Agricultural Biomass Residue Inventories and Conversion Systems for Energy Production in Eastern Canada

Final Report

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T. Helwig, R. Jannasch., R. Samson, A. DeMaio and D. Caumartin

Resource Efficient Agricultural Production (REAP) - Canada
Box 125, Ste. Anne de Bellevue, Quebec, H9X-3V9

Executive Summary

Interest in renewable energy has increased in recent years due to concerns about diminishing fossil fuel supplies and global climate change. Dedicated energy crops such as corn or short rotation forestry plantations can provide feedstock for bioenergy production, but agricultural residues are typically less inexpensive because production costs are included in the cost of producing the main crop or livestock product. This report provides an overview of available crop residues and livestock manure in eastern Canada. The inventories are linked to an assessment of energy conversion systems that are either in the commercial stage or are in the late development or pilot stage.

Crop Residues

Cereal straws and corn stover were identified as feedstocks with high potential for bioenergy production in eastern Canada, whereas hay, soybean stover, and crop residues from oilseed production had lower potential. Approximately 1.0 million oven dry tonnes (odt) per year (y) of cereal straw and 3.0 million odt/y of corn stover are available in eastern Canada. By region, 615 000, 310,00 and 65,000 odt of straw and 1.9 million, 1.1 million and 6 000 odt/y of corn stover are available per year in Ontario, Quebec and the Atlantic Provinces, respectively. Although corn stover represents a larger feedstock pool than cereal straw, procurement systems for stover require considerable development before this residue source can be utilized. The gross energetic potential of these residues is approximately 92 million GJ/year. Assuming a combustion efficiency of 50%, 46 million GJ of heat energy could be produced with a gross energetic value of 22.2 million GJ. By region, 821, 488 and 36.7 million litres of ethanol could be produced in Ontario, Quebec and the Atlantic provinces, respectively, provided feedstock could be economically transported to central processing facilities. If straw heating was used to replace oil-based heating systems, 4.0 million tonnes of CO_2 emissions could be displaced per year.

Livestock Manure

Farm intensification has been a visible trend in Canada's livestock industry and presents both a need for pollution control and an opportunity to generate energy while retaining the nutrient value of manure. The recoverable manure from the major livestock sectors in eastern Canada is approximately 46 000 tonnes/day in Ontario, 43 000 tonnes/day in Quebec and 7 000 tonnes/day in the Atlantic Provinces. The combined gross energetic production from anaerobic digestion of livestock waste was estimated as 16 million GJ/year. By region, Ontario, Quebec and Atlantic Canada could produce 20 830, 19 580 and 3325 GJ/day, respectively. The converted electrical energy potential in the same provinces or regions is 1650, 1550 and 260 MW hrs/day. If biogas were used to replace heating oil, 1.2 million tonnes of CO_2 emissions could be displaced per year. Significant quantities of methane, one of the most damaging greenhouse gases, could also be prevented from being released into the atmosphere.

In Ontario and Quebec, the dairy industry could produce the highest theoretical amounts of bioenergy (19 758 GJ/day) followed by swine (9 500 GJ/day), poultry (5 346 GJ/day) and lastly beef (3 722 GJ/day). In Atlantic Canada the poultry industry (598 GJ/day) has a slightly higher potential for energy production from anaerobic digestion systems than the swine sector (509 GJ/day). At the farm level, the greatest potential to produce electricity from biogas are the swine and poultry industries (on average 2.2 and 1.8 GJ/day per farm). These values are a reflection of the increasing size of many pork and poultry operations. In general, the costs per animal for establishing and operating biogas treatment systems decreases for larger sized operations. The economics of biogas

production from livestock waste could be improved in intensive production areas by constructing centralized treatment facilities and by accepting a variety of organic wastes from slaughterhouses and the food industry. Areas identified as having a high potential for the establishment of centralized biogas plants were the regions of Monteregie and 'centre du Quebec' in Quebec, King's County, Nova Scotia, Queen's County, Prince Edward Island and Perth, Wellington and Huron counties in Ontario.

Conversion Technologies

Bioenergy conversion systems with the most immediate potential are combustion, cellulosic ethanol production and anaerobic digestion of livestock manure. Straw burning systems can be implemented at both the farm-level, and in larger facilities for district heat or power generation using European technology. Widespread introduction of straw combustion systems would depend on developing proven, efficient, dependable and convenient technologies. Procurement of clean, dry straw, in large square bales, storage systems, dependable and functional bale feeding mechanisms and combustion control appear to be the major factors needing development. Current low energy prices and competing uses for straw are a disincentive to greater use of straw heating systems. Densification of crop residues into fuel pellets for combustion in space heaters and commercial-sized burners using systems based on the wood pellet heating market also represent a significant opportunity for low cost and environmentally friendly combustion methods. Although cellulosic ethanol production has great potential for converting low value agricultural feedstocks into a high value bioenergy form, the technology is still at the pilot stage of development. Cellulosic digestion technology is not economical at the farm level and crop residue inventories in eastern Canada are insufficient to support construction of large, centralized plants.

Anaerobic digestion of livestock waste is early stages of commercial development in Canada. Estimates of the minimum amount of livestock needed to operate a cogeneration plant profitably vary from 150 to 500 large cattle (or 1500 to 5000 hogs). An increasing number of farms in eastern Canada are capable of operating biogas systems on this scale, but as working models of these systems have yet to be installed, there is an urgent need for pilot scale and demonstration projects. Based on existing technology, investment costs are still very high on a per farm basis. Biogas can be used to produce electricity or it can be burned for space and water heating purposes. Widespread utilization of biogas on small to medium-sized farms would probable depend on heat-related applications rather than electricity generation.

The viability of bioenergy from agricultural residues most probably depends on linking environmental benefits with energy production. For example, in areas where public health issues concerning livestock waste have a high profile, anaerobic treatment could become a necessity rather than an economic option. Under this scenario, energy production could substantially offset treatment costs. Likewise, the production of bioenergy from agri-based residues allows Canada to replace fossil-based fuels and reduce greenhouse gas emissions, as prescribed by the Kyoto protocol. Energy prices may need to rise significantly to make existing biogas technologies more economically viable, and at current energy prices the benefits of energy recovery will likely remain secondary to the environmental benefits. The global estimates presented in this study represent a optimal, best case scenario theoretical for bioenergy production. It is clear that considerable potential for bioenergy production from agricultural residues and wastes exists in eastern Canada, but considerable work still remains to match appropriately scaled conversion technologies with existing feedstock supplies before the full potential of biofuels can be realized.

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1.0 General Introduction

Energy derived from biomass is of increasing political and economic importance in developing Canada's energy security. Sharp fluctuations in energy prices over the past few years demonstrate consumer vulnerability to price and supply. Other factors such as long-term military conflict in the Middle East and depletion of world oil and gas reserves are expected to increase price volatility and restrict supplies. Furthermore, the increasing domestic reliance on natural gas as an inexpensive fuel with low greenhouse gas (GHG) emissions may only be a temporary phenomenon. Robert Meneley, Chief Analyst for the Canadian Gas Potential Committee, warns that Canadian gas reserves are not large enough to support accelerated use of natural gas as a fuel source and not at the low prices enjoyed until now (Meneley, 2001).

Increased use of biofuels is essential to meeting Canada's GHG reduction targets under the Kyoto Protocol. Biomass fuels are essentially "carbon neutral" in that CO2 released by combustion is reabsorbed by biomass crops. Traditional supplies of biofuel such as wood are diminishing as inventories of surplus wood residue decline (Hatton, 1999) and alternate uses are found for wood fibre (Jannasch et al. 2001a). Progress is being made in the development of short rotation forestry plantations for energy, but concerns exist about the high cost of establishing, maintaining and harvesting these plantations (PERD, 2001). Considerable attention has focused on producing dedicated crops such as corn for ethanol production and oil seeds for biodiesel; however, these applications are controversial due to ethical issues surrounding the use of food crops or agricultural land for energy production (Pimental, 2001; Wang et al. 1999).

It is estimated that 10.4 Mtoe/yr of the estimated 18.7 Mtoe/yr of wood residues in Canada are currently being exploited, yet virtually none of the estimated 25 Mtoe/yr of agricultural residues are being used (Gogolek and Preto, 2000). Waste agricultural feedstocks are typically low cost because production costs have been included in the cost of producing the main crop. On average, 2.5 tonnes of biomass contain the equivalent energy potential of 1 tonne of oil (Panoutsou, 1998) and one tonne of dry straw contains approximately 17 GJ (Gogolek and Preto, 2000). There is strong interest in the farming community to increase energy self-reliance and identify non-food uses for agricultural crops (Jannasch et al. 2001). An additional source of biomass is livestock manure. Anaerobic digestion of livestock manure is the subject of increasing interest both for energy production and environmental protection. The biogas produced from anaerobic digestion systems can be converted to heat or electricity. For example, one tonne of dairy waste will yield approximately 30 m^3 of biogas or 0.6 GJ of gross energy.

Broad scale development of bioenergy from agricultural residues and wastes will depend on identifying useful sources of biomass and compiling feedstock inventories. The purpose of this study is to compile an inventory of waste agricultural feedstocks in eastern Canada suitable for conversion to energy and to assess waste types according to availability, homogeneity and procurement characteristics.

Although a considerable research effort has been directed at generating new biomass supplies in Canada, there is less information about appropriate conversion technologies. Research interest in conversion and feedstock procurement has not always been sustained during ebbs and flows in energy markets In the meantime, new conversion technologies have been developed (cellulosic and anaerobic digestion) which require sustained effort to bring to commercial production. This study will link the inventories of available biomass to an assessment of actual conversion technologies in order to assess the true potential of agricultural wastes to impact on the biofuel sector.

2.0 Inventory of Agricultural Waste Feedstocks

2.1 Crop Residues

2.1.1 Introduction

Major field crops in eastern Canada were assessed for potential biomass residues as sources for energy generation (Figure 1). This report concentrates primarily on cereal straws and corn stover. Soybean stover was considered for evaluation, but low stover yields, difficulty in harvesting and collecting dry stover and the need to keep residues as soil cover for erosion prevention are factors against using soybean stover for energy purposes (Bohner, 2002). Canola acreage was included from Ontario despite the small acreage grown because of its relatively high straw yield. An estimate of surplus and waste hay was included because considerable volumes go unused each year and large acres of hay land are under-utilized. The study specifically excludes wastes from the food processing industry even though they may contribute to the efficient functioning of anaerobic digesters. Although potatoes are a significant crop in Prince Edward Island (35-40,000 ha) and produce an ethanol yield of about 25% of corn grain (Klass, 1998), cull potatoes and processing wastes are in high demand as feed for the cattle industry.

Crop production statistics were obtained from the Ontario Ministry of Agriculture and Food and Rural Affairs, insurance data from the Quebec ASRA program (Assurance de Revenue Agricole), provincial crop specialists and Statistics Canada (2001).

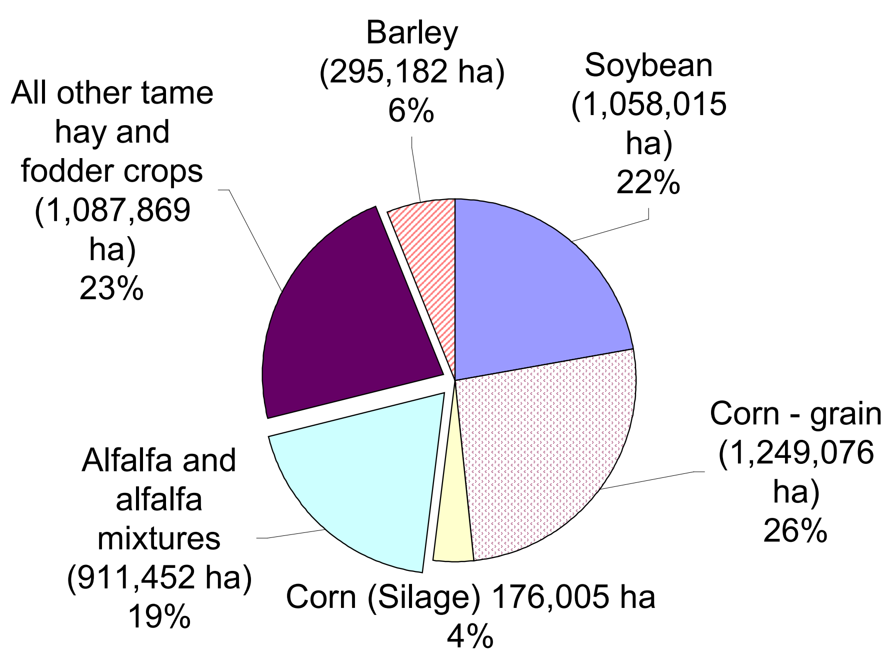


Figure 1: Major Field Crops in Eastern Canada

Several crop production trends between 1996 and 2001. Alfalfa production increased in all eastern provinces by 10%, grain corn increased by 13%, (mostly in Quebec), and soybean production rose by 21% (mostly in Ontario and Quebec). Decreasing acreages were planted to tame hay (-11%) and winter wheat (-24%). The acreage of other major field crops was fairly stable in all eastern provinces.

2.1.2 Methodology for estimating crop residues

Straw Yields

Straw yields were determined from published grain:straw ratios used in industry and adjusted to account for sustainable removal rates as described below. Straw yields ranging from 0.7 to 1.7 times grain yields have been reported for wheat straw on a dry matter basis (Price, 2002; Boswell, 2002; Klass, 1998). A common rule of thumb for estimating straw residues from wheat is one 18 kg straw bale per bushel of grain. Sources of cereal straw include wheat, oats, barley, rye, buckwheat and mixed grains. Straw to grain ratios of 1, 1.3 - 1.7 and 1.3 - 1.4 have been reported for corn, winter wheat and other cereals, respectively, in Ontario (OMAFRA, 2002). A complete breakdown of the crop residue inventory by cereal type is given in Appendix 1.

Sustainable Removal Rates

Estimating crop residues available for energy production must consider the effect of residue removal on soil quality. Sustainable removal rates depend on many factors, including soil type, slope of the land, soil fertility levels, crop rotation systems, tillage, cutting height, crop yield, weather and wind patterns.

Kerstetter et al. (2001) suggested not to remove any straw off lands with yields of less than 60-70 bushels per acre and to leave 8-10 inches of stubble. Other studies have suggested 750 kg/ha of stubble (about 20% of the crop residue) is adequate in reduced tillage systems (Stumborg et al., 1996), with more residue required under conventional tillage. In general, reduced tillage systems make the removal of more straw residues possible. For preventing wind erosion only, Larson (1979) suggested conserving 20% of residues for the Great Plains region (if soil organic matter were considered, this value would be higher). For the current study, removal rates of 60-75% for winter wheat and 70-75% for other cereals were used (Appendix 1).

The yield of corn stover is generally accepted to be equal to the quantity of corn harvested (Glassner 1988). Conserving corn residues can improve soil fertility, but the optimum level of residues necessary to maintain the organic viability of most soils in eastern Canada is not known (Billy, 2000). Corn residues have a high carbon to nitrogen (C:N) ratio which causes N to be released slowly. As a result, the removal of residues will not adversely affect soil N in the short term. Corn residues are an important source of soil C, and hence harvesting them in alternate years may be a viable option in order to maintain soil organic matter levels. In Quebec, residue removal on no-till fields facilitates seeding and permits the soil to warm up earlier in the spring (Mehdi and Girouard, 1999). Estimates of sustainable removal rates range from 70% of above ground residues (OSU, 1997) to 30% (Glassner et al. 1988). In an *in situ* study to determine the harvestable yield of windrowed corn residues in Quebec, Billy (2000) determined actual recovery rates of 44 to 64%. For the purposes of this study, a removal rate of 50% was used (Appendix 1).

2.1.3 Inventory of Crop Residues

Cereal Straw

The recoverable quantities of cereal straw in eastern Canada were estimated at 1 750 000, 880 000 and 185 000 oven dry tonnes (odt) for Ontario, Quebec and the Atlantic Provinces, respectively, or a total of 2.8 million odt Table 1). These estimates account for the quantity of residues conserved to maintain soil fertility. Five year yield data suggests straw yields can range from 2.8 to 3.5 million odt per year in eastern Canada, depending on growing conditions. 2001 was an extremely dry season.

Any attempt to use crop residues for energy production must consider how competing uses may affect prices and supply. Cereal straw has a number of alternate uses including livestock bedding, mulch and growing mediums for horticulture and specialty crops (Appendix 2). Livestock bedding is the primary use. Dubuc (1997) estimated that approximately 65% of existing straw residues are accounted for by competing uses. Based on this ratio, the available straw residues by region would be 615 000, 310 000 and 135 000 odt for Ontario, Quebec and the Atlantic provinces, respectively.

Corn Stover

The quantity of recoverable corn stover was estimated at 1.9 million, 1.1 million and 0.006 million odt for Ontario, Quebec and Atlantic Canada or a total of 3.0 million odt. Five year yield data suggest that total yields in eastern Canada can range from 3.0 - 3.3 million odt/year depending on growing conditions. There are currently no alternate uses for corn stover.

Hay

Although hay is produced for the livestock industry, there is potential to use waste hay as a feedstock for bioenergy production. Substantial amounts of hay are wasted each year, although the amount is not well documented in the literature. The quantity available for energy production was conservatively estimated at 5% or 220,000, 210,000 and 50,000 odt in Ontario, Quebec and Atlantic Canada, respectively (Table1).

Table 1: Inventory of available crop residues for eastern Canada					
	Residue Yield ('000 odt)	**Recoverable residue Yield ('000 odt)[1]**	**Residues Available for bio-energy[1,2] ('000 odt)**	**Recoverable Energetic Value ('000 GJ)[3]**	**Potential Ethanol Production ('000 l) [4]**
Ontario					
Straw	2 280 - 2780	1 750	615	11 050	184 100
Corn Stover	3 800	1 900	1900	34 775	570 060
Hay	4 400	4 400	220	3 740	66 000
Canola	20	14.2	14.2	256	4 270
Quebec					
Straw	1 030 - 1140	880	310	5 540	92 285
Corn Stover	2 230	1 115	1 115	20 400	334 495
Hay	4 240	4 240	210	3 610	63 660
New Brunswick					
Straw	100 - 110	80	30	510	8 455
Corn Stover	2	1	1	20	300
Hay	385	385	20	330	5 775
Nova Scotia					
Straw	20 - 25	15	15	95	1 565
Corn Stover	10	5	5	85	1 370
Hay	360	360	18	310	5 415
PEI					
Straw	115 - 145	90	90	570	9 425
Corn Stover	N/A	N/A	N/A	N/A	N/A
Hay	250	250	13	215	3 770
NFLD					
Straw	N/A	N/A	N/A	N/A	N/A
Corn Stover	N/A	N/A	N/A	N/A	N/A
Hay	25	25	1	20	360

Sourced from Statistics Canada (2001), Price (2002) and Boswell (2002)

Note: 1 - Recoverable residue yield accounts sustainable removal rates (amount of residues conserved to maintain soil fertility).
2 - Residue yield available for bio-energy accounts for alternate usages of cereal straw
3 - See section 2.1.4 for energetic content of residues by combustion and combustion efficiencies
4 - Assumed 300 l/odt of residues (see section 3.3.3 on ethanol production from agri-residues).

