



Assessing the Agri-Fibre Biomass Residue Resources for Creating a BIOHEAT Industry in Alberta

Final Report

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REAP-Canada is North America's most experienced agency in the development of densified agri-fibers as heating fuels with over 20 years of experience collaborating with farmers, government and the private sector to develop and commercialize sustainable agricultural business solutions for Canada's fuel, fibre and food needs. REAP-Canada has been working since 1991 on bioenergy systems development as a means to control greenhouse gases and enhance product demand for the agricultural sector. REAP-Canada was the first agency in Canada to perform research studies on warm season perennial grasses as energy crops and the first agency in the world to commercially pellet switchgrass and burn it successfully as a heating fuel. REAP-Canada provides services in bioenergy market development and economic forecasting, heat energy demand analysis and projections, biomass combustion efficiency, greenhouse gas accounting and assessments of land-use availability for energy grass production systems. Since 1992, REAP-Canada has been a lead contractor for bioenergy research development in Canada completing over 25 studies on energy crop production, combustion and market potential to date. In 2005, working with Nott farms of Clinton Ontario, REAP-Canada helped commercialize the first North American use of crop milling residue pellets as a fuel source. Twenty Ontario greenhouses have now switched to agri-fire pellet fuel heating from natural gas and coal heating and a major new industry is under development in Ontario.

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 China, Ethiopia, the Gambia and the Philippines.

Executive Summary

Renewable energy generation from energy crop production and crop residue utilization represents a new opportunity to increase prosperity for Alberta farmers while reducing GHG emissions. Strong international trade in wood pellets is creating an unprecedented interest in agri-fibre pellets or “agro-pellets” as a new raw material source to expand the industry. This report identifies the potential volumes of crop residues and crop milling by-products that could be sourced in Alberta as biomass energy resources for the emerging bioheat industry. As well, it identifies important biomass quality characteristics of the various bioresources that are available in Alberta.

In an average year, Alberta produces 15.8 million tonnes of cereal and canola straw as a by-product of crop farming. However, after deducting the volumes of these residues required for current levels of livestock production and sustainable soil erosion protection, 7.7 million tonnes of cereal and canola straw could be sustainably recovered. In years with favourable crops, this volume of residue recovery could increase to 13.2 million tonnes. However, in drought years, occurring one year out of every ten years, essentially no surplus residue is available for bioheat applications. The growing adoption of semi-dwarf wheat varieties by cereal producers will also decrease the availability of wheat straw for energy applications in the future. Crop milling residues from cereal grain production represents a much smaller volume of available residues in Alberta. However, these could be important feedstocks for initiating the agro-pellet industry in Alberta. With current capacity for wheat and oat processing in Alberta, an estimated 161,000 tonnes of wheat mill feed and 46,000 tonnes of oat hulls and pin oats could likely be available in the province. Other residues that may have some potential for development in the province include barley hulls and off-specification canola meal.

The most important factor affecting the development of these bioresources for bioheat applications is their biomass quality attributes. It is well known that herbaceous feedstocks are high in ash and can cause significant problems with clinker formation and corrosion in boilers. In particular, it is important to minimize the potassium and chlorine contents of feedstocks to prevent clinker formation and corrosion. Particulate emissions are also related to the content of aerosol forming compounds in feedstocks especially potassium, chlorine, sodium and sulfur contents. Crop milling residues were identified to have much lower levels of aerosol forming compounds than cereal and canola straw and strategically represent an easier raw material to develop in Alberta for initiating an agro-pellet industry. Calcium can also be used to reduce the potential for clinker formation and to reduce particulate load from agro-pellet combustion. The most promising clean heat option for Alberta would be to establish the agro-pellet industry utilizing mixtures of pelletized crop milling residues with calcium additives and to burn them in Lambda-controlled combustion boilers.

With rising gas prices there is presently a backwards fuel switching occurring in many areas of Canada from natural gas to coal. This is a major concern for efforts to reduce GHG emissions in Canada and to reduce health impacts from coal combustion. Agro-

pellets produced by Albertan farmers could represent a competitively priced fuel option to compete with natural gas in heat related energy applications. Based on current prices and experience in other districts, crop milling residues could be produced for about \$100/tonne or the equivalent of \$5.55/GJ in Alberta. A large agro-pellet industry could possibly be developed in Alberta if energy grass and straw pellets could be used for expansion of this industry. A major research effort is required to assess the potential for developing the biomass quality of field crop residues and energy grasses in Alberta to increase their suitability for domestic and export markets.

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1.0 Introduction

Albertan farmers have been amongst the most successful producers in Canada in developing new technologies to increase farm production. Unfortunately, this productive capacity of farmers has created major problems through the saturation of food markets, which has been the principle reason for declining prosperity in the agricultural sector. However, the recent demand enhancement that has been created in North America and Europe by the absorption of large volumes of grains and oilseeds for liquid biofuel production has helped strengthen farmer's livelihoods.

This report explores the potential for Alberta farmers to diversify the development of bioenergy markets by examining the potential of crop residues in the province for the emerging bioheat industry. Wood pellets have become a new bioenergy product that has experienced rapid development in North American and Europe. For example, Germany will have an estimated 90,000 installed pellet boilers using pellets made from wood residues by the end of 2007 (Ortner 2006). The industry is the most advanced in Austria with 50,000 pellet boilers installed in the country, which has a population of 2.5 times that of Alberta. The existing pellet boilers technology in Austria has now reached a combustion efficiency of 86-94% (Fiedler 2004)

Agro-pellets are now seen as the next wave of bioresource development in Europe as it is increasingly recognized that wood residue resources globally are quite limited. In 2006, several Canadian densification plants began selling pellets and cubes of crop milling by-products as fuel sources. There is a growing realization that the agro-pellet industry could be developed as a major new commercial heat source. The main advantages are the high energy output to input ratio the technology at 14:1 and its effectiveness as a strategy to mitigate greenhouse gases (Samson *et al.*, 2005).

New levels of efforts are required to assess the viability of this opportunity. As such, this report focuses on the biomass resource supply in Alberta as well as providing a basic understanding of the major biomass quality issues associated with developing the resources.

2.0 Agri-Fiber Biomass Supply

2.1 Selected Cereal and Oilseed Crop Production

An assessment was made of straw production from the main field crops in Alberta to determine the annual volumes of materials that potentially could be procured annually as well as year to year variability in the supply. Table 1 lists the area, yield and total production of the major cereal grains, as well as canola crops in Alberta, with data averaged over a 10 year period (1996-2005).

Alberta has approximately 6 Mha of cultivated land in wheat, barley, oat, flax and canola producing on average 15.3 Mt of cereals and oilseeds (Table 1). Wheat production was the highest followed by barley, canola and oat, producing approximately 6.8 Mt, 5.5 Mt 2.2 Mt and 0.8 Mt respectively. Flaxseed production in Alberta is considerably lower with only 0.03 Mt produced annually (Table 1). If processing mills were introduced in Alberta the area of the crop could expand in the future. Flax shives are commonly used for energy and thus the crop was included for comparison purposes. The grain yields in Alberta were highest for barley followed by wheat, oat, flax and canola (Table 1).

Table 1. Average cultivated area, production and yield of cereal grains and oilseeds in Alberta for the years 1996-2005 (Alberta Agriculture Statistics Yearbook, 2005; Statistics Canada 2007a)

		Wheat	Barley	Oat	Flax	Canola	Total
Area (Mha)	Avg	2.74	1.56	0.28	0.02	1.48	6.08
	Max	2.93	2.14	0.42	0.03	1.76	7.29
	Min	2.53	1.13	0.18	0.01	1.09	4.95
Prod (Mt)	Avg	6.81	5.45	0.79	0.03	2.21	15.29
	Max	8.36	7.08	1.08	0.05	3.65	20.22
	Min	3.70	2.57	0.37	0.02	1.02	7.68
Yield (t/ha)	Avg	2.70	3.09	2.43	1.71	1.28	2.24
	Max	4.05	3.86	3.18	2.10	1.89	4.05
	Min	1.36	2.28	1.56	1.50	0.58	0.58

2.2 Cereal and Oilseed Straw Production

Potential volumes of straw residues from wheat, barley, oat, flax and canola were determined using annual grain production (Table 1). The quantity of residues produced annually varies considerable with growing conditions and the type of crop (PAMI 2001). With typical conditions, the straw to grain ratio for wheat is at its lower limit is estimated at 1.3:1 (Klass, 1998; Levelton, 2000), but may be as high as 1.7:1 (Levelton, 2000). Similarly, other seed crops are assumed to have an average 1:1 ratio, but may be as high as 1.4:1 (Helwig *et al.*, 2002). Long term averaged straw to grain mass ratios adapted from Sokhansanj *et al.*, (2006) were used to estimate crop residues in cereal grains. In

their study, Sokhansanj *et al.*, (2006) extrapolated straw to grain mass ratios from previous studies (Agriculture and Agri-Food Canada 2003; PAMI 2001; Stumborg 1996; Lindstorm *et al.*, 1979) conducted on various crops types and soil zones. Straw to grain mass ratios used for Canola were determined using Agriculture and Agri-Food Canada's Prairie Farm Rehabilitation Administration 10 year average. The ratios adopted for this study are found in Table 2.

Ratio	Sokhansanj <i>et al.</i> , (2006)				PFRA estimates ¹
	Wheat	Barley	Oat	Flax	Canola
	1.1	0.8	1.1	1.2	2.2

¹Agriculture and Agri-Food Canada (2003)

The quantities of straw residue produced in Alberta were calculated by multiplying the grain production values found in Table 1 by the straw to grain mass ratios (Table 2). Moisture content of the grain were accounted for at the time of harvest and assumed to be 12% (wet basis). Alberta produces approximately 15.8 Mt of straw annually; ranging from a high of 21.6 Mt to a low of 7.9 Mt (Table 3). Wheat produced the highest volumes of straw with approximately 6.8 Mt, followed by canola and barley each with 4.3 Mt and 3.9 Mt respectively (Table 3). Limited quantities of oat and flax straw were available with 0.79 Mt and 0.003 Mt respectively. The straw yields were very similar for wheat, barley, oat and canola with flax having the lowest yield of 1.51 t/ha (Table 3).

