 15%, 36.42 million GJ of thermal energy would be needed from the biomass (Option 1). However, full coal replacement with biomass would require 243 million GJ of biomass energy per year.

Option 1: Cofiring with Agricultural Biomass to Provide 15% of Power Output:

The Nanticoke Power plant is located on the north shore of Lake Erie, close to a major agricultural region that has suffered economically in recent years due to low prices and the loss of markets (e.g. tobacco). A recent study by the David Suzuki Foundation[1] estimated that more than 3.5 Mt(dry)/yr agricultural residues are technically available in Ontario, with 0.95Mt(dry) deemed to be "practically available". To provide 5% of the energy needs of Nanticoke (1146 Million KWh) would require 0.76 Mt(dry) biomass, or most of the 'practically available' biomass. Assuming the residues could be purchased for $30/t(wet) and the average trucking distance was 155 km, the biomass could be delivered to the plant for about $54.42/t(wet) or **$47.93/MWh**.

Option 1: Cofiring Biomass with Coal to Provide 15% Bio-power

Cost Component	Biomass	Power	Cost	Total Cost
	Mt(dry)	million KWh	$/MWh	$M/y
Crop Residues	0.76	1,146	$47.93	$54.94
Biomass Crops	1.51	2,293	$63.87	$146.43
Delivered Biomass	**2.27**	**3,439**	**$58.56**	**$201.38**
Capital Retrofit			$2.00	$6.88
Maintenance & Ops			$16.00	$55.02
TOTAL			**$76.56**	**$263.28**
Greenhouse Gas/ Renewable Energy Credit			$(10.00)	$(34.39)
NET COST			**$66.56**	**$228.99**

To generate the remainder of the biomass for co-firing (10% or 2293 million KWh), it should be possible to pay farmers to grow about 2.02 Mt(wet) biomass such as switchgrass. At 25% water content and a production rate of 10 t(dry)/ha a total of 151,439 ha would be needed (this is only 24% of the 620,000 ha that the Suzuki Foundation (Ref 1, Table 4) estimates could be diverted from current production for the growth of biomass crops). Assuming that 20% of the land around Nanticoke was dedicated to the production of these crops at $60/t(wet), the average trucking distance would be 60 km and the delivered cost of the biomass would be $72.52 per tonne, or **$63.87/MWh**. Together with crop residues, the delivered biomass cost would be about $58.56 / MWh.

Allowing $2/MWh for capital retrofits to allow biomass power, and assuming $16/MWh for maintenance and operations, the cost of the biomass power would be $76.56. Assuming a federal greenhouse gas / renewable energy credit of $10.00 per MWh, the net cost of power would drop to **$66.56/MWh**.

Information: BIOCAP Canada Foundation Tel: 613 542-0025 Email: info@biocap.ca Web: www.biocap.ca

[1] Etcheverry, J et al. 2004. Smart Generation: Powering Ontario with Renewable Energy. David Suzuki Foundation. Table 6

Option 2: Replacement of 100% of the Coal with Agricultural and Forest Biomass.:

Using biomass to provide 100% of the feedstock for the Nanticoke plant is more of a challenge than a 15% cofiring strategy, but the province does have the capacity to achieve this from a combination of four sources:

- **Crop Residues:** This could provide 5% of the energy needs as described above.
- **Biomass Crops.** Our scenario envisages that 833,000 ha of biomass crops would generate 55% of the necessary biomass, totaling 8.33Mt(dry)/yr. Of this, about 3 Mt(dry) would be brought by truck from south-western Ontario, and an additional 5.3 Mt could come by ship from four shipping sites, each drawing on agricultural regions within 60 km of the port. These regions could be in eastern Ontario, Quebec, Ohio, New York or Michigan. This magnitude of demand for biomass crops would be transformative for the rural economy in Ontario, resulting in an agriculture investment of over $600M/y and creating a crop that would have more farm gate receipts than the entire corn crop in Ontario. According to the David Suzuki Foundation[2], 74% of the necessary land area needed (602,000 ha) could become available for biomass crops by diverting 10% of existing cropland, 30% of hay land and 30% of improved pasture in Ontario. The remaining land requirements could be from 'out-of-province' or by bringing back into production a small fraction of the 3 million hectares of farmland that has left agriculture in Ontario since 1951[3]. The delivered cost of this biomass was estimated to be $67-$70 / MWh.

Option 2: Replace Coal with Biomass at Atikokan

Cost Component	Biomass Mt(dry)	Power million KWh	Cost $/MWh	Total Cost $M/y
Crop Residues (5%)	0.76	1,146	$47.93	$54.94
Biomass Crops-local (20%)	3.03	4,585	$66.61	$305.45
Biomass Crops-shipped (35%)	5.30	8,024	$69.61	$558.56
Sustainable Forest harv. (40%)	5.73	9,171	$72.25	$662.60
Delivered Biomass	**14.82**	**22,927**	**$68.98**	**$1,581.55**
Capital Retrofit			$10.00	$229.27
Maintenance & Operation			$16.00	$366.83
TOTAL			**$94.98**	**$2,177.64**
Greenhouse Gas/ Renewable Energy Credit			$(10.00)	$(229.27)
NET COST			**$84.98**	**$1,948.38**

- **Forest Harvest.** The remaining 5.7 Mt(dry)/yr biomass could be obtained from a combination of residual forest biomass and sustainable forest harvest from dedicating forest management areas where the end product is energy instead of more traditional uses (e.g. pulp and paper). Our calculations are based on the latter option and assume that this biomass would be brought to the Nanticoke Generating station by ship from up to 6 or more ports on either the Canadian or US side of the Great Lakes. This would account for about 43% of the biomass that BIOCAP has estimated to be currently and sustainably available from the forested public lands in the province. At a delivered cost of about $72/MWh, this biomass is among the most expensive of the various sources. Accessing it for use as a bioenergy resource would also require policy changes.