Other potential crops

Canola and Sunflower

About 14,200 ha of canola were harvested in Ontario in 2001 (Statistics Canada, 2001). The average yield was 2.1 tonnes/ha. Based on a straw:grain ratio of 0.625 (Panoutsou, 1998) and assuming that 30% of this residue is left on the field to preserve soil fertility, about 12,000 and 3700 odt tonnes of canola residues might be available in Ontario and Quebec, respectively. Sunflowers are not a major crop in eastern Canada, but the crop's high straw:grain ratio of three (Panoutsou, 1998) is attractive. The 448 ha grown in Ontario in 2001 (OMAFRA, 2001) would be expected to yield 1900 tonnes of recoverable residues.

Soybean stover

In general, soybean stover should be retained as soil cover for erosion control purposes. In certain cases, however, no-till winter wheat can be seeded following harvest. Assuming that 70% of soybean residues are harvestable (straw:grain ratio = 1.5, Klass, 1998)., and 25% of the soybean acreage is subsequently seeded to winter wheat potentially 0.67 million tonnes of soybean stover are available in eastern Canada (mostly from Ontario).

2.1.4 Gross Energetic Potential of Crop Residues in eastern Canada

The energetic content of straw and corn stover is presented in Table 2. Applying these values to the crop residue inventory for Eastern Canada (Table 1), 54.0 million GJ/y, 18.0 million GJ/y, 8.0 million GJ/y and 12.0 million GJ/y of gross energy production in eastern Canada could potentially be produced for corn stover, straw, and waste hay, and soybean stover, respectively.

Table 2: Energy Content of straw and corn stover

Type of straw	Lower Heating Value (MJ/dry kg)	Ash Content (%)
Oat straw (dry)	18.0	-
Wheat straw (dry)	17.9	11.1 %
Barley straw (dry)	17.5	-
Corn stover (dry)	18.3	10.2 %

*Sources: PAMI (1995); Radiotis et al. (1996)

2.1.5 Converted Energetic Value of Crop Residues and biofuel production in Eastern Canada

Combustion

Most straw combustion systems burn whole bales in hot water furnaces and operate at about 30 to 60% efficiency. Grass pellet combustion systems are being development that burn at efficiencies as high as 82%, but the technology is still not commercially available. Assuming a combustion efficiency of 50%, 46 million GJ of heat energy could be produced in eastern Canada. By crop, 27 million, 9 million and 4 million GJ could be produced from corn stover, straw and waste hay, respectively. A major factor affecting combustion efficiency is the ash content of the feedstock. They vary according to straw type (Table 2). Feedstock with high potassium and chlorine levels can cause clinker (fused residue) formation (Samson and Mehdi, 1998; see section 3.3.1).

Ethanol Production

Theoretical ethanol yields using cellulosic digestion technology can reach 470 l ethanol/tonne of dry cereal straw and 510 l ethanol/dry tonne from corn stover (Hutchence, 1999). Billy (2000) reported production from a study on corn stover in Iowa to be 284 l/odt. A rule of thumb used by the Iogen Corporation for estimating ethanol production from biomass is 300 l ethanol/odt of biomass (Passmore, 2002; Stumborg et al. 1998).

Based on a 300 l ethanol yield per tonne of biomass, the total potential estimated yield from crop residues was 1.35 billion l in eastern Canada. The ethanol potential from corn stover in Ontario, Quebec and Atlantic Canada is 570, 334 and 1.7 million litres, respectively. Additional production from straw inventories could total 185, 90, 20 million litres in Ontario, Quebec and Atlantic Canada, respectively. The potential yield from from hay inventories is 66, 64 and 15 million litres in Ontario, Quebec and Atlantic Canada, respectively. However, based on an energy content of 21.1 GJ/tonne and a density of 0.789 g/cm^3 at 20 ºC (Klass, 1998) the gross energetic value of the produced ethanol is only 22.2 million GJ, compared to 92 million GJ of heat energy potentially available from the raw biomass. Despite the net loss of energy, ethanol is a more valuable fuel as it is more easily handles and transported.

Green house gas reductions from burning crop residues

Bioenergy production and greenhouse gas (GHG) reductions from burning crop residues varies according to the conversion system. Assuming a combustion efficiency of 50%, 46 million GJ/year of energy could be produced in eastern Canada, which could displace a significant amount of fossil fuel, based household heating. For example, regular heating oil releases 89.67 kg of CO2 per GJ of energy (NRCAN, 2001a). If this heating oil were replaced with straw heating, 4.0 million tonnes of CO_2 could be displaced per year.

2.1.6 Feedstock Procurement

Economical utilization of crop residues fro bioenergy generation depends as much on procurement factors (harvest, storage, transport) as on the total quantity of available feedstock. Moisture content of late harvested materials and cleanliness from mud are major factors affecting the usefulness of corn stover (Mehdi and Girouard, 1999; Billy, 2000). Designing cost effective harvest systems (Billy, 2000) and accounting for and minimizing harvest and storage losses (Sanderson and Egg, 1995), minimizing transportations costs (Huisman et al. 1997) are also important factors. Handling factors such as moving round or square bales are important for transport, storage and feeding methods for combustion systems. Storage infrastructure must also be considered. For example, small scale storage may be most economical with arched, fabric-covered structures whereas large-scale storage may be most economical in tall, steel structures where automated handling systems can be installed. Some of these issues are addressed in more detail in Section 3.

2.2 Inventory of Livestock Manure and Potential Energy Production by Anaerobic Digestion

2.2.1 Introduction

Farm intensification has been a visible trend in Canada's livestock industry, especially in the swine, poultry and beef sectors. For example, the number of farms in eastern Canada reporting cattle and calves in the 2001 census declined by 18% between 1996 and 2001while total livestock numbers dropped by only 5%. Hog farms decreased 18% while hog numbers *increased* by 16%. Similar, but less pronounced trends were evident in poultry , dairy and beef production.

Intensive livestock operations present new challenges to farmers with respect to manure management. Land application rates must be matched to the size of the disposal areas to guard against water pollution (Jewell, 1997). Nutrient runoff from manure can cause eutrophication in watersheds leading to elevated algae levels and fish kills. Improper manure storage and management can lead to increased nuisance odour and contamination of groundwater and surface waters (Miller, 1999).

Anaerobic digestion is a treatment method for manure which yields biogas (primarily methane) and destroys many pathogens that can be harmful to humans (Wright, 1996). The process also reduces odours in comparison to land application of untreated manure. An inventory of livestock waste as a potential feedstock for anaerobic digestion was compiled for the dairy, beef, poultry (broilers, layers, turkey), swine and sheep industries in Ontario, Quebec and the Atlantic Provinces. The energetic content of the material was calculated before and after conversion via anaerobic digestion and production of electricity.

2.2.2 Methodology for estimating livestock manure by sector/region

Livestock inventory data was obtained from Statistics Canada, OMAFRA (Ontario Ministry of Agriculture, Food and Rural Affairs), the Quebec ASRA program (Assurance de Revenue Agricole), provincial commodity groups and livestock associations. Daily manure production was estimated from the standing herd per sector using manure production rates from the American Midwest Plan (MPS, 1985). Daily rates rather than yearly totals were calculated because biogas that is produced by anaerobic digestion is most often used on site on a continuous basis rather than being stored and transported for use elsewhere. Daily production rates also allow for a realistic assessment of the potential for power (electricty) generation. For dairy the calculations included the amount of water added to the manure from the milk-house waste. A similar procedure was used for the sheep and poultry sectors. For broiler chicken and turkey production, the standing population size was estimated by dividing the yearly output by the average number of flocks/year. Appendix 3 contains a detailed breakdown of manure volumes by sector and by province.

Manure considered potentially available for anaerobic digestion refers to that part of the total amount generated which could likely be collected and/or transported to digestion facilities. The estimated recoverable portion of dairy, beef, poultry, swine and sheep manure were 75%, 25%, 85%, 85% and 10%, respectively. Even though full confinement housing is increasingly used for dairy cows, a significant number of animals are still grazed. The low recovery rate for beef cattle and sheep reflects that large number of animals kept on pasture, and the small size of many herds and overall low level of technological development in manure handling. The recovery rates for hogs and poultry are conservative and clearly could be higher on individual farms. It was assumed that livestock manure undergoing anaerobic digestion would not be diverted from normal applications as fertilizer because the digestion process does not drastically affect manure nutrient content. Appendix 4 presents sample calculations for estimating manure and biogas production.

2.2.3 Inventory of Livestock Manure and Energetic Potential from Anaerobic Digestion

The potential energy production from biogas produced by anaerobic digestion of livestock manure in Ontario, Quebec and Atlantic Canada was estimated as 20830, 19580 and 3325 GJ/day, respectively. The converted electrical energy potential in the same regions is 1650, 1550 and 260 MW hrs/day, respectively (Table 1). On a regional basis, the dairy sector produces the largest proportion of recoverable manure and theoretically could generate the most electricity. The proportional contribution of the beef, swine, poultry (layers and broilers), turkey and sheep sectors varies by region. In both Ontario and Quebec, the swine industry could support the next highest production of electrical power followed by the poultry industry. In Atlantic Canada, the poultry industry has a higher energy potential than the swine sector. The Ontario beef sector could produce approximately 208 MWh/day whereas in Quebec and Atlantic Canada, energy output would be 85 and 32 MWh/d, respectively. Generally the same ratios hold for generation of heat energy. A minor livestock group such as sheep has little potential for producing significant amounts of energy.

Table 3: Manure Production and corresponding energetic value (daily values)

Region	Sector	Total Manure Production (tonnes/day)	Recoverable Manure (tonnes/day)	Gross Energy (as biogas) GJ/day[1]	Gross Energy (as electricity) MW-hrs/day[2]
Ontario	Dairy	29 972	22 479	9 708	767
	Beef	33 281	8 320	2 645	208
	Swine	13 983	11 885	4 381	348
	Poultry	3 025	2 572	2 751	217
	Turkey	990	842	1 310	104
	Sheep	295	30	33	3
	Total	81 546	46 127	20 829	1 650
Quebec	Dairy	31 548	23 661	10 051	794
	Beef	13 540	3 385	1 077	85
	Swine	16 088	13 675	5 116	406
	Poultry	2 205	1 874	2 595	206
	Turkey	540	459	715	57
	Sheep	271	27	28	2
	Total	64 192	43 081	19 582	1 550
Atlantic Canada	Dairy	4 992	3 744	1 612	127
	Beef	5 065	1 266	402	32
	Swine	1 609	1 367	509	40
	Poultry	678	576	598	49
	Turkey	147	125	197	15
	Sheep	58	6	6	0,4
	Total	12 549	7 085	3 324	260

1 This assumes 30% of the potential energy is required to maintain temperatures in the reactor
2 Assuming a conversion efficiency of 20% (assumes that the energy required to maintain the reactor temperature can be accounted for by recycling the waste heat produced by the motor)
3 The gross energy value of the biogas are theoretical values and actual output would vary by the efficiency of the combustion system that is used

2.2.4 The potential for on-farm bioenergy production and use

The energy contained in biogas converted from manure, based on average farm size, ranges from 0.2 GJ (170 000 BTU) per day, to about 3.1 GJ/day (2 960 000 BTU) depending on the livestock sector and region. Variation between regions is largely a reflection of herd size rather than total livestock numbers. The converted electricity potential from dairy farms in Atlantic Canada and Ontario is 100 and 90 kWh/day, respectively, whereas in Quebec, where dairy farms are substantially smaller, the potential is 75 kWh/d. Accordingly, despite the small size of Atlantic Canada's entire dairy herd, the potential for electricity production from biogas per farm is similar to that in Ontario. The average Quebec dairy farm (40 milk cows) could produce approximately 0.90 GJ of heat/day or 75 KW-hrs/d (Table 4). Average household heating requirements for a 2,000 ft^2 home (in Ottawa) requires 90 GJ/year (NRCAN, 2001b). Assuming 30% is used to maintain the reactor temperature, 0.7 GJ/day would be available for heating which could meet daily household heating demands depending on the season. Increasing consolidation in the livestock sector, however, means that on many farms the potential for energy production from anaerobic digestion is substantially higher (see Section 3.3.4).

Table 4: Energetic Potential per farm (Accounting for manure recovery efficiencies on-farm)

Region	Sector	Converted Energy (Heat, '000 Btu/day) per farm[1]	Converted Energy (Heat, GJ/day) per farm[1]	Converted Energy (Electricity, KW-hrs/day) per farm[2]
Ontario	Dairy	1 110	1,2	90
	Beef	180	0,2	15
	Swine	1 550	1,6	130
	Poultry	1 550	1,6	130
Quebec	Dairy	890	0,9	75
	Beef	170	0,2	15
	Swine	2 100	2,2	175
	Poultry	2 960	3,1	250
Atlantic Canada	Dairy	1 160	1,2	100
	Beef	150	0,20	15
	Swine	1 420	1,50	120
	Poultry	1 830	1,9	160

1 This assumes 30% of the potential energy is required to maintain temperatures in the reactor
2 Assuming a conversion efficiency of 20% (assumes that the energy required to maintain the reactor temperature can be accounted for by recycling the waste heat produced by the motor)

The greatest potential to produce electricity from biogas on farm among all the livestock sectors is the swine (175 kW-hrs/d) and poultry (250 kW-hrs/d) industries of Quebec. These estimates are largely a reflection of the large size of many pork and poultry farms in the province. In Ontario and Atlantic Canada the potential to produce electrical energy is similar for farms of the same livestock type in all sectors.

Beef

Beef operations range from part-time and hobby operations (with or without pasture) to large, concentrated feedlots. In feedlots, the percentage of recoverable manure will depend on the type of surfacing (pavement, earth, slatted floors, straw bedding) and the animal diet. A high energy diet will produce a smaller volume of waste than a high forage diet and the composition of the manure can vary as well. Beef farmers, given the incentive to recover their manure could conceivably recover a much higher percentage of manure from their farm (i.e. improve surfacing of the feedlots and install manure collection infrastructure). For these reasons, the potential of biogas production from beef operations needs to be considered on a case by case basis. Currently, there are no biogas systems operating from beef manure in eastern Canada.

In a study using manure scraped from a Texas feedlot, Parker (2001) concluded that biogas could be produced, but additional study was needed to determine economic feasibility. Feedlots have potential for biogas production mainly because the concentration of cattle make manure recovery possible. Currently, there are about 18 feedlots in New Brunswick; however, only two finish more than 2000 head per year (Leblanc, 2002). There are approximately 40 feedlots in Ontario with over 700 head. Ontario and Quebec have 160 and 49 feedlots, respectively, producing between 275-699 head. Overall, the beef industry does not lend itself to widespread biogas production. However, in areas with heavy livestock concentrations, feedlots could make a major contribution to the manure supply of centralized biogas plants (see Section 3.3.4).

Dairy

Recent trends towards consolidation in dairy production bode well for biogas production in the future. Dairy farm numbers are declining and herd size is increasing. In New Brunswick, for example, average herd size increased from 52-63 cows between 1992 and 2001 while dairy farm numbers dropped from 500 to 300 (Snowdon, 2002). Although less than 10% of dairy farms milk more than 100 cows, there were no herds of this size 5 years earlier. Estimates for the minimum number of animals to run a cogeneration biogas plant range from 100-200 grown animals (Section 3.3.4). Increasing herd size has also decreased the number of pastured animals and increased the proportion of recoverable manure. Fifty-two percent of dairy farms now have slatted floors and collection lagoons compared to 17% in 1991 (Snowdon, 2002)

These trends are representative of the dairy industry across eastern Canada with the exception of Quebec. Average herd size in Quebec is smaller (40 milk cows) and the degree of consolidation less pronounced. Overall, there are few dairy farms with 200 cows and over, but on those farms there is strong potential for biogas production. If, as expected, the trend towards consolidation continues, the opportunities for biogas production based on economies of scale will continue to increase.

Swine

The number of pig farms in eastern Canada has declined over the past 5 years, but hog operations are increasing in size. Even though 50 sow farms are common, there is an increasing trend towards 1,600 sow operations like the Metz operation in New Brunswick. Most new farrowing facilities in Ontario operate with 2500 sows. Estimates for the minimum number of swine to run a cogeneration biogas plant range from 1,500 to 5,000 finishing pigs (section 3.3.4). Apart from the farowing units, most finishing operations consist of numerous barns containing 1,000 hogs located on different sites.

Further concentration of production is unlikely because of increasingly stiff land use regulations for manure application. Therefore, although hog production is becoming more concentrated, economical biogas production may still depend on developing centralized digestion facilities.

Poultry

As in the swine sector, there is a similar trend to consolidate poultry production in large operations. While the energetic potential of manure from poultry inventories is interesting (for example, as high as 2.5 GJ/farm/day in Quebec), the manure in most Canadian poultry operations is handled in a dry form that would need to be greatly diluted to encourage methane production in the digester. The added cost of manure management infrastructure would need to be accounted for as well as the cost of the digester system. Combustion was considered for poultry litter but clinker formation, loss of nutrient value (nitrogen) and inefficient combustion (producing particulate emissions) are factors against using manure for energy purposes.