Table 3. Estimation of 10 year averaged (1996-2005) straw produced in Alberta based on straw to grain mass ratios

		Wheat	Barley	Oat	Flax	Canola	Total Prod. & Average Yields
Straw Prod (Mt)	Avg	6.83	3.87	0.79	0.03	4.27	15.80
	Max	8.38	5.03	1.07	0.06	7.07	21.61
	Min	3.71	1.83	0.37	0.02	1.98	7.90
Straw Yield (t/ha)	Avg	2.49	2.49	2.84	1.51	2.89	2.44
	Max	2.86	2.34	2.53	1.85	4.02	4.02
	Min	1.47	1.61	2.02	1.32	1.81	1.32

2.3 Cereal and Oilseed Straw Residue Production

Retaining crop residues in cropping systems on the surface of the soil is the single most effective and practical means of controlling soil and wind erosion. Residue cover reduces wind speeds near the soil surface, making the soil less susceptible to wind erosion. It is also effective in stabilizing the soil to reduce water erosion (Agriculture and Agri-Food Canada 2003). Crop residues are also important in maintaining the soil tilth, humic content and fertility of the soil. Individual soil type requirements for crop residue incorporation depend on the soil fertility, pH, current fertilization practices, as well as the type of crop rotation patterns and tillage depth. The amount of surface residues required

for erosion control depend on soil texture and field slopes. In general coarse soils (sandy) require higher volumes of retained residues, followed by fine (clay) soils and medium (loam) soils requiring the least. Similarly as the field slope increases more residues are required to limit water erosion (Agriculture and Agri-Food Canada 2003). Bulman *et al.*, (1995) determined that between 750 and 1500 kg/ha of crop residues is essential to prevent wind erosion for prairie soils. Conservation tillage may reduce these requirements even further (Larson 1979). Sokhansanj *et al.*, (2006) estimated adequate straw for soil conservation in the prairie provinces as 1 t/ha and this value was assumed for our study. Oilseed residues break down more rapidly compared to cereal crop residues and as such 1.5 t/ha of straw residue was estimated to be adequate for soil conservation for canola. The net yield of straw in Alberta following the deductions for soil conservation results in a decrease from 15.8 Mt to 10.9 Mt (Table 4). The maximum straw available after soil conservation was 16.7 Mt and the lowest was 3.12 Mt (Table 4).

Table 4. Net yield and quantities of straw available after deduction for soil conservation and livestock requirements.

		Wheat	Barley	Oat	Flax	Canola	Total after soil conservation	Total after soil & livestock
Straw	Avg	5.02	2.67	0.59	0.01	2.63	10.93	7.67
Prod	Max	6.85	3.57	0.79	0.03	5.42	16.67	13.19
(Mt)	Min	1.48	0.94	0.24	0.01	0.45	3.12	0.08
Straw	Avg	1.83	1.72	2.12	0.71	1.43	1.73	
Yield	Max	2.34	1.66	1.87	1.10	4.17	3.57	
(t/ha)	Min	0.58	0.83	1.30	0.50	0.68	0.50	

The major competition for straw use in Alberta is for livestock use. Much of the straw baled is used for animal feeding and bedding for raising beef and dairy cattle. The quantity of straw used is regionally dependant within Alberta. Typically more feed and bedding days are required in northern Alberta relative to southern Alberta. Southern Alberta required 100 days for feeding and 50 days for bedding, central regions 135 days for feeding and 90 days for bedding and northern regions straw was used for 170 days for feeding and 140 days for bedding (Table 5; Sokhansanj *et al.*, 2006). Table 5 was adapted from Sokhansanj *et al.*, (2006) using current cattle numbers from Statistics Canada (2007b). Alberta requires approximately 3.2 Mt of straw for livestock use annually (Table 5). The net yield of straw available after accounting for soil conservation and livestock use in Alberta is approximately 7.7 Mt and ranged from a high of 13.2 Mt to a low of 0.08 Mt annually (Table 4).

Table 5. Number of cattle in Alberta (10 year average 1996-2005) and estimation of straw used for livestock production (adapted from Sokansanj *et al* 2006, Statistics Canada 2007b)

	Region	Percent of total	Number of cattle (millions)	Feeding		Bedding		Total straw required (Mt)
				days	kg/d	days	kg/d	
Alberta	Southern	45	2.81	100	2.5	50	2.5	1.06
	Central	35	2.19	135	2.5	90	2.5	1.23
	Northern	20	1.25	170	2.5	140	2.5	0.97
	<i>Total</i>	<i>100</i>	<i>6.26</i>					<i>3.26</i>

The net figures available in Table 4 present three issues of concern. The first is that it is evident from the data is that in drought years, almost no surplus biomass is available in the province. Severe droughts appear to occur about 1 year in 10 in Alberta based on recent data sets (Sokhansanj *et al.*, 2006). This problem could worsen considering the increasing concerns about climate change impacts on the prairies. Warming temperatures increase evaporation and drought and reduce the potential for irrigation due to reductions in river flow from the Rockies. Overall, the impact of drought and climate change on straw supply could be considerable. In particular, large industrial processors of straw could face high procurement costs as they would have to compete with the livestock industry in accessing supplies during drought years.

A second consideration that could add risk to straw utilization for energy is the ongoing efforts of plant breeders to increase cereal yields. Varieties of cereal crops grown on the prairies are continuously evolving and modified to meet environmental, climatic and economic conditions. In terms of wheat production in Alberta, there is a trend for growing new semi-dwarf varieties. Wheat breeders are developing semi-dwarf varieties as a means to increase grain production by shifting the partitioning of biomass from straw to grain (Spaner 2007). The rationale behind this strategy is that grain has traditionally had a much higher value per tonne to the farmer relative to straw. Given the limited soil moisture available in Alberta, producing cereal varieties for high grain and biomass with high straw yields may make these varieties more vulnerable to moisture stress. The main impact of the semi-dwarfing introductions to date has been observed in the semi-dwarf Canadian western red spring (CWRS) wheat. This class is the principal type grown on the prairies representing about 69.7% of Canadian wheat production (Canadian Wheat Board 2006). In Alberta, CWRS represented 75.3% of seeded hectares followed by Canadian western amber durum (CWAD) representing 13.5% (Canadian Wheat Board 2006). In the northern Great Plains, 75% of the new varieties under trial since the year 2001 have been semi-dwarf varieties between 78-83 cm in height. (NDSU, 2004). This will have significant impact on reducing available straw volumes as compared to estimates presented in Table 4. For example in the years 1998 to 2003, the dominant variety of CWRS cultivated in Alberta was AC Barrie, representing approximately 23.5% of seeded hectares. However in 2002 a new semi-dwarf variety called AC Superb was introduced and has since superseded Barrie as the most preferred wheat variety planted by Alberta farmers. AC Superb encompassed 22.3% of seeded hectares in 2006 and AC Barrie only

6.1% (Canadian Wheat Board Variety 1998-2006). The change in straw availability from the introduction of high yielding semi-dwarfs will be appreciable. AC Barrie has a straw length of about 88 cm while AC Superb has a straw length of 83 cm (Table 6). In terms of total straw production the AC Superb variety reduces potential straw by approximately 5.7% (Table 6). The decrease in straw production corresponds to approximately 0.60 Mt of straw produced annually in Alberta based on the average wheat straw production data from Table 3. The impact of these new semi-dwarf varieties could be substantial on the economic viability of straw removal for energy. It would reduce the average available straw supply after soil conservation and livestock needs are met by 0.44 Mt. This will create greater risks in drought years and increase recovery costs because of the increased acreage required to collect the fibre to meet the processing plants needs.

Table 6. Impact of new semi-dwarf CWRS wheat on recoverable straw

Characteristics	Variety	
	AC Barrie	AC Superb
Plant height	88	83
% straw reduction		5.7%
Yield index ¹	100.0%	108.7%
% increase in grain		8.7%
Straw-to-grain ratio	1.3	1.13
Harvest index	0.43	0.47
Average grain yield (kg/ha)	2133	2318
Total straw	2773	2615
Recoverable Straw (kg/ha)	1773	1615
Difference		158
Percent reduction in straw		8.9%

A third concern about recovering straw for energy is that even though adequate soil protection may be offered through no-till and leaving residual minimum straw levels, soil fertility may not be adequately maintained. This may be particularly the case in the lighter coloured soil zones of Alberta. With rising grain commodity prices, farmers will logically be less interested in straw sales in the future and more interested in increasing grain production through improved soil management practices. In a review of production and utilization of crop residues as global biofuel sources, Lal (2005) concluded the most appropriate use of crop residues is to enhance, maintain and sustain soil quality by increasing the soil organic matter pool, enhancing activity and species of soil fauna, minimizing soil erosion and non-source pollution, mitigating climate change by sequestering carbon in the pedosphere and advancing global food security through enhancement of soil quality. Lal (2005) recommended that efforts be undertaken to grow biomass on specifically dedicated land with species of high yield potential to minimize crop residue use for energy.

2.4 Regional Distribution of Straw Supplies in Alberta

To provide a more detailed analysis, the provincial straw production was broken down into census divisions (Figure 1) and regional locations within Alberta in order to determine the locations of excess straw province wide. Alberta census divisions were used for the analysis as data obtained from Alberta Agriculture, Food and Rural Development delineated their provincial cereal and oilseed production accordingly. The 19 census divisions were further grouped into three main regions, northern, central and southern. The rationale behind these three regions was to correspond with livestock distribution found in Table 5. Southern Alberta encompasses Medicine Hat, Lethbridge, Fort Macleod, Calgary and Banff (census divisions of 1, 2, 3, 5, 6 and 15; Figure 1) and corresponds to approximately 2.33Mh of crop land. Central Alberta consisted of Hanna, Stettler, Red Deer, Rocky Mountain House, Camrose-Lloydminster, Edmonton, St. Paul, Athabasca and Edson (census divisions 4, 7, 8, 9, 10, 11, 12, 13, and 14; Figure 1) and covers 2.96 Mh of cropland. Northern Alberta represents 0.97 Mh of crop land dedicated to cereal crops and canola and includes Fort McMurray, Slave Lake, Grande Cache and Grand Prairie (census divisions 16, 17, 18, 19; Figure 1).



