BIOMASS RESOURCE OPTIONS:

Creating a BIOHEAT Supply for the Canadian Greenhouse Industry

Phase I Research Report

Presented to

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Submitted by

Resource Efficient Agricultural Production (REAP)-Canada
Box 125 Centennial Centre CCB13,
Sainte Anne de Bellevue, Quebec, H9X 3V9

***Authors**: Stephanie Bailey-Stamler, Roger Samson and Claudia Ho Lem*

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Resource Efficient Agricultural Production (R.E.A.P.) - Canada

Box 125, Centennial Centre CCB13, Ste Anne de Bellevue, Quebec, Canada, H9X 3V9
Tel. (514) 398-7743; Fax (514) 398-7972; www.reap-canada.ca
Contact: Mr. Roger Samson; rsamson@reap-canada.com

REAP-Canada is an independent research, consulting and international development organization that has been working to support ecological food, fibre and energy systems since 1986. REAP is a world leader in developing bioenergy opportunities for rural development and greenhouse gas mitigation. In North America, Europe, Asia and Africa, REAP has created projects with the private and public sector to develop and commercialize dedicated bioenergy feedstocks and residues for biofuel applications, successfully completing over 20 biomass energy projects to date. REAP is currently working to develop bio-energy projects with farmers groups in Canada, China, Nigeria, the Gambia, and the Philippines.

Executive Summary

Greenhouse production in Canada is an energy intensive industry and is highly vulnerable to rising fossil fuel costs. In Quebec the industry is largely based on heating oil use while in Ontario, greenhouse producers are vulnerable to natural gas price peaks which coincide with the main heating period. Growers across Canada are seeking more economical alternative heating systems. British Columbia, Ontario and Quebec account for approximately 90% of the both the total greenhouse area and sales and are regions focused on for this report. This project analyzes the resource potential of low cost, greenhouse gas friendly biofuel energy resources as a substitute for fossil fuels in the main production areas in Canada. The biomass supply available for fuel switching for the greenhouse industry is highly region specific.

British Columbia is currently experiencing an over supply of wood residue due to the pine beetle outbreak. There appears to be abundant woody residue resources for making a conversion to biofuel heating and this is progressing well. The main problem appears to be logistics of getting the wood residue supply to the greenhouse producers in the southwestern corner of the province. It is likely that an expansion in the use of bark pellets could be realized in British Columbia. The BC forest industry in 2006 will produce 630,000 tonnes of largely residential wood pellets and the growth is expected to increase in wood pellet production. Some shipping of crop milling residues such as oat hulls from Alberta could also supplement the use of wood residues in greenhouse heating in British Columbia.

In Ontario and Quebec, the greatest biomass resource opportunity exists in the use of agri-fibres resources. Compared to British Columbia, greenhouse producers in the main production areas in these provinces have limited access to wood residue supplies and urban wood residue volumes appear to be modest. The greenhouse industry in both Ontario and Quebec are located within the major agricultural zones and access to agri-fibre residues is not hindered. The most promising agri-fibre biomass resources identified are crop milling residues, especially processing residues of the wheat, oat, and corn milling industries. These materials were generally of low to moderate cost and had few problems in terms of supply logistics or biomass quality for combustion. In the past year, approximately 30 Ontario farms and greenhouses have started to use oat hulls, pin oats, wheat mill feed and corn by-products for heat related energy applications. Especially in Ontario, large volumes of these milling residues are produced in close proximity to the main greenhouse industry. There are 26 medium to large crop milling industries in Ontario and 5 in Quebec producing wheat, corn or oats milling by-products. The most important residues identified were oat hull, wheat mill feed and corn bran. The potential quantity of crop milling residues that could be procured in Canada was assessed at 1,385,754 tonnes annually, most of which was produced in Ontario.

There also was considerable volumes of field crop residues that could be procured in Ontario and Quebec from corn and soybean fields. An estimated recovery of 2,143,076 tonnes annually could be achieved, with corn cobs and soybean stalks identified as the most viable feedstocks. The main problems with field crop residues are the supply logistics as the material is frequently wet at the time of crop harvest and the biomass quality in terms of combustion, appearing more problematic than for crop milling residues. There appears also to be some potential for whole plant corn to be harvested for greenhouse heating in mid winter in the more southerly regions of Ontario and Quebec. Very large volumes of energy crops could be grown in Ontario and Quebec with an estimated 14 million tonnes of warm season grass energy crops possibly produced. Another promising opportunity that was identified, particularly in the case of Ontario, was the development of combined heat and power (CHP) installations at large greenhouses using manure, corn silage and energy crops. Ontario's new renewable power purchase agreements could make these systems become viable. In Quebec there is an expanding bark pellet industry which is sold mainly in export markets. This material appears very competitive as a greenhouse heating fuel compared to the use of heating oil in the main greenhouse production area in the Montreal region.

A widely recognized problem with biomass quality with using agri-fibres is the high potassium and chlorine contents in the potential fuel sources. High levels of potassium and chlorine can lead to problems of clinker formation and corrosion inside the combustion unit. On average, crop milling residues contain 60% less potassium and 87% less chlorine than field crop residues. The crop milling residue with the best biofuel potential has been identified as oat hull as it has a very low value as a livestock feed and its increased use would likely not be affected by an upturn in farm commodity prices. Delayed harvest strategies for energy grasses and whole plant corn would eliminate any significant fuel quality combustion concerns with using these fuels in modern commercial greenhouse boilers.

In terms of supply, if it is assumed that the average greenhouse in Canada requires 10,000 GJ/ha of heat then the entire Canadian industry has a heat demand of 19.9 million GJ. Assuming a dry tonne of biomass contains 18.5 GJ/tonne, it would require 1.08 million tonnes of dry biomass or about 1 million tonnes to supply the British Columbia, Ontario and Quebec greenhouse industries. In total, the potential agri-fibre bioresources that could be made available dwarfs this requirement with up to 17.6 million tonnes annually produced through residue recovery or energy crop farming.

Financially, greenhouse producers could reduce their annual fuel costs by approximately 33% to 60% by switching from natural gas and heating oil to densified agri-fibre and woody biomass fuels. Many greenhouses in densely populated areas prefer using densified fuels as the supply logistics and clean combustion make it a preferable biofuel form for greenhouse producers. The 2545 Canadian greenhouse producers could save 150-200 million dollars annually in fuel costs if a complete fuel switching occurred. This would eliminate over 1 million tonnes of GHG emissions from the Canadian GHG inventory.

There appears to be no economic or supply barrier to create a large conversion of the Canadian greenhouse industry into biofuels. It is anticipated that the Canadian greenhouse industry will be the first major commercial heating industry in North America to make the large scale transition from fossil fuel heating to biofuel heating.

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1.0 Introduction

The rising costs of natural gas and heating oil combined with the need to develop "made in Canada solutions" to reducing our greenhouse gas emissions have created a strong rationale for a major fuel supply switch for the heat-intensive greenhouse industry. This report examines the possibilities of developing a large biomass resource supply for commercial heating of greenhouses. The purpose of this report is to examine the fuel supply options for the major greenhouse growing areas in Canada with emphasis on the southern areas of Ontario, Quebec and British Columbia. The focus of the analysis is on the quantity of various biomass resources available. It is widely recognized that not all biomass resources are easily used as heating fuels in commercial boilers. As such this report analyses certain biomass quality data. The report describes the diversity of available biofuels and identifies regionally which resources could be used for the Canadian greenhouse industry. Significant emphasis is placed on the potential use of agri-fibre fuel residues. The supporting rationale for agri-fibre residues as a biofuel option is that in eastern Canada there is a limited surplus of wood residue while both the greenhouse industry and the dominant agricultural regions are largely based in the southern areas of each eastern province. In western Canada, the British Columbia greenhouse industry has access to an abundant supply of wood residues due to the pine beetle outbreak, which is killing large areas of forest in the province. Historically, limited analyses have been conducted on the potential of agri-fuel resources as a fuel source for the commercial heating industry. In response, this report presents a comprehensive analysis of the agri-fuel potential for the Canadian greenhouse heating industry. In addition, the report examines the production potential of energy crop farming in Quebec and Ontario as a means to further increase the agri-fibre fuel supply thus enabling biofuels to become a major new energy source for commercial heating applications in Canada.

1.1 Overview of the Canadian Greenhouse Industry

The Canadian greenhouse industry is an important industry in the agri-food sector, it had retail sales of $2.2 billion dollars in 2004. The industry is divided into two main streams, vegetable production and ornamental flower and plant sales representing $727 million and $1.4 billion in sales respectively (Statistics Canada, 2006b). Greenhouses are located in all Canadian provinces, however, the primary concentration is in Ontario, Quebec and British Columbia. Together these three provinces account for approximately 90% of the both the total greenhouse area and sales (Table 1). In Canada there are 1989.1 hectares under greenhouse cultivation. Ontario is the largest producer with 52.5% of the greenhouse area, followed by British Columbia and Quebec with 25% and 12% respectively. Ontario and British Columbia have the largest sized operations with the average area under cultivation of about 0.9 ha, while Quebec and the rest of Canada are less than 0.35 ha (Statistics Canada, 2006b).

Table 1. Canadian Greenhouse Industry Statistics for 2005[1]					
Province	**Number of greenhouses**	**Total Area Plastic & Glass (ha)**	**Fruit & Vegetable Sales ($M)**	**Ornamental Flower & Plant Sales ($M)**	**Greenhouse Sales ($M)**
British Columbia	570	493.4	231	263	495
Alberta	345	115.6	30	79	110
Saskatchewan	165	23.2	0.65	21	22
Manitoba	130	24.7	0.20	3	31
Ontario	1200	1044.4	397	777	1,174
Quebec	775	235.2	61	165	227
New Brunswick	65	16.7			49
Nova Scotia	110	28.0	4	29	33
Prince Edward Island	10	2.1			1
Newfoundland & Labrador	55	5.9	0.17	6	6
Total Canada	*3425*	*1989.1*	*727*	*1,424*	*2,151*

[1]Statistics Canada, 2006b

The dominant vegetable crops grown in Canada are tomatoes, cucumber, sweet peppers and lettuce (Table 2). The ornamental flower and plant sales encompass cut flower production, potted plant production, cuttings and propagating material, and bedding plants. These are recorded by the number of stems and pots not by area and are therefore not directly comparable with the vegetable sector.

Table 2. Area of Major Greenhouse Crops in Canada (ha) 2005[1]				
Province	**Tomato**	**Cucumber**	**Sweet Pepper**	**Lettuce**
British Columbia	118	29	90	
Alberta	12	22	5.7	0.4
Ontario	254	154	119	3.2
Quebec	41	17	0.4	4.1
Nova Scotia	3.8	1.3		0.07
Total Canada	*431 (49%)*	*224 (26%)*	*215 (25%)*	*7.8 (0.8%)*

[1]Statistics Canada, 2006b

The greenhouse industry in all three major producing provinces, British Columbia, Ontario and Quebec, are located in the southern regions. The southern zones of these provinces have milder climates conducive to greenhouse production and are in close proximity to large domestic and U.S. markets. In British Columbia 95% of all greenhouse production is in the lower mainland district. The other 5% of greenhouses are located on Vancouver Island and the interior of British Columbia (BCAFF, 2003). Although most regions of Ontario have greenhouse production, 70% of the vegetable greenhouses are in the southern part of Essex County around the town of Leamington, which has the largest concentration of greenhouse vegetables in North America. Other prominent regions include the Niagara Peninsula and Haldimard-Norfold region (OGVG, 2006). Seventy-five percent of the floriculture industry is located in the counties surrounding the western end of Lake Ontario and the north shore of Lake Erie (Brown and Murphy, 2003). In Quebec, 70% of all greenhouse production is in the southern areas immediately surrounding Montreal and Quebec City. The remaining 30% is listed as "other regions" and mainly distributed in the south-west area of the province (Rioux, 2004).

The Canadian greenhouse industry saw a rise in total operation costs over the last year accounted for by a rise in payroll and fuel expenses. The fuel expenses rose 8% from the 2004-2005 year (Statistics Canada, 2006b) with the major heating costs occurring between the months of January and March, the coldest period of the year, when revenue is generally at its lowest. The majority of greenhouses in Ontario are heated with natural gas, usually purchased through producer-owned cooperatives. In Quebec, approximately 90% of greenhouses use heating oil (informal survey of farmers, January 2006). Furthermore in terms of energy demand the Quebec greenhouse industry is located in a cooler climatic area, which requires more winter heat demand than the industries in Ontario and British Columbia. In the past, British Columbian greenhouses relied heavily on natural gas, however most large growers are now switching over to biomass heating.

No data was sourced which described the average heat demand for the greenhouse industry in each province. A survey performed by the Quebec Institute for the Development of Ornamental Horticulture (IQDHO) in 2005 indicated some growers used approximately 12,410 GJ per year to heat one hectare of a greenhouse (Clement, M. Personal Communication, April 2006). The biomass fuel requirement for the conversion of the entire Canadian greenhouse industry would be significant given this number. If it is assumed that the average greenhouse in Canada requires 10,000 GJ/ha of heat then the entire Canadian industry has a heat demand of 19.9 million GJ. Assuming a dry tonne of biomass contains 18.5 GJ/tonne, 1.08 million tonnes of dry biomass or about 1 million tonnes would be required for the British Columbia, Ontario and Quebec greenhouse industries.

2.0 Biomass Supply

This section of the report addresses the existing biomass supply that could be directed for biofuel use for the greenhouse industry. We review recent data evaluating the wood residue availability from the forest processing industry along with issues surrounding the transportation of this bulky biomass. Assessments are made of field crop residues, such as corn stalk and soybean straw, as well as crop milling residues from the processing of crops such as wheat, oats and soybeans. Crop milling residues are generally dry and could be advantageous to blend with wet wood residues, used on their own or blended with grass pellets. Harvesting and transportation issues are also examined including costs associated with shipping wood pellets or agri-fibre fuel pellets from the Prairie Provinces into the southern areas of Ontario, Quebec and British Columbia.

2.1 Woody Biomass Supplies

An evaluation of the availability of mill wood residues in Canada in 2004 was prepared for Natural Resources Canada and the Forest Products Association of Canada[1]. We have highlighted the important data from this analysis that pertain to the availability of woody biomass residues and waste biomass resources for Ontario, Quebec and British Columbia.

Sawmills within British Columbia, Ontario and Quebec account for 81% of the forest residues produced in Canada (BW McCloy et al., 2005). Production of wood residues are typically dependant on the dominate wood industries. For example, the main forest industry in British Columbia is lumber production. British Columbia harvests 60% more lumber than Ontario and Quebec and produces the same amount of residue found in Quebec.

2.1.1 Current Surplus Residue

In British Columbia there was a surplus of 1.8 million BDt in 2004 with the demand for forest residues on the rise (Table 3). The increase in demand for forest residues has been offset by the increase in annual allowable cut (AAC) due to the mountain pine beetle infestation and the simultaneous increase in lumber production from the northern interior region mills. This upturn in forest harvesting and residue production is anticipated for the next 10 to 15 years. The abundance in supply is favouring the development of fibre processing industries and residues being used for bioenergy production.