Europe Generates power from Canadian Biomass

About 450,000 tons of wood pellets are shipped from BC to Europe per year for use in power generation. Prices (fob Vancouver) of $6-7/GJ are similar to the delivered cost of biomass in this case study for Nanticoke.

Overall, the delivered cost of biomass ($6.51/GJ) at 34% conversion efficiency yields power at $69/MWh. Add to this, a capital cost of $10/KWh and a M&O of $16/MWh, results in a gross price of $95/MWh. However, a federal renewable energy credit of $10/MWh provides a net cost for power of **$85/MWh**.

Conclusion. Ontario has the biological resources for the sustainable production of biomass to meet the current needs of the Nanticoke power station at a price of about $85/MWh. If the Ontario government were to choose this option for base power generation in the province, there would be a major stimulation to the rural economy of the province, both in the agriculture and forestry sectors.

It will be very important to ensure that the management strategies and technologies used to produce, harvest, transport and combust the biomass will have minimal adverse impacts on the environment. Ideally, a large scale integrated strategy[4] needs to be developed to explore the optimal development and use of the vast 'Biological Capital' of the province to address environmental goals as well as societal needs for heat and power, transportation fuels and industrial chemicals and materials, in addition to food, feed and fibre.

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[2] Etcheverry, J et al. 2004. Smart Generation: Powering Ontario with Renewable Energy. David Suzuki Foundation. Table 4

[3] Farmland Preservation Research Project, U of Guelph http://www.uoguelph.ca/~farmland

[4] Including integration with the fossil fuel infrastructure such as oil and gas pipelines, etc.

Appendix A: Cost per Energy Unit of Fossil Fuel and Biomass Feedstocks

1. Introduction

The following table provides the values that were used for energy content and price of various fossil fuel and biomass feedstocks in the calculation of the $2005C per Gigajoule (GJ) and per MWh. The footnotes on the next page refer to the reference numbers that are associated with either the values for energy content or the values for price per unit. These values were used in the creation of Fig. A1 and Fig.1 in this document.

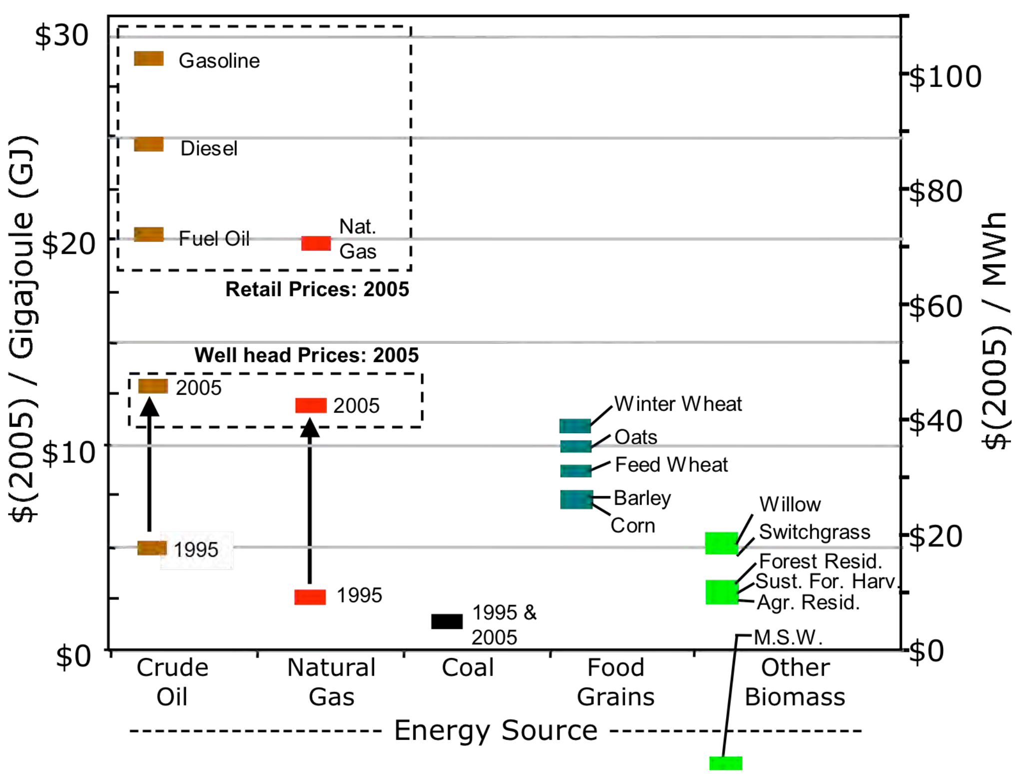
Table A1. Calculation of Cost ($2005) per GJ and per MWh for various energy sources