Environmental Benefits

Growing concerns about water quality, especially after the crisis in Walkerton, Ont., in which 7 people died from drinking water contaminated with *E-coli* from a livestock farm, is forcing restrictions on expansion of hog facilities. Quebec, provincial environment minister Andre Boisclair announced a partial moratorium on new pig farms in June, 2002, in the Lanaudière, Montérégie and Chaudière-Appalaches - where the soil is saturated with phosphorous, pollution that stems from pig manure. In Quebec`s other agricultural regions, existing farms will be allowed to expand by 250 pigs if they can meet stricter standards on waste treatment. Manure treatment systems must balance the needs of industry, public health and environmental requirements. The main objective of anaerobic treatment systems is usually waste stabilization or disposal. Environmental benefits are achieved by reducing bacterial contamination (i.e. destruction of pathogens) under correct operating conditions (hydraulic retention time, temperature, pH etc.) Anaerobic treatment systems are advantageous in that they treat the waste and reduce nuisance odours but allow for the preservation of the manure's nutrient value. However if the goal of the treatment is merely to dispose the material, aerobic systems (including composting) may be more effective at reducing the nutrient load. Another environmental benefit from anaerobic systems is that the produced bioenergy can replace fossil-based fuels, helping Canada meet its commitment under the Kyoto protocol.

There are legal environmental issues surrounding intensive livestock operations with respect to odour and water pollution. Furthermore, if on-farm pollution from manure adversely affects another person, the operator could be liable under common law action under nuisance or negligence (Washenfelder, 1999). It is difficult to put an economic value on the environmental benefits of waste treatment, but in cases where treatment becomes a necessity then energy production from anaerobic systems could help mitigate system establishment and operating costs.

Greenhouse Gas Emission Reductions

16 million GJ/year of bioenergy could be produced from manure biogas, which could displace a significant amount of fossil fuel. As stated in section 2.1.5, heating oil releases 89.67 kg CO_2/GJ of energy. If biogas were used to replace heating oil and assuming that the biogas heating system could operate at efficiencies of 85% (similar to natural gas; NRCAN, 2001b), aprroximately 1.2 million tonnes of CO_2 could be displaced.

2.2.5 Areas with Concentrated Livestock Production

Ontario

Intensification of livestock operations has led to significant concentrations of livestock in Perth, Wellington and Huron Counties in Ontario, followed Oxford County (Figure 2). For example, Huron County is home to 9% of the province’s 4.6 million hogs, 12.3% of the chicken population, and the province’s fifth largest dairy herd. Wellington Co. has half as many hog (223,000), almost 12% of the province’s chickens, but the 4th largest dairy herd (24 300 cows). Perth Co. produces only 7.6% of the province’s chicken, but 11% of the hogs and is home to the second largest dairy herd (30 000 cows). Huron, Perth and Wellington Counties have the potential to produce biogas totaling 2,328, 2,190 and 1,728 GJ/day, respectively, or if converted to electricity 129,291, 121, 509 and 95,968 KW-hrs/day, respectively (Table 5;Figure 2).

Quebec

The three regions with the most concentrated manure production in Quebec are Monteregie (East & West), Chaudiere-Appalaches and Centre du Quebec (Figure 3). Potential biogas production could total 6106, 4,633 and 3497 GJ/day, respectively (Table 6). Potential electricity production in the same regions is 338, 576, 256, 913 and 193, 938 KW-hrs/day, respectively (Table 6).

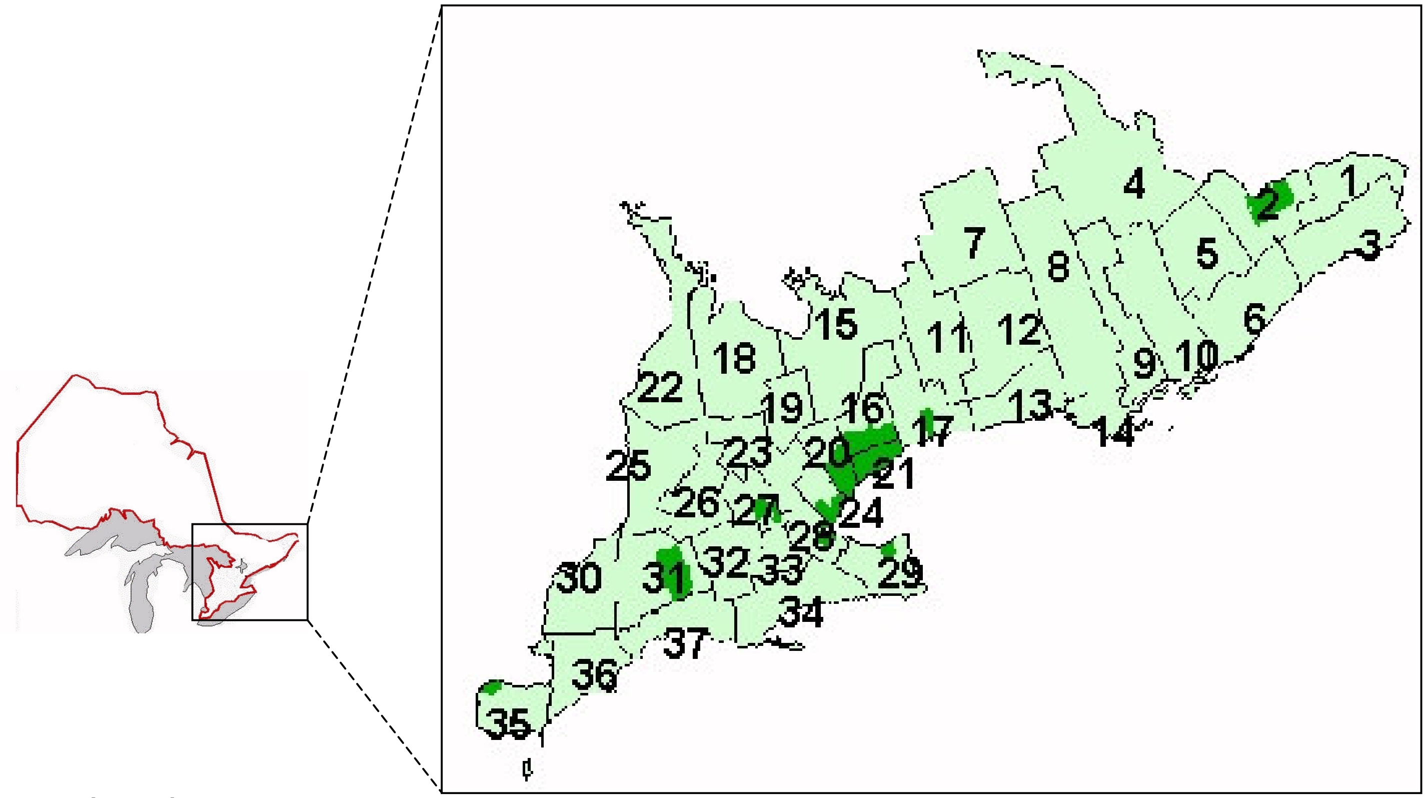
Atlantic Canada

The concentration of livestock in Atlantic Canada is significantly lower than in Ontario and Quebec, but three regions were identified with potential for centralized anaerobic digestion facilities. Detailed livestock statistics are unavailable on a per county basin in the region, but King's County, Nova Scotia, has one of the highest concentrations of livestock in Canada (Statistics Canada, 2001b). Livestock numbers are also increasing rapidly in Central Colchester County, N.S., as dairy, egg and chicken production shifts from the eastern and western regions in the province to the center. There is some concentration of livestock production, particularly swine, in Queen’s County, Prince Edward Island.

Assuming an average home has a 0.50 GJ/day heat demand during a 210 day heating season, then every 1000 GJ of biogas energy would provide enough energy to heat the equivalent of 1500 homes (assuming a conversion efficiency of 75%). Alternatively, the energy could be used for district heating systems or hot water heating. Converting the biogas to electricity would result in a net loss of energy, but the final product might be more easily marketed.

These statistics indicate there is considerable potential for the construction of centralized biogass plants similar to those operating in Europe and the theoretical case study developed by Jewell (see Section 3.3.4). The feasibility of constructing such plants would depend on a number of factors including, (1) transportation distances and costs, (2) the ability to mix different manure types in the same digester, (3) energy prices, and (4) plant construction costs. On the other hand, costs may be offset by environmental benefits such as improved odour and water quality standards. It is significant that many of the areas with concentrated livestock production are also regions with high human populations. This suggests that anaerobic digestion may became an environmental necessity and, as such, become an economic imperative.

Figure 2: Major Livestock Producing Counties in Ontario



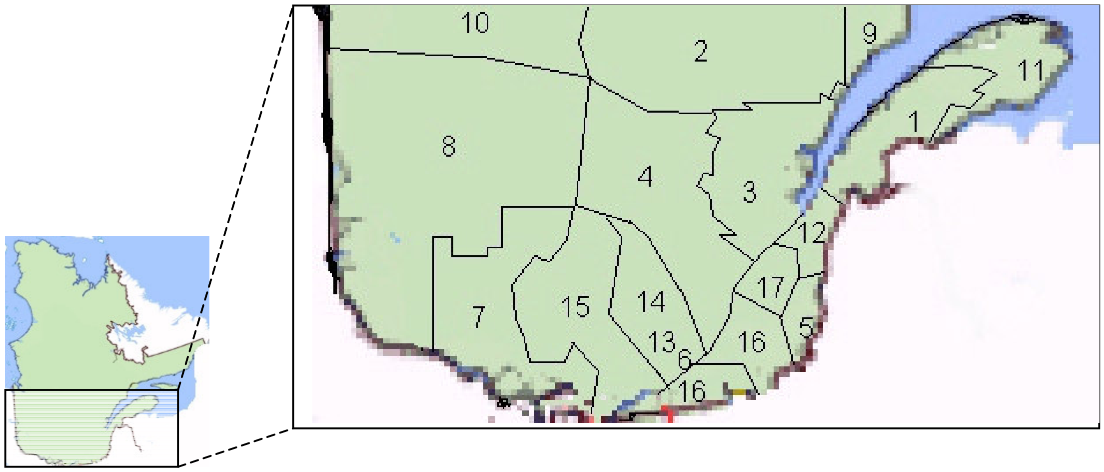
Legend

1 - Prescott Russel
2 - Ottawa
3 - Stormont/Dundas/Glengarry
4 - Renfrew
5 - Lanark
6 - Leeds/Grenville
7 - Haliburton
8 - Hastings
9 - Lennox
10 - Frontenac
11 - Victoria
12 - Peterborough
13 - Northumberland
14 - Prince Edward
15 - Simcoe
16 - York
17 - Durham
18 - Grey
19 - Dufferin
20 - Peel
21 - Toronto
22 - Bruce
23 - Wellington
24 - Halton
25 - Huron
26 - Perth
27 - Waterloo
28 - Hamilton
29 - Niagara
30 - Lambton
31 - Middlesex
32 - Oxford
33 - Brant
34 - Haldimand/Norfolk
35 - Essex
36 - Kent
37 - Elgin

Table 5: Recoverable manure in major livestock areas (Ontario)

Name of County	Recoverable Manure (tonnes/day)	Energetic Value of Produced Biogas (GJ/day)	Energetic Value of Biogas (if converted to electricity, KW-hrs/day)
1 - Prescott and Russell	1 644	772	42 752
3 - Stormont, Dundas and Glengarry	2 314	1 071	59 281
18 - Grey	1 215	545	30 148
22 - Bruce	1 762	809	44 781
23 - Wellington	3 033	1 728	95 968
25 - Huron	4 116	2 328	129 291
26 - Perth	4 097	2 190	121 509
27 - Waterloo	1 841	1 004	55 740
29 - Niagara	916	851	47 523
30 - Lambton	1 490	746	41 324
31 - Middlesex	2 231	1 156	64 105
32 - Oxford	3 583	1 895	105 108
Total	**28 247**	**15 095**	**837 531**

Figure 3: Map of Quebec Agricultural Regions



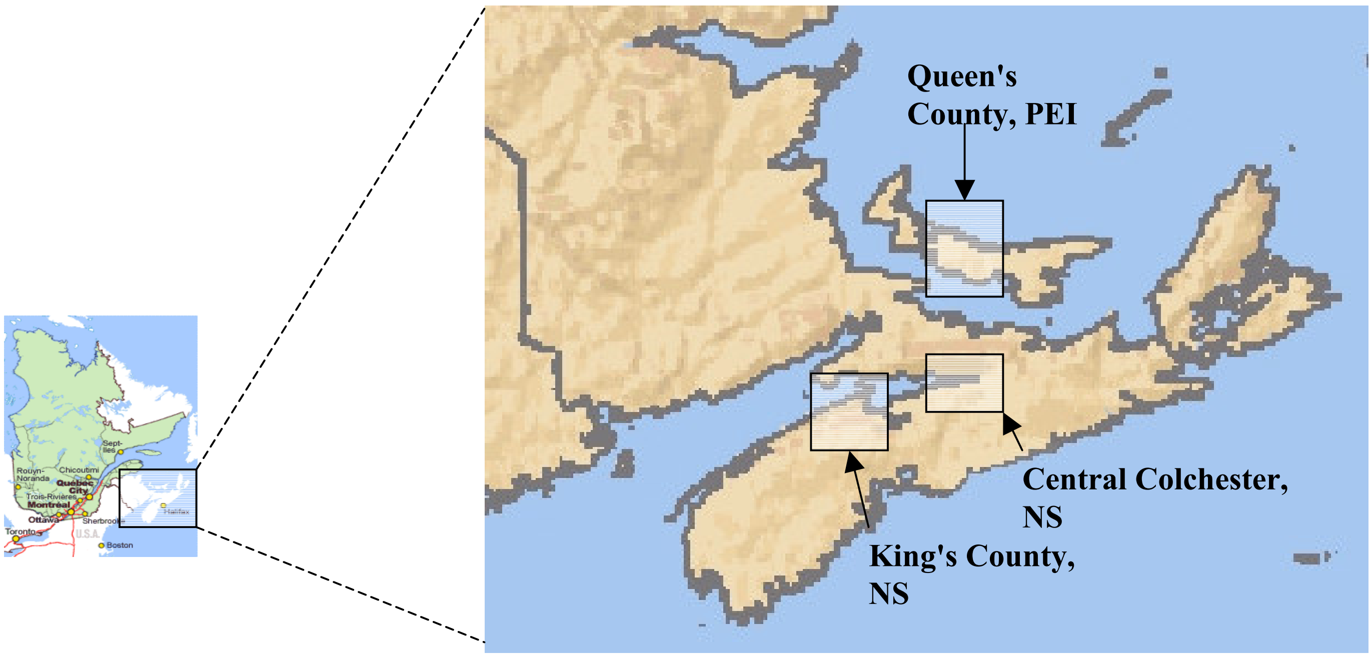
Legend:

1 - Bas - saint Laurent
2 - Saguenay, Lac Saint Jean
3 – Québec
4 – Mauricie
5 – Estrie
6 - Montréal
7 - Outaouais
8 - Abitibi-Temiscamingue
9 - Côte Nord
10 - Nord du Quebec
11 - Gaspésie, Iles de la Madeleine
12 - Chaudière-Appalaches
13,14 - Laval, Lanaudière
15 - Laurentide
16 - Montéregie (East, West)
17 - Centre du Québec

Table 6: Recoverable manure in major livestock areas (Quebec)

Name of Region	Recoverable Manure (tonnes/day)	Energetic Value of Produced Biogas (GJ/day)	Energetic Value of Biogas (if converted to electricity, KW-hrs/day)
1 -Bas-Saint Laurent	2 920	1 760	97 601
2 - Saguenay-Lac Saint Jean	1 510	970	53 814
3 –Quebec	3 875	2 411	133 702
4 – Mauricie	1 610	1 184	65 640
5 – Estrie	4 075	2 371	131 494
6 –Montreal	220	198	10 980
7 – Outaouais	525	303	16 791
8 - Abitibi-Temiscamingue	600	354	19 616
9 - Cote-Nord, 10- Nord du Quebec	10	8	429
11 - Gaspesie, Iles de la Madeleine	60	38	2 080
12 - Chaudiere-Appalaches	7 555	4 633	256 913
13- Laval, 14 - Lanaudiere	1 840	1 760	97 585
15 – Laurentides	815	596	33 023
16 - Monteregie (East, West)	9 055	6 106	338 576
17 - Centre du Quebec	5 330	3 497	193 938
TOTAL	**40 000**	**26 188**	**1 452 182**

Figure 4: Map of major agricultural regions in the Maritime Provinces



2.3 Conclusions on agricultural waste feedstock inventory

Cereal straws and corn stover have significant potential as biomass sources for energy generation. After accounting for the residues needed to maintain soil fertility and those diverted to competing uses, the quantities of cereal straw and corn stover available from eastern Canada were estimated at 1.0 million odt of straw and 3.0 million odt of corn stover. By region, the available quantities of straw were 615 000 oven dry tonnes in Ontario, 310 000 odt in Quebec and 65 000 odt in the Atlantic Provinces (Table 1). The quantity of recoverable corn stover was estimated at 1.9 million odt for Ontario, 1.1 million odt for Quebec and 6 000 odt from the Atlantic provinces. Technologies for harvesting, transporting and storing cereal straw are considerably more advanced than those for corn stover because corn residues currently do not have a market. The gross energetic potential of these residues was estimated as 92 million GJ/year. Assuming a combustion efficiency of 50%, 46 million GJ of heat energy could be produced in eastern Canada. By crop type, 27.0, 9.0 and 4.0 million GJ of energy in combustion systems could be produced from corn stover, straw and waste hay, respectively. Alternatively, 1 350 million litres of ethanol could be processed from this material. By region, 821, 488 and 36.7 million litres of ethanol could be produced in Ontario, Quebec and the Atlantic provinces, respectively. The impact of crop based biofuels would have a beneficial impact on greenhouse gas emissions by displacing fossil based fuels. If straw heating was used to replace heating oil, 4.0 million tonnes of CO_2 could be displaced per year.

There is also significant potential for bioenergy production from livestock manure in eastern Canada. Anaerobic digestion is an important method for reducing the potential bacterial contamination of water courses, while producing bioenergy and a nutrient rich digestate that can be used as a fertilizer. The energetic potential of biogas from livestock manure was estimated as 43 750 GJ/day or 16 GJ/year. The gross energetic production from anaerobic digestion of livestock waste was estimated as 16 million GJ/year. By region, Ontario, Quebec and Atlantic Canada could produced 20 830, 19 580 and 3 325 GJ/day, respectively. The converted electrical energy potential in the same provinces or regions is 1650, 1550 and 260 MW hrs/day. Potentially, 1.2 million tonnes of CO_2 could be displaced if rsidue-based bioenergy were used to displace heating oil.