[1]BW McCloy & Associates Inc. and Climate Change Solutions. 2005.Estimated Production, Consumption and Surplus Mill wood Residues in Canada-2004. A National Report. *Prepared for*, Natural Resources Canada, Canadian Forest Service Policy, Economics and Industry Branch and Forest Products Association of Canada. Nov. 2005. 60 pg. http://www.fpac.ca/Mill%20Residue/Mill%20Residue%20Inventory%20Canada_Final%20November%202005.pdf

Table 3. Selected Provincial Estimate Residue Surplus (2004)				
Province	**Lumber Production**	**Residue**		
	MMfbm	Production ('000 BDt)	Surplus ('000 BDt)	Estimated bark piles ('000 BDt)
British Columbia	13,994	6,554	1,815	N/A
Alberta	3,413	2,406	481	N/A
Saskatchewan	501	580	164	2,900
Manitoba	270	225	13	0
Ontario	3,698	2,602	121	6,712
Quebec	8,246	6,669	100	5,652
New Brunswick	1,712	1,373	0	257
Nova Scotia	756	601	13	148
Total	*32,590*	*21,010*	*2,707*	*15,669*

Source: BW McCloy et al., 2005

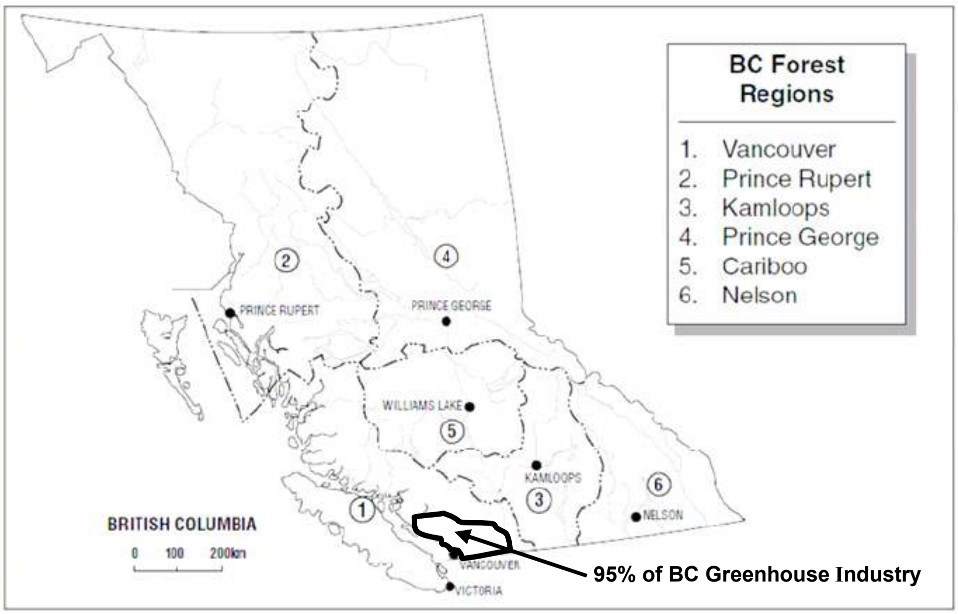
Ontario produces minimal levels of surplus residues, an estimated 121,000 BDt with an additional 6.7 million tonnes in potential bark resources (Table 3). It is predicted that wood supply will fall below industrial demand in 5-10 years. The predicted potential shortage in available wood residues has negative implications on sawmill production and the forest industry, however it may free up poor-quality wood for energy. The current environment has led to a highly competitive market for wood residues with customers paying premium prices and forcing traditional users to pay higher rates (BW McCloy et al., 2005). Quebec produced even less surplus residue in 2004 then Ontario with 100,000 BDt (Table 3). Approximately 5.6 million tonnes of potential bark resources are in piles. The decrease of the AAC by 20% for Quebec in 2005 will likely further decrease wood residue production. The impact of this reduction in combination with the rising Canadian dollar has led to significant closures in the wood processing industries.

2.1.2 Future Wood Residue Surplus

The current annual production of wood residue especially in Ontario and Quebec is almost completely committed and companies are now searching for non-traditional sources of residue. One type of "new" residue is the bark also referred to hog piles, which is the bark taken off during harvesting and/or processing. In the western provinces, this residue is frequently incinerated and no estimates of standing piles were available. In the eastern provinces these piles of residue were historically considered an environmental problem; however today companies are examining the potential of mining them for energy production (BW McCloy et al., 2005). Ontario is currently examining strategies to increase residue production through the recovery of forest floor residue following harvest. Forest-floor biomass has also become another area of interest as an energy source. Forest-floor biomass is the debris (branches and needles etc.) left behind after harvesting also referred to as slash. Harvesting methods that involve whole tree harvesting produce large piles of slash at the roadside of harvesting sites. In the past, these piles have been burned to free up land for future renewal and/or to prevent forest fires. The Ontario Ministry of Natural Resources is currently assessing the economic and environmental sustainability of this resource (BW McCloy et al., 2005).

2.1.3 Transportation Cost of Wood Residues

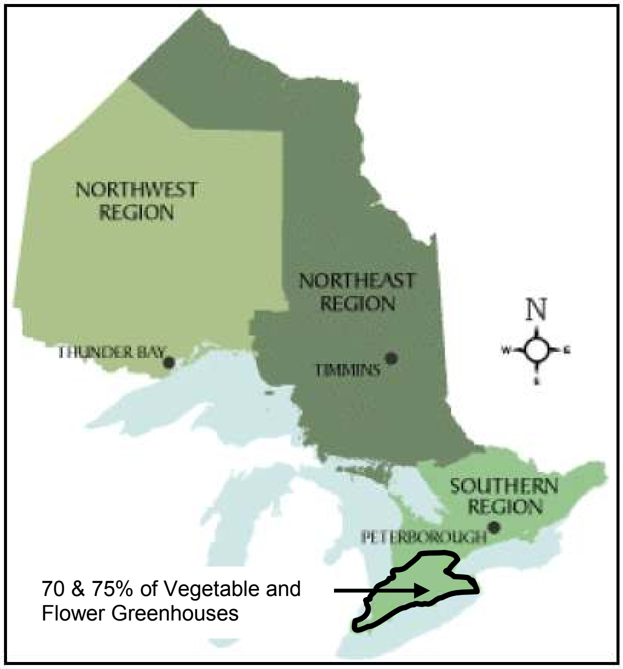
The transportation costs of shipping wood residues are essential in determining the value of the resource for the greenhouse industry. British Columbia has five regions (Figure 2) across the province with surplus wood residues, 80% of the residue is located in the northern interior of British Columbia (Regions 2, 4 and 5), however the greenhouse industry is in the surrounding Vancouver area, region one (Figure 1). Typically in western Canada transportation cost become excessive beyond a 200-km radius for wood residues used for power generation.



Source: (BW McCloy et al., 2005)

Figure 1: Forest Regions of British Columbia and location of the greenhouse industry

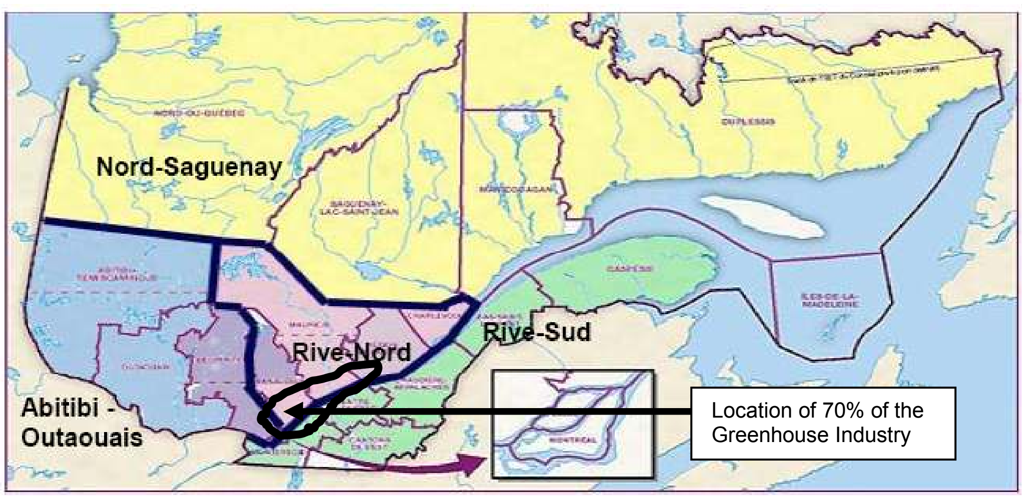
In Ontario 100% of the surplus residue and 95% of the estimated available bark piles are located in the northwest and northeast regions of the province (Figure 2). These wood residues are approximately 500-1200 km from the main greenhouse production zones in southern Ontario (Figure 2) and present a significant transportation issue. In Quebec 70% and 75% of the surplus wood residue and potentially available bark piles are located in the northern regions of the province (Nord-Saguenay, Abitibi-Outaouais, Rive-Nord regions, Figure 3). In eastern Canada sawdust is hauled around 500-km for the pulp-



Source: (BW McCloy et al 2005)

Figure 2**:** Forest Regions of Ontario and location of the greenhouse industry

digesters. However for both Ontario and Quebec the dominant wood residues are upwards of 1000-km away from the greenhouse industry (Figure 2 and 3). In terms of road transport of the raw residue this eliminates it as a potential fuel source. Furthermore, this type of wood residue is bulky and difficult to store and handle,



Source: (BW McCloy et al 2005)

Figure 3: Forest Regions of Quebec and location of the greenhouse industry

especially in the urban areas where the majority of greenhouses are located. A feasible option may be to pellet the bark fuel at the source (mills) and ship the material south by rail. In British Columbia at least 10 greenhouses are using wood pellets as fuel (Brand, P.

Personal Communication, March 16, 2006). In Quebec, several greenhouse producers have started using bark pellets. The Energex pellet plant in Lac Megantic currently produces 50,000 tonnes of bark pellets almost entirely for export. These bark pellets could be transported into the Montreal area greenhouse market for approximately $20/tonne in bulk trailers, or a delivered price of approximately $140/tonne. This is a promising material for helping develop a biofuel base to support the widespread conversion of oil heated greenhouses in Quebec to biofuel heating.

2.2 Wood Pellet Production

Wood pellets are produced out of wood waste such as sawdust and shavings. The material is dried and mechanically fractioned to size and then extruded under intense pressure into pellets. This process densifies the original waste by approximately 3.7 times and the product produced has a bulk density of 605 kg/m^3 (Samson et al., 2005) and a bulk storage factor of approximately 1.5-1.6 m^3/tonne (Melin, 2002). British Columbia had the highest pellet production of 490,000 MT in 2005 (Table 4). The outbreak of the mountain pine beetle and the projected increase of wood processing and residue has led to the expansion of the pelleting industry, particularly in northern British Columbia, with 2 new pelleting plants due to open in 2006-2007 (Swaan, J. Personal Communication, March, 17 2006). Quebec is second to British Columbia, with 175,000 MT of wood pellets produced annually, due to the high production of wood residue from the pulp and paper mill industry (Table 4). Both British Columbia and Quebec are presently increasing their production of pellets by an estimated 25% and 13% respectively. However, given the current situation with the Quebec forestry industry it is unsure if they will be able to meet the projected production target. Alberta, Ontario and Nova Scotia have only limited residues available, with less than 130,000 MT, with no projected increase in wood pellet production in 2006.

Currently, 1 million tonnes of wood pellets are used in industrial boilers and residential heating and over 600,000 tonnes are exported to the European market (Swaan, 2005). In 2005 over 500,000 MT and 120,000 MT of wood pellets were exported from British Columbia and Quebec destined for power generation and district heating in Europe (Swaan, 2005). In British Columbia and Quebec there likely is significant scope for using wood pellets as fuel for greenhouse heating as these provinces have significant pellet production and greenhouse heating industries.

Table 4. Canadian Wood Pellet Production in 2005 and projected production in 2006[1]				
Province	**Number of Plants**	**Production Capacity**	**Production 2005 (MT)**	**Projected 2006 (MT)**
British Columbia	6	625,000	490,000	630,000
Alberta	3	120,000	90,000	110,000
Ontario	4	80,000	80,000	80,000
Quebec	4	200,000	175,000	200,000
New Brunswick	1	20,000	15,000	15,000
Nova Scotia	2	150,000	130,000	130,000

[1]J. Swaan, Personal Communication, March 17, 2006) see Appendix 1

2.3 Urban Wood Recovery

Urban wood waste can include saw lumber, pruned branches, stumps and whole trees from street and park maintenance. The main components of urban wood waste are used lumber, shipping pallets, trees, branches and other wood debris from construction and demolition clearing and grubbing activities (USDA, 2002). In Canada 1.8 million tonnes of wood waste is produced annually from residential, industrial, commercial and institutional companies and construction, renovation and demolition industries (Statistics, 2004). This represents approximately 6% of total waste received at municipal solid waste landfills in Canada. Canada recovers 702,202 tonnes from the demolition and construction stream (Statistics Canada, 2004) of that anywhere from 19-34 per cent is wood waste amounting approximately 186,083 tonnes of recoverable wood (CG & S, 2000). However, these statistics do not take residential and municipality wood waste produced in urban centres. One company in Quebec is already using these resources for heat generation. Boralex in Montreal recycles 1,590,000 tonnes of forest residue a year along with approximately 70,000 tonnes from an urban recovery program in Montreal (Boralex, 2006). There is limited detailed information available about potential volumes of urban wood waste. However the volumes appear modest relative to agri-fibre biomass resources analyzed in this report.

2.4 Agri-fibre Inventory

It is evident that because of the relatively modest wood residue availability in Eastern Canada and the fact that the main greenhouse industries in Ontario and in southern Quebec are in agricultural regions, the use of agri-fibre fuel sources could be a major new opportunity. This section of the report focuses on the potential of agri-fibre residues as a fuel source in the greenhouse industry in British Columbia, Ontario and Quebec. The available field crop and milling residues in eastern and western Canada have been evaluated. In eastern Canada we focused on the most likely field crop residues to be utilized including corn stalks, corn cobs and soybean straw. We also analyzed by-products from the milling and oil crushing processes, for the wheat, oat, corn and soybeans crops. Crop production statistics were obtained from the Canadian Socio-economic Information Management System (CANSIM) from Statistics Canada.

Agricultural production from Ontario and Quebec (Table 5) and the Prairie Provinces (Table 6) from 2001 to 2005 was examined.