		Energy Content			Price per unit		$/GJ	$/MWh
		Gigajoules	per unit	Ref	$C(2005)	Ref.		
Wellhead or Commodity Prices								
Fossil Fuels	Oil (1995)	6.1	boe	1	$30.38	2,3	$4.98	$17.93
	Oil (2005)	6.1	boe	1	$78.04	2,3	$12.79	$46.06
	Gas (1995)	0.0346	m3	1	$0.092	3,4	$2.65	$9.53
	Gas (2005)	0.0346	m3	1	$0.400	3,5	$11.56	$41.62
	Coal (1995)	27.45	tonne	1	$39.33	3,6	$1.43	$5.16
	Coal (2005)	27.45	tonne	1	$45.64	3,6	$1.66	$5.99
Grain Crops	Winter Wheat	13.9	t(wet)	7	$153	8	$10.98	$39.54
	Oats	13.9	t(wet)	7	$140	8	$10.05	$36.18
	Barley	13.9	t(wet)	7	$105	8	$7.54	$27.13
	Corn	13.9	t(wet)	7	$100	8	$7.18	$25.84
	Feed wheat	13.9	t(wet)	7	$120	8	$8.61	$31.01
Biomass Feedstocks	Switchgrass	12.0	t(wet)	9	$60.00	est	$4.99	$17.96
	Willow	9.3	t(wet)	10	$50.00	est	$5.37	$19.32
	For Resid	9.3	t(wet)	10	$24.15	11	$2.59	$9.33
	SustForestHarv	9.3	t(wet)	10	$20.92	11	$2.25	$8.08
	Agric'l Residues	12.0	t(wet)	9	$30.00	est	$2.49	$8.98
	MSW	9.5	t(wet)	12	$(50.00)	est	$(5.26)	$(21.91)
Retail prices								
Heating Fuels	Heating Oil (1995)	0.0387	litre	2	$0.476	3,13	$12.28	$44.20
	Heating Oil (2005)	0.0387	litre	2	$0.780	13	$20.13	$72.48
	NatGas (1995)	0.0346	m3	2	$0.394	5	$11.38	$40.96
	NatGas (2005)	0.0346	m3	2	$0.670	5	$19.36	$69.68
	Propane	0.0254	litre	13	$0.630	4	$24.84	$89.43
	Cord of Wood	16.3	Odt	14	$184	est	$11.29	$40.66
Transportation Fuels	Gasoline (1995)	0.032	litre	1	$0.67	15	$20.94	$75.38
	Gasoline (2005)	0.032	litre	1	$0.90	15	$28.13	$101.25
	Petrodiesel (1995)	0.036	litre	1	$0.60	15	$16.67	$60.00
	Petrodiesel (2005)	0.036	litre	1	$0.89	15	$24.72	$89.00
	Bio-diesel	0.034	litre	1	$0.89	16	$26.18	$94.24
	Ethanol	0.0211	litre	1	$0.90	16	$42.65	$153.55

Footnotes:

1. from: http://bioenergy.ornl.gov/papers/misc/energy_conv.html
2. from:http://tonto.eia.doe.gov/dnav/pet/hist/rwtcM.htm
3. Assume Exchange rate of $C1.3557/ $US in 1995 (http://www.xe.com/ict/); $C1.15/$US in 2005; and a Canadian Consumer price index of 1.242 for 2005 relative to 1995 (http://www.bankofcanada.ca/en/cpi.html).
4. From: http://www.energy.gov.on.ca/index.cfm?fuseaction=conservation.guide13
5. From: http://www.energyshop.com/es/homes/gas/gaspriceforecast.cfm?r
6. From http://www.eia.doe.gov/emeu/aer/coal.html and http://www.eia.doe.gov/emeu/aer/coal.html
7. Lower Heat Value (LHV) for agricultural biomass having 15% water, and 6% hydrogen calculated from a higher heat value (HHV) of 18 GJ/t dry biomass (ref) as described in R. van den Broek, A. Faaij and A. van Wijk. Biomass combustion power generation technologies. Report commissioned by CEC-DG-XII, 102 pp. (No. 95029), Department of Science, Technology and Society, Utrecht University, Netherlands, 1995.
8. From Cdn Ag. Income Stabilization Program, Monthly 2005 Fair Market value list for major Ont field crops. From: http://
9. Lower Heat Value (LHV) for agricultural biomass having 25% water, and 6% hydrogen calculated from a higher heat value (HHV) of 18 GJ/t dry biomass (ref) as described in van den Broek, Faaij and van Wijk (see ref 7, above)
10. Lower Heat Value (LHV) for woody biomass having 45% water, and 6% hydrogen calculated from a higher heat value (HHV) of 20 GJ/t dry biomass (ref) as described in van den Broek, Faaij and van Wijk (see ref 7, above)
11. Assumes $US21/t(wet) for picking up slash, creating a composite log forwarding to logging road and chipping
12. Assumes whole tree harvest where 20% of tree is left on site. Of the 80% removed, 63% of that as roundwood ($US16.54/t(wet) for felling, forwarding and chipping) and 37% is slash (($US21/t(wet) as per footnote 11)
13. from: Stats Can (2006) Table 326-0009 Average retail prices for gasoline and fuel oil by urban centre
14. Lower Heat Value (LHV) for woody biomass having 12% water, and 6% hydrogen calculated from a higher heat value (HHV) of 20 GJ/t dry biomass (ref) as described in van den Broek, Faaij and van Wijk (see ref 7, above)
15. Ontario Ministry of Energy (2006) Oil and Gas Fuel Prices. http://www.energy.gov.on.ca/index.cfm?fuseaction=oilandgas.fuelprices

Fig A1. Comparison of fossil and biomass energy prices ($2005) in Canada.



Appendix B: Coefficients and Assumptions

Prepared by J Stephen, BIOCAP

1. Introduction

This appendix summarizes many of the coefficients and assumptions used in the calculations and case studies described in this document.