In Ontario and Quebec, the dairy industry has the highest potential to produce bioenergy (19 758 GJ/day) followed by swine (9 500 GJ/day), poultry (5 346 GJ/day) and lastly beef (3 722 GJ/day). In Atlantic Canada the poultry industry (598 GJ/day) has a slightly higher potential for energy from anaerobic digestion systems than the swine sector (509 GJ/day). At the farm level, the greatest potential to produce electricity from biogas is the swine and poultry industries (175 kW-hrs/d and 250 kW-hrs/d), largely a reflection of the immense size of many pork and poultry operations. In general, the costs per animal for establishing and operating biogas treatment systems decreases for larger sized operations. The economics of biogas production from livestock waste could be improved in intensive production areas by constructing centralised treatment facilities and by accepting a variety of organic wastes from slaughterhouses and the food industry. Areas in Quebec (the regions of Monteregie and 'Centre du Quebec'), Nova Scotia (King's County), PEI (Queen's County) and Ontario (Perth, Wellington and Huron) have a high potential for the establishment of centralised biogas plants.

The energy values calculated in this report represent theoretical values after accounting for recoverability and competing uses. Further economic feasibility studies are needed to account for appropriate harvest, storage and transport systems. Furthermore, there is still a need to develop low-cost anaerobic treatment systems for biogas systems to be feasible at the farm-level for average sized operations. Estimates of the minimum number of livestock needed to operate a cogeneration plant profitably vary from 150 to 500 large cattle (or 500 to 5000 hogs). There are an increasing number of farms in eastern Canada that are capable of operating biogas systems on this scale. The economics of biogas production from livestock waste could be improved in intensive production areas by constructing centralised treatment facilities. The current state of the technology suggests that the benefits of energy recovery will remain secondary to the environmental benefits. The production of bioenergy from agri-based residues allows Canada to replace fossil-based fuels and reduce greenhouse gas emissions, as prescribed by the Kyoto protocol. While it is difficult to place an economic value on the benefits of treating livestock manure, increasingly stringent environmental regulations may force the adoption of on-farm waste treatment technologies. To maximize the benefits from treatment technologies, environmental mitigation and energy production should be viewed as concurrent goals.

3.0 Opportunities for energy generation from agricultural residues

3.1 Introduction

Linking inventories of available biomass to an assessment of actual conversion technologies is an important step to move the biofuel industry beyond biomass production to more sustained and long-term biomass conversion. This section will profile a range of conversion technologies and identify successful applications and assess their short-term potential and limitations.

3.2 Methodology

A series of literature reviews and interviews were conducted to assess current energy conversion systems for agricultural waste in eastern Canada. A range of technologies are described including combustion, anaerobic digestion (particularly for livestock manure), cellulosic digestion and the production of liquid, gaseous and solid fuels including ethanol, methane and fuel pellets. The profiled technologies have either been successfully implemented on a commercial scale in Canada or Europe are under development with a good potential for commercial application. In addition, technologies that have thus far proven unsuccessful were identified and the barriers to implementation identified.

3.3 Results

3.3.1 Straw Combustion

Burning surplus straw to produce heat energy can be an economical method for on-farm heating. The most common straw heating systems use outdoor boilers and pipe heated water to buildings. Large, district straw heating systems have been developed in Europe. In Denmark, an aggressive plan to encourage straw combustion systems requires fossil-fuel based power plants to burn significant amounts of straw in order to reduce overall CO_2 emissions (Van de Lars, 2000).

In eastern Canada, only a small number of straw heating systems have been installed over the past two decades, and most have had a limited lifespan. Straw combustion systems range from manual feed, whole bale burners to automatically stoked systems. Automatic stoking mechanisms are needed for chopped or shredded straw (PAMI, 1995). Small square bale boilers are usually stoked by hand, while the large square and round bale boilers are fed by a front-end loader or alternative feeding system. Combustion efficiencies for straw combustion typically range from 25 to 60%.

The composition of agricultural residues affect combustion

The ash content of potential bioenergy feedstocks can affect combustion efficiencies. High potassium and chlorine levels reduce combustion efficiencies and increase the likelihood of clinker formation (fused residues; Samson and Mehdi, 1998). Radiotis et al. (1996) found that wheat straw had an ash content of 11.1 %, potassium and nitrogen levels of 1% and 0.7%, respectively. Corn stover has an ash content of 10.2% and a nitrogen content of 0.68%. Wood chips, by comparison, have an ash content of 1% or less, and levels of nitrogen, potassium and chlorine of 0.25%, 0.1% and 0.02% respectively. In general, agricultural residues contain higher ash levels than wood fibre and combustion properties and ash disposal issues must be evaluated on a case by case basis.

Case studies of straw combustion systems in Canada

Three case studies from Nova Scotia, Ontario and Prince Edward Island are profiled in this section. As well, a summary of a study involving 25 Manitoba farmers using straw combustion systems performed by the Prairie Farm Machinery Institute (1995) is provided.

<u>Study 1 – Lyndhurst Farms</u>

In 1978, a straw bale burner was installed by Lyndhurst Farms, a large hog and cereal operation in Canning, Nova Scotia. The goal was to reduce energy costs by utilizing the surplus straw from over 1000 acres of cereal crops to heat hog barns and operate a grain dryer. Technology was imported from Germany to burn large, round bales. According to the current owner of Lyndhurst Farms, Peter Peill, (minasseed@ns.sympatico.ca) the system operated under the “Smoltgas Principle” where straw is combusted under limited oxygen. The idea was to manage a controlled burn by limiting air induction, which caused the fuel to “smolder.” The heat was transferred to a water circulating system for heating the barns.

The straw burner operated for approximately five years. The fuel supply was satisfactory, although outdoor storage and bale retrieval during the winter was inconvenient. Initially, whole bales were burned in a two-tier burner with combustion taking place in a ground level chamber. Continuous feed was made possible by placing bales in a upper chamber (fitted with lid) separated from the combustion chamber by a sliding panel. Bales were delivered to the upper chamber by an overhead gantry. The major problems with the system were, (1) premature combustion during bale loading, (2) high temperatures (up to1100 ˚ C) causing extensive damage to the metal components, particularly the sliding panel, and, (3) low combustion efficiency (23-24%). To improve fuel loading efficiency, the system was later redesigned with an auger to feed chopped straw to the burner. Overall combustion efficiency was 23-24%. As energy prices declined in the early 1980s, the project was discontinued.

Study 2 - Burt's Greenhouses

Burt's Greenhouses in Odessa, Ontario (near Kingston) investigated the combustion of round straw bales for greenhouse heating in a study with the CANMET Energy Technology Centre in the 1990s. A final report was submitted by Burt et al. (2000).

The initial prototype consisted of a bale container and lid for a 1.2 m (100kg) round bale placed above a primary combustion zone supplied with forced air. The objective was to avoid smoldering. A secondary combustion zone to allow complete combustion of gases was situated below the primary combustion zone. The system was designed for complete combustion of the bale before loading a second bale.

Nine of 12 test bales burned completely without smoldering. Limitations were, (1) controlling the rate of heat release, (2) batch feeding bales limited operations, (3) there was no method to utilize the heat.

A second prototype included a 2 bale combustion unit with a hydraulically operated lid and the option of adding additional bales during combustion. Temperatures of over 1400º C were recorded. Limitations included, (1) poor bale positioning for optimum burn, (2) improper air distribution leading to uneven burn, (3) poor bale ignition, (4) fouling by ash and (5) explosions caused by gas accumulation.

A third prototype was designed to burn small, square bales (12 kg). Stable combustion periods of up to one hour were achieved (1 bale) and produced between 80 and 130 kW of energy for greenhouse heating.

Study 3 - Van Kampen Greenhouses

Van Kampen Greenhouses in Charlottetown, Prince Edward Island (902-894-5146), installed a Danish-made 100 HP, "Passat" straw-fired steam boiler (Passat Energi A/S, Tjele, Denmark) in 1979 to heat 2 acres of greenhouse space. The pressure steam system was a German design. Oil was retained as a backup heat source. The equipment operated until 1986. Current owner, Charlie Van Kampen explains that the overall system worked well, but a number of inconveniences combined with declining energy prices forced him to close it down.

The boiler was fed by a continuous feeding system. The feeding bed held four round bales. It was designed for large 3ftx4ftx8ft square bales, but this type of baling equipment was not available in PEI at the time. Shredding the round bales created a very uneven flow of straw for firing. Van Kampen believe the shredder and auger would have worked much more smoothly if large square bales had been available. A similar finding with round vs. square switchgrass bales was made by R.E.A.P. - Canada (Jannasch et al., 2001b). In the peak March heating season, the furnace was stoked three times daily, including at 3 am. A larger bed would have been an asset. Oil heat was used in the month of May.

Van Kampen recalls using a variety of straw types including barley, wheat, oat and rye straw. Each had distinct burning characteristics and ash levels. Barley straw was the most common feedstock. Procuring straw at the correct moisture level (10-15%) proved difficult as farmers often baled the material too wet. Often a Van Kampen employee had to travel into the field to test moisture before it was baled. This was a nuisance for both Van Kampens and the farmer who was forced to wait. Wet straw was inefficient to burn and tended to bind up the feeding augers. Enough rocks, wire and baler twine were caught up in the bales that a reversing mechanism had to be installed in order to avoid jamming the feeding augers

The Van Kampens built a 60 ft x 100 ft building for storing round straw bales. Total capacity was 1000-1300 bales – not quite large enough to supply the greenhouse during the peak spring growing season. Round bales were difficult to handle and transport.

Study 4:

The Prairie Agricultural Machinery Institute (PAMI) reported test results on a variety of homemade and commercial straw burners for small, square bales and large, round bales (PAMI, 1995). Straw is plentiful in the prairie provinces and represents disposal problems for most farmers. Most straw is burned as whole bales in hot water furnaces at efficiencies of 30-60%. PAMI reports lower heating values (LHV) of 19.97 MJ/kg, 18.01 MJ/kg, 17.9 MJ/kg, 17.5 MJ/kg and 18.3 MJ/kg for dry flax straw, oat straw, wheat straw, barley straw, and corn straw, respectively.

Table 7. Energy efficiency of straw burners in Manitoba		
	Square Bale Burner	Round Bale Burner
Efficiency (%)	30	40
Energy recovery	4.5 MJ/kg (1935 BTU/lb)	2150-2580 BTU/lb)
Output- Wheat straw - Flax straw	18 kW (61,400 BTU/h) 24 kW (81,900 BTU/h)	49 kW (167,000 BTU/h)*Oat 61 kW (208,140 BTU/h)
Heat utilization	22-24 % of maximum output	53-57 % of maximum output

PAMI concluded that the economic feasibility of burning straw increases as system output increases and system efficiency may be increased by using water to store the heat from straw burned at maximum capacity.

Case 5 – A Possible Scenario for Greenhouse Heating

A 0.5 ha greenhouse with a double layer of inflated plastic requires 364,000 l of # 2 heating oil or 14,141 GJ of energy consumed (10,600 GJ of delivered heat) to maintain year round daytime temperatures of 22º C and nighttime temperatures of16º C at night in a climatic region equivalent to Montreal (CREAQ, 1991). If the same greenhouse were heated with straw, 2388 or 1194 tonnes would be needed if the system functioned at a combustion efficiency of 25 or 50%, respectively. Over 4800, 250 kg bales (from approximately 400 ha) would be required to heat the greenhouse at the higher efficiency level. If the greenhouse were heated only for a three month season (March – May), the straw requirements would be much lower.

Summary of case studies:

Many of the straw combustion systems in Canada are homemade and designed to function with small square bales or round bales. These systems may be very well adapted to certain on-farm situations when the interest level of the operator is high. However, the nuisance factor associated with operations would appear to limit their application. Widespread introduction of straw combustion systems would depend on developing proven, efficient, dependable and convenient technologies. This might involve sizeable investment. Procurement of clean, dry straw in appropriately-sized bales, functional bale feeding mechanisms and combustion control appear to be the major factors needing development. Some Danish technologies (outlined below) could resolve many of the problems incurred in the Burts Greenhouses and Lyndhurst Farms trials, provided the investment costs were cost-effective relative to energy prices.

3.3.2 Straw combustion systems in Europe

According to the Danish Energy Agency, there are approximately 80,000 wood and straw boilers in Denmark. In 1995, a subsidy plan was introduced for small biomass-fired boilers and since that time, approximately 9,000 subsidized plants have been installed with a capacity of approximately 320 MW in total. In addition, some 2,000-3,000 plants have been constructed without subsidies since 1995 (Laursen, 2000).

In the 1970's, several manufacturers began to produce straw fired boilers for small bales that operated at efficiencies of 30-40%. Eventually boilers for round bale and larger bales were introduced. At the time there was little incentive to improve the design as the cost of the fuel (straw) and the combustion systems were low. From 1976 to 1990 the Bygholm Research Centre carried out a strategy of improving stove and boiler efficiencies. Newer systems implemented after the subsidy scheme of 1995 have efficiencies ranging from 70% to more than 80%. The plants are both manually and automatically fed, and the output in 1995 was typically 40 to 60 KW (wheras the demand is typically only 10-20 kW). Many of the systems currently marketed have outputs of 15-30 KW (Laursen, 2000).

For combined heat and power (CHP), the steam-turbine technologies used at larger facilities have been problematic at smaller boiler plants. Two potentially significant breakthroughs undergoing testing are gasification at 2 plants (Fock and Christiansen, 2000) and the use of the Stirling engine for wood chips at a single plant (Carlsen, 2000).

3.3.3 Direct combustion of other agricultural residues

Poultry Litter Waste

The litter and manure component of poultry waste has a high nutrient value and is most often disposed of as a fertilizer. However, for large-scale poultry operations in intensive livestock producing areas, the excessive application of manure can lead to a number of water quality problems and treatment/disposal procedures are required. The disposal option that is most often used is composting, an aerobic treatment method. Some of the disadvantages of composting include a loss in the nutrient content of the material (particularly nitrogen), and added labour and equipment costs.

Combustion of poultry litter is a disposal option that allows for the recovery of energy either as heat or electricity while allowing for the use of the ash as an organic fertilizer that retains most of the phosphorous and potash present in the fresh litter. The calorific value of poultry litter typically is about half that of coal (13.5 GJ/tonne) and has a low ash fusion temperature. This ash fusion can cause problems in conventional grate combustion systems. The most successful example of conversion of poultry litter to energy involves the use of mass burn combustion systems and step-grate combustion systems. The Suffolk (UK) poultry-litter fired power plant generates a gross output of 14 MWe supplied to a 33 Kv power line for distribution through local energy networks. Mass burn combustion systems are large-scale incineration units with typical volumes of waste ranging from 10 and 50 tonnes per hour (Kelleher et al. 2002). There have been several co-firing trials using poultry litter waste as a supplement in coal-fired generation plants but the trials examined in literature were met with only limited success.

Waste Grains

Besides the combustion of straw bales and fuel pellets, waste grain can also be used as a heating fuel. Although the amounts of waste grains were not quantified in the inventory, they are a viable biofuel for combustion systems and there are instances when stored grains are contaminated and need to be destroyed. Ray Pattemore, an Ontario farmer/entrepreneur, experimented with some success using waste grains in a wood chip combustion system installed by Grove Wood Heating (Girouard et al. 1997). Pattemore uses wood chip heating for a multi-faceted enterprise that includes greenhouses, a piggery and fish farms.

3.3.4 Straw Gasification

The 'producer' gas produced by biomass gasification consists mostly of hydrogen and carbon monoxide and can be used to power a motor for driving an electric generator. After conversion, the gas is converted to water, CO_2 and nitrogen compounds. An advantage of this system is its simplicity; it can operate economically even for small systems. A gasification system consists of a gasifier, a purification unit and energy converter (e.g. a boiler or an internal combustion engine). Mixed with air, the producer gas can be used in a gasoline or diesel engine with little modifications. Theoretically, almost all kinds of biomass with a moisture content of 5-30% can be gasified, however, obtaining the gas in its proper form can be problematic. Most developed gasification technologies are used with common fuels such as coal and wood. Fuel properties such as surface, size, shape, moisture content, volatile matter and carbon content influence gasification. The gasification research carried out over the past century has clearly shown that the key to successful gasification is for the system to be specifically designed for a particular type of fuel (Turare, 1997).

As mentioned above, gasification technology has largely been developed for relatively homogeneous fuels such as charcoal and wood. Coconut shells and maize cobs have been successfully tested for fixed bed gasifiers without problems. However, most cereal straws with ash contents above 10% present slagging problems in downdraft gasifiers. Rice husks with ash contents above 20% can be difficult to gasify (Turare, 1997).

Current state of gasification technology in Europe

Gasification is not a new technology and was widely used in Europe around the time of the second world war. The technology largely disappeared with the widespread adoption of liquid fuels. Interest in gasification has increased with rising fossil fuel prices and there have been significant improvements to modernize the technology. No commercial applications of biogasification systems using agricultural residues in Canada were documented in our literature search.

Two cases in Denmark, however, suggest that biogasification technology can be cost effective for combined heat and power generation. The first Danish biogasification plant was constructed in 1993 based on an updraft-gasifier capable of firing fuel with a water content of 50%. After several modifications, plant output (using wood chips) was increased to twice the original estimation by 1993. A major breakthrough was the implementation of a gas-cleaning technique which allowed for the gas to be used in two engine generator plants with an overall electrical output of 1.5 MW. The co-generated heat meets the demand of 600 households connected to the plant. While this plant has operated dependably over the course of the past two years, a second plant experienced technical problems due to the sizing requirements of the feedstock. This second plant was based on the down-draft principle and operated for 3 years. It is currently being converted to use ordinary wood chips as a fuel (Elvver-Christensen, 2000).

3.3.5 Biomass Densification

One strategy to increase the accessibility of biomass heating fuels is densification of the feedstock. Pelleting techniques used in the livestock feed industry can be used to produce fuel pellets from dedicated biomass crops and agricultural residues in North America and Europe (Samson and Duxbury, 2000; Jannasch et al. 2001). Densified fuel pellets have several advantages:

- The amount of dust produced is minimized
- The fuel is free flowing, which facilitates material handling and transport
- The energy density is increased, easing storage and transportation
- Uniformity and stability permit more efficient combustion control.