2.5 Agricultural land use and production in Ontario and Quebec

In Ontario and Quebec, the largest field crops in production are hay and grain corn. Quebec in particular is a large hay producer with 45% of its agricultural land base in hay crops. Annual field crops and their residues mainly have been targeted to date for biofuel applications and are examined in detail. Corn grain production consists of 5.4 million tonnes and 3.3 million tonnes in Ontario and Quebec respectively (Table 5). The second largest annual field crop in terms of acreage in both provinces is soybean. However volumes of the oilseed are much lower at 1.8 and 0.4 million tonnes annually (Table 5). Ontario also produces significant amounts of wheat, with approximately 1.6 million tonnes produced annually while Quebec is a relatively small wheat producer (Table 5).

Table 5. Average cultivated area, production, and yield of selected crops in Ontario and Quebec over the last 5 years (2001-2005)[1]

Grain	**Ontario**			**Quebec**		
	Area (1000 ha)	Yield (t/ha)	Production (1000 t)	Area (1000 ha)	Yield (t/ha)	Production (1000 t)
All Wheat	342	4.7	1618	46	3.2	149
Spring	53	3.5	186	45	3.2	143
Winter	289	4.9	1432	1.9	2.8	5.5
Oats	39	2.7	105	97	2.7	260
Barley	112	3.4	375	142	3.2	452
All Rye	25	2.3	56	1.6	2.0	3.2
Corn- Grain	728	7.5	5379	431	7.6	3259
Corn- Fodder	126	29.8	3742	46	32.9	1524
Soybean	868	2.1	1847	157	2.5	384
Tame Hay	948	5.1	4802	751	4.8	3638

[1]Statistics Canada, 2006a

An analysis of selected field crops as potential sources of agricultural biomass from the Prairies was also performed. In particular it is anticipated that crop milling residues from wheat and oat processing could become major fuel resources because of fuel quality advantages which are discussed in Section 5 of this report. The western provinces of Alberta, Saskatchewan and Manitoba were identified to have a total cereal production of 19 million tonnes of wheat and 9.8 million tonnes of oats (Table 6). Large volumes of both wheat and oat milling by-products could be generated for use in commercial heating applications. These milling residues could potentially be shipped to Ontario, Quebec and British Columbia greenhouses in a pellet fuel form. Whole grains are also transported outside of the prairies for milling, thereby generating significant volumes of milling residues within Ontario, Quebec and British Columbia.

Table 6. Average cultivated area, production and yield of selected crops in the three western Canadian provinces over the last 5 years (2001-2005)[1]									
	Alberta			**Saskatchewan**			**Manitoba**		
Grain	Area (1000 ha)	Yield (t/ha)	Production (1000 t)	Area (1000 ha)	Yield (t/ha)	Production (1000 t)	Area (1000 ha)	Yield (t/ha)	Production (1000 t)
All Wheat	2412	2.5	5962	5690	1.8	10007	1410	2.7	3706
Spring	1985	2.5	4985	3803	1.8	6715	1295	2.6	3290
Winter	37	2.9	110	67	2.3	149	102	3.7	385
Oats	270	2.5	681	592	2.0	1162	342	2.8	941
Barley	1558	2.9	4670	1685	2.3	3886	407	3.2	1287
All Rye	30	2.0	65	50	1.8	98	21	2.5	53
Corn- Grain	2.3	4.7	11	-	-	-	48	5.6	283
Corn- Fodder	13	36.2	460	-	-	-	21	26.5	367
Soybean	-	-	-	-	-	-	52	1.7	85
Tame Hay	2264	2.3	5284	1370	1.9	2727	856	3.1	2682

[1]Statistics Canada, 2006a

2.6 Agri-fiber Residue Supply

Potential volumes of agri-fibre residue from corn and soybean were determined using the production numbers from tables 5 and 6. For both corn and soybean straw residue a straw to grain ratio was used to determine the total quantity of residue produced. However, we determined the recoverable quantity of residue that could be harvested sustainably. Ontario could potentially produce 1.6 million tonnes of recoverable agri-fibre residue annually, followed by Quebec with 494,923 and Manitoba with 63,170 tonnes, respectively. (Table 7)

2.7 Potential of Selected Field Crop Residues in Ontario and Quebec

2.7.1 Corn Stalk

Corn is the largest field crop in both Ontario and Quebec and these provinces produce an estimated 5.1 and 3.1 million tonnes of corn stalk respectively. The quantity of actual recoverable residue available following sustainable management practices is estimated in Ontario at 319,360 tonnes and in Quebec 193,488 tonnes (Table 7) which represents 6.25% of the total production. Details on the quantity of recoverable corn stalk as well as recovery methods are addressed in section 4. The major problems associated with field corn residue utilization are the relatively high moisture content (Table 18) at fall harvest makes storing the feedstock impractical and the removal of this bulky biomass on wet soils in the fall problematic. As well, the high potassium and chlorine content of corn stalks at fall harvest would strongly suggest they are difficult to burn. Spring harvesting of stalks is the most likely possible approach to corn stalk utilization. At this time of the year the stalks are dry and the over-wintering period had leached out the chemical components improving biomass quality. Another possible approach to using corn could be whole plant harvesting in mid winter. This opportunity is discussed further in section 4.

Table 7. Average Total and Available Production of Corn Stalk and Soybean Straw by Province (2001-2005)						
Stalk & Straw Residue[1]	**Production (tonnes) by Province**					
	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia
Total Production						
Corn Stalk[2]	3,095,813	5,109,765	268,755	-	10,165	-
Soybean Straw[3]	575,625	2,770,875	67,350	-	-	-
Corn Cobs[4]	602,868	995,059	52,336	-	1,980	-
Recoverable Residue				-		-
Corn Stalk[5]	193,488	319,360	16,797	-	635	-
Soybean Straw[6]	-	831,263	-	-	-	-
Corn Cobs[7]	301,434	497,525	26,168	-	990	-
Totals						
Total Production	*4,274,306*	*8,875,700*	*388,442*	-	*12,145*	-
Total Recoverable	*494,923*	*1,648,153*	*42,965*	-	*1,625*	-

[1]Statistics Canada 2006a
[2]Corn Stover: Straw to grain yield 0.95 (Zan, 1998)
[3]Soybean Straw: Straw to grain yield 1.5 (Klass, 1998)
[4]Corn Cob: Cob to grain yield 0.19 (Zan, 1998)
[5]Recoverable straw and stalk is estimated at 20%
[6]Revoverable straw is estimate at 0% and 30% in Ontario and Quebec respectively
[7]Corn cob estimated recovery rate of 50%

2.7.2 Soybean Straw

Soybean straw residues in Ontario and Quebec are sizable in volume, with 575,625 and 2.7 million tonnes produced annually (Table 7). Soybeans do not produce large volumes of field crop residues compared to corn. After combine harvest, only 30% field cover remains in the field following soybean harvest which is just sufficient to adequately protect soils from erosion (OMAFRA 2002). The soil erosion problem could largely be avoided in Ontario if winter wheat can be no-till planted into soybean fields in the fall which will help protect fields from erosion. Currently most of the acreage of winter wheat in Ontario is planted after soybean using no-till methods. In Quebec and Manitoba, the soil erosion and soil organic matter loss problem from soybean stalks removal prevents their sustainable recovery. It is estimated that 30% of the Ontario soybean residue could be harvested sustainably. This would leave recoverable volumes of 831,263 tonnes in Ontario. The main advantage of soybean stalks are the stalks are relatively dry at the time of harvest and have a high energy content. Some producers are already collecting small volumes of soybean stalks for use as livestock bedding. However, there could be significant potential for recovery of this resource if energy markets for the material could be developed.

2.7.3 Corn Cobs

In Ontario there are 1.0 million tonnes and in Quebec 600,000 tonnes of corn cobs produced each year (Table 7). Corn cobs represent an interesting feedstock as they tend to be drier at harvest than corn stalks, they have a reasonably good energy density and the cobs can be collected at harvest in modified combines or through whole ear harvest and storage in cribs. It is estimated that 50% of this resource could be sustainably recovered if a market for the material can be developed in the commercial heating industry. The total recoverable resource is estimated at 497,525 and 301,434 tonnes for Ontario and Quebec respectively.

2.8 Crop Milling Residues Processed in Canada

This section of the report analyses the total production of crop milling residues from the Canadian agricultural sector. It places a strong analysis around crop milling residues which appear to be a valuable low cost fuel resource and have distinct combustion advantages compared to field crop residues. Almost all of the crop milling residues are presently used in the livestock feed industry. Use in biofuel heating, will therefore be dependent on providing a stronger economic incentive to use these materials than their market value in the feed industry. An inventory was performed of the corn, oat, wheat and soybean milling industries in British Columbia, Ontario and Quebec.

2.8.1 Wheat Processing

Wheat milling uses 70-75% of the grain for flour production and the remaining 25%-30% of the grain is available as wheat by products commonly referred to as millfeed, wheat mill run or wheat middlings[2]. Generally there is no separation between the different names of wheat by products and as a consequence the inconsistency in terminology presents difficulties in establishing quantities (Blasi et al., 1998). For the purpose of our report we will use the term millfeed. A portion of the millfeed is used for human consumption in the form of wheat bran, while the majority is used in the livestock feed industry. Saskatchewan can potentially produce 2.8 million tonnes of millfeed annually, followed by Alberta and Manitoba at 1.6 and 1 million tonnes (Table 8). Ontario and Quebec combined only have the potential to produce 1.3 million tonnes of millfeed. However, wheat is shipped across country or exported and milled where demand requires. Ontario, for instance, grows 8% of Canadian wheat but processes 40% of all wheat processed in Canada (Table 9). The province processes its own winter wheat as well as imported western wheat.

Table 8. Average Total Production of Milling Residues from Selected Crops by Province (2001-2005)

Milling Residues[1]	**Production (tonnes) by Province**					
	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia
Millfeed[2]	886,875	444,943	1,019,266	2,752,014	1,639,481	15,393
Oat Hull[3]	62,460	25,170	225,876	278,802	163,506	13,458
Pin Oats[4]	28,628	11,536	103,527	127,784	74,940	6,168
Soybean Hulls[5]	38,375	184,725	8,505	-	-	-
Totals						
Milling Residue	*733,218*	*1,661,434*	*1,409,511*	*3,158,600*	*1,879,907*	*35,019*

[2] Blasi, D.A., Reed, C.J, Kuhl, G.L., Trigo-Stockli, D.M., Drouillard, J.S., Behnke, K.C., Fairchild, F.J.1998. Wheat middlings: compositon, feeding value, and storage guidelines. Kansas State University Agri. Experiment Station and Cooperative Extension Service. p 21.

[1]Statistics Canada 2006a
[2]Millfeed 27.5% of unprocessed grain (Blasi et al., 1998)
[3]Oat hull: 24% of unprocessed grain (Brown et al., 2001)
[4]Pin Oats: 11% of unprocessed grain (Nott, D. Personal Communication, April 2006)
[5]Soybean hulls: 10% of unprocessed grain (Forbes, R. Personal Communication, March 23, 2006)

The majority of the mills in Ontario are located in the southern part of the province in the major cities close to the majority of greenhouse growers (Appendix 3). A total volume of 391,029 tonnes of millfeed are produced in Ontario (Table 9). Furthermore, just south of the border in Buffalo, New York there is an additional 219,589 tonnes of millfeed produced a year. This makes the available fuel resource for the greenhouse industry at approximately 610,618 tonnes a year. Quebec also is a major producer of millfeed, representing 24% of all Canadian wheat milling or 201,071 tonnes respectively. British Columbia is a relatively small processor with only 4 % of the millfeed available in Canada (Table 9). Alberta, Saskatchewan and Manitoba process a combined total of 1,067,322 MT or 30% of the wheat processed in Canada (Table 9).

The average millfeed price in Canada over the last two years ranged from $63-$79 in provinces processing more than 1000 tonnes daily (Table 11). This represents the largest, relatively low cost biofuel resource in close proximity to the main greenhouse industry in Canada. Typically millfeed was the cheapest in Ontario ($64.57) followed by Quebec ($78.54) and the most expensive in British Columbia ($107.79; Table 11). The tendency for millfeed to be more expensive in Quebec is related to the subsidizing of feed crop commodities in the province as well as most wheat is imported. The majority of wheat in British Columbia is imported from the prairies and the shipping costs increase the cost of the residue.

Table 9. Estimated Yearly Wheat Processing and Millfeed Production by Province

Location	Wheat					Millfeed		
	Daily Capacity (tonnes)[1]	Estimated storage (tonnes)[1]	Estimated processing (tonnes)	Average feed wheat selling price (2 yr)	Feed wheat selling range (5 yrs)	Estimated millfeed residue (tonnes)	Average millfeed selling price/tonne (2 yr)[2]	Millfeed selling range/tonne (5 yrs)[2]
British Columbia	625	7,020	182,500	$131.40	$130-225	40,150	$107.79	$106-170
Alberta	2,531	32,805	739,052	$107.76	$104-194	162,591	$68.96[3]	N/A
Saskatchewan	1,223	36,204	295,292	$97.81	$96-175	64,964	$62.60[3]	N/A
Manitoba	434	2,160	126,728	$134.31	$131-176	27,880	$85.96[3]	N/A
Ontario	6,087	291,640	1,777,404	$113.72	$109-180	391,029	$64,57	$63-117
Quebec	3,130	265,815	913,960	$148.83	$137-237	201,071	$78.84	$78-140
Nova Scotia	436	30,375	127,312	$174.58	$169-252	28,009	$297.50	$285-298
Buffalo, NY	3,038	272,700	998,131			219,589		
Overall	*12,909*	*625,599*	*4,162,248*	*$129.77*	*$96-$252*	*915,695*	*$63-298*	*$63-298*

Assumptions: Based on 90% utilization of capacity and 22% of the grain available as millfeed
[1] World Grain 2006 and Market Analysis Division, 2006a
[2]Market Analysis Division, 2006b and Independent milling processors (Appendix 3)
[3]Calculated by using a 64% cost difference from feed grain to millfeed residue

2.8.2 Oat Processing

Oats are processed for human consumption as rolled oats or when cleaned and processed for horse feeding produce pin oats (small sized oats) and oat hulls as by products. There is a combined estimate of 41,000 tonnes of pin oats produced from oats grown in Ontario and Quebec (Table 8). In addition to the pin oats Ontario and Quebec potentially produces 87,000 tonnes of oat hull annually (Table 8). Alberta, Saskatchewan and Manitoba theoretically produce 307,000 tonnes of pin oats (Table 8). These western provinces produce a much larger volume of oat hulls than eastern Canada with 668,000 tonnes of oat hulls annually (Table 8). The above estimates of oat residue production are based on the quantity of oats grown in each province, however oats are not always processed where they are produced. For example prairie oats are transported east to Ontario for processing in Peterborough, Ontario.

Eighty percent or 588,088 tonnes of oat processing is performed by large milling companies in western Canada (Table 10). Modest volumes of oats are produced in Ontario and even smaller volumes in Quebec. However, Ontario and Quebec import 75,920 tonnes of oats for processing from western Canada, producing 25,054 tonnes of oat hull annually (Table 10).