Description	*Number*	*Units*	*Ref*
Energy Conversion			
Joules to BTU	1055	J/BTU	1
Electrical Energy	3.6	MJ/kWh	1
Oil Energy	6.1	GJ/boe	1
Coal Energy (bituminous)	27	GJ/t	1
Coal Energy (lignite)	17.4	GJ/t	1
Energy Content of Natural Gas	34.6	MJ/m3	1
Energy Content of Crops & Crop Residues (dry)	18	GJ/t(dry)	1,2
Energy Content of Crops & Crop Residues (25% water)	16	GJ/t(dry)	1,2
Energy Content of Forest Biomass (dry)	20	GJ/t(dry)	1,3
Energy Content of Forest Biomass (45% water)	16.9	GJ/t(dry)	1,3
Area and Distance			
Tortuosity – grid roads	1.3	Km/km	7
Tortuosity - forest roads	2.4	Km/km	7
Average Distance to area within a Circle	66.7% of radius	km or m	7
Transportation Costs			
Trucking Transportation Cost	$0.125	$/tonne/km	8
Rail Transportation Cost	$0.023	$/tonne/km	9
Shipping Transportation Cost	$0.0079	$/tonne/km	10,11
Loading/Unloading Costs	$4 to $5	$/tonne	8
Biomass Costs			
Crown Dues on Forestry Logging	$0.59	$/m3	14
Felling Cost	$5.75	$/tonne	15,16
Composite Log Production Cost	$10.35	$/tonne	15,16,17
Forwarding of Logs/Composite Logs	$3.45 to $4.60	$/tonne	15,16,17
Chipping	$8.05	$/tonne	15,16,17
Overhead for Harvesting	$1.15	$/tonne	15,16
Biomass Crops	$60.	$/tonne	18,19
Crop Residues / Straw for biomass	$30	$/tonne	20,21
Power Generation Costs			
Capital cost – Coal plant retrofit for cofiring at 15%	$2.00	$/MWh	22
Capital cost – Retrofit Coal plant for biomass	$10.00	$/MWh	23
Operations and Maintenance –	$16.00	$/MWh	23
Policy Incentives			
Federal Renewable Power Production Incentive	($10.00)	$/MWh	24

Unit magnitudes

Term	Abbreviation	Exponent
Deca	da	10
Hecto	h	10^2
Kilo	k	10^3
Mega	M	10^6

Term	Abbreviation	Exponent
Giga	G	10^9
Tera	T	10^{12}
Peta	P	10^{15}
Exa	E	10^{18}

References:

1. Oak Ridge National Laboratory (2005) Bioenergy Conversion Factors. http://bioenergy.ornl.gov/papers/misc/energy_conv.html
2. Lower Heat Value (LHV) for agricultural biomass having 25% water, and 6% hydrogen calculated from a higher heat value (HHV) of 18 GJ/t dry biomass (ref) as described in R. van den Broek, A. Faaij and A. van Wijk. Biomass combustion power generation technologies. Report commissioned by CEC-DG-XII, 102 pp. (No. 95029), Department of Science, Technology and Society, Utrecht University, Netherlands, 1995.
3. Lower Heat Value (LHV) for woody biomass having 45% water, and 6% hydrogen calculated from a higher heat value (HHV) of 20 GJ/t dry biomass (ref1) as described in van den Broek, Faaij and van Wijk (see ref 2, above)
4. Oak Ridge National Laboratory (2005) Bioenergy Feedstock Characteristics. http://bioenergy.ornl.gov/papers/misc/biochar_factsheet.html
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10. Choosing the Site of a Steel Mill (Accessed 10/02/2006) http://home.earthlink.net/~schuessler/Class_Projects/LakeSuperiorPage/Lake_Superior_Math.htm
11. Waterway Fact Sheet (Accessed 10/02/2006) http://www.tulsaweb.com/port/facts.htm
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Appendix C: Biomass Energy Potential

Prepared by S Bates, DB Layzell and SM Wood, BIOCAP

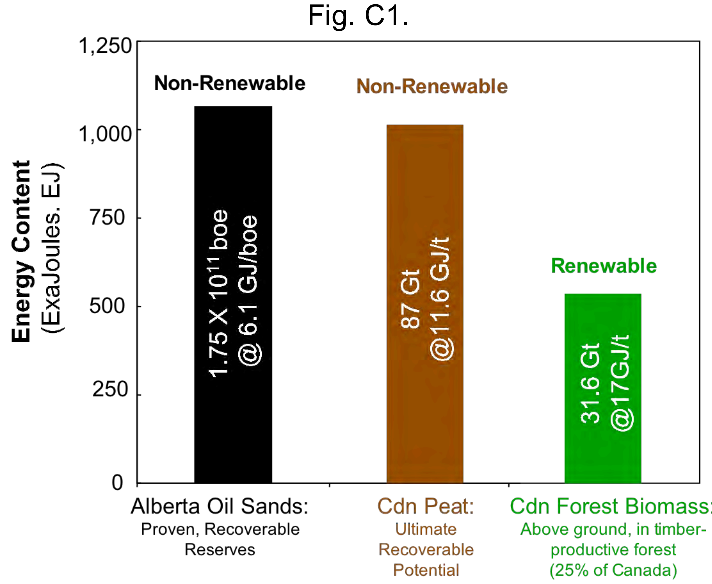
1. Introduction

This Appendix will consider the potential for the sustainable production of biomass to provide a renewable energy resource. The section will explore the national biomass reserves of Peat and Forest biomass with the Proven Recoverable Reserves of the Alberta Oil Sands. Then a review of past estimates of sustainable biomass production capacity in Canada and in Ontario will be presented, and compared to a new inventory of biomass energy capacity.