Figure 1. Alberta Census divisions

Table 7 list the volumes of straw available by census division after deductions for soil conservation and straw volumes available by regions after deducting competing uses of livestock. Alberta has limited production of flaxseed and therefore only provincial wide production data was obtained. Southern Alberta contains the highest volume of wheat straw and the second highest volume of barley straw in the province with 2.39 Mt and 1.17 Mt respectively (Table 7). Minimal volumes of canola and oat straw volumes are located in southern Alberta. Central Alberta has the highest volumes of barley, oat and canola straw available following soil conservation deductions with 1.43 Mt, 0.40 Mt and 1.26 Mt respectively. Northern Alberta has moderate volumes of wheat and canola straw and minimal volumes of barley and oat straw (Table 7). After deductions for livestock uses, central Alberta has the highest volumes of straw with 3.87 Mt possibly available for bioheat options. Southern Alberta follows central Alberta with 3.0 Mt of available straw and northern Alberta with 0.43 Mt of straw potentially available (Table 7). Regional maximum and minimum estimated straw production volumes from 1996-2005 are in Appendices 1 and 2.

Table 7. Estimated average quantities of straw available by census divisions and regions in Alberta after deductions for soil conservation and livestock requirements (1996-2005).

Region	Census division	Wheat (Mt)	Barley (Mt)	Oat (Mt)	Canola (Mt)	Division totals after soil (Mt)	Regional total after soil & livestock (Mt)
Southern	1	0.40	0.04	0.00	0.03	0.48	
	2	0.65	0.24	0.01	0.11	1.01	
	3	0.18	0.20	0.01	0.03	0.41	
	5	0.87	0.33	0.01	0.20	1.40	
	6 & 15	0.29	0.36	0.02	0.09	0.76	
<i>Southern Total</i>		<i>2.39</i>	<i>1.17</i>	<i>0.05</i>	<i>0.46</i>	<i>4.06</i>	<i>3.00</i>
Central	4	0.18	0.03	0.01	-	0.22	
	7	0.46	0.21	0.05	0.22	0.94	
	8	0.21	0.32	0.03	0.15	0.71	
	9	0.01	0.01	0.01	0.00	0.02	
	10	0.62	0.37	0.10	0.38	1.46	
	11	0.31	0.20	0.07	0.28	0.86	
	12	0.05	0.10	0.04	0.06	0.25	
	13	0.17	0.18	0.08	0.17	0.61	
14	0.00	0.01	0.01	0.00	0.02		
<i>Central Total</i>		<i>2.01</i>	<i>1.43</i>	<i>0.40</i>	<i>1.26</i>	<i>5.10</i>	<i>3.87</i>
Northern	16	0.00	0.01	0.01	-	0.02	
	17	0.21	0.06	0.04	0.09	0.41	
	18	0.03	0.01	0.01	0.01	0.06	
	19	0.47	0.12	0.07	0.25	0.91	
<i>Northern Total</i>		<i>0.71</i>	<i>0.20</i>	<i>0.12</i>	<i>0.35</i>	<i>1.40</i>	<i>0.43</i>

2.5 Straw Potential from Forage Seed Production

It may be possible to recover grass seed residue, as it is standard practice for growers to remove grass seed straw after seed harvest, as doing so helps improve seed yields the following year. Typically the by-products from the grass seed industry are underused. Alberta's forage seed production industry produces approximately 54% of Canada's forage seed. Alberta has approximately 165, 615 ha under forage seed production (Statistics Canada, 2001), of which 83% or 130,000 ha are located in the Peace River region of Alberta. Alberta is renowned for the production of Creeping Red Fescue seed, which accounts for 50% of the forage seed hectares in the region. Other dominate species include: Smooth Bromegrass, Meadow Bromegrass, Hybrid Bromegrass, Tall Fescue, Meadow Fescue, Orchardgrass, Timothy, and Wheatgrasses (AAFRD, 2007b). If we look at only 80% of the current acreage production and assume a straw recovery rate of 1.5 t/ha an estimated 198,738 tonnes of grass seed straw could be procured. The main concern about this resource is its biomass quality attributes may prove unsuitable for combustion.

3.0 Crop Milling Residues Processed in Alberta

This section of the report analyses the total production of crop milling residues produced in Alberta. The dominate use of crop milling residues presently is in the livestock feed industry. It was determined from western Canada that wheat mills operate at approximately 85% production capacity. In terms of calculating conservative estimates, crop milling residues were calculated with the assumption that cereal and oilseed mills operate at 80% of their production capacity. As stated in section 2, limited production of flaxseed is grown in Alberta, and in terms of milling not data was obtained. Two small mills were found to processes flaxseed (Appendix 6), however it is anticipated limited quantities of flax residue is available.

3.1 Wheat Processing

Alberta accounts for approximately 30% of all Canadian wheat produced annually, second only to Saskatchewan with 47% of the total wheat grown in the country. Wheat milling for flour production uses approximately 70%-75% of the unprocessed grain while the remaining 25%-30% is available as wheat residues including bran, shorts and germs ((Blasi et al 1998; Appendix 3). Typically these by-products are mixed in various proportions and referred to as millfeed, wheat mill run or wheat middlings (Blasi et al 1998). In terms of establishing quantities of wheat by products available, inconsistent terminology can create some difficulty, and therefore for the purpose of this report all wheat by products will be referred to as millfeed. A portion of the millfeed, wheat bran, is used for human consumption, while the majority is used in the livestock feed industry.

Alberta has the potential to produce an estimated 1.2 million tonnes of millfeed annually, with a peak volume of 1.4 million tonnes and a low volume of 650,971 tonnes (Table 8). However, not all wheat produced in Alberta is processed in Alberta, wheat is exported and milled where demand requires. Samson et al (2006) determined that 40% of Canadian wheat is processed in Ontario, while Alberta, Saskatchewan and Manitoba combined processed 30% of Canadian wheat. The wheat milling industry in Alberta has an annual capacity of approximately 730, 292 tonnes and produces on average 160, 664 tonnes of millfeed (Table 9).

Table 8. Average total production of milling residues from selected crops in Alberta (1996-2005)¹

	Milling Residue Production ¹ (tonnes)					Total
	Millfeed ²	Oat Hulls ³	Pin Oats ⁴	Barley Hulls ⁵	Canola ⁶	
Avg	1,198,761	152,340	69,823	490,589	1,058,683	2,970,196
Max	650,971	71,059	32,569	231,219	489,888	1,475,706
Min	1,470,973	207,264	94,996	636,849	1,752,672	4,162,754

¹Adapted from Table 1; ²Millfeed 27.5% of unprocessed grain (Blasi *et al.*, 1998); ³Oat hull: 24% of unprocessed grain (Brown *et al.*, 2001); ⁴Pin oats: 11% of unprocessed grain (Nott 2006); ⁵Barley hulls: 12% of the unprocessed grain (Bhatty, 1993); ⁶Canola meal: approximately 60% of the unprocessed seed (Canola Council of Canada, 2007)

3.2 Oat Processing

There are three main markets for oats in Canada; 1) the performance oats market, 2) the milling oats market, and 3) feed oats markets. The quality of the oats produced is a key factor in determining the appropriate market. The milling oats are oats processed for human consumption, typically rolled oats produces oat hulls as a by product, while the performance oats are those cleaned and processed for horse feeding produced pin oats (small sized oats) as well as oat hulls (Appendix 4). Based on oat production in Alberta, approximately 152,340 tonnes of oat hulls and 69,832 tonnes of pin oats could be produced annually (Table 8). The highest volumes of both oat hull and pin oats were estimated at 207,264 and 94,996 respectively. However not all oat grain produced in Alberta is processed in Alberta and based on oat milling capacity in 2007 approximately 30, 835 and 14,133 tonnes of oat hulls and pin oats respectively were potentially available, for a total of 44,968 tonnes of oat by products (Table 9). Samson et al (2006) determined that 88% of all oat milling occurred in western Canada with the highest production of oat hulls and pin oats produced in Saskatchewan followed by Manitoba with 103,491 tonnes and 48,180 tonnes respectively.

Table 9. Estimated yearly crop processing and milling residues production of selected crops in Alberta in 2007¹

	Daily Capacity (tonnes) ²	Estimated storage (tonnes) ²	Estimated crop processing (tonnes/yr)	Estimated milling residue (tonnes)
Millfeed	2,501	32,400	730,292	160,664
Oat hulls	440	11,060	128,480	30,835
Pin oats				14,133
Barley hull	-	-	654,000	24,804
Off-specification canola meal	3,820	-	1,115,440	33,463
Totals	6,761	43,460	2,628,212	236,899

¹Based on 80% utilization of capacity and 22%, 24%, 11%, 12%, 60% of the grain available as millfeed, oat hulls, pin oats, barley hull and canola meal respectively. Available barley hull and off-specification canola are assumed to be 5%.

²Market Analysis Division, 2006

3.3 Barley Processing

Two types of barley are grown for the food industry, hulled and hullless barley. The predominate barley type by far is the covered form, with the tough fibrous outer coat (hull) strongly adhered to the barley kernel. In the case of the hullless type, the hull is lost during harvest (similar to wheat) and the resulting kernel or berry can be processed directly into food products. In the case of traditional barley, the tough fibrous hull is literally cemented to the kernel and must be removed using a milling process and represents approximately 12% of the grain by weight (Bhatty 1993; Appendix 5). In

Alberta approximately 75% of the barley grown is for the livestock feed industry, while the remaining 25% is used in the malting industry. Based on barley production in Alberta, it is estimated an average of 490,589 tonnes of barley hull a year could be produced from the feed barley (Table 8). Over the last 10 years an estimated maximum production of 636,849 tonnes and a minimum production of 239,219 tonnes of barley hull were produced annually for the feed industry (Table 8). It is assumed that 5% of the barley hull could be recovered from the feed and barley seed industry for bioheat options representing approximately 24,804 tonnes of barley hull a year (Table 8).

3.4 Canola Crushing

The prairie provinces of Alberta, Saskatchewan and Manitoba are the dominant producers of canola in Canada. The canola industry in Canada currently consists of 13 major crushing and refining/packaging plants across the country, of which 3 are located in Alberta. Smaller crushing mills can be found in Alberta (Appendix 7), however these production volumes are considered minimal. Alberta represents 34% of the Canadian canola crushing industry which has a capacity of 4 million tonnes of canola seed annually (Canola Council of Canada, 2007). Canola is traditionally crushed for its oil, which is considered a premium edible vegetable oil; however the remaining solids, called meal, are an important protein source in the beef and specialty feed (Appendix 6). Forty percent of the unprocessed seed produces canola oil, while the remaining 60% is the solids used to produce the canola meal (Canola Council of Canada 2007).