Pelletized sunflower hulls were shown to have an energy content of 20.0 GJ/odMg compared to 19.2 GJ/odMg for dedicated biomass crops such as switchgrass and Short Rotation Willow, respectively (Samson and Duxbury, 2000). Danish experiments have shown that straw pellets with a calorific value of 16.3 MJ/kg (8% water and a volume weight 4 times greater than big straw bales) can be used as fuel in large boilers where the risk of ash and slagging problems is low (CBT, 1998).

Table 8. Summary of pelleting quality and chemical analysis for four different pelleting feedstocks

	Pine Needles	Switchgrass	Sunflower Hulls	SRF Willow
Estimated throughput (lbs/Hp)	50-75	45-70	50-75	35-45
Pellet hardness	>30	>30	>30	>30
Fines	None	Low	Trace	Trace
% Ash	5.9%	3.5%	3.6%	1.5%
Energy content (GJ./odMg)	21.3	19.2	20.0	19.2

Sourced from: Samson and Duxbury (2000).

Improvements in the combustion efficiency of pellet stoves and furnaces by the development of close coupled gasifier technology has led to combustion efficiencies exceeding 80% (Jannasch et al. 2001).

A 1 million BTU prototype pellet furnace using close coupled gasifier technology is currently being tested by Grove Wood Heat Inc. (York, P.E.I.) in collaboration with Shaw Resources (Milford, N.S.) to burn high ash pellets made from wood bark and agricultural residues (Jannasch et al. 2001).

Barriers to the rapid development of fuel pellet production include a lack of pelleting infrastructure, lack of expertise in producing high quality pellets and a modest range of combustion units adapted to efficiently burn pellets. Innovations in pelleting technology in Italy (www.etaflorence.it) indicate a 25-40% reduction in pelleting costs over the $60 per tonne reported by REAP-Canada (Jannasch et al. 2001) may be feasible. Rapid technological advances in pellet fuel heating in Europe combined with the development of efficient portable and semi-portable pelleting equipment bode well for pellet fuel heating in the future (Jannasch et al. 2001). In Itlay, Kemyx and Ecotre have begun commercial manufacturing of pelleting units that contain several major advances include:

- No pretreatment of material (no steam or additives)
- Ability to process higher moisture content material at a lower HP demand.
- Portability - mobile units.
- Higher throughput and low wear.

3.3.6 Celllulosic ethanol production from agri-crop residues

Ethanol is produced by the fermentation of sugars normally obtained either from corn or sugar cane. An alternate source of feedstock is fibrous plant biomass. Biomass is composed of cellulose, hemicellulose, lignin, ash and soluble substances called extractives. Cellulose is a polymer of glucose and is difficult to break down into sugars because of its structure (Kerstetter et al. 2001). Hemicellulose is composed of 7 different sugars including the 6-carbon sugars glucose, galactose and mannose and the 5 carbon sugars arabinose and xylose. Hemicellulose is easily broken down into its individual sugars. Ligin can be described as the glue that binds the cellulose and hemicellulose together.

There are different methods of ethanol production including: 2-stage dilute acid hydrolysis, concentrated acid hydrolysis and enzymatic hydrolysis. In general, the 4 steps for ethanol production are as follows:

(1) Pretreatment (to make the cellulose and hemicellulose more accessible and remove any foreign matter that may interfere with further processing steps).
(2) Hydrolysis
(3) Initial Fermentation
(4) Separation and concentration of ethanol by fermentation

No commercial ethanol production using cellulosic digestion technology is currently operating in Canada; however, IOGEN Corp, Gloucester, Ont. Currently operates a large scale pilot plant. IOGEN is a manufacturer of commercial enzymes and uses the enzymatic hydrolysis process for making ethanol. They developed a technology called steam explosion that increases accessibility of the enzymes to cellulosic materials. IOGEN removes the lignin and other non-fermentables from the process and burns that material to produce steam and electricity for the plant (Agriculture Canada, 2000a). They holds patents on both the steam explosion technology and the enzymes that hydrolize the cellulose to sugar. In the late 90's, Iogen constructed a pilot ethanol plant (40 tonne/day capacity) that uses cereal straw as a raw material in Gloucester, Ontario. Originally conceived as a plant that could be upgraded to a commercial operation, the cost of biomass in Eastern Ontario proved to be too expensive to proceed with plant upgrading to a commercial scale. Other cellulosic materials were considered, including corn stover. Initial trials with corn stover proved problematic; harvesting was inefficient and the harvested material was often muddy and gave less ethanol yield than estimated). Petro Canada, a partner of IOGEN for the project, has plans to construct 3 commercial ethanol plants to service its ethanol requirements (for octane additives in gasoline) once the pilot plant has proven its commercial viability. IOGEN is willing to pay $35/tonne for wheat straw while locally produced straw bedding and switchgrass sell for $70/tonne (Passmore, 2002).

3.3.7 Anaerobic Digestion

Anaerobic digestion (or methane fermentation) allows for the stabilization and disposal of waste biomass while producing a useful fuel gas. Millions of low-cost digesters have been operated for many years in China and India on farms and in cooperative villages systems to generate biogas from animal manure (Klass, 1998). This section briefly describes the potential for anaerobic digestion systems for Canadian farms and outlines some of the issues related to their adoption in Canada. The status of anaerobic digestion use in Canada is assessed and three Canadian case studies are described.

Biogas properties

Biogas possesses a low energy density (19-22 megajoules per cubic metre or 500-600 BTU/ft3) with 130 volumes of compressed biogass (1380 kP) needed to provide the equivalent energy as one volume of diesel fuel (NRAES, 1999). Biogas volume can be reduced under higher pressure, but this becomes impractical due to the greater wall thickness required for storage tanks. In general, it is uneconomic to transmit biogas via pipeline due to its low heating value. The most practical way to use biogas is to consume it as it is being produced. Most situations, however, do not have a consistent need for heat and many on-farm requirements such as grain drying are seasonal with exceptionally high energy demand (2.1 GJ/hour) which cannot be supplied by individual livestock herds. Consequently, energy may be wasted unless the biogas is used to produce electricity. Electricity production involves a further energy loss in the form of heat from the internal combustion engine used to power the generator. About 75% of fuel energy in such motors is rejected as waste heat, although partial recovery (7000 BTU per hour per kW of generator load) is possible by redirecting it to the digester and to space heating applications on the farm (Koelsch et al. 2001).

Biogas is about 55% methane, with the balance made up of carbon dioxide and hydrogen sulfide (HS). Hydrogen sulfide is extremely corrosive to metals and the biogas should be purified before being used to run spark-ignition motors. Biogas can be purified by a stripping process, by passing the gas through either an absorbent liquid or by alternatively cleaned by precipitating out the HS by passing the biogas through an iron sponge or even iron filings (Jewell et al.,1997).

End Uses of Biogas

<u>Electricity:</u>

Transforming biogas into electricity has the advantage of producing a marketable and transportable form of energy. A disadvantage is that in most parts of North America electricity prices are relatively low in comparison to other regions such as Europe and no preferential rates are paid for power supplied to the grid from biogas facilities. Estimates of the livestock numbers needed to operate a cogeneration plant profitably vary from 500 cows or 5000 finishing hogs (Morrison, 2001), 150-200 large cattle (Leggett and Graves, 1996). Jewell et al. (1997) estimated that a 100 cow dairy can power a 20 kW generator whereas a 30,000 cow facility could fuel a 5 megaWatt power plant. Van Die (1987) argues that electricity production on small to medium-sized Canadian farms cannot be justified because of high demands on capital and labour.

Space Heating:

From an energetic stand point, it is more efficient to use biogas for space heating than to produce electricity. Many heating appliances that are built to operate on natural gas (e.g. boiler type hot water-heat exchangers) could alternatively use biogas without modification. Less heat will be delivered from the original heating unit (roughly half). Full output maybe restored on some appliances by enlarging the metering orifice. The same rule applies for butane and propane (Jewell et al., 1997)

Biogas production in cool climates

Biogas production is a highly temperature dependent process. Biogas systems appear more suited to tropical climates (temperatures >25 Celsius). However, anaerobic digesters can be operated year round in Canada 's cold climate with sufficient biogas production available to produce the supplemental heat required to maintain the digestion process in the winter (Van Die, 1987). The practical Eurapean long term experience suggests that manure digesters do operate well and are of economic value in cooler climates, similar to Canada (Agriculture Canada, 2001).

In some cases the digester temperature is heated to increase methane production. Fulhage (1993) stated that approximately one third of the energy in the manure gas is needed to maintain the necessary temperatures (950 F) in the digester. For systems that use the biogas to generate electricity, recovery of waste heat is possible from the spark ignition engine that is used to drive the generator. About 75% of fuel energy in such motors is rejected as waste and can be used to warm the digester (Koelsch et al., 2001). Heat can be recovered from the engine water cooling system and the engine exhaust by commercially available heat exchangers. Properly sized heat exchangers will recover about 7000 Btu of heat per hour for each kilowatt of generator load (Koelsch et al., 2001).

Current state of anaerobic digestion usage on Canadian farms

The energy crisis of the 1970's led to increased interest in renewable energy technologies and from 1973 to 1986 twenty-eight (28) anaerobic digestion projects were researched, developed and installed on Canadian farms (AD-Net, 1999). These projects were carried out mostly part by University researchers and engineering firms. In the U.S., there has been a great deal of research done on anaerobic digestion for the dairy sector while in Canada most research was done for the hog industry. None of these early projects are still in operation today because there were various design and operational problems and in most cases, the plants produced less biogas than expected. The studies suggested that the energy and cost savings from the produced biogas did not justify the large capital investment, operating costs and management of anaerobic digesters, especially for small to medium sized operations (Van Die, 1987).

The main driving forces for anaerobic digestion research in Canada today are environmental regulations. There is a trend in the livestock industry to develop larger, more intensive operations. Following the Walkerton (Ontario) crisis in May, 2000, increased attention has been paid to water quality issues. Low-cost and easy to operate anaerobic digestion systems need to be developed to control odour and treat high strength agricultural wastewaters. With higher energy prices in recent years there has been renewed interest in the technology for Canada; however, infrastructure costs are still prohibitive. Unless a low cost anaerobic system is developed, the benefits of energy recovery will remain a secondary gain associated with the environmental benefits of treating agricultural waste, and except for large operations, the associated economic advantages will be marginal.

Case study 1

A farm-scale anaerobic digester was installed in the fall of 1977 at an Ontario swine farm (a 95-sow, farrow to finish operation). The project was carried out by the Research Branch of Agriculture Canada (Engineering and Statistical Research Institute) with the cooperation of farmer J. Fallis at Millbrook, Ontario. Research suggested that biogas production was technically feasible, although not necessarily economical under Canadian weather and labour conditions.

An estimated 7,000 litres of liquid manure was produced per day without the addition of water to dilute the manure prior to loading the digester. The digester was constructed of reinforced concrete with rubber waterstop seals installed at the roof and bottom construction joints to provide a suitable seal and allow for operation at pressures up to 2.5 kPa. A heating system was installed to achieve and maintain the required temperature in the digester. The heating system was installed 50 mm above the floor. The grid was made of nominal 25 mm black iron pipe arranged in a series of 14 return loops. A mixing system was included, consisting of an aerator, which was basically functioning as a gas lift pump. A Myers 0.6 KW centrifugal pump was used to transfer the liquid manure from the barn gutter to the 5 cm feed pipe and into the digester.

A number of problems occurred after the first three months of operation when the loading rate was increased from 1000 l/day to 3600 l/day. There were problems with the mixing system due to a build up of corrosion between the steel rotor and the carbon vanes. A second problem related to the gas lift mixer system arose due to plugging of the gas diffuser in the bottom of the mixer. Failure of the digester's gravity overflow unloading caused a gradual increase in the volume of manure housed inside the digester which also reduces the volume of the head-space above the liquid. After six months it was decided to shut down operation and repair the mixer. Upon examination, it was found that the outlet was clogged with a mixture of manure solids and hog hair bristles. After cleaning, the mixer was fitted with a cable system to allow for removal. An elbow and cap were fabricated to allow a plumber's snake to be used in the case of blockage.

The environmental benefits from the digester system were promising. Results from two separate tests done at three and four months after startup showed an average of 88% reduction in total volatile solids

(TVS) and a 90% reduction in COD. Production of biogas was measured over a ten-day period at the three month point as just below 70 m^3 biogas/day. While the environmental benefits were encouraging, it was hard to evaluate the economic benefits of the digester due to the operational problems that occurred. The modified system worked continuously for a month before the submersible pump failed. After repair the system operated intermittently for 6 months; during that period the pump failed twice. Besides blockage in the digester, corrosion also caused numerous problems. After 28 months of operation the digester was scheduled to undergo a complete overhaul in order to solve the various problems that had been prevalent. It was not clear whether the system was ever upgraded.

Case Study 2

A Taiwanese treatment technology was evaluated at the pilot plant scale under Manitoba climate and farming conditions in the winter of 1998-1999. The project was initiated by DGH Engineering and Hon International Inc. (Danesh, 2000) with the goal of introducing and demonstrating a reliable Taiwanese technology under Canadian climatic conditions. The treatment included the following four sequential processes: solid-liquid separation, anaerobic digestion, aerobic treatment and settling basins. The anaerobic digesters consisted of a series of six anaerobic basins where manure digestion occurred. Hot water coils were added to keep the temperature around 20 ºC in the digesters. Following the digester was a series of 3 aerobic basins, with aeration supplied by two compressors and a grid of diffusers located in each basin. The reason for having the aerobic treatment is to oxidize and reduce the remaining organic matter left from the anaerobic process. Some of the settled solids are removed (through quiescent conditions) and use as activated sludge to be returned to the aeration chambers to enhance treatment process or discharged to the existing manure storage in the farm. The final effluent from the settling units was recycled to the barn to hydraulically remove manure and the excess discharged to the manure storage.

Treatment efficiencies averaged 98% reduction of COD at the low organic load rate but only 84% removal at the high organic rate. The plant did not achieve treatment levels that would permit discharge to surface waters, as is the case in Taiwan. There was a noticeable improvement in barn air quality and odour problems, as well as a reduction in nitrogen and phosphorous (from the aerobic treatment stage) which would result in a significant reduction in the land base required for disposal. Most likely the operational temperature difference between the pilot plant (15 to 21 ºC) and the tropical conditions in Taiwan (> 25 ºC) were the cause of this. Very little biogas production was observed under the covers of the anaerobic conditions and gas production was not measured.

The greatest amount of treatment occurred in the anaerobic section of the system (approximately 50% to 75% reduction in total COD); however, treatment efficiency in the aerobic section was low, probably because of low dissolved oxygen levels or the biomass activity was lower than expected. The recycled sludge to the aerobic basins may have been composed of an aged microbial population due to insufficient sludge removal from the settling tanks. Also the system appeared to be over-designed in terms of volume and hydraulic retention time. An economic analysis of treatment options for large scale hog operations indicated that elimination of the aerobic and separation system components would dramatically reduce costs with only a limited potential impact on performance. Further evaluation is require to confirm the range of treatment possible with only the anaerobic system.

Case Study 3

Finnie Distributing (1997) Inc., St. Mary's, Ontario (near Cambridge), grind and mix eat and meat by-products for the pet food industry. The operation produces 12,000 gallons of waste water daily with a relatively high Biological Oxygen Demand. Owner, Gary Richardson (519-284-3444) chose anaerobic digestion as a waste water purification method partly because the process will destroy a range of pathogenic bacteria. Energy generation was a secondary objective. A pilot project was funded by the Canadian Innovation Centre, and the current digestor was funded by the Agricultural and Environmental Stewardship Initiative and the Agricultural Adaptation Council of Ontario. The digester unit was designed by Geomatrix (Waterloo, Ont).

Mr. Richardson says the project has only been operational a few months, but the results are extremely encouraging. Wastewater is now land applied with government approval, either by injection on corn or soybean land or direct spreading on hay land, on area farms. The effluent contains moderate concentrations of nutrients, which substitute for some fertilizer requirements. Mr. Richardson anticipates being able to "polish" the water suitable for direct discharge into water courses. A further goal is to capture biogas and use it to heat the processing plant during winter and to heat water during the summer months.

He claims, "The biggest reason anaerobic digestion hasn't worked for some people is because they couldn't keep it warm enough to function in winter. You need a minimum of 95-98 ˚ F. We built the walls 22 inches thick covered in two inches of insulation and steel siding to keep off the wind. So far this has maintained the temperatures very well."

The Economics of biogas generation

Washenfelder (1999) performed a cost-benefit analysis of on-farm anaerobic digestion systems for Saskatchewan hog farms, and, based on Danish case studies, capital costs of unheated digesters were found to range from 50 - 75 $ US per m3 capacity. Total costs were estimated to range from $US 27 822 for a 300 head swine operation to $US 181 590 for a 5 000 head swine operation. Yearly operational costs ranged from $US 4 726 for the 300 head swine operation to $ US 42 867 for a 5 000 head swine facility.

Jewell et al. (1997) evaluated anaerobic digestion options for groups of dairy farms in upstate New York. Dairy farms in the area are generally larger than Canadian farms, but the comparison was useful. It was found that anaerobic digesters and cogeneration facilities were more economic for larger operations. Capital costs were on the order of $1,500 US/cow for dairies with less than 100 lactating cows. Capital costs leveled off for farms with more than 300 animals at 450$ US/cow. These costs are comparable with the findings of Waschenfelder (1999) if it is extrapolated that on a per-animal basis, the costs of manure treatment are roughly 10 times the amount for a dairy farm than for a swine operation due to higher manure generation rates of milk cows to pigs. Danesh et al. (1997) reported that for the Manitoba swine industry costs were in the order of 26$ Cdn per pig for the installation of anaerobic digester based on Taiwanese technology. Jewell et al. (1997) found that the cost of the methane digester was generally the same in terms of proportion of total costs (44%), regardless of the size of the facility. For larger facilities, the cost of cogeneration increased in terms of overall spending (from 25% for a 25 cow herd to 50% for a 1,200 cow herd).

If the costs from Jewell's study are used to assess the practicality of constructing anaerobic digestion systems on Canadian farms, investment in such systems still does not appear to be economically justified for most average sized operations. Using the capital costs from the New York study (Jewell et al. 1997), costs would range from $90,000 CDN to $180,000 CDN for dairy farms ranging in size from 40 to 80 lactating milk cows for Canadian digester and cogeneration facilities. Even if cogeneration equipment were omitted and the biogas was solely used for space heating applications, overall costs would still be $68,400 CDN for a 40 cow herd, which would produce only enough energy to cover household heating. Improved technologies should improve the economics of biogas digesters at the farm level in the near future using cheaper materials for the storage of the biogas and the anaerobic reactor tank.