2. Comparison of Oil Sands and Biomass Reserves in Canada

The Proven Recoverable Reserves[10] in Alberta's Oil Sands (1.75 X 10^{11} barrels of oil equivalent (boe)) are the second largest on earth, eclipsed only by Saudi Arabia. Since each barrel of oil has an energy content of 6.1 GJ[11], the Alberta Oil Sands contain about 1,068 EJ of energy (Fig. C1), an amount equivalent to approximately 100 years of Canada's total energy use in 2003 (10.5 EJ/yr).

Fig. C1.



By comparison, Canada's peat resource (effectively non-renewable as it has taken about 10,000 years to accumulate) is approximately 87 X 10^9 dry tonnes (32% of which is in Ontario)[12]. Given an energy content of 11.61 GJ/t, the nation's peat resources contain about 1011 EJ of energy, an amount similar to the Proven Recoverable Reserves in the oil sands.

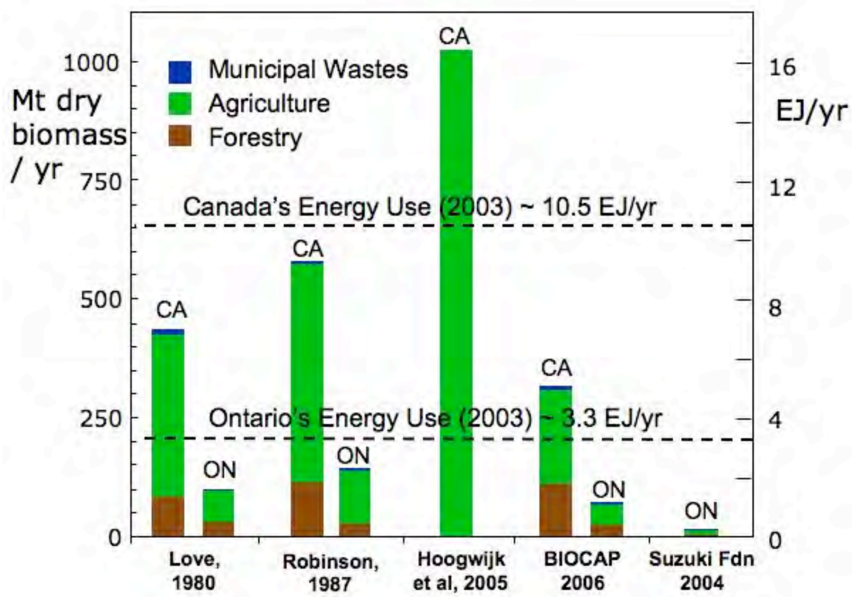
To calculate the magnitude of the renewable biomass reserves, it seems reasonable to consider – as a first approximation - the energy that exists in the above ground biomass that is present in Canada's Timber Productive Forest, a 245 M ha land area that accounts for about 25% of Canada. The above-ground biomass in this forest has been estimated to contain about 15,835 Mt carbon, or about 31.7 Gt dry biomass[13]. Assuming an energy content of 16.9 GJ/t, the timber productive forest contains about 535 EJ of energy, or about 50% or that of the proven Recoverable reserves in the Alberta Oil Sands. Moreover, this reserve is renewable if managed appropriately. As a renewable resource, the key issue is sustainable production of the biomass.

[10] The total oil present within the oil sands of Alberta has been estimated as 2 X 1012 boe, 11 times the proven recoverable reserves (http://www.oilsandsdiscovery.com/oil_sands_story/resource.html)
[11] http://bioenergy.ornl.gov/papers/misc/energy_conv.html
[12] From Robinson, J 1987. An Embarrassment of Riches: Canada's Energy Supply Resources. **Energy** 12: 379-402.
[13] Wood, SM and Layzell, DB 2003. A Canadian Biomass Inventory: Feedstocks for a Bio-based Economy. Prepared for Industry Canada, Contract # 5006125

3. Sustainable Biomass Production Capacity: A Literature Review

Over the past 30 years, there have been a number of studies that have attempted to calculate the potential for sustainable biomass production in Canada and in the Province of Ontario. The results from four earlier studies and a new analysis are presented here. A summary of the findings for all Canada, and for Ontario is presented in Fig C2. For reference purposes, Canada's and Ontario's 2003 energy use of 10.5 and 3.3 exajoules (EJ)/yr, respectively, are shown as dashed lines.

Fig. C2: Estimates of sustainable biomass energy potential in Canada and in Ontario compared to the total energy demand (all forms of energy) in Canada and Ontario.



Canadian Potential. One of the first attempts at quantifying the biomass energy potential was a report prepared in 1980 for Energy, Mines and Resources Canada by Peter Love[14]. This study calculated a sustainable biomass production capacity of 425 Mt dry biomass per year, with a total energy content of about 7.0 EJ, equivalent to 66% of Canada's total energy demand in 2003 (Fig. C2).

Seven years later, John Robinson published[15] a detailed inventory in which he estimated that 567 Mt dry biomass could be produced, having an energy content of about 9.3 EJ, or 89% of Canada's total energy demand in 2003 (Fig. C2).