Canola crop production statistics over the last 10 years (Table 8) demonstrate that Alberta could potentially produce approximately 1.1 million tonnes of canola meal annually, with a maximum of 1.8 million tonnes and a minimum of 489,888 tonnes a year. However based on Canola processing statistics from the three major canola crushing companies in Alberta (ADM, Bunge and Canbra) approximately 1,115,440 tonnes of canola seeds are crushed annually producing an estimated 669,264 tonnes of canola meal. However, it is assumed that 5% of the canola meal produced would be off-specification, representing 33,463 tonnes (Table 9).

3.5 Regional Distribution of Crop Milling Residues in Alberta

The distribution of crop milling residues within the province was analyzed by the location of milling and crushing facilities within each census division and region similar to the straw residue estimates in Section 1. Southern Alberta was estimated to have the highest annual processing capacity with approximately 943,160 tonnes of cereal and oilseed crops processed annually producing an estimated 155,955 tonnes of crop milling residues (Table 10). Central Alberta, processes approximately 1 million tonnes, producing approximately 105,966 tonnes of crop milling residues (Table 10). Northern Alberta has very small potential for crop milling residue recovery (Table 10).

Table 10. Estimated yearly crop processing and residue production of selected crops by census division and region in Alberta

Region	Census division	Daily capacity (t/day)	Estimated crop processing (t/yr)	Estimated milling residue (tonnes)
Southern	1	496	144,832	32,250
	2	1,809	528,228	56,145
	3			1,948
	5			3,094
	6 & 15	925	270,100	62,520
	<i>Southern Total</i>	<i>3,230</i>	<i>943,160</i>	<i>155,955</i>
Central	4			321
	7			1,896
	8	360	105,120	25,820
	9			73
	10	2,031	593,052	22,527
	11	1,050	306,600	43,637
	12			851
	13	90	26,280	10,781
	14			61
	<i>Central Total</i>	<i>3,531</i>	<i>1,031,052</i>	<i>105,966</i>
Northern	16			64
	17			631
	18			75
	19			1,206
	<i>Northern Total</i>	<i>0</i>	<i>0</i>	<i>1,975</i>

4.0 Biomass Quality

Within biomass fuel materials, there are considerable differences in combustion quality characteristics. Agri-fibres for instance, are well known to be generally more difficult to burn than wood residues. High-ash energy crops and crop residues tend to form clinkers and corrode conventional boilers, which has been the major factor slowing their commercial development as combustion fuels, 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 and the emissions of particulate matter and pollutants during combustion. This analysis assesses various agri-fibre biomass feedstocks and strategies that can optimize their suitability for combustion in Alberta, especially for smaller-scale combustion appliances, which may have the best economic viability for use. Pellets exported out of Alberta to Japan or Europe will also likely be required to meet strict environmental regulations and standards.

4.1 Nutrient Content and Management of Agri-Fuels

High nutrient contents, particularly chlorine and also potassium, can cause clinker formation and corrosion inside of combustion units (Elbersen *et al.*, 2002). Chlorine specifically has been identified as a major factor in ash formation and corrosion by facilitating stable high-temperature, gas-phase, alkali compounds such as potassium chloride to be formed and transported to furnace surfaces, where corroding sulfate compounds can then be formed (Jenkins *et al.*, 1998). Without chlorine present, these gaseous alkali compounds would be oxidized and emitted as combustion gases. Maximum target values of 0.2% K and 0.1% Cl have been recommended for efficient use of biofuels for power generation in Denmark (Sander 1997).

In Table 11, an analysis of biomass quality of the most readily available agricultural residues for bioheat applications in Alberta is made, grouping the straw/stalks, grains, and milling residues. In analyzing the groupings of these selected crops, 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 industry in Alberta. Rye likely has the best potential as a lower-cost feed grain for use as a fuel at present pricing. Some off-specification or heated grains might also be able to be utilized. Crop milling residues generally have distinct price advantages over whole grains and similar quality for combustion. Increasing farm commodity prices with increasing bioenergy demand will likely make whole grains uncompetitive with other biofuel options in the future. Crop milling residues appear to represent a more promising option.

Table 11. Biomass Quality of grains, straw and milling residues¹

Residue Type	Energy (GJ/ODt)	Bulk Density (kg/m ³)	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	-	91	4	8	0.64	0.24	2.4	0.78	0.22
Barley	19.2 ²	82 ²	90	4	7	0.64	0.33	2.1	0.67	0.16
Rye	18.25 ³	-	89	4	6	0.64	0.24	1.0	0.24	0.11
Flax	18.1 ²	-	-	-	4	0.88	-	-	0.23	0.12
Canola ¹⁰	15.65	-	87	-	6	0.57	0.76	1.05	0.38	0.34
Alfalfa hay	-	120 ¹²	88	13	8	-	1.18	1.50	0.35	0.21
Grass hay	-	-	88	30	6	-	0.60	2.0	-	0.20
Grains and Oilseeds										
Wheat	18.75 ⁴	668 ²	89	14	2	2.24	0.05	0.4	0.09	0.15
Oat	17.74 ⁴	498 ²	89	13	4	2.08	0.05	0.5	0.11	0.2
Barley	17.5 ²	614 ²	89	12	3	1.92	0.06	0.6	0.18	0.16
Rye	17.1 ⁵	641 ⁶	89	12	2	1.92	0.07	0.5	0.03	0.17
Flax	17.2 ²	697 ²	-	-	4	0.60	-	-	0.32	0.16
Canola	-	-	-	38	-	-	-	-	-	-
Canola meal ¹¹	-	-	90	35	6	-	0.63	1.22	.10	0.85
Milling Residues										
Wheat bran	-	216 ⁸	89	17	7	2.72	0.13	1.4	0.05	0.24
Wheat middlings	17.15 ⁴	310 ⁸	89	19	5	3.04	0.15	1.4	0.05	0.2
Oat hulls	19.5 ²	235 ⁹	93	4	7	0.64	0.16	0.6	0.08	0.14
Pin oats	-	-	89	8	6	1.28	0.12	0.6	-	0.24
Barley grain screenings	-	-	-	-	4	-	0.7	-	-	-

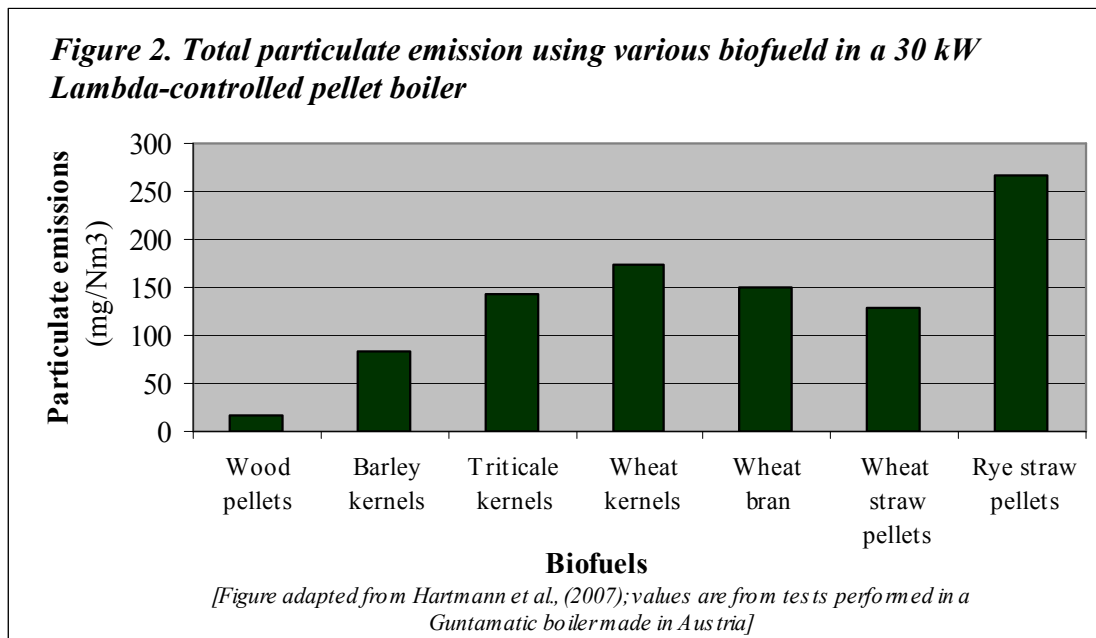
¹Preston (2006); ²Reisinger *et al.* (2006); ³Staniforth (1979); ⁴AURI (2001); ⁵FAO (2004); ⁶Murphy (1993); ⁸Blasi *et al.* (1998); ⁹Shaw and Tabil, 2006; ¹⁰Newman *et al.* (2003); ¹¹Hickling (2001); ¹²Granatstein *et al.* (2002).

Milling byproducts of the oat processing industry were identified to have potassium contents below 1%. Relatively low chlorine contents (<0.1%) were also found in wheat milling by-products and oat hulls. Oat hulls and pin oats also appear to be promising feedstocks for combustion as they possess moderately low potassium, chlorine and nitrogen contents. Using mixtures of these fuels may provide some benefit in terms of pelletization and ease of combustion. Wheat bran for example, appears to be a promising binder for higher fibre agri-fibre resources like energy grasses or oat hulls. It can also increase throughput on the mills and improve pellet durability.

Straw and stalk residues as a group are considerably more problematic for combustion with their high potassium and chlorine content. Delayed harvest of cereal straw may help improve their opportunities to be used as combustion fuels. Using stripper-headers for harvesting cereals may enable straw to be left standing in the field and to allow weathering processes to leach potassium and chlorine from these fuels. This approach should be assessed in Alberta. Some success has also been achieved in Europe using potassium fertilizers that contain no chlorine (Sander 1997). More analysis and combustion experience is required to more accurately assess the potential of the various crop milling residues and field crop residues as combustion fuel for industry in Alberta.