Biogas Systems in Europe

In Denmark, 20 centralised biogas plants for treating livestock wastes have been established over the past 12 years. The largest plants receive manure from about 80 livestock herds (Tafdrup and Hiort-Gregersen, 1999). The gas is used almost exclusively for combined heat and power generation (Elmose and Hiort Gregersen, 1999). Many of the plants also have storage infrastructure, allowing the plants to convert the gas to electricity when the price of power is high. In 1998, there was 3.65 million KWh of electrical power that was generated, which was double the amount produced of the previous year. Most of the plants treat other types organic waste from industry, which has vastly improved the economics of plant operation since the plants charge a tipping fee for the service. Normally a 4:1 ratio of livestock manure to industrial organic material is used. The 20 plants in 1999 treated 250,000 tonnes of industrial organic waste. The Danish government considers biogas plants to be an important component of their renewable energy program and pay preferential rates for power as well as providing set-up grants.

Centralized facilities in Canada

For areas with a high density of livestock production in Canada, centralized facilities may be economically viable options for the treatment of waste and production of on-site energy. It should be noted that for most of the cases in Denmark, even with a preferential price paid for the electricity and government subsidy provided for the installation of biogas plants, the centralized facilities were only successful when other organic wastes were treated as well as manure (Tafdrup and Hiort Gregersen, 2000). Overall, biogas production may only be feasible in Canada when advantages such as energy self-sufficiency, reduced greenhouse gas emissions, diversion of food wastes from landfills, odour control, and water quality protection are “married” together. It is unlikely that biogas production will be feasibly for purely economic reasons.

4.0 Conclusions

There is considerable potential to produce bioenergy in eastern Canada from both crop residues and livestock manure. After accounting for sustainable removal rates and competing uses, there are approximately 1.0 - 1.3 million tonnes of straw and 3.0 - 3.3 million tonnes of corn stover available for bioenergy production. The gross energetic potential of these residues is approximately 92 million GJ/year. Although corn stover represents a larger feedstock pool than cereal straw, procurement systems for stover require considerable development before this residue source can be utilized.

Straw combustion is a proven technology that has been adopted on a limited scale in Canada even though combustion efficiencies are generally low. Straw burning systems can be implemented at both the farm-level, and in larger facilities for district heat or power generation using European technology. Widespread introduction of straw combustion systems would depend on developing proven, efficient, dependable and convenient technologies. Procurement of clean, dry straw, in large square bales, storage systems, dependable and functional bale feeding mechanisms and combustion control appear to be the major factors needing development. Stoves and commercial-sized burners for densified fuel pellets made from straw and other agricultural residues are in the early commercialization stage and could make a significant impact on the biomass energy market in Canada. Recent improvements in small-scale pelleting technology will also improve the availability of low cost pellets.

Unlike straw combustion, cellulosic ethanol production is still at the pilot stage of development. The technology is suited to large-scale, centralized plants and is not economical at the farm level. IOGEN Corp. has reported that commercial cellulosic ethanol production is not feasible in eastern Canada due to the insufficient supply and high cost of feedstock. Some potential exists for gasification technology, but applications are not yet at the commercialization stage. By and large, energy production from crop residues in eastern Canada is more suited to small and medium scale conversion systems rather than large, centralized facilities.

The latest generation of anaerobic digestion technology for livestock waste is still in the pilot stage of testing in Canada. The technology is generally considered economically feasible for large livestock operations. Estimates of the minimum number of livestock needed to operate a cogeneration plant profitably vary from 150 to 500 large cattle (or 1500 to 5000 hogs). The swine sector has the greatest potential for energy production on individual operations. There is potential to establish biogas systems in large beef feedlots and poultry operations but the economic factors vary on a case by case basis. The gross energetic value of the biogas from livestock manure is approximately 16 million GJ/year. An increasing number of farms in eastern Canada are capable of operating biogas systems on this scale, but as working models of these systems have yet to be installed, there is an urgent need for pilot scale and demonstration projects. Based on existing technology, investment costs are still very high on a per farm basis. For intensive livestock areas, the implementation of this technology in centralized facilities could likely improve the economic viability of biogas production. Electricity generation from biogas produces the highest value energy form, overall energy losses during the conversion process are high. Widespread utilization of biogas would depend on implementing combustion systems capable of utilizing biogas on an on-going basis.

The viability of agri-residue based bioenergy most probably depends on linking environmental benefits with energy production. For example, in areas where public health issues concerning livestock waste have a high profile, anaerobic treatment could become a necessity rather than an economic option. Under this scenario, energy production could substantially offset treatment costs. Likewise, the production of bioenergy from agri-based residues allows Canada to replace fossil-based fuels and reduce greenhouse gas emissions, as prescribed by the Kyoto protocol. There are a number of technically feasible systems for converting biomass to energy that could be adopted in eastern Canada, but current energy prices make them economically unattractive. Energy prices could rise significantly to make existing biogas technologies more economically viable, but at current energy prices the benefits of energy recovery will likely remain secondary to the environmental benefits.

If energy prices were to increase significantly these technologies could become more commonplace.
The key factor in realizing the full potential of energy derived from agricultural residues is scale. Implementation of bioenergy systems depends either on the development of efficient, small scale conversion technologies for on-farm applications or locating larger, centralized combustion or anaerobic digestions plants in areas where sufficient feedstock supplies can be transported at a reasonable cost. Development of energy systems based on agricultural residues requires a long-term research and development effort designed to harness the many benefits of bioenergy production independent of fluctuations in energy markets and prices.

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APPENDIX 1: CROP RESIDUE STATISTICS BY PROVINCE

Ontario Crop Statistics (2001)

	Hectares ('000)	Yield ODT/ha	Production 000 ODT	Straw/Stover Yield ODT/ha*	Straw/Stover Yield ('000 ODT)
Winter wheat	218.5	4.3 (4.1)	942.8	4.3	942.8
Spring wheat	46.5	3.2 (2.9)	149.0	3.2	149.0
All wheat	265.1	4.1 (3.9)	1 089.5	4.1	1 089.5
Cereals					
Oats	28.3	2.3 (2.1)	65.9	1.6	65.9
Barley	109.3	3.2 (3.2)	350.0	2.2	350.0
All rye	24.3	2.0 (2.2)	49.7	1.4	49.7
Mixed grains	68.8	2.8 (3.1)	195.5	2.0	195.5
Canola	14.2	2.1 (2.2)	29.3	1.3	18.3
Buckwheat	1.6	1.7	2.7	1.2	2.7
Soybeans	862.0	1.3 (2.2)	1 091.3	-	-
Fodder Corn	125.5	26.2 (31.0)	3 300.0	-	-
Grain Corn	777.0	4.9 (5.2)	3 800.4	2.4	1 900.2
Tame Hay	853.9	4.7 (6.3)	4 000.0	-	-

Values in parentheses are average yields (1997 to 2001).
Source: 2001 OMAFRA

- Straw yields for wheat in Ontario ranging 1.3 to 1.7 times grain yields have been reported (Levelton, 2000). Assuming a factor of 1.3 and that approximately 25% of this should be left on the field as soil cover, we will assume that the available straw to grain ratio is 1.0.
- A straw to grain ratio of 1.0 was assumed for the other cereals as per Boswell and Price (personal communication, 2002). This was adjusted to 0.7 to account for residues needed as a soil cover.

Quebec Crop Statistics (2001)

Crop	Hectares '000	Yield ODT/ha	Production 000 ODT	Straw/Stover Yield ODT/ha*	Straw/Stover Yield ('000 ODT)
Winter Wheat	0.7	2.4	1.7	2.4	1.7
Spring Wheat	36.0	2.9	103.4	2.9	103.4
All wheat	36.7	2.9 (2.8)	105.7	2.9	105.7
Cereals					
Oats	74.0	2.5 (2.2)	187.1	1.8	187.1
Barley	143.0	3.1 (2.5)	437.9	2.1	437.9
Fall rye	1.6	1.8	2.9	1.3	2.9
Mixed Grains	21.5	2.6	56.6	1.8	56.6
Canola	4.5	2.1	9.4	1.3	5.8
Buckwheat	0.6	1.2	0.7	0.8	0.7
Soybeans	147.5	1.9 (2.6)	285.9	-	-
Corn for Grain	425.0	5.2 (5.3)	2 230.0	2.6	1 115.0
Fodder Corn	46.0	32.4	1 488.0		
Tame Hay	780.0	4.9	4 244.0		

Values in parentheses are average yields (1994 - 1997)

- The same straw to grain ratios applied in Ontario were used for Quebec

New Brunswick Crop Statistics (2001)

Crop	**Hectares ('000)**	**Yield ODT/ha**	**Production '000 ODT**	**Straw/Stover Yield (ODT/ha)**	**Straw/Stover Yield ('000 ODT)**
Spring Wheat	3.2	3.3	10.8		
Winter Wheat	0.8	5.6	4.5		
All Wheat	4.0	3.8	15.3	2.83	11.45
Cereals					
Barley	16.2	4.0	64.8	2.85	46.14
Oats	8.1	4.4	36.0	2.83	22.91
Mixed Grains*	0.002	2.7	0.0	2.3	0.005
Grain Corn	0.4	7.1	2.9	2.67	1.08
Tame Hay	70.8	5.1	362.3	-	-
Naturalized and unimproved Pasture	20.2	4.4	90	-	-

Source: Mike Price - Field Crops Specialist, (Personal communication, 2002)
* except for mixed grains (Statistics Canada data 2001)

Calculation of Straw Residues	Tonnes grain/ha	Tonnes/straw
Wheat	2,5 - 3,3	2,83
Oats	2,7 - 3,7	2,3
6 row barley	2,2 - 2,9	2,7
2 row barley	2,7 - 3,6	3
Soybeans	-	

Source: Mike Price - Field Crops Specialist, (Personal communication, 2002)

PEI Crop Statistics (2001)

Crop	Hectares ('000)	Yield (ODT/ha)	Production ('000 ODT)	Straw Yield** (ODT/ha)	Straw Production ('000 ODT)
Wheat	8,90	2,52 (2.8)	22,43	1,76	15,70
Oats	4,00	1,62 (2.2)	6,48	1,13	4,54
Barley	38,40	2,25 (2.8)	86,40	1,58	60,48
Soybeans	3,40	1,44 (1.9)	4,90		
Mixed Grains*	6,27	2,06 (2.8)	12,92	1,44	9,05
Tame Hay*	54	5,19	279,30		

Values in parentheses are average yields (1995 - 1999)

Data provided by Peter Boswell (personal communication, 2002) except for mixed grains and hay (Stats Can 2001). Yields for that crop year lower than long term average due to drought conditions from July to September.

**Boswell recommended for PEI a straw to grain ratio of 0.7.

Nova Scotia Crop Statistics (2001)

Crop	Hectares ('000)	Yield ODT/ha	Production '000 ODT	Straw/Stover Yield ODT/ha*	Straw/Stover Yield ('000 ODT)
Winter wheat	1.8	3.3 (3.6)	5.9		
Spring Wheat	0.8	2.1 (2.5)	1.7		
All wheat	2.6	2.9 (3.3)	7.6	2.0	5.3
Oats	2.6	2.0 (1.9)	5.2	1.4	3.7
Barley	3.8	2.4 (2.6)	9.2	1.5	5.9
Grain Corn	1.9	4.7 (4.2)	9.1	2.3	4.6
Fodder Corn	2.0	25.9 (24.1)	53.0	-	-
Tame Hay	69.6	4.7 (6.3)	361.0	-	-

Values in parentheses are average yields (1997 - 2001)

Source: Statistics Canada Data 2001

* A straw to grain ratio of 0.7 was used

Newfoundland/Labrador (2001)

Crop	Hectares ('000)	Yield ODT/ha	Production 000 ODT
Tame hay	5.1	4.7	24.0

A note on variations in crop yields from year to year:

By examining census data for 1996 and 2001, the major trends in crop production were noted as follows: there were increases in the area planted to alfalfa (+10%) in all eastern provinces, grain corn (+13%, mostly in Quebec) and soybean production (21%, mostly in Ontario and Quebec). There was a decreasing trend for the areas planted to tame hay (-11%) and winter wheat (-24%). The area planted to the other major field crops was fairly stable in all eastern provinces.

Examining standard deviations over the 5 years of data, wheat yields can be expected to deviate +-10% from the average yields, +-15% for the other major cereals and +- 12.5% for corn.

Appendix 2: Competing Uses for Crop Residues

Any attempt to use crop residues for energy production must consider how competing uses may affect prices and supply. Although corn stover currently has no major uses, cereal straws have numerous markets such as livestock bedding, mulch and growing mediums for horticulture and specialty crops. Straw availability and price fluctuate depending on demand, availability and intended use.

Livestock Bedding

The amount of cereal straw actually used for livestock bedding is difficult to calculate given the great diversity of the Canadian livestock sector. Dubuc (1997) estimated that of the estimated 2,780,000 tonnes of straw available in eastern Canada, at least 1.5 million tonnes were used as livestock bedding. Decreased straw usage resulting from a shift towards full concrete and slatted floors in dairy production may be offset by expansion of the beef feedlot sector, which traditionally uses large quantities of straw.

Horticultural Crops

Ginseng

There are approximately 3600 acres of ginseng in SW Ontario requiring, on average, over a three year production cycle, 16,400 tonnes of straw annually. Stong demand typically inflates prices in ginseng production areas (C. Brown, OMAFRA, personal communication, 2002).

Strawberries

Approximately 1900 and 1750 ha of strawberries are grown in Quebec and Ontario, respectfully, with substantially smaller acreages in Atlantic Canada. Strawberries typically require 5-8 tonnes of straw per hectare for winter protection, which generates a need for 30,000 tonnes of straw annually in eastern Canada (G. Townsend, OMAFRA, personal communication, 2002).

Wild Blueberries

About 13,000 ha of wild blueberries are grown in Nova Scotia which are pruned every other year by flail chopping or burning. Burning 50% of the crop with straw every other year would require approximately 1-2000 tonnes of straw annually.

Mushroom Compost

Expansion of the mushroom industry in Ontario has created a considerable demand for hay and straw. Precise statistics on straw consumption in mushroom production have not been compiled due to the many compost mixes used for a variety of mushroom types, yet there is an increasing trend to replace hay with wheat straw (D. Duncan, 2002). The mushroom industry creates a waste product called spent mushroom compost (SMC) that has potential as an energy feedstock. Analyses from an Irish study showed that, on a dry ash free basis, SMC has a calorific value equivalent to sewage sludge which has been successfully fired for many years (Williams et al., 2001).

Existing energy generation

IOGEN Corp. currently uses wheat feedstock for its cellulosic ethanol plant in Gloucester, Ontario. The bulk of this material, however, is imported from markets outside the province, including U.S., at a lower cost than domestic markets. There is no significant usage of straw as a combustible biofuel.

Straw Prices

Straw prices are dependent on a number of factors including bale size, season and the intended use. In the Spring, 2002, prices in Ontario were $90-100/tonne for small bales (20 kg) and $50-75/tonne for big bales (D. Duncan, mountain Trucking, pers. comm.). IOGEN Corp. pays $35/t for imported wheat straw used in cellulosic ethanol production rather than $65/t ($3.6/GJ) for straw from SW Ontario. A similar price range exists in the other eastern Provinces with the exception of Newfoundland where local cereal production is negligible and straw fetches up to $150 per tonne.

Other factors that can influence prices include:

- The size of the previous year's harvest. Straw yields can be reduced by drought or winterkill in the case of winter cereals.
- End use. Ginseng growers in sw Ontario can offord to pay more for straw than livestock farmers in eastern Ontario.
- Straw type. Winter wheat straw is preferred over other cereal straws for many applications

Although most competing uses for cereal straw other than livestock bedding represent a very modest proportion of the total straw supply, certain industries in specific geographic areas, such as ginseng in southwest Ontario, can significantly effect local availability and supply. The impact of these industries is probably greater in regions such as Atlantic Canada where fewer cereals are grown than in Ontario and Quebec. Overall it appears that between 50 and 75% of recoverable cereal residues are potentially available for bioenergy applications.