Then in October 2005, a Dutch group of researchers[16] included Canada in a detailed analysis of biomass energy potentials out to 2100 for four IPCC SRES land-use scenarios. Even though, their study considered only the potential for sustainable biomass crop production, they calculated that Canada would be able to produce about 1000 Mt dry biomass having an energy content of about 16 EJ, or 152% of Canada's total Energy demand in 2003.

To put these numbers in perspective, Canada's current agricultural and forest harvest involves about 270 Mt dry biomass per year[17] (of which about half ends up in food, feed or fibre 'products'). Therefore, to achieve the full bioenergy potential identified by these authors would require a doubling or tripling in the size of the annual forest and agricultural production in Canada. Even achieving a portion of these targets would be a major stimulation to the rural economy.

Ontario Potential. Peter Love and John Robinson also estimated the biomass energy potential of each province in Canada, including Ontario. They estimated that Ontario could sustainably produce

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[14] Love, P. 1980. Biomass energy in Canada. Its potential contribution to future energy supply. A report prepared for Energy, Mines and Resources, Canada. Report ER 80-4E March 1980.
[15] Robinson, J, 1987. An Embarrassment of Riches: Canada's Energy Supply Resources. **Energy** 12: 379-402.
[16] Hoogwijk, M, Faaij, A, Eickhout, B, deVries, B and Turkenburg, W. 2005. Potential fof biomass energy out to 2100, for four IPCC SRES land-use scenarios. Biomass and Bioenergy 29: 225-257.
[17] Wood, SM and Layzell, DB 2003. A Canadian Biomass Inventory: Feedstocks for a Bio-based Economy. Prepared for Industry Canada, Contract # 5006125

105 and 148 Mt dry biomass, respectively, resulting in a total energy input of 1.7 and 2.4 EJ/yr, respectively. These values are equivalent to 53% and 74%, respectively, of the total energy demand in the Province of Ontario.

A very different approach was taken in the Suzuki Foundation report of 2004, "Smart Generation: Powering Ontario with Renewable Energy[18]", where power generation opportunities from biomass resources were limited to modest conversion of readily available waste fractions associated with forestry, agriculture and urban waste. The estimated available biomass totaled only 15 Mt, but closer analysis shows that only those resources whose use was linked with other positive environmental benefits were considered. This means, for example, that biomass from forestry was restricted to mill and pulp processing wastes, as well as bark, and that agricultural biomass was restricted to crop and animal residues, or only biomass crop production that could be linked to land diverted from food production.

Other options, such as the dedicated harvest of forest resources for energy production or rejuvenation of abandoned farmland for biomass crop production were not included, presumably because some of these options could have adverse environmental impacts that may not be offset by the benefits. Consequently, this study offers a limited view of the potential of biomass in the Province of Ontario, but it does point to the fact that biomass production, procurement and use falls along a continuum of environmental and economic impacts. The challenge is to find an appropriate balance that allows rural communities to meet needs for employment and economic opportunity, while ensuring that society has a clean source of energy and a healthy environment. This requires research, debate and prudent policy decisions.

4. A New Estimate of Biomass Energy Potential for Ontario

To provide a more detailed and updated estimate of biomass energy potential for Ontario, BIOCAP offers the following analysis, with results compiled in Table C1 and plotted in Fig. C2.

The energy value of a tonne of biomass is determined by four major factors:

- **Chemical composition:** oils and fats have more energy per t than cellulose, which has more energy than organic acids. Typically, dry wood has an energy content of about 20 GJ/t whereas fully dry agricultural crops have an energy content of about 18 GJ/t.
- **Water content:** If energy is going to be extracted from biomass by combustion, gasification or pyrolysis, the water content is a problem since the water must be boiled off before combustion. Therefore, biomass with high water content has lower extractable energy. For woody biomass at 45% water, the effective energy content (Lower Heat Value, LHV) drops from 20 GJ/t (dry) to 16.9 GJ/t(dry) or 9.3 GJ/t(wet). In comparison, agricultural biomass at 25% moisture content has an effective energy content of 16 GJ/t(dry) or 12 GJ/t(wet) instead of the initial 18 GJ/t(dry).
- **Biomass processing technology.** With microbial processing technologies such as Anaerobic Digestion, the extractable energy content is not adversely affected by water content; in fact water is required for the microbial activity in the production of methane. Consequently, this technology has benefits for wet biomass. However, for power generation, AD is a multi step process (first methane production, then methane combustion to produce power), whereas direct combustion has one less step. Therefore, power output from direct combustion is typically about 35% efficient whereas production of biogas from anaerobic digestion is only about 17 % efficient. Power production using biogas in a combined cycle conversion process runs at about 52% efficiency.

[18] http://www.davidsuzuki.org/files/Climate/Ontario/Smart_Generation_full_report.pdf

- **Desired end product.** If electrical power generation is the only desired end product, then energy conversion efficiencies will be lower (typically 30-50% efficient) than when heat is required or both heat and power (up to 80% efficient or more).

Consequently, in the following discussion of biomass feedstocks there will be a brief discussion of the assumptions that have been used to calculate energy conversion efficiency in Table C1.