4.2 Particulate Matter Emissions

Particulate matter (PM) or aerosol emissions absorb and scatter atmospheric radiation, possibly contributing to radiative forcing around the globe, and also have significant negative impacts on human health. Particulates are a critical pollutant in flue gas and may be a limiting factor for industry to meet increasingly rigorous emission standards. Hartmann *et al.*, (2007) found a strong difference in particulate emissions between woody biomass and herbaceous fuels. This appears to be a function of both the aerosol-forming potential of the fuel and the physical form of the biomass. Compared with emissions from wood pellets (17 mg/Nm³), particulate matter emissions from crop milling residues and feed grains ranged from 80-200 mg/Nm³ (Hartmann *et al.*, 2007). Cereal straw pellet samples tested in the 125-275 mg PM /Nm³ emission range. Figure 2 illustrates the particulate emissions found for the various feedstocks.



Processed fuels can significantly improve combustion quality and decreased particulate loading when compared with bulk fuels due to the increased uniformity of the fuel, less fines and better control over the combustion process. Biomass fines can significantly impact particulate matter emissions as the combustion air carries away fines with emissions before they are completely combusted. To reduce fuel fines, high quality pellets with improved durability can be used.

Particulate emissions are also strongly related to fuel type, and specifically, their content of aerosol-forming compounds including potassium, chlorine, sodium and sulphur and even lead and zinc (Hartmann *et al.*, 2007). Using fuels that are low in the “dust critical” elements K, Cl, Na and S is of particular importance for achieving high quality biomass fuels and lowering particulate emissions during biomass combustion. Obernberger (2007)

suggested a target of less than 0.1% for these elements to minimize concerns of aerosol formation. Please refer to Table 11 for the K, Cl and S contents of various biomass fuels. Biomass combustion appliance manufacturers often recommend the addition of lime (CaO) to fuels when burning agro-pellet fuels or grains to avoid problems with clinker formation and slagging. Hartmann *et al.*, (2007) found that this practice, although having no impact on the emission of carbon monoxide, volatile hydrocarbons or other gaseous pollutants, did reduce particulate loading by approximately 15%.

4.3 Pollutant Emissions

NO_x compounds play an important role in the production of particulate matter and atmospheric haze, smog, acid rain and eutrophication from nitrogen deposition in aquatic areas. Hartmann *et al.*, (2007) found that in flue gas emissions, NO_x emissions are clearly a function of the element (in this case nitrogen) content in the fuel when compared with other pollutants such as carbon dioxide (CO₂), carbon monoxide (CO) and volatile hydrocarbons (TOC). Lower N containing fuels such as wood chips, wood pellets and miscanthus fuels had NO_x emissions below 200 mg/Nm³, while grain fuels had emissions from 400-600 mg NO_x/Nm³.

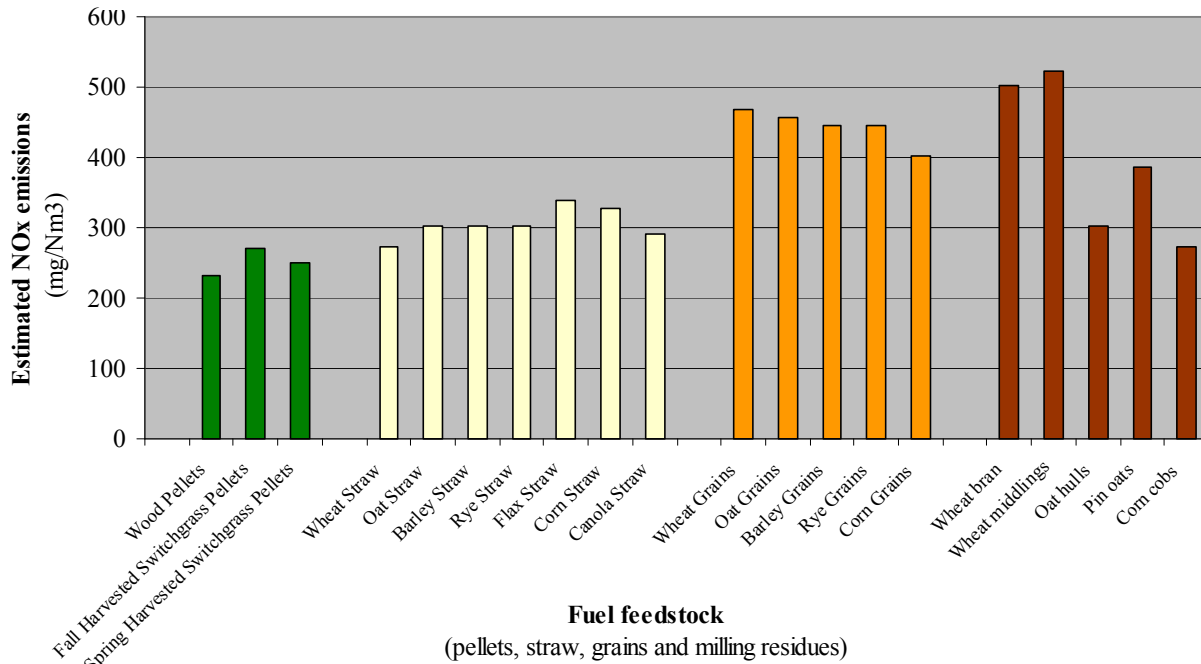
Table 12. NO_x Emissions Associated with Nitrogen content of feedstock

Residue	Nitrogen Content¹ (%)	Estimated NO_x Emissions (mg/Nm ³)
Wood Pellets	0.3 ²	232
Energy Crop Pellets		
Fall Harvested Switchgrass	0.46 ³	270
Spring Harvested Switchgrass	0.37 ³	250
Straw Residues		
Wheat	0.48	274
Oat	0.64	303
Barley	0.64	303
Rye	0.64	303
Flax	0.88	338
Corn	0.8	327
Canola	0.57 ⁴	291
Grains		
Wheat	2.24	469
Oat	2.08	457
Barley	1.92	445
Rye	1.92	445
Corn	1.44	402
Milling Residues		
Wheat bran	2.72	502
Wheat middlings	3.04	522
Oat hulls	0.64	303
Pin oats	1.28	386
Corn cobs	0.48	274

¹Preston (2006); ²Obernberger and Thek (2004); ³Average of Goel *et al.*, (2000); and Adler *et al.*, (2006); ⁴Newman *et al.*, (2003)

Hartmann *et al.*, (2007) determined that NO_x emissions from biomass combustion in a small scale Guntamatic Powercorn 30 Lambda-controlled boiler were equivalent to 353.9 times the N content (%) to the power of 0.35 using a regression analysis. Using this relationship, NO_x emissions were estimated from the nitrogen content for common agricultural feedstocks, the results of which are presented in Table 12 and illustrated in Figure 3.

Figure 3. Estimated NO_x emissions associated with N content of feedstock in a small-scale Lambda-controlled boiler



Low nitrogen-containing fuels having an N content less than 0.5% were identified to have the lowest overall estimates for NO_x emissions, with the overwintered switchgrass feedstock approaching the low levels achieved by the wood pellets. Some milling byproducts, specifically oat hulls and corn cobs also had low NO_x estimates and appear to be promising feedstocks for combustion based on their N content. Straw fibres also possessed moderately low nitrogen contents. However, all of the grain fuels and the processed wheat residues were estimated to produce high levels of NO_x, between 400-500 mg/Nm³. Using mixtures of these fuels may provide some benefit in terms of pelletization, increase combustion efficiency and will keep NO_x emissions at acceptable levels.

4.4 Strategies to commercialize pelletized biofuels

There exist a number of strategies which can assist in the commercialization of the agri-fibre biomass feedstock industry in Alberta. Optimization of fuel quality is of

fundamental importance, reducing contents of K, Cl and other “dust critical” elements such as Na and S. 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. In addition, the combination of the use of low-nitrogen fuels and Lambda-controlled combustion boilers is a best management strategy to reduce NO_x emissions from biomass combustion in Alberta. Lambda-controlled boilers, which optimize combustion based on air-flow control rather than temperature control, can decrease the emission of pollutants and particulates. They reduce the potential for N from excess combustion air to contribute to NO_x formation and increase overall boiler efficiency. The most likely scenario for uptake of agro-pellets in Alberta is to follow efforts in Ontario, where commercial pellets producers are mixing pin oats, oat hull and wheat bran to make pellets. Lime is also being used to help improve combustion and reduce slagging.

5.0 Biomass Cost and Transport

Estimates were made of the delivered prices of field crop residues and crop milling residues by estimating the value of the resources at the farm or crop milling facility and adding in transport costs to a conversion facility. With the recent upward trends in farm commodity prices there appears to be increasing costs associated with procuring by-products of crop production.

5.1 Straw Cost

Cereal and oilseed prices, straw and crop milling residue selling ranges and average costs over the last 5 years were determined for wheat, oats, barley and canola (Table 13). The value of straw was determined based on its opportunity value as a substitute for hay in livestock feeding programs. The current value of livestock hay was determined from reviewing hay commodity prices advertised in Alberta farm papers and through discussions with hay brokers. Livestock feed hay was estimated to be worth \$60/tonne in May 2007 at the farmgate. Based on their respective feed values versus hay, wheat, barley and oat straw are estimated to be worth 48%, 52% and 64% respectively of the hay market price (AAFRD, 2007c). The value of straw depends on the crop grown, the propensity of the field to erode, the amount of residue on the field, the soil organic matter and fertility level as well as the value of straw for bedding or feed. The demand for hay in Alberta for livestock is predicted to rise with increasing farm commodity prices, this will continue to put more upward pressure on straw prices. Wheat crops in Alberta produce 46% of all straw available after soil conservation in the province, followed by barley with 24% and oats with only 5% of provincial straw production (Table 4). The opportunity value of the various straws as livestock feed in May 2007 are estimated at \$28.80, \$31.20 and \$38.40 per tonne for wheat, barley and oats respectively at the farm gate (Table 12). Additionally costs will be incurred for transport expenditures of the straw to a biomass conversion facility (Table 14).

5.2. Crop Milling Residue Costs

The average millfeed price in Alberta over the last 5 years ranged from \$47.04-\$129.34, and averaged approximately \$82.50 over the 5 year period. (Table 13). Currently the cost of millfeed is estimated at approximately \$109.80 (Table 13). Millfeed is the largest volume crop milling residue available (Table 9) in Alberta and represents approximately 68% of the crop milling residues resource in Alberta.