Appendix 3:

Inventory of Livestock and Manure Production by Province

- All Livestock data sourced from Statistics Canada (2000 - 2001).
- Unless specified otherwise, all estimates of manure and biogas generation are based on the methodology from the Midwest Plan Service (1992).
- The following presents the *potential* livestock manure supply. Losses, and the actual recoverable amount of manure waste is reflected in section 2.2.3
- See Appendix 4 for sample calculations

Total Inventory per Farm Type, Ontario

Ontario BEEF

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)*2	Heating Value ('000 Btu/day)[1]	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Bulls	21.1	1 092	27.9	493 908.8	0.5	28.7
Milk cows	0.0	0.0	0.0	0.0	0.0	0.0
Beef cows	399.0	13 466	329.2	5 837 370.0	6.2	339.2
Milk heifers	0.0	0.0	0.0	0.0	0.0	0.0
Beef heifers - breeding	71.0	1 917	46.9	830 984.0	0.9	48.3
Beef heifers - slaughter	133.6	4 509	110.2	1 954 568.0	2.1	113.6
Steers	251.9	6 801	166.3	2 948 237.6	3.1	171.3
Calves	388.0	5 238	128.0	2 270 576.0	2.4	131.9
TOTAL	**1 264.1**	**33 023.5**	**808.4**	**14 335 644.4**	**15.1**	**832.9**

Ontario DAIRY

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)*2	Heating Value (10^3 Btu/day)[1]	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Bulls	4.9	254	11.5	203 330.4	0.2	11.9
Milk cows	373.0	19 303	611.0	10 834 605.6	11.4	631.9
Beef cows	0.0	0.0	0.0	0.0	0.0	0.0
Milk heifers	174.0	6 421	203.6	3 610 152.0	3.8	210.5
Beef heifers - breeding	0.0	0.0	0.0	0.0	0.0	0.0
Beef heifers - slaughter	11.4	385	16.7	295 659.0	0.3	17.2
Steers	28.1	759	32.9	583 018.8	0.6	34.0
Calves	194.0	2 619	113.5	2 012 556.0	2.1	117.4
TOTAL	**785.4**	**29 739.4**	**989.1**	**17 539 321.8**	**18.5**	**1 022.9**

Ontario Swine

Category	Number of animals '000	Manure Production ('000 kg/day)	Biogas Production ('000 m3/day)*2	Heating Value ('000 Btu/day)[1]	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Boars 6 Months & Over	13	65	4	75 102.3	0.08	4.4
Sows and Gilts	372	5 530	117	2 287 467.0	2.41	134.1
Under 45 Lbs	989	1 024	29	567 108.4	0.60	33.2
45 Lbs. To 130 Lbs	916	2 885	83	1 612 762.5	1.70	94.5
Over 130 Lbs	852	4 370	125	2 441 971.4	2.57	143.1
TOTAL	**3 143**	**13 874**	**358**	**6 984 411.5**	**7.36**	**409.3**

Ontario Poultry

	Number of Birds ('000) Yearly production	Manure Production ('000 kg/day) Based on Standing flock	Biogas Production ('000 m^3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Energy Value of biogas ('000 KW-hr/day)
Broilers	188 677	2 161	180	3 576 989.0	3.77	209.2
Ontario Egg Production						
	Average Number of Layers('000)	**Manure Production ('000 kg/day**	**Biogas Production ('000 m^3/day)**	**Heating Value ('000 Btu/day)**	**Heating Value ('000 GJ/day)**	**Energy Value of biogas ('000 KW-hr/day)**
Egg layers	8 897	841	40	807 829.8	0.85	45.9
Ontario Turkey Production						
	Number of Birds ('000) Yearly production	**Manure Production ('000 kg/day) Based on Standing flock**	**Biogas Production ('000 m^3/day)**	**Heating Value ('000 Btu/day)**	**Heating Value ('000 GJ/day)**	**Energy Value of biogas ('000 KW-hr/day)**
Turkeys	8 733	982	105	2 088 914.2	2.20	122.2

Total Inventory per Farm Type, Quebec

Quebec BEEF

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Bulls	14.0	724.5	18.5	327 712.0	0.35	19.0
Milk cows	0.0	0.0	0.0	0.0	0.00	0.0
Beef cows	216.0	7 290.0	178.2	3 160 080.0	3.33	183.6
Milk heifers	0.0	0.0	0.0	0.0	0.00	0.0
Beef heifers - breeding	36.0	972.0	23.8	421 344.0	0.44	24.5
Beef heifers - slaughter	8.8	297.0	7.3	128 744.0	0.14	7.5
Steers	56.5	1 525.5	37.3	661 276.0	0.70	38.4
Calves	194.5	2 625.8	64.2	1 138 214.0	1.20	66.1
TOTAL	**525.8**	**13 434.8**	**329.2**	**5 837 370.0**	**6.2**	**339.2**

Quebec DAIRY

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)*2	Heating Value (10^3 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas (KW-hr/day)
Bulls	6.0	310.5	14.0	248 976.0	0.3	14.5
Milk cows	426.0	22 045.5	697.8	12 374 107.2	13.0	721.6
Beef cows	0.0	0.0	0.0	0.0	0.0	0.0
Milk heifers	176.0	6 494.4	205.9	3 651 648.0	3.8	213.0
Beef heifers - breeding	0.0	0.0	0.0	0.0	0.0	0.0
Beef heifers - slaughter	1.2	40.5	1.8	31 122.0	0.0	1.8
Steers	2.6	70.2	3.0	53 944.8	0.1	3.1
Calves	173.5	2 342.3	101.5	1 799 889.0	1.9	105.0
TOTAL	**785.3**	**31 303.4**	**1 024.0**	**18 159 687.0**	**19.1**	**1 059.1**

Quebec Swine

Category	Number of animals '000	Manure Production (kg/day)	Biogas Production (m3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Boars 6 Months & Over	8.9	44.1	2.6	51 110.9	0.1	3.0
Sows and Gilts	371.3	5 513.8	117.0	2 284 608.9	2.4	133.7
Under 45 Lbs	1 139.7	1 179.6	33.5	654 506.9	0.7	38.3
45 Lbs. To 130 Lbs	1 142.2	3 597.9	103.1	2 014 680.9	2.1	117.9
Over 130 Lbs	1 097.0	5 627.6	161.3	3 149 925.8	3.3	184.3
TOTAL	***3 759.1***	15 963.0	***417.5***	8 154 833.4	8.6	477.1

Quebec Poultry

	Number of Birds ('000) Yearly production	Manure Production ('000 kg/day) Based on Standing flock	Biogas Production ('000 m^3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Energy Value of biogas ('000 KW-hr/day)
Broilers	154 099	1 779.2	192. 0	3 590 765. 6	3.8	209.99
Quebec Egg Production						
	Average Number of Layers('000)	**Manure Production ('000 kg/day)**	**Biogas Production ('000 m^3/day)**	**Heating Value ('000 Btu/day)**	**Heating Value ('000 GJ/day)**	**Energy Value of biogas ('000 KW-hr/day)**
Egg layers	4 474. 0	426.16	25.9	545 272. 59	0.57	31. 88
Quebec Turkey Production						
	Number of Birds ('000) Yearly production	**Manure Production ('000 kg/day) Based on Standing flock**	**Biogas Production ('000 m^3/day)**	**Heating Value ('000 Btu/day)**	**Heating Value ('000 GJ/day)**	**Energy Value of biogas ('000 KW-hr/day)**
Turkeys	4774.15	540,57	54,18	1 140 389,49	1,20	66,69

Total Inventory per Farm Type, New Brunswick

New Brunswick BEEF

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Bulls	1.12	57.96	1.39	26 216.96	0.03	1.52
Milk cows	0.00	0.00	0.00	0.00	0.00	0.00
Beef cows	22.80	769.50	17.74	333 564.00	0.35	19.38
Milk heifers	0.00	0.00	0.00	0.00	0.00	0.00
Beef heifers - breeding	8.10	218.70	5.04	94 802.40	0.10	5.51
Beef heifers - slaughter	3.90	131.63	3.04	57 057.00	0.06	3.32
Steers	7.60	205.20	4.73	88 950.40	0.09	5.17
Calves	17.62	237.88	5.49	103 118.09	0.11	5.99
TOTAL	**61.14**	**1 620.87**	**39.68**	**703 708.85**	**0.74**	**40.89**

New Brunswick DAIRY

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)	Heating Value (10^3 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas (KW-hr/day)
Bulls	0.28	14.49	0.62	11 618.88	0.01	0.68
Milk cows	20.60	1 066.05	31.83	598 372.32	0.63	34.90
Beef cows	0.00	0.00	0.00	0.00	0.00	0.00
Milk heifers	7.70	284.13	8.50	159 759.60	0.17	9.32
Beef heifers - breeding	0.00	0.00	0.00	0.00	0.00	0.00
Beef heifers - slaughter	0.00	0.00	0.00	0.00	0.00	0.00
Steers	0.00	0.00	0.00	0.00	0.00	0.00
Calves	8.68	117.17	4.79	90 035.95	0.09	5.25
TOTAL	**37.26**	**1 481.84**	**48.48**	**859 786.75**	**0.91**	**50.14**

New Brunswick Swine

Category	Number of animals '000	Manure Production (kg/day)	Biogas Production (m3/day)	Heating Value ('000 Btu/day)[1]	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Boars 6 Months & Over	0.60	2.97	0.18	3439.80	0.00	0.20
Sows and Gilts	10.80	160.38	3.40	66339.00	0.07	3.89
Under 45 Lbs	36.50	37.78	1.07	20925.45	0.02	1.23
45 Lbs. To 130 Lbs	38.70	121.91	3.49	68144.90	0.07	3.99
Over 130 Lbs	38.40	196.99	5.64	110073.60	0.12	6.45
TOTAL	**125.00**	**520.02**	**13.79**	**268922.75**	**0.28**	**15.76**

New Brunswick Poultry

	Number of Birds ('000) Yearly production	Manure Production ('000 kg/day) Based on Standing flock	Biogas Production ('000 m^3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Energy Value of biogas ('000 KW-hr/day)
Broilers	**15 343**	**175.75**	**14.68**	**291 727.82**	**0.31**	**17.06**
New Brunswick Egg Production						
	Average Number of Layers('000)	Manure Production ('000 kg/day)	Biogas Production ('000 m^3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Energy Value of biogas ('000 KW-hr/day)
Egg layers	**721.00**	**26.68**	**3.20**	**39 279.21**	**0.04**	**2.2**
New Brunswick Turkey Production						
	Number of Birds ('000) Yearly production	Manure Production ('000 kg/day) Based on Standing flock	Biogas Production ('000 m^3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Energy Value of biogas ('000 KW-hr/day)
Turkeys	**470.01**	**21.93**	**5.66**	**115722.46**	**0.12**	**6.58**

Total Inventory per Farm Type, Nova Scotia

Nova Scotia BEEF

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Bulls	0.34	17.60	0.42	7 958.72	0.01	0.46
Milk cows	0.00	0.00	0.00	0.00	0.00	0.00
Beef cows	26.40	891.00	20.55	386 232.00	0.41	22.44
Milk heifers	0.00	0.00	0.00	0.00	0.00	0.00
Beef heifers - breeding	10.40	280.80	6.48	121 721.60	0.13	7.07
Beef heifers - slaughter	5.00	168.75	3.89	73 150.00	0.08	4.25
Steers	6.60	178.20	4.11	77 246.40	0.08	4.49
Calves	10.56	142.56	3.29	61 797.12	0.07	3.59
TOTAL	**59.30**	**1 678.91**	**41.06**	**728 105.84**	**0.77**	**42.30**

Nova Scotia DAIRY

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)	Heating Value (10^3 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas (KW-hr/day)
Bulls	1.36	70.38	2.30	56 434.56	0.059	3.29
Milk cows	25.4	1 314.45	41.60	737 798.88	0.77	43.03
Beef cows	0.00	0.00	0.00	0.00	0.00	0.00
Milk heifers	10.00	369.00	11.70	207 480.00	0.22	12.10
Beef heifers – breeding	0.00	0.00	0.00	0.00	0.00	0.00
Beef heifers – slaughter	0.00	0.00	0.00	0.00	0.00	0.00
Steers	0.00	0.00	0.00	0.00	0.00	0.00
Calves	21.44	289.44	12.93	222 418.56	0.23	12.97
TOTAL	**58.20**	**2 043.27**	**69.03**	**1 224 132.00**	**1.29**	**71.39**

Nova Scotia Swine

Category	Number of animals '000	Manure Production (kg/day)	Biogas Production (m3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Boars 6 Months & Over	0.50	2.48	0.15	2 866.50	0.00	0.17
Sows and Gilts	11.00	163.35	3.47	67 567.50	0.07	3.96
Under 45 Lbs	39.40	40.78	1.16	22 588.02	0.02	1.32
45 Lbs. To 130 Lbs	39.90	125.69	3.10	60 454.49	0.06	3.54
Over 130 Lbs	38.20	195.97	5.62	109 500.30	0.12	6.42
TOTAL	**129.00**	**528.26**	**13.49**	**262 976.81**	**0.28**	**15.41**

Nova Scotia Poultry

	Number of Birds ('000) Yearly production	Manure Production ('000 kg/day) Based on Standing flock)	Biogas Production ('000 m^3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Energy Value of biogas ('000 KW-hr/day)
Broilers	20 377.9	233.42	18.70	371 474.32	0.39	21.72
Nova Scotia Egg Production						
	Average Number of Layers('000)	**Manure Production ('000 kg/day)**	**Biogas Production ('000 m^3/day)**	**Heating Value ('000 Btu/day)**	**Heating Value ('000 GJ/day)**	**Energy Value of biogas ('000 KW-hr/day)**
Egg layers	322.00	30.43	1.43	29 236.96	0.03	1.66
Nova Scotia Turkey Production						
	Number of Birds ('000) Yearly production	**Manure Production ('000 kg/day) Based on Standing flock)**	**Biogas Production ('000 m^3/day)**	**Heating Value ('000 Btu/day)**	**Heating Value ('000 GJ/day)**	**Energy Value of biogas ('000 KW-hr/day)**
Turkeys	803.01	58.10	9.99	198 556.89	0.21	11.61

Total Inventory per Farm Type, Prince Edward Island

PEI BEEF

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Bulls	0,80	41,40	1,00	18 726,40	0,02	1,09
Milk cows	0.00	0.00	0.00	0.00	0.00	0.00
Beef cows	17,00	573,75	13,23	248 710,00	0,26	14,45
Milk heifers	0.00	0.00	0.00	0.00	0.00	0.00
Beef heifers - breeding	8,90	240,30	5,54	104 165,60	0,11	6,05
Beef heifers - slaughter	2,40	81,00	1,87	35 112,00	0,04	2,04
Steers	2,40	81,00	1,87	35 112,00	0,04	2,04
Calves	16,75	226,13	5,21	98 021,00	0,10	5,70
TOTAL	65,65	1 697,18	39,18	736 474,20	0,78	42,79

PEI DAIRY

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)	Heating Value (10^3 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas (KW-hr/day)
Bulls	0,20	10,35	0,44	8 299,20	0,01	0,48
Milk cows	15,70	812,48	24,26	456 041,04	0,48	26,60
Beef cows	0.00	0.00	0.00	0.00	0.00	0.00
Milk heifers	6,60	243,54	7,28	136 936,80	0,14	7,99
Beef heifers - breeding	0.00	0.00	0.00	0.00	0.00	0.00
Beef heifers - slaughter	0.00	0.00	0.00	0.00	0.00	0.00
Steers	0.00	0.00	0.00	0.00	0.00	0.00
Calves	8,33	112,39	4,59	86 363,55	0,09	5,04
TOTAL	30,83	1 178,75	36,58	687 640,59	0,72	40,10

PEI Swine Category	Number of animals '000	Manure Production (kg/day)	Biogas Production (m3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Boars 6 Months & Over	0,70	3,47	0,21	4 013,10	0,00	0,24
Sows and Gilts	13,00	193,05	4,10	79 852,50	0,08	4,68
Under 45 Lbs	46,20	47,82	1,36	26 486,46	0,03	1,55
45 Lbs. To 130 Lbs	39,50	124,43	3,57	69 553,58	0,07	4,08
Over 130 Lbs	32,60	167,24	4,79	93 447,90	0,10	5,48
TOTAL	132,00	536,00	14,02	273 353,54	0,29	16,02

PEI Poultry

	Number of Birds ('000) Yearly production	Manure Production ('000 kg/day) Based on Standing flock	Biogas Production ('000 m^3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Energy Value of biogas ('000 KW-hr/day)
Broilers	2 196.98	25.17	2.10	41 644.98	0.04	2.44
PEI Egg Production						
	Average Number of Layers('000)	**Manure Production ('000 kg/day)**	**Biogas Production ('000 m^3/day)**	**Heating Value ('000 Btu/day)**	**Heating Value ('000 GJ/day)**	**Energy Value of biogas ('000 KW-hr/day)**
Egg layers	113.00	10.68	0.50	10 260.37	0.01	0.60
PEI Turkey Production						
	Number of Birds ('000) Yearly production	**Manure Production ('000 kg/day) Based on Standing flock**	**Biogas Production ('000 m^3/day)**	**Heating Value ('000 Btu/day)**	**Heating Value ('000 GJ/day)**	**Energy Value of biogas ('000 KW-hr/day)**
Turkeys	0.00	0.00	0.00	0.00	0.00	0.00

Total Inventory per Farm Type, Newfoundland

NFLD BEEF

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Bulls	80	2 608,2	99,0	1 872 640,0	2,0	108,8
Milk cows	0.00	0.00	0.00	0.00	0.00	0.00
Beef cows	500	17 009,7	386,8	7 315 000,0	7,7	425,0
Milk heifers	0.00	0.00	0.00	0.00	0.00	0.00
Beef heifers - breeding	100	2 721,6	61,9	1 170 400,0	1,2	68,0
Beef heifers - slaughter	100	3 401,9	77,4	1 463 000,0	1,5	85,0
Steers	100	2 721,6	61,9	1 170 400,0	1,2	68,0
Calves	33	680,4	10,3	195 066,7	0,2	11,3
TOTAL	913	29 143,3	697,3	13 186 506,7	13,9	766,1

NFLD DAIRY

	Number of animals '000	Manure Production (' 000 kg/day)	Biogas Production ('000 m3/day)	Heating Value (10^3 Btu/day)[1]	Heating Value ('000 GJ/day)	Electricty value of biogas (KW-hr/day)
Bulls	0.02	1.04	0.04	829.92	0.00	0.05
Milk cows	4.30	224.30	6.60	124 902.96	0.13	7.28
Beef cows	0.00	0.00	0.00	0.00	0.00	0.00
Milk heifers	0.70	26.04	0.77	14 523.60	0.02	0.85
Beef heifers - breeding	0.00	0.00	0.00	0.00	0.00	0.00
Beef heifers - slaughter	0.00	0.00	0.00	0.00	0.00	0.00
Steers	0.00	0.00	0.00	0.00	0.00	0.00
Calves	0.03	0.45	0.02	345.80	0.00	0.02
TOTAL	5.05	251.83	7.44	140 602.28	0.15	8.20

NFLD Swine

Category	Number of animals '000	Manure Production (kg/day)	Biogas Production (m3/day)	Heating Value ('000 Btu/day)[1]	Heating Value ('000 GJ/day)	Electricty value of biogas ('000 KW-hr/day)
Boars 6 Months & Over	0.10	0.50	0.03	573.30	0.00	0.03
Sows and Gilts	0.30	4.46	0.09	1 842.75	0.00	0.11
Under 45 Lbs	0.70	0.72	0.02	401.31	0.00	0.02
45 Lbs. To 130 Lbs	0.80	2.52	0.07	1 408.68	0.00	0.08
Over 130 Lbs	0.70	3.59	0.10	2 006.55	0.00	0.12
TOTAL	2.60	11.79	0.32	6 232.59	0.01	0.37

NFLD Poultry

	Number of Birds ('000) Yearly production	Manure Production ('000 kg/day) Based on Standing flock	Biogas Production ('000 m^3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Energy Value of biogas ('000 KW-hr/day)
Broilers	8 600.02	98.51	7.06	140 226.34	0.15	8.20

NFLD Egg Production

	Average Number of Layers('000)	Manure Production ('000 kg/day)	Biogas Production ('000 m^3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Energy Value of biogas ('000 KW-hr/day)
Egg layers	322.00	581.53	20.90	29 236.96	0.03	1.66

NFLD Turkey Production

	Number of Birds ('000) Yearly production	Manure Production ('000 kg/day) Based on Standing flock	Biogas Production ('000 m^3/day)	Heating Value ('000 Btu/day)	Heating Value ('000 GJ/day)	Energy Value of biogas ('000 KW-hr/day)
Turkeys	0	0	0	0	0	0

Appendix 4:

Sample Calculations
Manure and Biogas Production

Poultry

For illustrative purposes: use Ontario - broilers

Yearly Production	**188 677 500** broilers
Population*	**34 305 000** broilers
Yearly Production	**647 163 825** lbs

There are 3 different sources for the inventory of chickens produced in Canada :
* Agriculture Canada Poultry Factsheets (population)
* Canada Census Data (population)
* Statistics Canada Data (Annual Production)

Assumptions:
*** 5.5 flocks/year for broilers**
*** 3 flocks/year for turkeys**
*** Standing flock (population) = 188,677,500/5,5 = 34 305 000**
*** Wt./animal = / 188,677,500 animals = 3.43 lbs/animal**

For broilers: the manure calculations are based animals that weigh 1 kg (2 lbs). Since it takes 38-40 days for broilers to reach ~1.5-2 kgs, only about half the population will weigh the amount that the manure calculations are based upon…. With this in mind, Agriculture-Canada data for poultry population was used since it corresponds with the other data as the proportion of mature animals.