Biomass from forest resources: *All forest biomass sources are assumed to have 45% water content, and therefore an LHV of 16.9 GJ/t dry biomass. It is assumed that the biomass will be combusted to generate heat which can be converted into power at an efficiency of 34-35%.*

- **Residues from existing forest harvest:** When trees are harvested in Ontario, a portion of the tree is not usable in existing fibre markets. This portion is equivalent to at least 25% (potentially up to 100%) of the roundwood harvested and removed from the site (Ontario roundwood harvest: 11.5 Mt dry biomass per year). However, the smaller branches and needles must be left on the site to maintain nutrients in support of forest regrowth. OMNR's BSAT model estimates that **1.5 Mt** dry biomass or 13.5% of the annual harvest on provincial lands (i.e. slash) can be removed for bioenergy use. An additional **0.25 Mt** dry biomass is thought to be available from private forest lands. Also, when trees are being harvested for the pulp and paper industry, the wood is often chipped at the harvest site. Spillage and waste from this operation (i.e. chip frass) is estimated to be 2% of the annual cut, or **0.23 Mt** dry biomass. Once at the lumber mill, about 25% of the harvested fraction ends up as mill residue, including sawdust and end cuts. Much of this (over 80%) is currently used for energy or other purposes, leaving about **0.5 Mt** dry biomass from mill residues that could be used as a bioenergy feedstock. Therefore, the amount of biomass potentially available from existing forestry activities is conservatively estimated at **2.48 Mt dry biomass** per year.

- ***Accessing unused Annual Allowable Cut:*** Every year, the Ontario forest industry is awarded an Annual Allowable Cut (AAC) from designated areas of the provincial forest lands to ensure a sustainable yield. Typically, this amounts to about 15.5 Mt dry biomass, but the companies do not harvest all of the areas assigned to them, for a variety of reasons[19]. In some cases, market value of the trees does not warrant the investment to harvest, in other cases, the species or quality of the tree is undesirable, and finally, some harvest regions are difficult to access economically because of a lack of road infrastructure; unharvested trees amount to about **4 Mt of dry biomass**[20] that would work well as a bioenergy feedstock.

- ***Harvesting forests after disturbance:*** Every year in Ontario, large numbers of trees are lost to fires, pests and disease. While it is not practical to harvest this entire fraction, and some trees must be left to ensure biodiversity, there are significant opportunities to harvest biomass for energy at sites where concentrated impacts have occurred. Assuming that only 25% of the dead trees from disturbance impacts in the managed forest areas were harvested for energy, this would amount to **1.2 Mt** dry biomass from fire loss, **0.9 Mt** from pest loss and **1.7 Mt** from disease loss, for a total of **3.8 Mt dry biomass.**

- ***More intensive forest management (silviculture):*** Forest management practices such as pre-commercial thinning, replanting after harvest with elite trees, or selective harvest strategies are well known to increase the productivity of forests over time, potentially by two or three fold[21]. Assuming widespread use of more intensive forest management practices result in a 120% increase in forest productivity, and the additional productivity is diverted to energy use, improvements in silvicultural practices could provide an additional sustainable yield of **13.8 Mt**

[19] D. DeYoe, OFRI, Sault Ste. Marie, 2005
[20] Values from Biomass Spatial Analysis Tool (BSAT) Model, OMNR (2005)
[21] Atlantic Provinces Economic Council (2003) The New Brunswick Forest Industry Potential Economic Impact of Proposals to Increase Wood Supply. (http://www.gnb.ca/0078/APEC-e.pdf)

dry biomass per year (11.5 Mt X 1.2) for energy production. Due to the slow growth rate of trees, this magnitude of an increase in forest productivity would take many decades to be realized. Another option for increased flow of biomass to energy uses would result if the economics of sustainable forest harvest for domestic energy use were better than the economics associated with the production of traditional forest products.

- ***Dedicated harvest of forest resources:*** Traditionally, the AAC has been established to support the needs of forest industries such as timber and pulp and paper manufacturers. Recent stresses in these industries mean that some trees that might have been harvested are now left behind as a consequence of mill closures or declining markets. Not only does this have very harmful consequences for the local economies, but it also results in declining forest health, as trees age and become more susceptible to insect infestation and forest fire. Proper management and regular harvest results in vigorous forest growth. Consequently, it is important to explore the use of dedicated harvest of trees for energy production; it is estimated that **3 Mt of dry biomass** (comprising 2 Mt roundwood + 1 Mt slash) could become available.

Biomass from agricultural sources: *Crop Residues and biomass crops are assumed to have 25% water content, and therefore an LHV of 16 GJ/t dry biomass. It is assumed that the biomass will be combusted to generate heat which can be converted into power at an efficiency of 34-35%; Manure is assumed to be processed by Anaerobic Digestion, therefore heat production from combusting the biogas is 17.3% of the energy in the biomass (assuming 16 GJ/t(dry)) and power generation from the biogas is 52% efficient.*

- **Crop Residues:** Ontario has approximately 3.5 M ha under crop and forage production, primarily for food and animal feed. About **8.2 Mt dry biomass** of residues are produced from the 7 largest grain crops in Ontario, over half of which is derived from corn[22]. A portion of this (about 33%) must be left on the field for retention of soil carbon stocks and nutrients. In addition, there are some existing markets (example animal bedding) for the remaining biomass. Assuming 70% of the remaining biomass is available for bioenergy, grain crop residues available for energy use would amount to **3.8 Mt dry biomass**. Also, in growing seasons with adequate moisture, there is often surplus hay in Ontario equivalent to 5% of total production, yielding an average of **0.2 Mt/yr**, for a total crop residue potential of about **4.0 Mt dry biomass**.
- **Manure as an energy resource**: In 1996, Ontario cattle, swine and poultry produced 30.9 billion litres[23] of manure, which is considered a valuable soil amendment that returns nutrients to support crop production on about 18.9% of tillable land in the province. Anaerobic digestion technology allows capture of methane from the equivalent of **7.7 Mt dry** manure for production of heat and power at the farm or regional level. Full realization of this potential for distributed energy production depends upon successfully overcoming technological and regulatory hurdles.
- **Bioenergy Crops:** Analyses offered by Samson[24,25] have estimated that 620,000 ha could be diverted from current agricultural usage to support the development of biomass crops, and that about 800,000 ha of poorer quality class 4 and 5 land could be brought into active agricultural production in the near term. When adjusted to eliminate possible overlap between these two figures and to anticipate grower response to emerging energy crop markets, an estimated 2 Mha of agricultural land could be used for biomass production. Under fast-growing lignocellulosic crops like willow or switchgrass, with an average yield of 10 t dry biomass per ha, **20 Mt dry biomass** would be available for energy production.