Oat hulls are a relatively cheap fuel source ($10-$35/tonne) and compared to the cost per tonne of wheat millfeed they are on average much cheaper on a cost per GJ basis. Additionally, the benefit of oat hulls is that they have amongst the lowest feed value of a crop milling industry by-product, which translates to little competition for livestock feed uses. There is potential to export oat hull pellets from Manitoba and Saskatchewan into Ontario and Quebec. Alberta oat processors could potentially export oat hull pellets into the British Columbia market. They could be a useful fuel for blending with wet wood waste commonly available in BC.

Table 10. Estimated Yearly Oat Processing and Oat Hull Production by Province

Province	Oats					Oat Hull		
	Daily Capacity (tonnes)[1]	Estimated storage (tonnes)[1]	Estimated processing (tonnes)	Average Oat selling price (2yr)[2]	Oat selling range (5 yr)[2]	Estimated Residue (tonnes)	Average Ground Oat hull selling price/tonne (2yr)[3]	Ground Oat hull selling range/tonne (5 yr)[3]
Alberta	440	11,060	128,480	N/A	N/A	42,398	N/A	N/A
Saskatchewan	1,074	19,194	313,608	$129,99	$129-213	103,491	$20,00	$10-35
Manitoba	500	5,250	146,000	$140,01	$131-203	48,180	$20,00	$10-35
Ontario	260	60,200	75,920	$203,92	$196-310	25,054	N/A	N/A
Overall	*2,274*	*95,704*	*664,008*	*$157,97*	*$129-$310*	*219,123*	*$20,00*	*$10-35*

Assumptions: Based on 90% utilization of capacity and 33% of the grain available as oat hull
[1]World Grain 2006 and Market Analysis Division 2006a (Appendix 4)
[2]Market Analysis Division 2006c
[3]Nott (Personal Communication, April 2006)

2.8.3 Soybean Processing

Soybeans production represents a sizeable acreage in Ontario and Quebec. During the crushing process the hull of the soybean, representing approximately 10% of the whole bean, is removed[3]. Eighty-three percent of the soybeans processed in Canada or 1.84 million tonnes, come from Ontario (Table 5). The remaining 17% corresponding to 384,000 tonnes of soybeanss are produced in Quebec (Table 5). The majority of soybean produced and processed in Canada occurs in Ontario. There is additional processing in Quebec, however processing volumes were not able to be determined. According to industry data, Ontario produces 200,531 tonnes of soy hull annually (Table 11). However not all of the soybean hull is readily available for sale from the soybean processing mills as some mills blend it back into soybean meal sold to the feed industry. Soybean hull generally has a higher feed value than oat hulls or wheat middlings thus its energy use is likely to be somewhat modest relative to its feed applications.

Table 11. Estimated Yearly Soybean Processing and Soy Hull Production by Province

Province	**Soybean**				**Soy Hull**	
	Daily Capacity (tonnes)[1]	Estimated processing (tonnes)[1]	Average Soybean selling price (2005)[2]	Soybean selling range (2005)[2]	Estimated Residue (tonnes)	Soy hull selling price (2yr)[3]
Ontario	6,700	2,005,310	$241.66	$219-289	200,531	$110.00
Quebec	N/A	N/A	N/A	N/A	N/A	N/A
Overall	*6,700*	*2,005,310*	*$241.66*	*$219-$289*	*200,531*	*$110.00*

Assumptions: Based on 82% utilization of capacity and 10% of the grain available as soy hull
[1]Market Analysis Division, 2006a along with independent milling contacts (Appendix 5)
[2]Bakker 2005
[3]Confidential. Personal communication. March 23, 2006

Soybean hulls are an important source of protein for the feed industry and this is reflected in the significantly higher cost per tonne ($110.00; Table 11) than wheat and oat residues. Soybean hull are commonly pelleted in the US and Canada and used as a filler in livestock feed manufacturing. It is unlikely that soy hull would be a major biomass source for the greenhouse industry, due to the high cost of the residue, the importance it plays in the livestock feed industry and the relatively modest volumes produced.

2.8.4 Corn processing

The goal of corn milling is to separate the germ, fibre, protein and starch constituents from the kernel[4]. The primary component to be isolated is starch which is sold directly or converted into ethanol. Starch is commonly dried and sold as-is or converted to a wide

[3] Blasi, D., Drouillard, J., Titgemeyer, E., Paisley, S. and Brouk, M. 2000. Soybean Hulls: Composition and feeding value for beef and dairy cattle. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. p 16. <http://www.oznet.ksu.edu/library/lvstk2/mf2438.pdf>

[4] Blasi, D., Drouillard, J., Brouk, M. and Montgomery, S. 2001. Corn Gluten Feed: Composition and feeding value for beef and dairy cattle. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. p 14. http://www.oznet.ksu.edu/library/lvstk2/mf2488.pdf

variety of products, including corn syrups and high fructose corn sweeteners. By products produced from the milling include bran, broken kernels, germ residue after oil extraction, and inseparable fractions of germ, pericarp, and endosperm (Stock et al., 1999). These materials are either sold separately or mixed and sold into the feed industry as corn gluten feed or corn gluten meal. Corn gluten feed is the part of the shelled corn that remains after the extraction of the large portion of the starch, gluten and germ. It is composed primarily of bran and steep liquor (liquid separated after steeping). It can contain up to 40-60% bran. As a livestock feed it is lower in quality than corn gluten meal and hence it is the lowest priced corn by-product in the marketplace. It is lower in crude protein (14-24%, DM basis) and valuable rumen by-pass protein than corn gluten meal (Stock et al, 1999). Corn gluten meal is a dry feed ingredient made from the protein remaining after the removal of starch and bran from the corn. It is possible to obtain the corn bran separately (not added to the gluten feed). Corn bran is the outer coating of the corn kernel, with little or none of the starchy part of the germ (Stock et al., 1999) and represents 15% of the total grain (Braisher et al., 2006). During the milling processes corn kernels become cracked and/or broken, these remnants are pooled together into what is know as corn screenings. Approximately 4% corn screenings are produced from each tonne of corn processed (Peak, J. Personal Communication, August 2005).

Limited information is available on corn processing volumes in particular with corn bran, however data was obtain from two of the major starch producing companies in Ontario. It is therefore estimated that in Ontario a minimum of 195,129 tonnes of corn bran and approximately 55,807 tonnes of corn screenings could be recovered from the corn starch milling industry in Ontario. This material is currently being developed by Evergreen biofuels and partner companies as a fuel pellet resource in Ontario (Drisdelle, M. Personal Communication. May, 2006).

Table 12. Estimated Yearly Capacity for Corn ethanol and starch and sweeteners in Ontario[1]

Processing	Corn				Residue		
	Daily Capacity (tonnes)[1]	Estimated processing (tonnes)[1]	Average Corn selling price (2005)[2]	Corn selling range (2005)[2]	Residue Type	Estimated Residue (tonnes)	Residue selling price (2yr)[1]
Starch & sweeteners	4,200	1,226,400	$97.49	$90-$105	Bran	195,129	$100.00
					Corn Screenings	55,807	$100.00
Overall	*4,200*	*1,226,400*	$97.49	$90-$105		*250,936*	

[1]World Grain 2006, Market Analysis Division, 2006a and independent milling contacts (Appendix 6)
[3]Market Analysis Division, 2006d

2.9 Residue Transportation Feasibility

In order to determine the feasibility of transporting milling residues we performed an analysis on the cost of shipping western feed wheat across the country. The dominant trends found was that shipping wheat to Quebec and eastern Ontario from Manitoba and Saskatchewan was similar in price and cheaper than shipping to London, Ontario. It was more expensive to ship wheat west from Manitoba and Saskatchewan to Vancouver British Columbia.

Table 13. Transportation costs (CAD) to ship wheat per tonne by CPR rail.

Origin	Shipping Destination				
	British Columbia	Ontario			Quebec
	Vancouver	London	Hamilton	Port Colborne	Montreal
Thunder Bay, ON	NA	29.14	26.00	26.00	26.04
Winnipeg, MB	64.87	54.67	51.32	51.32	51.36
Brandon, MB	61.97	57.45	54.10	54.10	54.13
Saskatoon, SK	50.83	61.08	57.73	57.73	57.77
Golden Prairie, SK	47.92	62.12	58.77	58.77	58.81

[1]Source: CPR 2006.
[2]Assumptions: based on hopper with carrying capacity (132 m^3) or 88 tonnes, fuel surcharge of 10.5%

The cost of shipping millfeed from Manitoba, or Saskatchewan to Ontario or Quebec would be approximately $56.32 per tonne. In order for this to become a viable option the cost of millfeed in Ontario and Quebec would need to be above $120.90 and $135.17, respectively. Millfeed prices change depending on the market demand and have ranged from $69-$117 in Ontario and $78-$140 in Quebec in the last five years (Table 9), therefore given seasonal variation over the year it may be possible to ship additional millfeed east to Ontario and Quebec. The cost of millfeed in British Columbia is on average $107.79 and the cost to ship a tonne of millfeed from Saskatchewan and Manitoba to British Columbia is approximately $56.40, for a minimum selling price of $164.18 per tonne. The range of millfeed in British Columbia has been between $106-$170 in the last five years (Table 9), so again it is possible but not probable given the wood pellet market. Given that millfeed has approximately the same energy content and quality as feed grains it appears to be a likely candidate for fuel use if grain commodity prices are relatively low. If prices rice, millfeed may still be useful as a binding agent in pellet production

Oat hull is significantly cheaper compared to millfeed, costing approximately 15-20% the cost of the oat grain itself (Table 10). Oat hull ranged from $10-35/tonne in the last two years, if we include the cost of shipping oat hull from Saskatchewan and Manitoba to Ontario and Quebec, oat hull would sell at approximately $66.33-91.33. Similarly oat hull would have a minimum selling price of $66.40-$91.40 in British Columbia. Because of the low cost it is feasible to ship it in a pelleted form from the prairies to British Columbia and Ontario and Quebec.

The current availability of local or regional processing facilities for drying, densifying, pelletizing, and storing biomass are listed in Appendix 2. As well, many feed mills (perhaps more than 100) in Canada can process crop milling residues into pellets. The average cost to pellet crop milling residues varies from region to region. In western Canada it costs approximately $10-12 dollars a tonne and in eastern Canada $15-20 a tonne to pellet crop milling residue (Confidential. Personal Communication, April 2006). Producing wood pellets are significantly more expensive, costing approximately $39 a tonne if no drying is required (Mani et al., 2006). The major cost factor to make biomass pellets economical is low raw material costs. By using a low cost milling residue, agri-fibre pellets could potentially be produced for approximately $120-140/tonne in the main greenhouse producing areas.

3.0 Energy Crop Farming

Agriculture presents significant opportunities for the development of biomass feedstocks for the emerging bioenergy industry. Along with the use of agricultural residues as pellet feedstocks, dedicated perennial energy crops offer an important land use strategy that may create demand enhancement for the agricultural market as farmers diversify and shift production towards energy products from food products.

3.1 Potential for Energy Crop Production in Quebec and Ontario

An evaluation of the production potential of switchgrass and other grasses for use as energy feedstocks in Ontario and Quebec was performed. It was found that there is a large potential area of agricultural land suitable for switchgrass production in Ontario and Quebec, and as provincial energy consumption continues to increase, so will the demand for sustainable biofuels. Crop lands currently dedicated to the production of wheat, oats, barley, rye, corn and soybean or marginal lands are ideal for switchgrass production due to the low value return for these commodities in international and local markets. Converting 20% of these lands to biomass production would allow the development of a significant bioenergy industry.

The conversion of forage lands to dedicated energy crop production may be an attractive option due to the decline of the beef industry in eastern Canada. As producing livestock in western Canada is significantly more economical, the industry is no longer competitive in the east. In eastern Canada converting up to 40% of lands currently used for forage production (including tame hay and improved pasture) into perennial bioenergy feedstocks is emerging as an interesting new option.

The U.S. Department of Agriculture recently performed an analysis of the economic potential of biofuels and determined that bioenergy crops could be produced at a profit greater than existing agricultural uses for the land while also raising traditional crop prices (Walsh et al., 2003). The study illustrated that a conversion of 10% of existing crop, pasture and fallow land in the U.S. to bioenergy crops could produce 171 million tonnes of biomass while increasing crop prices by up to 14% above baseline values.

3.1.1 Energy Crop Yields

Warm season grasses are ideally suited to become a primary energy feedstock for the greenhouse heating industry in Ontario and Quebec because this industry is largely situated in the southern portions of the provinces, regions that are favorable for warm-season grass production and the regions lack wood residues.

Most efforts in the development of warm season grasses have been focused on the production of switchgrass, a native warm season grass in Canada. Switchgrass was chosen as a model herbaceous energy crop species in the early 1990's by the U.S. Department of Energy as it had a number of promising features including its moderate to high productivity, adaptation to marginal farmlands, drought resistance, stand longevity, low N requirements and resistance to pests and diseases (Samson and Omielan, 1994; Parrish and Fike 2005). Prairie cordgrass is another warm-season species that could prove more productive on all soils and is especially well adapted to poorly drained soils in Ontario and Quebec. Cool season grasses could also be produced in southern Ontario and Quebec but these are generally less productive, have higher N requirements and have lower quality in combustion applications.

Yield data for switchgrass has been collected in southern Ontario and Quebec since 1992 as part of project partnerships between REAP-Canada, McGill University and Alfred College of Guelph University. The switchgrass variety Cave in Rock has proven to be one of the more adapted and productive varieties for this region with yield data collected from various locations including Guelph and Alfred in Ontario and Ste Anne de Bellevue in Quebec. Field yield assessments have also been made from commercial fields in eastern Ontario and south western Quebec. A summary of the fall harvested yield data from the variety *Cave-in-Rock* from these Canadian trials can be found in Table 14.

Table 14. Summary of fall harvested switchgrass yields from the variety Cave in Rock in Canada

Location	**Average Yield (ODT/ha)**		**Comments**
	First Production Year Crop	**Fully Established Crop**	
Small plot yields			
Alfred Ontario [1]	7.2	10.0	Established crop 2 yr. average, sandy soil
Alfred Ontario [1]	4.5	12.8	Established crop 2 yr average, clay soil
Ste Anne de Bellevue, Québec [4]	10.9	13.3	Established crop 2 yr average, sandy loam
Semi-commercial fields (>2 ha)			
Guelph Ontario [3]	8.1	-	First year crop data only available
Ste Anne de Bellevue Québec [1]	8.8	11.9	Established crop 6 yr. average, sandy loam
Commercials fields (>5 ha)			
Valleyfield, Quebec[2]	9.0	10.5	Established crop 2 yr. average, clay loam
Berwick, Ontario [2]	6.1	10.8	Established crop 2 yr. average, clay loam
Production Average	**7.8**	**11.6**	
Overall Average	**9.4**		Assuming a weighted average of the first production year and 5 years established crop together with no harvest the year of seeding.