Manure Production[1]

	Wt. of animal by category from above table (lbs)[1]	Wt of manure (lbs/animal/day)[1]
Broilers	2	0,14
Layers	4	0,21

See <American Midwest Handbook>: each 2 lb broiler chicken produces

Animal Wt (lbs)	Manure Production/day (lbs)	Manure Production (gals)
3	**0,14**	**0,018**

Total Manure production by weight = 0.14 lbs/day X 34,305,000 broilers = **4 802 700 lbs** **2 178 000 kgs** Per day

Manure Production by volume: 0.018 gallons/day x 34,305,000 broilers = **617 490** Gallons/day

Biogas Production:

There are different methods of estimating biogas production, 3 of which are presented here for illustrative purposes

a - Based on theoretical gas production rate of 13.3 ft3/;b of VS destroyed [where 1 lb COD stabilized = 5.62 of CH4 and assuming the CH4:CO2 ratio is 6-:40 and the conversion factor for VS to COD is 1.42]

b - Based on values from well managed commercial scale digesters. Biogas production rates 50% of these values have also been reported

Method 1:

***Method 1:** a - From 'Energy reclamation from Agricultural Waste', b - American Midwest Plan*

Volume of biogas (per lb of VSS added)[a]	**8,60**	ft3/day
VSS production/hen[b]	**0,025**	Lbs/day

Biogas Production = 0.025 lbs/day VSS X 34,305,500 poultry X 8.6 ft3/day biogas/lb of VSS

Biogas Production for Ontario Poultry = **7 375 575** **ft3/day of biogas**

Method 2:
From 'American Midwest Handbook'

Volume of biogas (per 1000 lb bodyweight)	**51**	ft3/day (per 1000 lb bodyweight)

Volume of biogas = 51 ft3/day/1000 lbs bodyweight X 34,305,000 broilers X 2 lbs/broiler

Biogas Production for Ontario Poultry =	**3 499110**	ft3/day of biogas	'best' value

Method 3:
From'Energy Reclamation from Agricultural Waste'

Volume of biogas (per 1000 lb bodyweight)	**110,9**	ft3/day

Volume of biogas = 110.9 ft3/day/1000 lbs bodyweight X 34,305,000 broilers X 3.43 lbs/broiler

Biogas Production for Ontario Poultry = **13 049 176** ft3

Energy Value:
See American Midwest Handbook

% methane	**60**	%
Heating Value per 1000 lb body weight:	**30 400**	Btu/1000 lb bodyweight
Heating Value / volume	**596**	btu/ft3
Energy = 30 400/1000 * 34 305 000 broilers x 3.43 lbs		
Energetic heating value (btu)	**3 577 050 960**	btu
1 GJ = 948,500 Btu		
Energetic heating value (GJ)	**3 771**	GJ

b - Conversion efficiency of 20% was assumed (for when the methane is burned in an internal combustion engine to drive an electric generator).So this is not a mere conversion from BTU to W-hrs, the effciency was already taken into account.

Energy value (KW-hrs/day)[b]

KW-hr/day per 1000 lb bodyweight	**1,78**	KW-hrs/day

Energy (# KW-hrs/day) = (1.78 KW-hrs/day)/1000 lbs body wt * 3.43 lbs/broiler* 34 305 000 broilers

Energy (KW-hrs/day)	**209 445**	KW-hrs/day

Beef

For illustrative purposes: use Quebec - beef cows

216 000 beef cows

Manure Production

See <American Midwest Handbook>: A 1250 lb beef cow produces

Animal Wt (lbs)	Manure Production/day (lbs)	Manure Production (gals)
1 250	**75**	**9,4**

Total Manure production by weight = 75 lbs/day X 216,000 beef cows = **16 200 000** lbs/day of manure

Manure Production by volume: 9.4 gallons/day x 216,000 beef cows = **2 030 400** gallons/day

1 - The estimate is an approximate value. " The actual characteristics of a manure can easily have values 20% or more above or below the table values. The volume of waste that a waste handling
system has to handle can be much larger than the table values due to the addition of water, bedding etc."

	Wt. of animal by category from above table (lbs)[1]	Wt of manure (lbs/animal/day)[1]
Bulls	2000 lbs	115
Beef cows	1250 lbs	75
Beef heifers - breeding	1000 lbs	60
Beef heifers - slaughter	1250 lbs	75
Steers	1000 lbs	60
Calves	500 lbs	30

Biogas Production:

There are different methods of estimating biogas production, 3 of which are presented here for illustrative purposes

Method 1:

Method 1: a - From 'Energy reclamation from Agricultural Waste', b - American Midwest Plan

Volume of biogas (per lb of VSS added)[a]	**6,70**	ft3/day
VSS production/beef[b]	**7,40**	lbs/day

a - Based on theoretical gas production rate of 13.3 ft3/;b of VS destroyed [where 1 lb COD stabilized = 5.62 of CH4 and assuming the
CH4:CO2 ratio is 6-:40 and the conversion factor for VS to COD is 1.42]

b - Based on values from well managed commercial scale digesters. Biogas production rates 50% of these values have also been reported

Biogas Production = 7.4 lbs/day VSS X 216,000 beef cows X 6.7 ft3/day biogas/lb of VSS

Biogas Production **10 709 280 ft3 of biogas**

Method 2:

From 'American Midwest Handbook'

Volume of biogas (per 1000 lb bodyweight)	**22**	ft3/day

Volume of biogas = 22 ft3/day/1000 lbs bodyweight X 216,000 beef X 1250 lbs/cow

Biogas Production = **5 940 000** ft3 best' value

= 178 000 m3

Method 3:

From'Energy Reclamation from Agricultural Waste'

Volume of biogas (per 1000 lb bodyweight)	39,5	ft3/day

Volume of biogas = 39.5 ft3/day/1000 lbs bodyweight X 216,000 beef X 1250 lbs/beef
Biogas Production = **10 665 000** ft3

Energy Value:
See American Midwest Handbook

% methane	**53**	%
Heating Value per 1000 lb body weight:	**11 700**	Btu/1000 lb bodyweight

Heating Value / volume **532** btu/ft3
Energy = 11,700 Btu/1000 lb bodyweight x 216,000 beef x 1250 lbs/beef
Energetic heating value (btu) **3 159 000 000** btu
1 GJ = 948,500 Btu
Energetic heating value (GJ) **3 331** GJ

Energy value (KW-hrs/day)[b]

KW-hr/day per 1000 lb bodyweight **0,68** KW-hrs/day
Energy (# KW-hrs/day) = (0.68 KW-hrs/day)/1000 lbs body wt * 1250lbs/beef* 216,000 beef
Energy (KW-hrs/day) **183 600** KW-hrs/day

b - Conversion efficiency of 20% was assumed (for when the methane is burned in an internal combustion engine to drive an electric generator). So this is not a mere conversion from BTU to W-hrs, the effciency was already taken into account.

Dairy

For illustrative purposes: use Quebec/category 2 – milk cows
426 000 milk cows

Manure Production

See <American Midwest Handbook>: A 1,400 lb milk cow produces

Animal Wt (lbs)	Manure Production/day (lbs)	Manure Production (gals)
1 400	**115**	**13,9**

1 - The estimate is an approximate value. " The actual characteristics of a manure can easily have values 20% or more above or below the table values. The volume of waste that a waste handling system has to handle can be much larger than the table values due to the addition of water, bedding etc."

	Wt. of animal by category from above table (lbs)[1]	Wt of manure (lbs/animal/day)[1]
Bulls	2000 lbs	115
Milk cows	1400 lbs	115
Milk heifers	1000 lbs	82
Calves	500 lbs	30

Total Manure production by weight = 115 lbs/day X 426,000 milk cows =	**48 990 000**	lbs/day of manure
Manure Production by volume: 13.9 gallons/day x 426,000 milk cows =	**5 921 400**	Gallons /day

Biogas Production:

There are different methods of estimating biogas production, 3 of which are presented here for illustrative purposes

***Method 1:** a - From 'Energy reclamation from Agricultural Waste', b - American Midwest Plan*

Volume of biogas (per lb of VSS added)[a]	**4,70**	ft3/day
VSS production/dairy cow[b]	**12,00**	lbs/day

a - Based on theoretical gas production rate of 13.3 ft3/;b of VS destroyed [where 1 lb COD stabilized = 5.62 of CH4 and assuming the CH4:CO2 ratio is 6-:40 and the conversion factor for VS to COD is 1.42]

b - Based on values from well managed commercial scale digesters. Biogas production rates 50% of these values have also been reported

Biogas Production = 12 lbs/day VSS X 426,000 boars X 4.7 ft3/day biogas/lb of VSS
Biogas Production **24 026 400** **ft3 of biogas**

Method 2:
From 'American Midwest Handbook'

Volume of biogas (per 1000 lb bodyweight)	**39**	ft3/day

Volume of biogas = 39 ft3/day/1000 lbs bodyweight X 426,000 milk cow X 1400 lbs/milk cow
Biogas Production = **23 259 600** **ft3 of biogas** 'best' value
697 788 m3

Method 3:
From'Energy Reclamation from Agricultural Waste'

Volume of biogas (per 1000 lb bodyweight)	**40,9**	ft3/day

Volume of biogas = 40.9 ft3/day/1000 lbs bodyweight X 426,000 milk cows X 1400 lbs/milk cow

Biogas Production =	**24 392 760**	**ft3 of biogas**
Energy Value:		
See American Midwest Handbook		
% methane	**54**	%
Heating Value per 1000 lb body weight:	**20 700**	Btu/1000 lb bodyweight
Heating Value / volume	**531**	btu/ft3
Energy = 586 X 127,400 ft3 =		
Energetic heating value (btu)	**12 345 480 000**	btu
1 GJ = 948,500 Btu		
Energetic heating value (GJ)	**13 016**	GJ
Electricity (KW-hrs/day) [b]		
KW-hr/day per 1000 lb bodyweight	**1,21**	KW-hrs/day

Energy (# KW-hrs/day) = 1.21/1000 lbs body wt * 1400 lbs/milk cow* 426,000 cows

Energy (KW-hrs/day)	**721 644**	KW-hrs/day

b - Conversion efficiency of 20% was assumed (for when the methane is burned in an internal combustion engine to drive an electric generator).

So this is not a mere conversion from BTU to W-hrs, the effciency was already taken into account.

Swine

For illustrative purposes: use Nova Scotia/category 1 – boars

500 Boars

Manure Production[1]

See <American Midwest Handbook>: A 350 lb boar produces

Animal Wt (lbs)	Manure Production/day (lbs)	Manure Production (gals)
350	**11**	**1,4**

Total Manure production by weight = 11 lbs/day X 500 boars = **5 500** lbs/day of manure

Manure Production by volume: 1.4 gallons/day x 500 boars = **700** gallons/day

1 - The estimate is an approximate value. " The actual characteristics of a manure can easily have values 20% or more above or below the table values. The volume of waaste that a waste handling system has to handle can be much larger than the table values due to the addition of water, bedding etc. For example, liquid waste systems for swine sowing and gestation units may have to handle twice as much volume as indicated; swine nurseries 3 to 4 times as much, because of large amounts of wash and wasted water."

*** Assumptions for other categories:**

sow and litter: ASAE data + 8 pigs at 1 lb/day

Class	Weight	Wt of manure (lbs/animal/day)[1]
Boars	350 lbs	11
Sows and Gilts	375 lbs	33
Under 45 Lbs	35 lbs	2,3
45 Lbs. To 130 Lbs	65 to 150 lbs	7
Over 130 Lbs	150 to 200 lbs	11,4

Biogas Production:

There are different methods of estimating biogas production, 3 of which are presented here for illustrative purposes

***Method 1:** a - From 'Energy reclamation from Agricultural Waste', b - American Midwest Plan*

Volume of biogas (per lb of VSS added)[a]	**7,30**	ft3/day
VSS production/swine[b]	**0,84**	lbs/day

a - Based on theoretical gas production rate of 13.3 ft3/;b of VS destroyed [where 1 lb COD stabilized = 5.62 of CH4 and assuming the CH4:CO2 ratio is 6-:40 and the conversion factor for VS to COD is 1.42]

b - Based on values from well managed commercial scale digesters. Biogas production rates 50% of these values have also been reported

Biogas Production = 0.84 lbs/day VSS X 500 boars X 7,3 ft3/day biogas/lb of VSS

Biogas Production **3 066** **ft3 of biogas**

Method 2:

From 'American Midwest Handbook'

Volume of biogas (per 1000 lb bodyweight)	**28**	ft3/day

Volume of biogas = 28 ft3/day/1000 lbs bodyweight X 13,000 boars X 350 lbs/boar

Biogas Production = **4 900** ft3 'best' value

147 m3

Method 3:
From'Energy Reclamation from Agricultural Waste'

Volume of biogas (per 1000 lb bodyweight)	**43**	ft3/day

Volume of biogas = 43 ft3/day/1000 lbs bodyweight X 500 boars X 350 lbs/boar
Biogas Production = **7 543** ft3

Energy Value:
See American Midwest Handbook

% methane	**58**	%
Heating Value per 1000 lb body weight:	**16 400**	Btu/1000 lb bodyweight

Heating Value / volume	**586**	Btu/ft3

Energy = 16 400/1000 lbs body wt X* 350 lbs/boar * 500 boars =

Energetic heating value (btu)	**2 870 000**	Btu

1 GJ = 948,500 Btu

Energetic heating value (GJ)	**3.0**	GJ

Electricity (KW-hrs/day)[b]

KW-hr/day per 1000 lb bodyweight	**0,96**	KW-hrs/day

Energy (# KW-hrs/day) = 0.96/1000 lbs body wt * 350lbs/boar* 13,000 boars

Energy (KW-hrs/day)	**168**	KW-hrs/day

b - Conversion efficiency of 20% was assumed (for when the methane is burned in an internal combustion engine to drive an electric generator).
So this is not a mere conversion from BTU to W-hrs, the effciency was already taken into account.

Diesel Oil Equivalent (DOE)

Energy (gallons DOE)/1000 lbs body weight	**0,11**	gallons DOE/1000 lbs bodyweight

Energy (gallons DOE) = 0.11/1000 lbs bodyweight * 350*13,000

Energy (gallons DOE)	**19**	galloons DOE/day

Appendix 5: Useful Contacts and Internet Links

Agricultural Biomass Residues and other statistics

(1) Statistics Canada Agricultural Data (Inventories of Dairy, Beef Pig, Sheep, Lamb, Poultry and Egg Production)
http://www.statcan.ca/english/Pgdb/Economy/primar.htm#agr

(2) Agricultural Census Data 2001 http://www.statcan.ca/english/Pgdb/Economy/census.htm

1996 http://www.statcan.ca/english/censusag/tables.htm

(3) Quebec Agricultural Insurance Data
http://www.raaq.gouv.qc.ca/produits_assurance/asrec/statistiques.html

Biological Materials characteristics
(1) Biomass Feedstock Composition and Property Database (including physical and chemical composition of agricultural residues. This database contains over 150 biomass samples).
http://www.ott.doe.gov/biofuels/progs/search1.cgi

Bioenergy Technologies
(2) The U.S. Department of Energy (DOE) National Biofuels Program
http://www.ott.doe.gov/biofuels/

(3) Energy Efficiency and Renewable Energy Network (EREN; U.S. DOE) http://www.eren.doe.gov/RE/bio_fuels.html

(4) Sustainable Energy Successes in Central & Eastern Europe http://www.zpok.hu/inforse/

(5) Biopower website (electricity from plant material) maintained by The U.S. DOE and EREN: Direct fired combustion, Co-firing, Gasification, Small Modular Biopower
http://www.eren.doe.gov/biopower/technologies/index.htm

Canadian Manufacturers of Appliances Designed for Pellet Combustion

Mr. V. Court
Grove Wood Heat Inc.
Little York, P.E.I. C0A-1P0
(902) 672-2090
Also a distributor of Finnish TP030 kW stove

Dell-Point Technologies
Blainville, Quebec
http://www.pelletstove.com

Mr. M. Frey
Maco Enterprises

R.R. 2, Drayton Ontario N0G-1P0
(510) 638-2746

Mr. T. Gunnel
Sylva Energy Systems Inc.
519 Richard St., Thunder Bay, Ontario P7A-1R2

Mr. B. Rosen
KMW Energy Systems
150 White Oak Road, London, Ontario N6E-3A1
(519) 686-1771

Canadian Consultants for Small-Commercial Biomass Combustion
Mr. Ron Braaten
Energy, Mines and Resources Canada
CCRL/CANMET
555 Booth St., Ottawa K1A-0G1

Mr. Charles LeMay
IRTA
P.O. Box 250, Clarence Creek, Ontario
K0A-1N0
(613) 448-2618

Mr. Bruce McCallum Ensight Consulting
Hunter River, PEI C0A 1N0
(902) 964-2297

Mobile Pelleting Equipment

Ecotre System
Via delle Cantoine, 12-50040
Settimello (Fl) Itlay
Tel. 39 55 8827441
Fax 39 55 8827441
E-mail: ecotresystem@tiscalinet.it

VIFAM Pro-Services Inc,
125 Boulevard Kirkland, QC
H9J-1P1
Tel. 514 426 4482
Fax: 514 695 0408