Table 13. Estimated yearly crop processing and residue production of selected crops in Alberta (2002-2007)(AAFRD, 2007a)

	Selling range (\$/t)	Average selling price (\$/t)	Current selling price (\$/t)
<i>Grains</i>			
Wheat	\$73.50 - \$183.29	\$119.72 - \$135.14	\$167.00 - \$170.00
Oat	\$68.10 - \$260.00	\$124.68 - \$145.53	\$155.60 - \$170.00
Barley	\$59.70 - \$206.70	\$112.87 - \$125.98	\$170.00 - \$172.00
Canola	\$303.40 - \$434.00	\$356.61	\$347.60
<i>Straw</i>			
Wheat			\$28.80
Oat			\$38.40
Barley			\$31.20
<i>Crop Milling Residue</i>			
Millfeed ¹	\$47.04 - \$129.34	\$76.62 - \$86.40	\$108.80 - \$110.80
Oat hulls ²	\$13.62 - \$52.00	\$24.94 - \$29.11	\$31.12 - \$34.00
Barley hulls ²	\$11.94 - \$41.34	\$22.57 - \$25.20	\$33.52 - \$34.00

¹Calculated by estimating the feed value of wheat millfeed is 64% of the feed wheat price;

²Calculated by estimating oat hull has a feed value 20% of the value of oats.

Oat hulls (including pin oats) were estimated to cost from \$13.62 to \$52.00 over the last five years, with an average cost of approximately \$27.00 (Table 13). Currently oat hulls are selling between \$31.12 and \$34.00 across the province (Table 13). Oat hulls are a relatively cheap compared to the cost per tonne of wheat millfeed and are on average the lowest cost resource on \$ 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. Barley hulls are very similar to oat hull in terms of cost, ranging from \$11.94 to \$41.34 in the last five years and currently estimated to have a value of \$33.52 and \$34.00 (Table 13). Barley hulls are an additional cheap source of biomass, relative to wheat millfeed.

Canola meal is a widely used protein source used in animal feeds, and is considered the second most widely traded protein ingredient after soybean meal. Canola meal is commonly pelleted in the US and Canada and sold to the livestock feed industry. Due to the high protein content of the meal (approximately 34%), and high demand in the livestock feed industry, it is not expected to be an important residue for use in the emerging bioheat industry.

5.3 Biomass Transportation Costs

Transport costs play an important role in reducing the delivered costs of biomass to conversion facilities. Biomass may be transported in many forms, 'raw' biomass (silage, bales, chopped), or more dense energy carriers such as pellets or cubes. Numerous factors play a role in the size and mode of transportation, specifically the form and bulk

density of the biomass, the transport distance to biorefinery, and the current infrastructure available for transport (e.g. silage, bulk, or baled) and truck transport is generally well developed and is usually the cheapest mode of transport but becomes expensive as travel distances increase (Sokhansanj and Fenton, 2006). Transportation costs are heavily influenced by the travel distance from the biomass source to the biomass destination as well as the moisture content and density of the biomass to be transported. Biomass may be directly transported to the end user, minimally processed (e.g. ground), or densified (eg. pelleting or cubing). Each process adds additional costs to the total delivered biomass cost.

Some estimates have been recently made of transport costs for bioresources in western Canada. Sokhansanj and Fenton (2006) determined the cost for transporting 36 large square bales (1.2m x 1.2m x 2.4 m) on a 14.2 m flat bed truck a fixed distance of 100km and a variable distance between 20 and 100km as \$13.41/tonne (\$15.45 CAD) and \$19.92/tonne (\$22.95 CAD) respectively, including the cost of loading and unloading the bales as well as transport. Adjusting for inflation, Cameron et al (2004) determined the cost of transporting straw 50km as \$18.95 (\$24.69 CAD) per green tonne based on a fixed distance. Loading and unloading of bales was determined as \$5.95 (\$6.69 CAD) per green tonne and a variable cost variable cost that covers labor, fuel, and capital recovery of the truck at \$0.13 (\$0.18 CAD) per tonne per km. Stumborg and Townley-Smith (2004) determined loading, unloading and transportation of straw 50 km at \$16.72 per tonne after adjusting for inflation. REAP-Canada recently reviewed strategies to reduce transport costs for herbaceous biomass in eastern Canada. An assessment of transportation costs for Foley Farms near Ottawa, who custom hauls switchgrass bales was performed. Foley Farms custom hauls switchgrass bales from 45 ha of switchgrass from their farm near Arnprior to a Metcalfe Ontario mushroom compost facility (approximately 160 km return trip). In, 2006 Foley Farms custom hauled 20 tonnes of switchgrass bales (0.86m x 0.81m x 2.3m; 291 kg/bale at 12% m.c.) for \$300 per trip or approximately \$15/tonne. The breakdown for this cost was estimated by Foley farms to cost \$66.66 for loading and \$33.33 for unloading for each trip as well as \$1.25 per km per round trip less than 200 km (both ways). For destinations of round-trip less than 100 km, Foley Farms would charge \$2.00 per km.

Larger bales may help reduce the loading and unloading costs. Higher density bales could also likely reduce hauling and handling costs. Girouard and Samson (1996) found bale density of spring harvested switchgrass using a New Holland baler of 3'x4' (0.85m x 1.2m x 1.5 m) dimensions to be 136 Oven dry kg/m³. Girouard *et al.*, (1998) found bale density of spring harvested switchgrass using a New Holland 2000 large square baler producing 2.07m x 0.96 x 1.22 m bales to be 322 kg per bale at 13% moisture. Thus the bale density is 116 oven dry kg/m³. Other studies have found very large switchgrass round bales (1.83m diameter x 1.52m) width to have similar densities of 135 kg/m³ (Bransby *et al.*, 1996). Krone Corporation has introduced a "Big Pack" 1290 High Density Press large scale press to the market which produces 0.90m x 1.20m bales using a pre-chopper device that pre-compresses material as well as a higher-than-normal compression bale chamber (Figure 4a). These two features increase bale density by 20-25% compared to their standard large square baler. The company indicates that if

material on an as-is basis is baled with their 1290 High Density Press baler they could increase bale density to 200-220 kg/m³ (or 170-187 dry kg/m³) versus the normal 160-180 kg/m³ range achieved with their traditional large bale technology. If we assume a



mean bale density of 150 dry kg/m³, or approximately 389 dry kg per 0.9m x 1.2m x 2.4m bale, the average load hauled to a pellet plant would be 21.8 tonne at 12% moisture and cost \$9.17/tonne. If the 1290 High Density Press bale technology could obtain a bale density of 180 dry kg/m³ the load would be increased to 26.2 tonnes at 12% moisture. This could reduce hauling costs to about \$7.63/tonne if the return haul to a pelleting plant is less than 50km.

Crop milling residues may be hauled using a walking floor trailer (Figure 4b). A basic walking floor trailer has a 100m³ volume capacity and a load capacity of approximately 40 tonnes. Wheat middlings and oat hulls have bulk densities of 310kg/m³ and 235kg/m³, (Table 11) enable one truck load to haul approximately 31 tonnes and 17 tonnes, respectively. If we assume similar transport rate per km as for hauling straw (\$1.25/km) and a loading and unloading rate of \$5/tonne the cost to haul wheat middlings and oat hulls less than 50 km is \$9.03/tonne and \$12.35/tonne respectively. A study conducted by Hogue et al (2006) compared the cost of transporting various forest residues and wood pellets with both road and rail transportation. The study found that for transporting pellets in a pellet truck cost approximately \$1.39 (\$1.60 CAD) per km for a load of 35 tonnes and a volume of 80m³. The study also found that transportation of pellets less than 50 km costs on average of \$5.70 (\$6.56 CAD) per tonne and the cost increased by 2.5 times with an increase of distance to 200km to \$13.99 (\$16.12 CAD) per tonne.

The cost to deliver cereal straw and crop milling residues to a processing facility or end user was calculated for a return transport distance of 50km (Table 14). Oat hulls, wheat straw and barley hulls had the lowest delivery cost at \$44.91, \$45.52 and \$46.11 per tonne respectively. Wheat middlings had the highest delivered cost at \$118.83, however the purchase price of the residue was significantly higher relative to the other crop milling and straw residues. In terms of cost per gigajoule, a value of 16.5 GJ/tonne was used based on biomass residues with 12% moisture and a lack of testing on residues grown in western Canada. Shaw and Tabil (2006) recorded energy values for western wheat straw and oat hull in the range of 16.4 and 16.6 GJ/tonne. Oat hulls, wheat straw

and barley hulls were the cheapest fuels on a GJ basis at \$2.72, \$2.76 and \$2.79 respectively (Table 14). Wheat middlings were the highest cost fuel per GJ at \$7.20, this is reflective of the higher value for livestock feed. Wheat middlings is a valuable binder for use in mixtures with high fibre biomass resources to produce agro-pellets. Costs for pelleting crop milling residues would add an additional \$1.50/GJ to pellet costs, while straw pelleting costs would likely add an estimate \$2/GJ to fuel costs. Total production costs of crop milling residues and straw pellets would be expected to be in the range of \$80-100/tonne or approximately \$5-\$6/GJ in Alberta which would make it a competitive fuel with natural gas especially if GHG abatement incentives were applied to agro-pellets.

Table 14. Estimated delivered cost and cost per GJ of cereal straw and crop milling residues transported 50 km

Residue type	Estimated residue cost (\$/t)	Estimated transport cost (\$/t) ¹	Estimated delivery cost (\$/t)	Estimated cost per GJ ³
<i>Straw</i>				
Wheat	\$28.80	\$16.72	\$45.52	\$2.76
Oat	\$38.40	\$16.72	\$55.12	\$3.37
Barley	\$31.20	\$16.72	\$47.92	\$2.90
<i>Crop Milling Residue</i>				
Wheat middlings	\$109.80	\$9.03	\$118.83	\$7.20
Oat hulls	\$32.56	\$12.35	\$44.91	\$2.72
Barley hulls	\$33.76	\$12.35	\$46.11 ²	\$2.79

¹ Estimated straw transport distance is based on Stumborg and Townley-Smith (2004) and estimated to be \$16.72; ²The estimated transport costs was assumed to be the same as oat hulls; ³The energy content was assumed to be 16.5 GJ/t for all feedstocks on as delivered basis. Further analysis is required of alberta feedstocks to determine actual values for these commodities.