[1]Jannasch et al.., 2001
[2]Samson et al., 1999
[3]Samson et al., 1995
[4]Madakadze et al., 1998

In comparison, the United States Department of Energy estimates average regional switchgrass crop yields to be 10.9 (Mg/ha/yr) (7.9-12.4) for the Northeast, 10.8 (7.9-13.5) for the Lake States and 13.4 (11.1-15.1) for the Corn Belt (Walsh et al., 2003).

3.1.2 Land Availability for Energy Crop Farming

This analysis examined land use throughout the country, accounting for hectares in improved pasture and summer fallow (Table 15), and tame hay and crops including wheat, oats, barley, rye, corn and soybean (Tables 4 & 5 above). Saskatchewan has the largest total farm area follow by Alberta, Manitoba, Ontario and Quebec (Table 15).

Table 15. Canadian farm land area use						
Land Use (ha)	**Region**					
	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	British Columbia
Summerfallow	4,860	14,235	255,733	3,131,640	1,235,592	36,765
Improved Pasture[2]	182,841	313,085	383,474	1,405,734	2,230,892	233,044
Unimproved Pasture	185,905	531,892	1,580,374	5,126,442	6,678,899	1,207,553
Total Cropland[3]	1,849,938	3,656,705	4,714,830	15,375,929	9,728,181	617,545
All Other[4]	1,193,482	1,950,316	667,369	1,225,600	1,193,923	429,211
Total Farm Land[5]	***3,417,026***	***5,466,233***	***7,601,779***	***26,265,645***	***21,067,486***	***2,587,118***

[1]Statistics Canada, 2001
[2]Includes all tame and seeded pasture lands
[3]Includes all crops except Christmas tree production
[4]Includes Christmas tree production
[5]Includes farm land for all farms reporting income from agricultural production

3.1.3 Energy Grass Production Potential of Ontario and Quebec

Using the land areas from Table 15, it is found that by converting 20% of crop land 450,847 ha of land becomes available in Ontario and 188,012 ha in Quebec for biofuel production (Table 16). Assuming yields of 9.3 tonnes/ha for Ontario and Quebec (Table 14), this would result in the production of 5,941,389 tonnes of biomass in the two provinces. Similarly, converting 40% of forage land would allow 504,434 ha to become

Table 16. Land Availability and Biofuel Production Potential in Ontario and Quebec								
Agricultural Product	**Ontario**				**Quebec**			
	Total Land Area (ha)[1]	Land Converted to grasses (%)	Land for Biofuel (ha)	Yield (tonnes)	Total Land Area (ha)[1]	Land Converted to grasses (%)	Land for Biofuel (ha)	Yield (tonnes)
Crops								
All Wheat	342,000	20	68,400	636,120	46,000	20	9,200	85,560
Oats	39,000	20	7,800	72,540	97,000	20	19,400	180,420
Barley	112,000	20	22,400	208,320	142,000	20	28,400	264,120
Rye	25,000	20	5,000	46,500	16,000	20	3,200	29,760
Corn (grain)	728,000	20	145,600	1,354,080	431,000	20	86,200	801,660
Corn (fodder)	126,000	20	25,200	234,360	46,200	20	9,240	85,932
Soybean	868,000	20	173,600	1,614,480	157,000	20	31,400	292,020
Summer Fallow[2]	14,235	20	2,847	26,477	4,860	20	972	9,040
Total – Crop land	*2,254,235*	*20*	*450,847*	*4,192,877*	*940,060*	*20*	*188,012*	*1,748,512*
Forages								
Tame hay	948,000	40	379,200	3,526,560	751,000	40	300,400	2,793,720
Improved Pasture[2]	313,085	40	125,234	1,164,676	182,841	40	73,136	680,165
Total – Forages	*1,261,085*	*40*	*504,434*	*4,691,236*	*933,841*	*40*	*373,536*	*3,473,885*
Total - Crops and Forages	***3,515,320***	***27***	***955,281***	***8,884,113***	***1,873,901***		***561,548***	***5,222,396***

[1]Statistics Canada, 2006a (5 year averages)
[2]Statistics Canada, 2001

available in Ontario and 373,536 ha in Quebec for biofuel production. Again assuming yields of 9.3 tonnes/ha, this conversion would result in the production of 8,165,121 tonnes of biomass in the two provinces. Considering these changes in both crop and forage lands, the overall potential exists to produce 14,106,510 tonnes of biomass for energy in Ontario and Quebec annually.

Productive annual species such as sorghum, sweet sorghum or corn could be grown as annuals for winter harvest. Whole plant corn has been researched by German scientists (Schneider and Hartmann, 2005) and tested on a pilot scale by at least one southern Ontario greenhouse producer. Under this scenario, the harvesting technology is the same as corn silage harvesting, forage wagons can handle the bulk material. These tall thick stemmed species lend themselves well to winter harvest on frozen ground in regions of Canada which have modest winter snow cover such as the main Corn Belt region southwest of London Ontario and south of Montreal in Quebec. No detailed analysis of this potential is presented in this report however, the yield potential of these crops is substantial at approximately double the field crop corn yield for the provinces.

4.0 Field Crop Harvesting Practices

As crop residues of corn and soybeans are abundantly available in the main greenhouse production areas of southern Ontario and southern Quebec, greater understanding of the issues related to harvesting these materials is required. Soybean stalks and corn cobs appear to be the most easily recovered materials as a bioenergy feedstock for combustion. Corn stalks however, appear to be significantly more difficult to recover in the relatively humid environments of Ontario and Quebec. The main problems related to the corn stalk harvest are the high moisture content of the corn stalk material and the biomass quality problems associated with the early fall harvest of corn stalks (see section 5). As well, corn is harvested in the late fall when soils are generally in a humid state. Hauling off large amounts of biomass in wet fall conditions could lead to serious soil compaction problems. In terms of timing of harvest, soybeans stalks and corn cobs appear to be managed best as fall harvested residues, whole plant corn can be mid-winter harvested or spring harvested, and corn stalks are most practically spring harvested in eastern Canada. There are no special equipment requirements for soybean stover harvesting, standard hay harvesting equipment is presently being utilized by producers using the material for livestock bedding applications. The recovery of corn cobs and stalks is more technically challenging.

4.1 Corn Harvesting Practices

Traditionally, corn residue has been harvested for use as animal feed, bedding and/or cattle grazing. Corn is harvested either with a grain combine which leaves the stover on the field, with a forage harvester taking the whole corn plant for silage or with corn pickers that harvest the ear (cob and grain are left intact). The harvesting method determines the resulting by products. Conventional combine harvesting separates the grain from the cobs and remaining stover, and spreads the cobs and stover back on the field. Forage harvesting mixes all corn components together and downsizes the residues into a medium-fine chopped state. Corn pickers strip the ears from the stalk, and leaves the stalks standing in the field. These current practices, with modification, can allow for simultaneous or subsequent residue collection.

4.2 Harvesting Corn Residue Sustainably

Corn harvesting usually has focused on the grain or whole plant silage for livestock feeding. However in recent years other parts of the corn plant (leaves, stalks, cobs) have emerged as potential biomass sources. Factors contributing to the greater interest in this material are not only bioenergy markets but higher hay and feed costs, more farmland production in row crops and the availability of large balers and stackers that can effectively harvest corn residue (Myers, 1992). However, corn residues play an important nutritive and structural role in the regeneration and maintenance of healthy soil as they are important for soil organic matter, protect the soil from erosion, strongly influence radiation balances and energy fluxes and reduce the rate of evaporation from the soil through the establishment of the next crop (Wilhelm et al., 2004). Removal of corn residue must therefore be at a level that will maintain soil productivity for future crops. Previous studies (Nelson, 2003; Shinners et al., 2003; Nelson, 2002; Sheehan et al, 2002); McAloon et al., 2000) have estimated residue removal at rates between 20% and 60% depending on conventional tillage practices or no-till practices and soil conditions. For adequate protection of soil from erosion, 30% ground residue cover after planting is the standard adopted in the US and Eastern Canada. It has been estimated that based on the need to adequately protect soil from erosion, 20% (Nelson, 2002) to approximately 30% (McAloon et al, 2000) of the actual amount of stover can be removed. For the purpose of this study we have adopted a 25% rate of residue removal due to the mix of tillage systems and soil conditions and assumed 25% of the corn acreage could be accessed for a winter or spring harvest. Thus the total recovery of corn stover is estimated at 6.25% of the total resource available (Table 7).

4.2.1 Corn Stover Recovery Practices

With the conventional combine harvesting method there are two options for collecting the residue: 1) stover collection after the grain harvest or 2) a single pass system. Collection of stover includes using hay and forage handling equipment to bale the stover after harvest. Two or three different operations are usually conducted in the field to collect the stover which is both expensive and labour intensive (Quick and Tuetken, 2002). Picking up the swathed material results in dirt and trash collected with the stover and very few of the cobs are recovered. Furthermore during the grain harvest stover is knocked to the ground and run over by the combine, trucks and wagons, leading to a 50%-70% biomass loss (Billy, 2000; Montross et al., 2002; Pordesimo et al., 2002; Perlack and Turhollow, 2002). The single pass approach is where equipment is hitched directly behind the combine to catch the waste stream (stover and/or cobs). Several methods have been tested for collecting the stover and cobs (Shields and Shields, 2003; Quick and Tuetken, 2002). The advantages of this system over separate baling operations include: reduced cost, reduced soil compaction, simplified logistics, less contamination of the product with soil, less susceptibility to late season weather damage, reduced straw losses and removal of weed seed from the field (Atchison and Hettenhaus, 2004). The main problem however with the fall harvest is that the moisture content of the stalks is very high, typically in the moisture range of 50% or more in Eastern Canada (Savoie and Decouteaux, 2004). In Germany, Schneider and Hartmann (2005) found whole plant corn to have 30% moisture content in mid October, with stalks at 55% moisture, and grain at 10% moisture. Corn stalk bale drying has been assessed in eastern Canada. The energy costs associated with using natural gas as a heat source at \$8.33/GJ and electrical fan energy however cost \$77/tonne per tonne to dry the material to 12% moisture (Savoie and Decouteaux, 2004). They concluded that efficiency gains could be further made in the drying system but that dry storage likely was only practical for material that could be field recovered at 30% moisture. There are currently some farmers in eastern Ontario who have been recovering corn stalks for the mushroom industry (Duncan, D. Personal Communication, June 2006). This is currently being done in the fall as spring harvested material in eastern Ontario is problematic in terms of timing of operations. Farmers that are no-till planting soybeans are also concerned about soil compaction associated with running over the fields to recover the material (Duncan, D. Personal Communication, June 2006). The present system being utilized by one progressive eastern Ontario farmer is to recover stalks from fields with early maturing cultivars, and cut stalks with a cutter bar at the time of combining, allow the material to dry in the field and then windrow and bale (Duncan, D. Personal Communication, June 2006). Single pass systems may be possible in the drier areas of the US Midwest but they do not seem practical for Eastern Canada.

4.2.2 Corn Cob Recovery Methods

It appears the most promising option for corn residue field recovery in Eastern Canada would be corn cobs. Recovering the cob offers more "value-added" co-product opportunities as cobs require little to no investment for stable storage (Atchison and Hettenhaus, 2004). There already is a limited recovery of corn cob for use in the mushroom industry in Ontario and Quebec. Farmers can harvest the ears with older corn picker equipment or with large modern sweet corn picker heads. This harvesting process leaves the cobs and grain intact and returns the stalks and leaves to the field. The ears can then be dried in traditional cribs or new modern metal cribs. Crib drying may be naturally or mechanically ventilated with the latter using either ambient or heated air. With a naturally ventilated system, the corn may not completely dry before the winter and will then require some drying in the spring to prevent spoilage. Grain yield and quality can be superior for cribbed corn. In addition, significant fuel savings can be realized compared with common bin drying techniques. Recovering the cob offers more "value-added" co-product opportunities as cobs require little to no investment for stable storage (Atchison and Hettenhaus, 2004).

Source: (Bérubé, C. December 16, 2005)

Figure 4: Example of modern corn cribbing used in Quebec, Canada

The second option is to recover the cobs off the back of a combine in a trailing wagon using a corn cob collecting apparatus (Flamme, 1999). This technology uses an air separation process to separate the cobs from the stalks and leaves. A corn cob collecting apparatus is being used in Quebec to recover corn cobs. The main problem with this system is that the cobs require some type of drying system as they typically may be recovered at about 35-40% and do not store well above 20% moisture. Corn cobs are typically considerably higher than the grain moisture content, especially at kernel humidity contents above 15% (Table 17).

Table 17: Kernel Versus Cob Moisture Contents for Corn

Kernel moisture (%)	10	13	15	20	25	30	35	40
Cob moisture (%)	9	13	18	33	45	52	56	59

Source: ASAE Standards, 1994

4.2.3 Whole-Plant Corn Harvesting

Harvesting of whole plant corn for silage normally occurs when the plant is at 70% field moisture. However, if corn is grown as a bioheat crop, the harvest can be delayed until stalk moisture levels approach 20%. One Ontario greenhouse operator has successfully field tested the mid-winter delayed harvested option. There are some disadvantages associated with delayed harvest, including yield losses and dependence on favourable weather conditions for low moisture at harvest and minimal snow cover. This system could be possible for use in southern Ontario and some areas of southwestern Quebec when the soil is frozen. The forage harvester is the only method now commercially available for one-pass corn harvesting (Atchison and Hettenhaus, 2004). It removes the whole plant and cuts it into small pieces for ensiling. This systems offers distinct advantages in terms of improving fuel quality with the moisture content and potassium and chlorine content being significantly improved (Schneider and Hartmann, 2005). This could help the logistics of biomass storage as material could be stored in field for use on an ongoing basis. It would likely be possible to use this system in some greenhouse growing areas in the months of February and March.

4.3 Biomass Harvesting Techniques

In the past, the main technical barrier to the development of herbaceous biomass for combustion was the high potassium and chlorine content of the material and the resulting difficulties these elements present during combustion. Increased understanding of delayed-harvesting practices can optimize biomass combustion quality and recoverable biomass yields.

The harvesting of switchgrass is best delayed not just until biomass growth has ceased, generally in August or September, but rather until shoots have senesced and died, which may not be until November or December (Parrish and Fike 2005). Previous studies (Sanderson *et al.,* 1999; Vogel *et al.,* 2002) reported yield declines of approximately 15% from August to November, however this decline actually represents the transfer of nutrients from above ground to below storage (Parrish and Wolf, 1992, 1993), and is vital for stand sustainability. Best management strategies for switchgrass in northern latitudes recommend a single harvest taken after the tops have completely died back (Parrish and Fike 2005). Biomass yields have been found to further decrease as the stand is overwintered, mainly due to mechanical breakage and loss from leaves and seed heads (Goel *et al.,* 2000). In southwestern Quebec, spring-harvested switchgrass yields were found to be approximately 24 percent lower than that of early October harvested switchgrass, with the loss of dry matter at 4 percent from the stem component, 11 percent from leaf sheaths, 30 percent from leaves and 80 percent from seed heads compared to fall harvesting. Other studies in Quebec have found on fully established switchgrass stands spring yields 15 percent below late October fall harvests where the crop is fully dormant (Girouard *et al.,* 1998).