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[22] Ontario Ministry of Agriculture, Food, and Rural Affairs (2005) Field Crop Statistics (http://www.omafra.gov.on.ca/english/stats/crops/index.html
[23] Ontario Pork Industry Profile (2006)(http://www.ontariopork.on.ca/who/industryprofile.htm)
[24] David Suzuki Foundation (2004) Smart Generation: Powering Ontario with Renewable Energy.
[25] Samson, R.; Girouard, P.; Zan, C.; Mehdi, B.; Martin, R.; and J. Henning (1999) The implications of growing short-rotation tree species for carbon sequestration in Canada. REAP Canada.

Biomass from municipal sources: *Municipal biomass is assumed to be processed by Anaerobic Digestion, therefore heat production from combusting the biogas is 17% of the energy in the biomass (assuming 16 GJ/t(dry)) and power generation from the biogas is through combined cycle and therefore 52% efficient.*

- **Municipal solid wastes (MSW):** Ontario residents generate approximately 1 tonne MSW[26] per person per year, resulting in around 12,000,000 tonnes MSW each year.[27] About 77% of Ontario's MSW is sent to landfill for disposal (less than 2% combusted) and about 20% (primarily non-biomass components) is recycled and therefore diverted from disposal. Ontario thus has an existing unused yearly potential of approximately 9.3 Mt MSW containing about 7.4 Mt of usable biomass. Assuming 50% water content in the biomass fraction, there should be 3.7 Mt dry weight available for energy use. MSW may be handled in a variety of ways for energy production including combustion, pyrolysis, gasification and Anaerobic Digestion (AD). AD involve the controlled industrial microbial digestion in the absence of oxygen resulting in production of biogas (methane and carbon dioxide) and a peat-like, lignin-rich organic residue[28].. The biogas can either be upgraded to natural gas pipeline quality or combusted directly to provide net product electricity and surplus heat. A total of **3.7 Mt dry biomass in MSW** could be used to produce **1.5 TWh/yr.**
- **Biosolids.** Human waste production in Ontario is about 300,000 dry tonnes/yr, which could produce an additional **0.12 TWH/yr** through AD. The total power potential from municipal sources is **1.6 TWh/yr**.

Table 1: Summary Biomass Resources and Calculation of Potential for Power Generation

	Mt dry biomass/yr	*Energy Content (GJ/t dry)* [b]	*Thermal Energy (PJ/yr)*	*Power. (TWhr)*[c]
Forestry				
Residues from Existing Forestry	2.5	16.9	42.3	4.11
Accessing unused annual allowable cut	4.0	16.9	67.6	6.57
Harvesting forests after disturbance	3.8	16.9	64.2	6.24
Silviculture	13.8	16.9	233.2	22.67
Dedicated harvest for energy	3.0	16.9	50.7	4.93
TOTAL for Forestry:	**27.1**		**458.0**	**44.52**
Agriculture				
Crop Residues	4.0	16.0	64	6.22
Animal Manure[a]	7.7	16.0	21	3.10
Biomass Crops	20.0	16.0	320	31.1
TOTAL for Agriculture:	**31.7**		**405**	**40.4**
Municipal Waste				
Solid Waste[a]	3.7	16.0	10.2	1.48
Biosolids[a]	0.3	16.0	0.8	0.12
TOTAL for Municipal & Ind. waste:	**4.0**		**11.0**	**1.60**
GRAND TOTAL	**62.8**		**874.4**	**86.54**

[26] MSW is defined as the solid, non-hazardous waste material generated by households, industries, institutions and construction activities.
[27] Statistics Canada. 2004. Waste Management Industry Survey, Business and Government Sectors 2002. Catalogue no. 16F0023XIE http://epe.lacbac.gc.ca/100/201/301/statcan/waste_manage_business_govt/16F0023XIE2002001.pdf
[28] A. Kani Associates and Enviros Ris. 2001. WDO Study: Implications of Different Waste Feed Streams (Source-Separated Organics and Mixed Waste) On Collection Options and Anaerobic Digestion Processing Facility Design, Equipment and Costs. Waste Diversion Organization Ontario. http://www.csr.org/wdo/iwdo_reports/ORGANICS/ORG%20R3-21.pdf

[a] **Assumed to be processed by Anaerobic digestion, therefore the thermal production only is achieved by burning the biogas, which captures 17% of the energy in the biomass.**
[b] Lower heat value expressed as Gigajoules (GJ) per tonne dry biomass. These values have been discounted to allow for the fact that the biomass typically has significant water content, which must be removed for thermal processing. These values assume about 45% water in forest biomass and 25% in crops and agricultural residues.
[c] Calculated as 3.6 GJ/MWhr at 35% efficiency for biomass combustion energy, or 52% efficiency for biogas combined cycle generation.