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7.0 Appendices

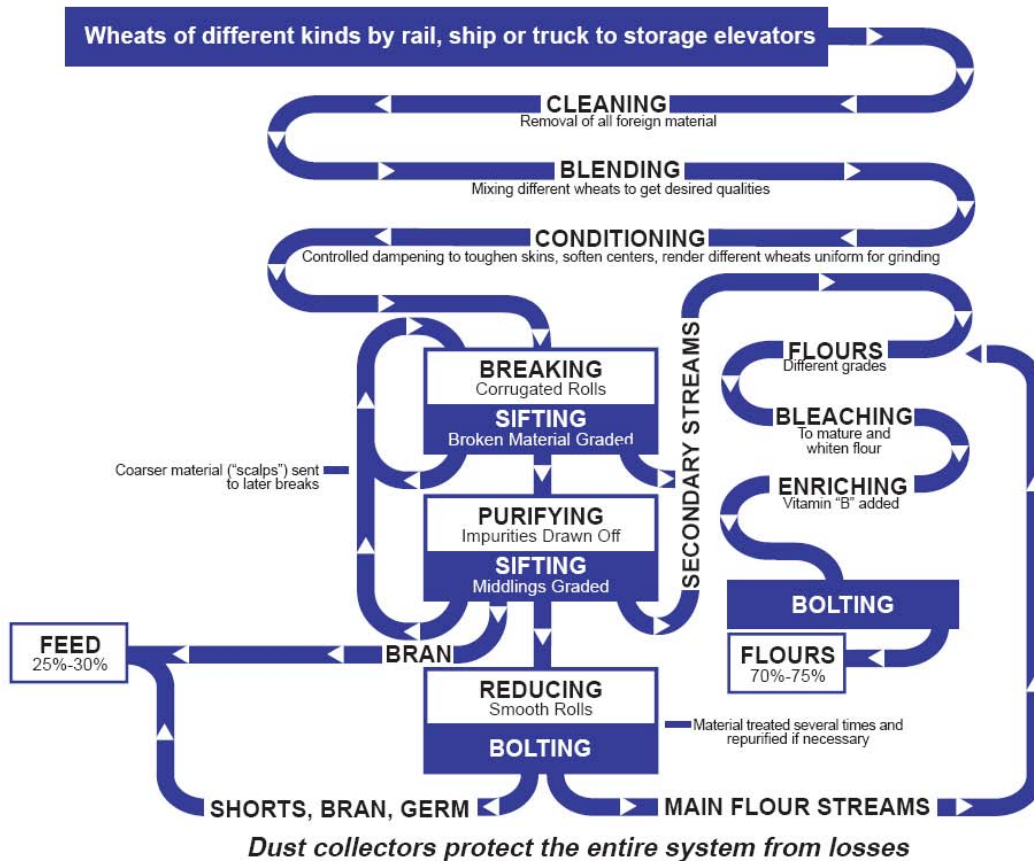
Appendix 1. Estimated maximum quantities of straw available by census divisions and regions in Alberta after deductions for soil conservation and livestock requirements.

Region	Census division	Wheat (Mt)	Barley (Mt)	Oat (Mt)	Canola (Mt)	Division totals after soil (Mt)	Regional total after soil & livestock (Mt)
Southern	1	0.59	0.06	0.01	0.09	0.74	
	2	0.92	0.32	0.01	0.24	1.50	
	3	0.33	0.31	0.02	0.14	0.81	
	5	1.25	0.43	0.02	0.63	2.33	
	6 & 15	0.40	0.44	0.05	0.26	1.15	
<i>Southern Total</i>		<i>3.50</i>	<i>1.56</i>	<i>0.10</i>	<i>1.37</i>	<i>6.53</i>	<i>5.40</i>
Central	4	0.38	0.06	0.05	0.04	0.53	
	7	0.72	0.28	0.09	0.62	1.71	
	8	0.30	0.46	0.05	0.36	1.17	
	9	0.01	0.02	0.01	0.00	0.05	
	10	0.95	0.48	0.17	1.19	2.78	
	11	0.50	0.29	0.10	0.79	1.68	
	12	0.09	0.28	0.07	0.18	0.63	
	13	0.30	0.28	0.13	0.41	1.11	
	14	0.00	0.01	0.02	0.01	0.05	
<i>Central Total</i>		<i>3.24</i>	<i>2.17</i>	<i>0.69</i>	<i>3.59</i>	<i>9.70</i>	<i>8.38</i>
Northern	16	0.00	0.01	0.01	0.00	0.02	
	17	0.31	0.10	0.07	0.43	0.91	
	18	0.05	0.02	0.02	0.05	0.14	
	19	0.68	0.16	0.10	0.96	1.89	
<i>Northern Total</i>		<i>1.04</i>	<i>0.27</i>	<i>0.21</i>	<i>1.45</i>	<i>2.97</i>	<i>1.93</i>

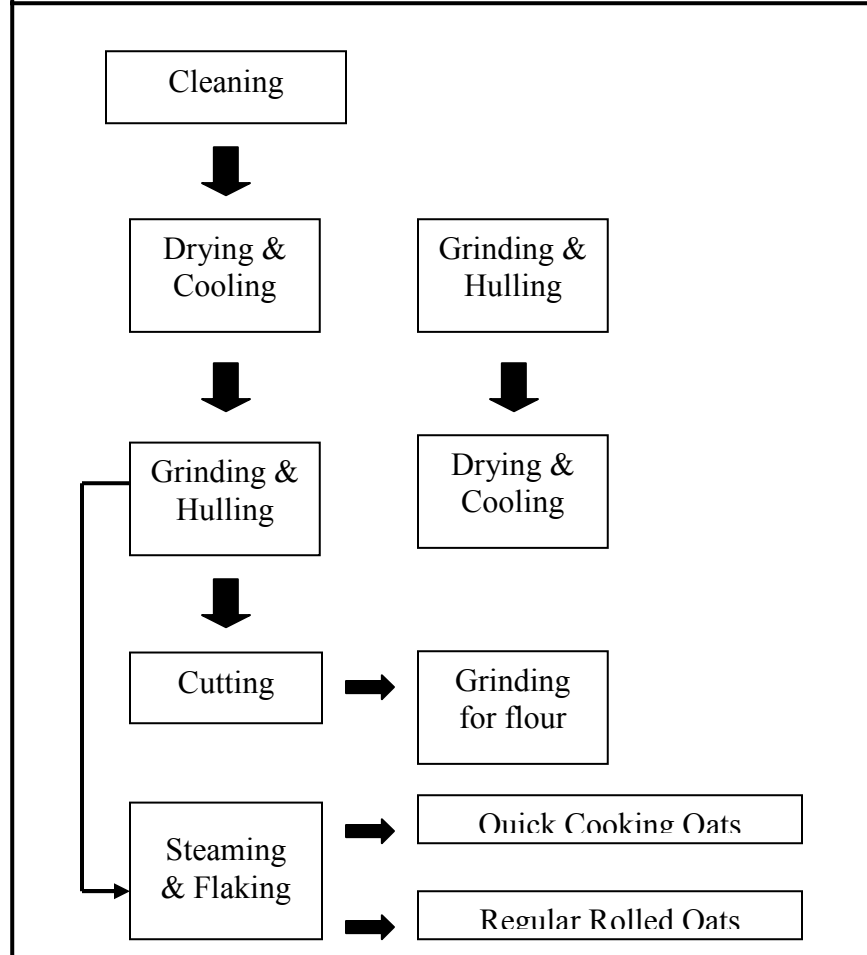
Appendix 2. Estimated minimum quantities of straw available by census divisions and regions in Alberta after deductions for soil conservation and livestock requirements.

Region	Census division	Wheat (Mt)	Barley (Mt)	Oat (Mt)	Canola (Mt)	Division totals after soil (Mt)	Regional total after soil & livestock (Mt)
Southern	1	0.12	0.00	0.00	0.01	0.13	
	2	0.28	0.15	0.00	0.05	0.47	
	3	0.03	0.03	0.00	0.00	0.06	
	5	0.14	0.08	0.00	0.06	0.28	
	6 & 15	0.13	0.27	0.01	0.02	0.43	
<i>Southern Total</i>		<i>0.69</i>	<i>0.52</i>	<i>0.01</i>	<i>0.14</i>	<i>1.37</i>	<i>0.39</i>
Central	4	0.01	0.01	0.00	-	0.01	
	7	0.00	0.14	0.00	-	0.14	
	8	0.06	0.12	0.00	0.05	0.23	
	9	0.00	0.00	0.00	0.00	0.01	
	10	0.00	0.22	0.00	-	0.22	
	11	0.03	0.04	0.02	0.10	0.18	
	12	0.00	0.01	0.01	0.01	0.03	
	13	0.00	0.08	0.02	0.07	0.17	
	14	0.00	0.00	0.00	0.00	0.01	
<i>Central Total</i>		<i>0.10</i>	<i>0.60</i>	<i>0.06</i>	<i>0.24</i>	<i>1.01</i>	<i>0.00</i>
Northern	16	0.00	0.00	0.01	0.00	0.01	
	17	0.04	0.03	0.00	0.10	0.18	
	18	0.01	0.00	0.01	-	0.02	
	19	0.33	0.05	0.05	0.20	0.63	
<i>Northern Total</i>		<i>0.38</i>	<i>0.10</i>	<i>0.07</i>	<i>0.30</i>	<i>0.84</i>	<i>0.00</i>