Losses of biomass also occur during field operations (eg. cutting, baling, transport), with. Sanderson *et al.,* (1997) reporting a 5% biomass loss from conventional fall harvesting of switchgrass (mower and baler) over a two-year study. A study conducted by REAP-Canada (Girouard and Samson 1996) found that conventional spring harvesting (mower and baler) of switchgrass resulted in a 45% loss of biomass (32% as mowing losses and 13% as baling losses). Losses of this magnitude were also witnessed by Hemming (1995) with reed canary grass where a mower conditioner was used. A subsequent comparison in Quebec between spring mowing and baling with spring swathing and baling found biomass losses of approximately 25.3% and 12.5% respectively (Girouard and Samson 1997). However, a follow up study by Girouard *et al.,* (1998) witnessed a 3% decrease of biomass with the swathing and baling method. This was accounted for by the lowering of the cutting height from 16 cm to 13 cm compared to the 1997 study. Fall mowing and spring baling techniques require further investigation as approaches to reduce the breakage losses over winter.

5.0 Biomass Quality

There is a wide variety of qualities between different types of biofuels. It is well known that agri-fibres are more difficult to burn then wood residues and this has been major limitation for their commercial development as combustion fuels. The main technical factor limiting conversion of energy crops and crop residues into commercial bioheat applications has been the ash quality characteristics of the biomass make it difficult to burn efficiently in conventional boilers. The tendency for clinker formation and corrosion of the boilers has resulted in slow commercialization of these feedstocks and limited use especially in small scale boilers (Elbersen et al., 2002; Obernberger and Thek, 2004). Improving biomass quality of agri-fibres for combustion applications is primarily dependant upon minimizing their nutrient, ash and moisture content. In particular, high potassium and chlorine contents can cause clinker formation and corrosion inside the combustion unit (Elbersen et al., 2002). Sander (1997) stated that for efficient use of biofuels for power generation, the target values off K and Cl should be as low as possible. Target values of maximum 0.2% K and .1% Cl were created for biofuels in Denmark (Sander, 1997). High nitrogen contents in biomass will also increase NOx emissions during combustion. There are a variety of technologies currently available that allow for ash removal and clinker reduction. Improving understanding of factors influencing agri-fibre quality is an important area of research and development.

Within agri-fibre materials, there are considerable differences in biomass fuel quality. For example, various components of crops have distinct quality difference and delayed harvesting of energy crops and crop residues can improve fuel quality. Blending different agri-fibres and using agri-fibre wood fuel mixtures can also increase the acceptability of these materials in commercial boilers. The analysis in this chapter includes a preliminary comparative analysis of agri-fibre biomass feedstock and their suitability for combustion. A more detailed and representative sampling of these feedstocks within Canada needs to be performed.

5.1 Biomass Feedstock Characteristics

5.1.1 Quality Characteristics of Agricultural Residues

In Table 18, groupings are made of selected crop straw/stalks, grains, and milling residues. In analyzing the groupings of the most readily available agricultural residues for bioheat applications, there appears to be distinct quality advantages associated with crop milling residues and grains compared to straws/stalk of the same plants. Limited potential exists for grain combustion as it is unlikely to be a competitive fuel source for the Canadian greenhouse industry. Crop milling residues generally have distinct price advantages over whole grains and similar combustion quality. Increasing farm commodity prices with increasing bioenergy demand for agricultural land will likely make whole grains uncompetitive with other biofuel options in the future.

Milling byproducts of oat and corn processing industries were identified to have potassium contents below 1%. Corn bran had a very low potassium content (.1%) which is likely due to this material being leached of potassium during the wet milling process used in the starch industry. Relatively low chlorine contents (<0.1%) were found in soybean hulls, wheat milling by-products and oat hulls.

Overall, oat hulls and pin oats appear to be amongst the most promising feedstocks for combustion as they possess moderately low potassium, chlorine and nitrogen contents. Of the other milling residues, washed corn bran also looks to be a relatively easy to use fuel for commercial combustion applications. Using mixtures of these fuels may provide some benefit in terms of pelletization and ease of combustion. Wheat mill run for example, appears to be a promising binder for higher fibre agri-fibre resources like energy grasses and increase throughput on the mills.

Straw/stalk residues are as a grouping, considerably more problematic for combustion with their high potassium and chlorine content. Within the field crop residues grouping, soybeans stalks may have the best quality for combustion due to their relatively high energy content and relatively low potassium. This may be due to the fact that soybeans, unlike cereal crops or corn, drop their leaves at harvest and primarily stems are harvested. Delayed harvest of corn stalks or cereal straw may help improve their opportunities to be used as combustion fuels. More analysis and combustion experience is required to more fully assess the potential of the various crop milling residues and field crop residues as combustion fuel for the Canadian greenhouse industry.

Table 18. Quality of grains, straw and milling residues[1]

Residue Type	Energy (GJ/ODt)	Bulk Density (kg/m3)	DM (%)	CP (%)	Ash (%)	N (%)	Ca (%)	K (%)	Cl (%)	S (%)
Straw Residues										
Wheat	18.45[2]	79[2]	91	3	8	0.48	0.16	1.3	0.32	0.17
Oat	18.10[2]	NA	91	4	8	0.64	0.24	2.4	0.78	0.22
Corn	18.4[2]	NA	80	5	7	0.8	0.35	1.1	0.30	0.14
Barley	19.2[2]	82[2]	90	4	7	0.64	0.33	2.1	0.67	0.16
Rye	18.25[3]	NA	89	4	6	0.64	0.24	1.0	0.24	0.11
Soybean	19.1[4]	NA	88	5	6	0.8	1.59	0.6	NA	0.26
Grains										
Wheat	18.75[5]	668[2]	89	14	2	2.24	0.05	0.4	0.09	0.15
Oat	17.74[5]	498[2]	89	13	4	2.08	0.05	0.5	0.11	0.2
Corn	18.8[6]	640[6]	88	9	2	1.44	0.02	0.4	0.05	0.12
Barley	17.5[2]	614[2]	89	12	3	1.92	0.06	0.6	0.18	0.16
Rye	17.1[7]	641[8]	89	12	2	1.92	0.07	0.5	0.03	0.17
Milling Residues										
Wheat Bran	NA	216[9]	89	17	7	2.72	0.13	1.4	0.05	0.24
Wheat Middlings	17.15[5]	310[9]	89	19	5	3.04	0.15	1.4	0.05	0.2
Oat hulls	19.5[2]	128[12]	93	4	7	0.64	0.16	0.6	0.08	0.14
Pin Oats	NA	NA	89	8	6	1.28	0.12	0.6	NA	0.24
Corn Cobs	18.4[5]	272[6]	90	3	2	0.48	0.12	0.8	0.16[11]	0.4
Corn Screenings	NA	NA	86	10	2	1.6	0.04	0.4	0.05	0.12
Corn Bran	17.46[13]	208[12]	91	11	3	1,76	0.04	0.1	0.13	0.08

Soybean hull	17.61[5]	170[10]	90	13	5	2.08	0.55	1.4	0.02	0.12

[1]Source: Preston (2005)
[2]Reisinger et al. (2006)
[3]Staniforth (1979)
[4]Barnard and Kristoferson (2005)
[5]AURI (2001)
[6] White and Johnson (2003)
[7]FAO (2004)
[8]Murphy (1993)
[9]Blasi et al. (1998)
[10]Blasi et al. (2000)
[11]Smeenk and Brue (2000)
[12]ASI Instruments 2006
[13]Braisher et al. (2006)

5.1.2 Quality Characteristics of Energy Grasses

As with agricultural residues, the quality of dedicated energy grasses for combustion applications are also primarily dependant upon minimizing nutrient, ash and moisture contents, particularly those of potassium and chlorine (Samson et al., 2005). The incineration of biomass containing chlorine at high temperatures may also result in the production of polynuclear aromatic hydrocarbons (PAH), dioxins, furans and other volatile organic compounds (VOC) (Chaggera et al, 1998). High nitrogen contents in biomass will also increase NOx emissions during combustion, which can react with the PAH and other gases present in the emissions to form any number of possible polychlorinated compounds. However, biofuel ash may be the most limiting factor during combustion as it can form deposits on or corrode surfaces in the appliances and severely affect the operation of power plants (Cassida et al., 2005). These technical problems can now be resolved with a dual strategy to improve biomass quality (particularly lowering potassium and chlorine content) while utilizing advanced combustion systems. Samson *et al.,* (2005) identified advances in plant breeding and crop management to reduce the chlorine, alkali and silica content. As well, combustion systems of advanced design specifically designed to burn higher ash fuels are now available (Obernberger and Thek, 2004).

Harvest timing of grasses plays an important role in nutrient management of energy crops. Summer harvested switchgrass can have high chlorine, potassium, sulphur and nitrogen contents (Table 19). As the months pass and the crop overwinters, these nutrients are translocated into the root systems or leached by rainfall, achieving their lowest concentrations during the spring. Overwintering material is extremely effective in reducing nutrient contents of biomass with 95% of the potassium leached out of the switchgrass fibre over winter (Goel et al., 2000). Overwintered switchgrass has potassium and chlorine levels (Table 19) that approach levels of these elements in wood pellets of 0.05% and 0.01% respectively (Obernberger and Thek, 2004).

Table 19. Effects of delayed harvest on elemental composition of switchgrass[1]

Date of Harvest	N (%)	Ca (%)	K (%)	Cl (%)	S (%)
July	1.35	0.49	1.33	0.26	0.11
August	0.78	0.50	0.98	0.22	0.08
November	0.45	0.59	0.30	0.10	0.06
December	0.46	0.59	0.20	0.06	0.08
February	0.53	0.65	0.10	0.02	0.08

[1]Unpublished Nicola Yates, 2003

Trials of upland switchgrass ecotypes including Cave-in-rock, Dacotah, Pathfinder, Sunburst, Forestburg, and Nebraska 28 confirm that potassium and chloride levels decrease as the crop is overwintered (Table 20).

Table 20. Potassium and chloride concentration in switchgrass plants *(Christian et al., 2002)*

Trial year	**Potassium Concentration (%)**		**Chloride Concentration (%)**	
	Dead Stem	Over wintered Harvest	Dead Stem	Over wintered Harvest
1993	0.873	-	-	-
1994	0.221	0.140	0.101	0.047
1995	0.220	0.167	0.113	0.061
1996	0.127	-	-	-
1997	0.201	-	-	-

The production of switchgrass on clay soils has also been found to lead to much higher ash contents due to the higher uptake of silica in these soils (Samson and Mehdi, 1999. Elbersen et al., 2002). Silica enters the plant through water uptake (Jones and Handreck, 1967) and represents about two-thirds of the ash content found in grasses. Sandy soils, which have less monosilicic acid, produce feedstocks lower in ash content. In eastern Canada, the ash content of switchgrass grown on a sandy loam soils was 15% below that of clay loam soils (Samson et al 1999). However, delayed harvesting of the grass (overwintering the grass and harvesting the following spring) had an even bigger influence than soil type by reducing ash content by 39%.

The potassium and chlorine contents of herbaceous species such as switchgrass at harvest is affected by resident levels of these elements in the soil, the rate of potassium fertilizer applied to the crop, the type of potassium fertilizer applied, the content of these elements at crop maturity, and the rate and duration of leaching of these elements that occur in the period following maturity until harvest time (Samson *et al.,* 2005). An effective way to reduce potassium content in the fall is to use early maturing varieties that have a longer period to leach out material prior to late fall harvest (Elberson et al., 2002).

Physiological ecotype, or characteristics of certain varieties due to their latitude of origin, can have a significant effect on biomass quality. Southern varieties of grasses may have higher water contents as they mature later and have thicker stems (Elbersen et al., 2002), leading to reduced leaching in the stem and higher concentrations of K and Cl in the biomass (Table 21).

Table 21. Switchgrass nutrient content as affected by variety and maturity *(Elbersen et al. 2002)*

Switchgrass variety	**Latitude of Origin**	**Clay Site**			**Sandy Site**		
		Ash (%DW)	Cl (kg/tonne)	K (kg/tonne)	Ash (%DW)	Cl (kg/tonne)	K (kg/tonne)
Forestburg	44	7.37	0.34	1.40	1.9	0.32	1.38
Summer	41	6.38	0.32	1.83	2.0	0.26	1.53
Cave-in-rock	38	7.01	0.78	3.93	1.7	0.78	2.61
Blackwell	37	8.00	0.69	2.77	2.6	0.81	2.52

Carthage	35	6.90	1.01	4.48	2.3	0.68	3.02

Plant morphology can also have a significant effect on biomass quality. Lowland types of switchgrass are characterized by tall, coarse stems with rapid growth and are adapted to poor drainage and often found in floodplains. They differ notably from upland types which are characterized by short, fine stems with a high drought tolerance (Cassida et al., 2005). Upland types have been found to have higher ash concentrations than lowland types (Cassida et al., 2005); however, they also tend to have lower chlorine and potassium levels and lower water contents. It is likely that these thinned stemmed upland ecotypes both dry out more quickly and have their elements leached more readily by rains. Lowland types have been found to have lower nitrogen concentrations due to their higher stem contents and low leaf content.

Different components of the energy grass plants themselves have also been found to have varying degrees of biomass quality (Samson et al., 2005). Stem sections of the plant contain significantly lower levels of ash than the leaves, and moderately less than the leaf sheaths or seed heads (Table 22).

Table 22. Ash content of switchgrass components *(Samson et al., 2005)*

Plant Component	*Switchgrass Ash Contents (%)*			
	Sandy Loam Soils		**Clay Loam Soils**	
	Spring 1998	Fall 1998	Spring 1998	Fall 1998
Leaves	6.20	7.40	7.67	9.19
Leaf sheaths	2.46	4.47	3.67	5.75
Stems	1.08	2.39	0.98	2.40
Seed heads	2.38	4.66	n/a	4.82
Weighted Average	2.75	4.50	3.21	5.24

When considering that the ratio between plant components the stem component, which has the best fuel quality, is the most important plant component at either spring (over wintered) or fall harvest (Table 23). Overall it would appear through site selection, breeding for increased stem content, and using a delayed harvest technique, considerable improvement in switchgrass as a combustion fuel can be achieved. From the data above, it appears the aforementioned biomass quality targets of 0.2% K and 0.1% chlorine established in Denmark are readily achievable using a delayed harvesting system on switchgrass. As well the higher silica content of switchgrass is not considered a serious problem for commercial boilers as many commercial boilers are capable of burning higher ash fuels like low grade coal. Overall it appears the development of overwintered warm season grasses have no significant supply, technical or environmental issues associated with its development as a commercial greenhouse heating fuel.

Table 23. Switchgrass composition considering soil type and harvest *(Mehdi et al., 1999)*

Soil and Harvest Type	% Average Composition				
	Seed Head	Leaves	Stem	Leaf Sheath	Leaf Sheath + Stem
Sand Site					
Spring Harvest	2.4	28.2	53.1	16.3	69.4
Fall Harvest	9.8	25.4	48.4	16.5	64.8

Clay Site					
Spring Harvest	5.0	25.0	51.4	18.3	70.0
Fall Harvest	7.4	23.0	55.1	14.5	69.9

6.0 Financial Summary

In order to put potential biomass resources into perspective with natural gas and heating oil prices, an analysis of estimated costs to heat a typical greenhouse the size of 0.8 hectares was performed (Table 24). Futures of heating oil and natural gas prices for the winter of 2006 were used to estimated the cost per unit of each heating fuel (Oil Intelligence Link, 2006). We also took delivery costs required for each respective fuel for commercial operations (Enbridge Energy, 2006). Assuming on average an 0.8 hectare greenhouse requires approximately 9,928 GJ of heat energy per year. On average a transition to biofuels would save greenhouses heated with oil and natural gas 60% and 33%, respectively, in yearly fuel costs.

Table 24. Projected Annual Fuel Costs for Heating a 0.8 hectare Greenhouse in Canada

Fuel Type	Cost per Unit	Unit	Energy Content (GJ)	Cost per GJ	Efficiency	$ GJ Heat delivered	GJ heat demand for 0.8 ha (9,928 GJ)
Conventional Fuels							
Heating Oil	$ 0.75	Litre	0.039	$ 19.38	80%	$ 24.22	$ 240 503.88
Natural Gas	$ 0.48	m^3	0.037	$ 10.63	85%	$ 12.50	$ 149 128.94
BioFuels							
Corn	$ 150,00	Tonne	15.8	$ 9.49	80%	$ 11.87	$ 117 816.46
Switchgrass Pellets	$ 150,00	Tonne	18	$ 8.33	80%	$ 10.42	$ 103 416.67
Crop Milling Residue Pellets	$ 130,00	Tonne	17.1	$ 7.60	80%	$ 9.50	$ 89 132.60
Bark Pellets	$ 140,00	Tonne	18	$ 7.37	80%	$ 9.21	$ 91 422.11

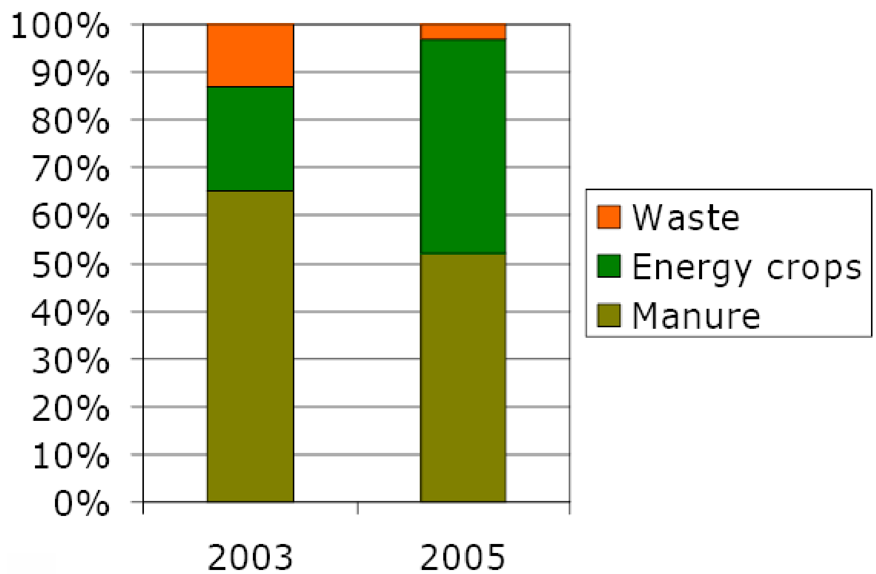
In Ontario the majority of greenhouse heating is done with natural gas. The greenhouse industry in southern Ontario is well situated to use the 416,083 tonnes of available milling residues (Table 9 & 10), including over 1.6 million tonnes of straw and stalk residues (Table 7) and potentially 9 million tonnes of switchgrass production (Table 16). These three biofuel types in a pelleted form would have the potential to decrease costs to the 1200 provincial greenhouse growers by 82 million dollars annually.

In Quebec, 90 % of greenhouses are heated with heating oil (informal survey of farmers in January 2006). The location of Quebec's greenhouses in the southwestern part of the province is ideal for accessing the 494,923 tonnes of straw and stalk (Table 7), 201,071 tonnes of millfeed (Table 9) and potentially 5 million is switchgrass (Table 16). Furthermore, high-ash wood pellet production in the province could also be considered as an important fuel source. The 775 greenhouse growers could save a potential 43 million dollars in heating costs by using these and other alternative fuel sources.

British Columbia has relied on natural gas in the past, but many greenhouse growers have or are in the process of switching over to biofuels. With access to wood residues and wood pellets relatively easy, this seems to be the most likely source for alternative heating. The 570 greenhouse growers could potentially save 41 million dollars in heating costs with a complete switch to bark pellets.

7.0 On-site Biogas Production Potential

A promising new opportunity for greenhouse heating that may be especially appropriate for the Ontario greenhouse industry is the use of biogas. A detailed analysis of the potential of this opportunity is outside the scope of this report. However there appears to be already some commercial interest amongst Ontario greenhouse growers in this opportunity. Biogas systems have historically used manure as an energy feedstock. In Germany where the technology is evolving rapidly, there were 2700 biogas systems in 2005 producing 650 MW of power (BIOPRO, 2006). Through fermentation, biomass produces the renewable energy gas known as methane. This gas is subsequently burnt to provide heat and power.

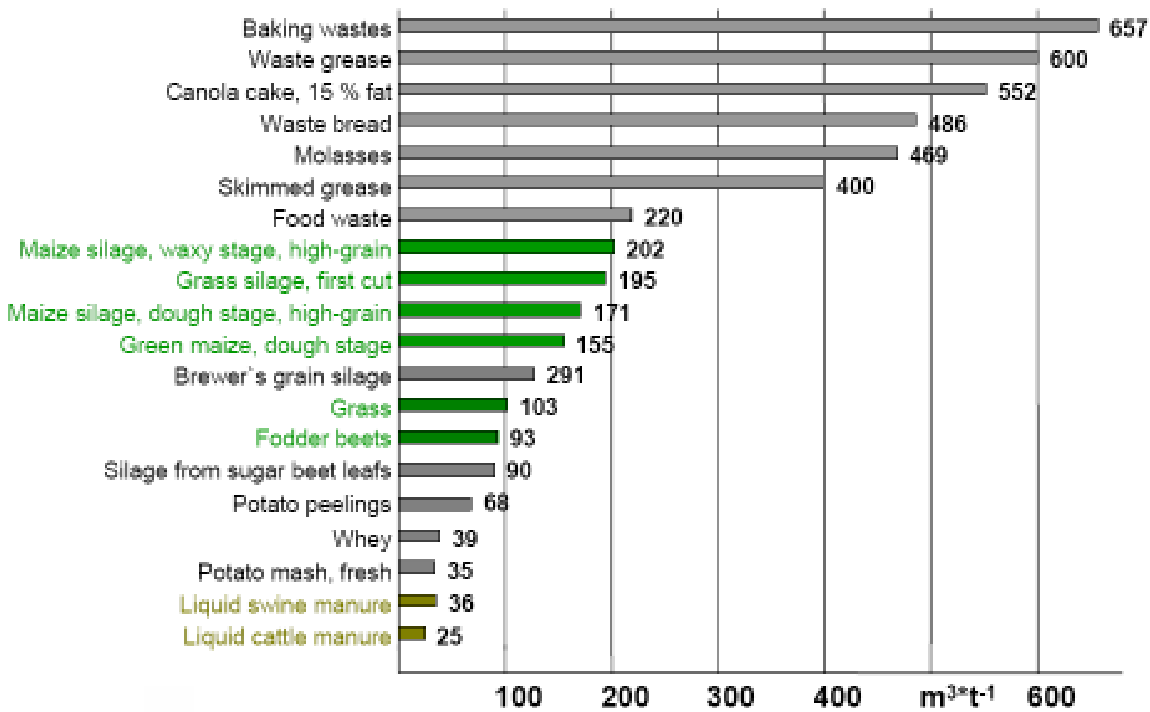


Source: Effenberger, 2006

Figure 5: Proportion of biogas production from different feedstocks in the province of Thuringia, Germany.

In the province of Thuringia, Germany, 40% of the biomass used for biogas systems is coming from energy crops such as perennials forages and corn silage (Figure 5). The potential use of biogas for heating Ontario greenhouses appears limited if manure is the primary feedstock. Unfortunately, much of Ontario's greenhouse industry is located in areas where relatively limited livestock farming occurs. However, if biogas heating systems were run on corn silage or energy grasses grown in these areas, a very large feedstock supply could be created. The heartland of the Ontario greenhouse industry is Leamington which is situated near the border between the corn producing counties of Kent and Essex. These two counties produce approximately 650,000 tonnes of corn annually in Ontario (Statistics Canada 2006a) and large volumes of corn silage and perennial forages could be derived from the surrounding farmlands to fuel greenhouses in these areas.

In 2006, Ontario greenhouse producers can access the new feed-in tariffs for renewable electricity of 11 cents per kwh. Including peak pricing of 14.5 cents per kwh, the average price received by growers is estimated at 12-13.5 cents per kwh of power produced (Jake DeBruyn, OMAFRA, Personal communication, July 2006). Furthermore the Leamington area has significant electrical load problems which would work well with strengthening the power supply in this area as there can be periods of insufficient capacity. In the case of greenhouse producers they have a strong demand for heat especially in the January to March period, while some heat also is used year round for reducing humidity in greenhouses. In the rapidly evolving biogas industry in Germany, some provinces are using energy crops as 40% of the feedstock used to run the plants (Effenberger, 2006). Presently in Germany it is common to use both manure and energy crops to fuel biogas reactors. In the case of Ontario's greenhouse industry, it is likely that they would mainly access energy crops due to the limited manure production in the main greenhouse producing areas. The biogas yields from various feedstocks are outlined in Figure 6.



Source: Effenberger, 2006

Figure 6: Potential Biogas Yield from various biomass products

The main factors which contribute to high biogas production from corn silage and grass feedstocks were reviewed by Amon et al (2002). High protein, fat, cellulose, hemi-cellulose, and starch content contribute to high methane yields. They recommended harvesting late maturing corn silage varieties or forages such as clover, harvested in the head emergence stage. They also recommended that sustainable biogas production from energy crops must not be based on maximum yields from individual crops but on maximum methane yields from sustainable and environmentally friendly crop rotations. In North America there has been limited analysis of the biogas potential of various perennial forages.

Figure 7: An integrated manure utilization system in Vegreville-Alberta.

Overall in the case of Ontario, biogas appears to be a promising new opportunity for greenhouse producers to produce electricity and heat. The economics of this opportunity will likely be dependent on installing systems into the largest greenhouses where a minimum of approximately 500kw of power are produced. Accessing low cost manure and by-products of the food processing industry can likely also help improve the economics.

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10.0 Appendices

Appendix 1: **List of Canadian Wood Pellet Manufacturers for 2006**

Province	Company	Address	Phone	Website
British Columbia	Armstrong Pellet Inc.	P.O. Box 280 3480 Pleasant Valley Rd Armstrong, BC V0E 1B0	250-546-8484	www.armstrongpellets.com
	Pacific BioEnergy Corp. (PFI Pellet Flame Ltd.)	12080 Willow Cale Forest Rd., Prince George, BC, V2N 4T7	250-963-7220	www.pelletfame.bc.ca
	Pinnacle Pellet Inc.	4252 Dog Prairie Rd., Quesnel, B.C. V2J 6K9	250-747-1714	www.pinnaclepellet.com
	Premium Pellet Ltd.	Box 125 Vanderhoof, BC V0J 3A0	250-567-2110	www.premiumpellet.com
	Princeton Co-Generation Corp.	210 Old Hedley Rd., Princeton, BC, V0X 1W0	250-295-6940	
	Westwood Fibre Products Ltd.	2677-A Kyle Road Kelowna, BC V1Z 2M9	250-769 - 1427	www.westfibre.com
Alberta	La Crete Sawmills Ltd.	La Crete, AB	780-928-2292	www.lacretesawmills.com
	Kentucky Komfort	11607-178th St., Edmonton, ABT5S 1N6	877-303-3134	www.kentuckykomfort.com
	Ecobiofuel INC	1024 Shawnee Dr, Calgary, AB T2Y 2T9	403-714-0066	www.ecobiofuel.com
	Vanderwell Contractors Ltd.	P.O. Box 415 Slave Lake, AB T0G 2A0	780-849-3824	
Ontario	Lakewood-Industries Pellet Division	Ear Falls, ON	807-222-3616	
	N.S. Bauman Ltd.	R.R. 3 Wallenstein, ON N0B 2S0	519-669-5447	
	NorWa Wood Pelleting Mill	164 Mills Drive Wawa ON, P0S 1K0		

***Appendix 1:* List of Canadian Wood Pellet Manufacturers for 2006**

Province	Company	Address	Phone	Website
Quebec	Cubex Inc.	2199 Cote des Cascades, Papineauville, QC J0V 1R0	819-427-5105	www.cubexpellets.com
	Energex Pellet Fuel Inc	Lac-Megantic QC	819-583-5131	www.energex.com
	Granules Causap Inc.	190, rue Cartier, Causapscal QC, G0J 1J0	418-756-5200	
	Granules L.G. Inc.	750, Chemin de la Moraine, St. Félicien, QC G8K 0A1	418-679-2647	www.granuleslg.com
	Industries Valbor Inc	745, boulevard Industriel, Blainville, QC J7C 3V3	450-435-0095	
New Brunswick	Advanced Wood Technology	P.O. Box 338 Fredericton	506-451-7788	
Nova Scotia	Shaw Resources	P.O. Box 60 Shubenacadie, NS B0N 2H0	800-607-2509	www.shawresources.ca