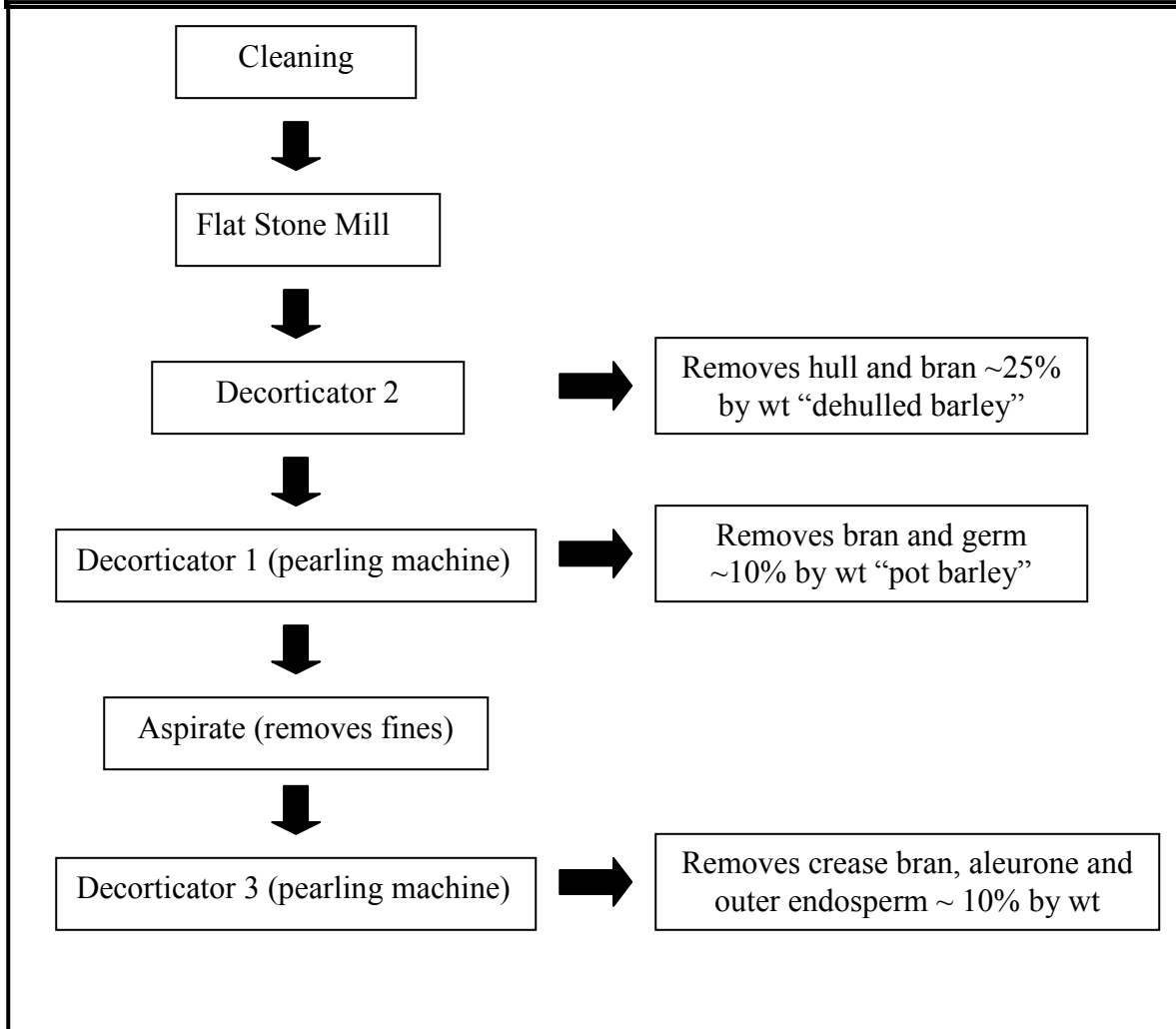
Appendix 3. Simplified flow chart of modern milling operations from Blasi et al (1998) adapted from Storck and Teague (1952)



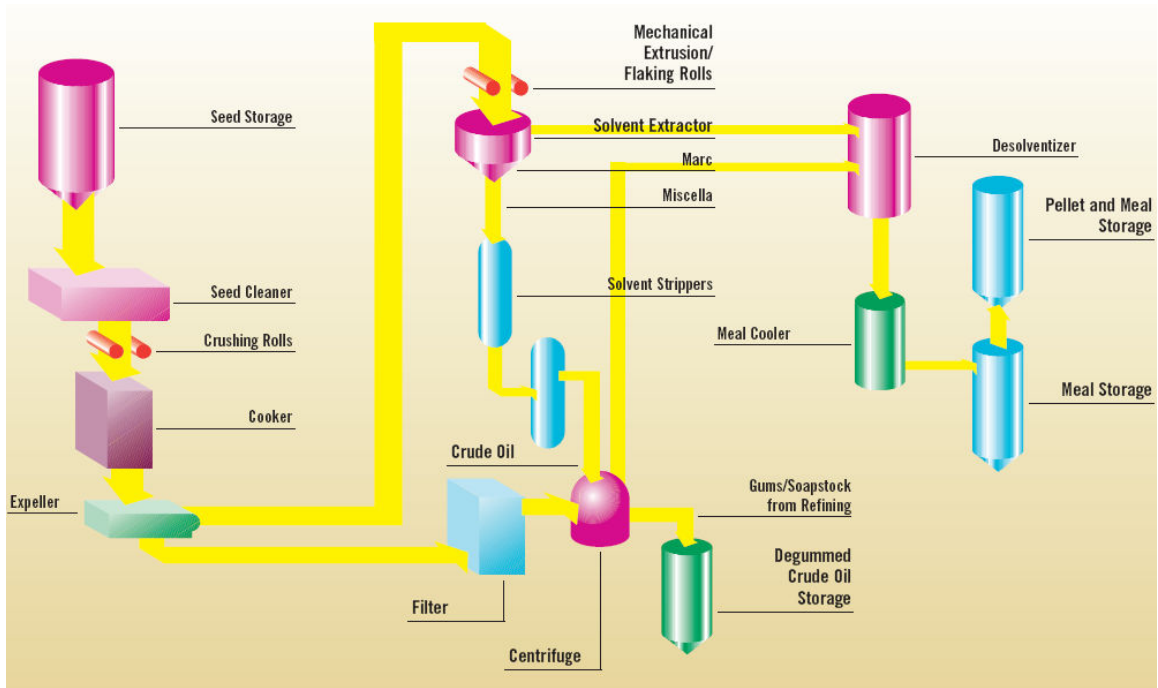
Appendix 4 Traditional oat milling adapted from North American Millers Association



Appendix 5 Traditional barley processing adapted from Bhatti 1993



Appendix 6. Traditional canola seed crushing processing (Hickling 2001)



Appendix 7: Alberta Crop and Oil Processing Facilities-2007

Province	Company	Processed	Address	Website	Telephone
Flour Milling	ADM Milling*	WF, SWF, WWF	4002 Bonnybrook Rd. S.E. Calgary, AB T2G 4M9	www.admworld.com	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
	Permolux (API)*	WF, LF, E	8010 Edgar Industrial Cr. Red Deer, AB T4P 3R3	www.permolux.com	403-347-7557
	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
Durum Milling	Ellison Milling*	DP	1301 Second Ave. S. Box 400 Lethbridge, AB T1J 3Z1	www.ellisonmilling.com	780-672-3675
Oat	Alberta Oats Milling Ltd.*	OP	P.O. Box 228, R.R. 6 Edmonton, AB T5B 4K3	www.albertaoats.com	780-973-9101
	Can-Oat Milling*	OF, OP	P.O. Box 4615 Barrhead, AB T7N 1A5	www.con-oat.com	780-674-3960
	Royal Commodities Limited	OP	55068 Rge. Rd. 204 Fort Saskatchewan, AB T8L 4B6	www.royalexports.ca	780-998-0003
Barley	Canada Malting Co*	M, FP	3316 Bonnybrook Rd. SE Calgary, AB T2G 4M9		403-571-7000
	Rahr Malting Canada Ltd.*	M	Box 113 Alix, Alberta T0C 0B0	www.rahrcanada.com	403-747-2777
	Hamilton's Barley Flour	BF	RR2 Olds, AB T4H 1P3	www.hamiltonsbarley.com	403-556-8493

Mixed Grains	Agricore United	W,B,R,O, F,C	301, 2116 - 27 Ave. Calgary, AB T2E 7A6	NE	www.agricoreunited.com	403-974-3650
	Highwood Farm Ltd	WWF,RF, FS,OP,CO	Box Aldersyde, AB T0L 0A0	25	www.highwoodcrossing.com	403-652-1910
	Peace Country and Grain	FI,OL,F	Box 5, Site 4, Sexsmith, AB T0H 3C0	RR2		780-568-4069
	Sun Prairie Organics	SGG	Box Nanton, AB T0L 1R0	1063	www.sunprairie-organic.com	403-646-5752
	JRK Farms	WF,BF,RF	RR2 Three Hills, AB T0M 2A0			403-443-7317
Canola	ADM*	CO,CMP, CM	4805 - 62 Ave. Lloydminster, AB T9V 2B3		www.admworld.com	780-871-8200
	Bunge Canada*	CO,CM,C MP	Box 3506 Fort Saskatchewan, T8L 2T4	AB	www.bungecanadafortask.com	780-998-1223
	Canbra Foods Ltd.*	CO,CBY	PO Box 99 Lethbridge 3Y4	AB T1J	www.canolaharvest.com	403-329-5500
	Sunora Foods Ltd.	CO	205, 4616 Valiant Dr. Calgary, AB T3A 0X9	NW	www.sunora.com	403-247-8300
Flax	Gold Top Manufacturing & Distribution Ltd.	FO,FM	16831 - 110 Ave. T5P 1G8	Edmonton, AB	www.goldtoporganics.com	780-483-1504
	Nature's Nutraceuticals Inc.	FO,FM	Box 1907 Brooks, AB T1R 1C6		www.naturesnutraoils.com	403-362-7507

*Mills included in crop milling analysis

Note: B-Barley; BF-Barley flour; C-Canola; CO-Canola oil; CM-Canola meal; CMP- Canola meal pellets; CBP-Canola by products; DP-Durum Products; F-Flax; FO-Flax oil; FM-Flax meal; FS-Flaxseed; FI-Flour; LF-Livestock feed; O-Oats; OF-Oat Flour; OP-Oat Products; OL-Oilseeds; RF-Rye Flour; SGG-Stone ground grains; SWF-Soft Wheat Flour; W-Wheat; WF-Wheat flour; WWF-Wheat Flour

Appendix 8: List of Alberta Agri-Fibre Pellet and Cube Manufacturers 2007

Company	Fiber Type	Address	Phone	Fax	Website
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	780-837-2510	
Green Prairie International	AF	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	780-961-3399	www.alfatec.ca
Lomond Alfalfa Products Ltd.	AF	Box 268 Lomond, AB T0L 1G0	403-792-2411	403-792-2144	
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	403-381-9078	
Welling Alfalfa Cubing Inc.	AF	Box 100 Welling AB T0K 2N0	403-752-3773	403-752-3030	www.wellingalfalfa.com

Note: AF-Alfalfa; TH-Tame Hay

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).