Appendix 2: **List of Canadian Agri-Fibre Pellet and Cube Manufacturers 2006**

Province	Company	Fiber Type	Address	Phone	Website
Alberta	Bow Island Dehy Ltd	AF	Bow Island, AB	403-545-2293	
	Cool Spring Alfalfa	AF	Falher, AB	780-837-2244	
	Falher Alfalfa Ltd.	AF	Box 177 Falher, AB T0H 1M0	780-837-2244	
	Green Prairie International	AF TH	RR 8 S30 C11 Lethbridge, AB T1J 4P4	403-327-9941	www.greenprairie.com
	Hills Alfalfa Ltd	AF	Rolling Hills AB	403-964-3593	
	Kentucky Komfort	AF	11607-178th St.,Edmonton, AB T5S 1N6	877-303-3134	www.kentuckykomfort.com
	Legal Alfalfa Products Ltd.	AF	Box 480 Legal, AB T0G 1L0	780-961-3958	www.alfatec.ca
	Lomond Alfalfa Products Ltd.	AF	Box 268 Lomond, AB T0L 1G0	403-792-2411	
	Seven Persons Alfalfa	AF	Medicine Hat, AB	403-832-2070	
	Sun Cured Alfalfa Cubes Inc.	AF	Box 640 Coalhurst AB T0L 0V0	403-381-4764	
	Welling Alfalfa Cubing Inc.	AF	Box 100 Welling AB T0K 2N0	403-752-3773	www.wellingalfalfa.com
Saskatchewan	Arborfield Dehy Ltd.	AF	Box 250 Arborfield, SK S0E 0A0	306-769-8622	
	Central Butte Feed Inc	FPGS	Central Butte, SK	306-796-4490	
	Dawn Food Products (CSP Foods)	PGS	75 33rd St. E. P.O. Box 190 Saskatoon, SK S7K 3K7	306-934-3207	www.dawnfoods.com
	Elcan Forage Inc.	AF	Box 55 Broderick, SK S0H 0L0	306-867-8080	
	Hudson's Bay Dehydrators Mutual Ltd	AF	Hudson Bay, SK	306-865-3366	
	Melville Seed Processors Ltd	GSP	180 Service Rd Melville SK	306-728-4490	

Appendix 2: **List of Canadian Agri-Fibre Pellet and Cube Manufacturers 2006**

Province	Company	Fiber Type	Address	Phone	Website
			S0A 2P0		
	Parkland Alfalfa Products Ltd	AF	Site 2 Box 20 RR 1Ridgedale, SK , S0E 1L0	306-873-2000	
	Popowich Milling Corp	GSP	Myrtle Avenue, Yorkton, Saskatchewan S3N 1R1	306-783-2931	www.popowichmilling.com
	Robin Hood Multifood Inc	GSP	First Ave. and 33rd St. E. P.O. Box 537 Saskatoon, SK S7K 3L6	306-665-7114	
	Tisdale Alfalfa Dehy Ltd.	AF	Box 1688 Tisdale, SK S0E 1T0	306-873-2605	
	West Central Pelleting Ltd	FGSP	Box 298 WIilkie, SK S0K 4W0	866-422-2242	
	Western Alfalfa Milling Co. Ltd.	AF	PO Box 568 Norquay SK S0A 2V0	306-594-2362	
	Weyburn Inland Terminal	FGSP	P.O. Box 698 Weyburn, SK S4H 2K8	306-842-7436	www.wit.ca
Manitoba	Prairie Bio-Energy Inc.	FL	La Broquerie	204-424-5313	
	Alfalfa Products Ltd	AF	PO Box 90 Rpo Fort Whyte Winnipeg, MB	204-895-8008	
	Coldstream Alfalfa Processing	AF	PO Box 337 Stn Main Dauphin MB, R7N 2V2	204-638-9781	
Ontario	Eco Comfort Fuel	AF?	Wroxeter ON	519-291-4602	
	Don Nott Farms	CMR	RR#4, Clinton, O.N., N0M 1L0	519-482-7439	
	Langs Dehy Ltd.	AF	R.R.#1 Palmerston, ON N0G 2P0	519-343-3353	
	Lorenz Farms	AF	St. Jacobs, ON N0B 2N0	519-699-5663	

***Appendix 2:* List of Canadian Agri-Fibre Pellet and Cube Manufacturers 2006**

Province	Company	Fiber Type	Address	Phone	Website
	Kraehling Farms Inc.	AF	1441 Erbs Road St. Agatha ON N0B 2L0	519-886-6276	
	Veenstra Farms	WS	Sherkston, ON	905-894-4030	
Quebec	Les Luzerniers Belcan du Lac St-Jean Inc.	AF	251 rue Joseph Hamel Hebertville-Station QC G0W 1T0	418-343-2000	

Note: AF-Alfalfa; TH-Tame Hay; FPGS-Fortified Pelleted Grain Screenings; GPS-Grain Pelleted Screenings; FL-Flax Shives; WS-Wheat Straw; CMR-Crop Milling Residue

In terms of alfalfa processing Canada is ranked in the world's top five largest exporter of alfalfa pellets and alfalfa a cubes (Market Analysis Division 2004). Annually Canada produces 322,000 tonnes of alfalfa pellets and 169,000 tonnes of alfalfa cubes and exports 80% per cent to Asian, European markets. (AAFC 2003). Alberta and Saskatchewan are the major alfalfa processing provinces in Canada, processing 90% of the Canadian total (Wenger and Su 2003).

Appendix 3: **Canadian Wheat Processing Facilities-2006**

Province	Company	Processed	Address	Website	Telephone
Flour Milling					
British Columbia	Rogers Foods Ltd. (Interior)	WF, RF, WWF	4420 Larkin Rd. Armstrong, BC V0E 1B0	www.rogersfoods.com	250-546-8744
	Rogers Foods Ltd. (Pacific)	WF, RF, WWF	44360 Simpson Rd. Chilliwack, BC V2R 4B7	www.rogersfoods.com	250-546-8744
Alberta	ADM Milling	WF, SWF, WWF	4002 Bonnybrook Rd. S.E. Calgary, AB T2G 4M9		403-267-5600
	ADM milling	WF	1222 Allowance Ave. S.E. P.O. Box 160 Medicine Hat, AB T1A 3H1	www.admworld.com	403-328-6622
	Ellison Milling Co.	WF, WWF, RF	1301 Second Ave. S. Box 400 Lethbridge, AB T1J 3Z1	www.ellisonmilling.com	780-672-3675
	Permolex (API)	WF	Red Deer, AB		403-526-2876
	Prairie Sun Grains 2000, Inc.	WF	4601 51st Ave. P.O. Box 1570 Camrose, AB T4V 1X4		306-934-3200
	Schroeder Milling	WF	Camrose, AB	www.schroedermilling.ca	306-682-3932
Saskatchewan	Dawn Foods (Organic)	WF	1309 Railway Ave. P.O. Box 3430 Humboldt, SK S0K 2A0	www.dawnfoods.com	306-682-3932
	Dawn Foods	WF	75 33rd St. E. P.O. Box 190 Saskatoon, SK S7K 3K7	www.dawnfoods.com	306-665-7111
	FarmGro Organic Food	WF	Regina SK		204-925-2100
	Nutrasun Foods	WF	1695 Dewdney Avenue Regina SK S4N 4N0	www.nutrasunfoods.com	705-526-7861

***Appendix 3:* Canadian Wheat Processing Facilities-2006**

Province	Company	Processed	Address	Website	Telephone
	Robin Hood Multifoods*	WF	First Ave. and 33rd St. E. P.O. Box 537 Saskatoon, SK S7K 3L6		204-353-2895
Manitoba	ADM Milling	WF, SWF, WWF	Seven Higgins Ave. Winnipeg, MB R3B 0A1	www.admworld.com	905-819-7000
	Prairie Flour Mills Ltd.	WF	11 Janzen Rd. P.O. Box 301 Elie, MB R0H 0H0	www.flour.com	905-826-2701
Ontario	ADM Milling	WF, WWF	P.O. Box 369, 202 First Street Midland, ON L4R 4L1	www.admworld.com	876-968-7221
	ADM Milling	WF	1770 Barberton Road Mississauga, ON L5M 2M5	www.admworld.com	800-621-0588
	ADM Milling	WF	209 Winward Rd. Kingston, WI 2 JAM	www.admworld.com	
	ADM Milling	WF, WWF, SWF	P.O. Box 310, Port Colborne, ON L3K 5W1	www.admworld.com	905-851-1194
	ADM Milling	SWF	62 Albert St. Strathroy, ON N7G IV5	www.admworld.com	519-660-0199
	Arva Flour Mills Ltd.	SWF, WWF, RF	Arva Flour Mills Ltd. 2042 Elgin St. Arva, ON N0M 1C0		905-834-4556
	Dover Mills	WF	P.O. Box 3368, 140 King Street, Cambridge, ON N3H 4T3	www.dovergrp.com	905-374-7111
	Golden Gate Mills	WWF	73 Sinclair Blvd Brantford, ON N3S 7X6		505-743-3260
	Grain Process Enterprise Inc.	SWF	39 Golden Gate Ct. Scarborough, ON M1P 3A4		514-846-8500

Appendix 3: **Canadian Wheat Processing Facilities-2006**					
Province	Company	Processed	Address	Website	Telephone
	Halton Flour Mills	WF	62 Mill Street West Halton Hills Acton ON, L7J 1G4	www.dovergrp.com	866-221-2278
	HayHoe Mills	WF, SWF, WWF	201 Pine Grove Road Woodbridge, ON, L4L 2H7	www.hayhoe.com/	800-265-5510
	Kraft Milling	SWF, WF	27 Reid Drive Mississauga, ON, L5M 2B1		519-523-4241
	New Life Mills	WF, SWF	P.O. Box 219 Hanover, ON, N4N 3C5		519-245-2250
	Port Royal Mills	WWF	240 Industrial Parkway S. Aurora, ON L4G 3V6		514-527-8971
	Robin Hood Multifoods	WF	Sherwood Forest Lane Port Colborne, ON L3K 5V8		905-713-1712
Quebec	ADM Milling	WF,WWF	950 Mill St. Montreal, QB H3C 1Y4	www.admworld.com	514-846-8500
	ADM Milling	WF, WWF	3800 Notre Dame St. E. Montreal, QB H1W 2T5	www.admworld.com	514-343-4000
	Cereal Foods	WF, WWF	380 Rue Oak Montreal, QB H3K 3G2		902-429-0622
	Robin Hood Multifoods	WF	2110 Notre Dame St. W. Montreal, QB H3J 1N2		514-934-3234
Nova Scotia	Dover Mills	WF	Marginal Rd. P.O. Box 2185 Halifax, NS B3J 3C4	www.dovergrp.com	
Durum Milling					
Alberta	Ellison Milling	DP	1301 Second Ave. S. Box 400 Lethbridge, AB T1J 3Z1	www.ellisonmilling.com	

Appendix 3: **Canadian Wheat Processing Facilities-2006**

Province	Company	Processed	Address	Website	Telephone
Saskatchewan	FarmGro Organic Food	DP	Regina SK		306-751-2440
	Robin Hood Multifoods*	DP	First Ave. and 33rd St. E. P.O. Box 537 Saskatoon, SK S7K 3L6		306-665-7111
Ontario	ADM Milling	DP	P.O. Box 310, Port Colborne, ON L3K 5W1	www.admworld.com	
	Howson & Howson Limited	DP	390 Mill Street Blyth, Ontario N0M 1H0	www.howsonandhowson.ca	519-523-4241
	Kraft Milling	DP	Woodbridge, ON	www.admworld.com	
Quebec	ADM Milling	DP	950 Mill St. Montreal, QB H3C 1Y4	www.admworld.com	514-846-8500

Note: WF-Wheat flour; WWF-Whole Wheat Flour; SWF-Soft Wheat Flour; RF-Rye Flour; DP-Durum Products

*This is a swing mill-mills both durum and wheat flour.

Appendix 4: **Canadian Oat Milling Facilities-2006**

Province	Company	Processed	Address	Website	Telephone
Alberta	Westglen Milling	OF, OP	P.O. Box 4615 Barrhead, AB T7N 1A5	www.conagrafoodingredients.com	780-674-3960
	Alberta Oats Milling Ltd.	OP	P.O. Box 228, R.R. 6 Edmonton, AB T5B 4K3	www.albertaoats.com	780-973-9101
Manitoba	Emerson Milling Inc.	OF, OP	Box 424, Riverlot #58, Emerson, MB R0A 0L0	www.emersonmilling.com	
	Can-Oat Milling	OF, OP	Box 520, Portage La Prairie, MB R1N 3W1	www.can-oat.com	
Saskatchewan	Can-Oat Milling	OF, OP	Box 1299 Martensville, SK S0K 2T0 CAN	www.can-oat.com	306-975-0083
	Smucker Foods	OF	First Ave. and 33rd St. E. P.O. Box 537 Saskatoon, SK S7K 3L6		306-665-7110
	Popowich Milling Corporation	OF, OP	Myrtle Avenue, Yorkton, Saskatchewan S3N 1R1	www.popowichmilling.com	306-783-2981
Ontario	Quaker Oats.	OF, OP	Quaker Park, 14 Hunter St. East Peterborough, ON K9J 7B2	www.qtgcanada.com	505-743-3260
	Smucker Foods Of Canada Co.	OF	Sherwood Forest Lane Port Colbourn, ON L3K 5V8 CAN		905-834-4555

Note: OF-Oat Flour; OP-Oat Products

Appendix 5: **Canadian Soybean Oil Crushing Facilities-2006**

Province	Company	Address	Website	Telephone
MB	Jordan Mills	Carman, MB		
Ontario	ADM	P.O. Box 7128 Windsor, ON N9C 3Z1	www.admworld.com	(519) 972-8100
	Bunge Milling	701 Richmond, Street Chatham, ON N7M 5K6	www.bungenorthamerica.com	(905) 825-7900
	Helin Oils	280 Hopkins St Whitby, ON L1N 2B9		(905) 430-6646
	Huron Commodities Inc.	P.O. Box 1353, Clinton, ON N0M 1L0	www.huron.com	(519) 482-8400
	Jackson Seed Service	1315 Jackson St.Dresden, ON N0P 1M0		(519) 683-4413
	Nature's Milling	2141 Woodburn Road R.R. # 1 Binbrook, ON, L0R 1C0		(905) 692-0197
	Sunfield Oilseed	RR 1 Wingham, ON, N0G 2W0		(519) 335-3589
	Tri-County Protein Corp.	12206 Gypsy Lane, P.O. Box 414, Winchester ON, K0C 2K0		(613) 652-1282

Appendix 6: **Canadian Corn Ethanol and Milling Facilities-2006**

Province	Company	Processed	Address	Website	Telephone
Ontario	Commercial Alcohols	Ethanol	Bruce Energy Centre 4th Concession Road Tiverton, Ontario N0G 2T0	www.comalc.com	519-368-7723
	Commercial Alcohols	Ethanol	275 Bloomfield Road Chatham, Ontario N7M 5J5	www.comalc.com	519-436-1130
	Suncor Energy	Ethanol	P.O. Box 307, 1900 River Road Sarnia, Ontario N7T 7J3	www.suncor.com	519-337-2301
	Casco Inc.	CS, S	1100 Green Valley Road London, ON N6N 1E3	www.casco.ca	519-686-3160
	Casco Inc.	CS, S	55 Invertose Drive Port Colborne, ON L3K 5X7	www.casco.ca	905-835-8220
	Casco Inc.	CS	4040 James Street Cardinal, ON K0E 1E0	www.casco.ca	613-657-3131
	Bunge	BG, CF, CM	701 Richmond Street, Box 580 Chatham, ON N7M 5K6	www.bungenorthamerica.com	519-351-1060

Note: CS-Corn Starch; S-Sweetener; BG-Brewers Grit; CF-Corn Flour; CM-Corn Meal