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A Logistics Roadmap for Biomass in Saskatchewan

Joy Agnew, Carrie Sampson, and Les Hill

Prairie Agricultural Machinery Institute, Box 1150, Humboldt SK, S0K 2A0 Canada

Abstract. This paper summarizes the key findings of a biomass logistics study conducted by the Prairie Agricultural Machinery Institute (PAMI) in Saskatchewan, Canada. The study focused on agricultural residues and dedicated energy crops and includes a comprehensive review of the cost of biomass production, processing, and transportation by truck, as well as the factors that affect biomass logistics. The results indicated that densification did not significantly lower truck transportation costs due to the high cost and low capacity of trailers required to haul densified material. Centralized processing was more cost-effective than field-side processing due to the inefficiency of field-side equipment. The results also showed that straw bales could be delivered to a coal combustion facility for $3.62/GJ which is comparable to the cost of delivered coal. However, the cost of infrastructure upgrades to handle and convey biomass at the biorefinery must also be assessed.

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Introduction

The use of biomass can help reduce our dependence on fossil fuels. The collection, processing, and transportation of bulky biomass materials need to be optimized so biomass can be delivered to the biorefinery in a cost-effective manner. The Prairie Agricultural Machinery Institute (PAMI) in Saskatchewan, Canada developed a spreadsheet tool to help determine the biomass production, processing, and transportation costs while accounting for the factors that influence the biomass supply chain.

The supply chain and costs associated with woody biomass are relatively well defined in Canada so this work focused on costs associated with agricultural residues and dedicated energy crops. The availability of agricultural residues and the potential for energy crop production in Saskatchewan makes agricultural biomass a very attractive option for bioenergy production. Several end uses for biomass were identified and considered in the full report including cellulosic ethanol production, generation of bioproducts, and co-combustion with coal. The focus of this paper is on the use of biomass as a cofiring fuel for electricity generation.

This paper is a brief summary of the logistics study completed by PAMI. The complete report (240 pages) includes guidelines on dedicated energy crop production for Western Canada and a detailed analysis of biomass processing and transportation costs. This paper will focus on the effect of densification on transportation costs, a comparison of field-side and centralized processing, and the cost to deliver biomass to a cofiring facility.

Biomass Availability in Saskatchewan

Saskatchewan is a land-locked province in central Canada and is home to just under 20 million cultivated hectares of agricultural land (Saskatchewan Ministry of Agriculture, 2010). There is a large amount of land available for dedicated energy crop production, but traditional energy crops do not yield well in the cool, semi-arid climate of the province. However, the land that is currently cultivated for the production of other crops produces a considerable amount of crop residue in the form of straw and chaff. With the increasing use of zero tillage in Saskatchewan, these residues are either left on the field or burned. The use of biomass feedstock for the bioenergy, biofuel, and bioproduct industries would provide Saskatchewan farmers with additional markets for their crops and residues, as well as increased employment opportunities.

The estimated amount of straw available for bioenergy in Saskatchewan varies from approximately 2 million tonnes per year (Coxworth et al., 1995) to 7.9 million tonnes per year (Sokhansanj et al., 2006). These estimates account for soil and livestock requirements. Sokhansanj et al. (2006) note that the variability in the estimate of available straw is indicative of the uncertainties in straw yields due to weather and other uses for straw.

Data on the yield potential of dedicated energy crops is lacking for Saskatchewan's climate and soil zones. Table 1 summarizes the yield data for Saskatchewan and Canada for a variety of crops. The available yield data suggests that Saskatchewan has the potential to produce dedicated biomass crops even if only a fraction of Saskatchewan's 20 million hectares of agricultural land was used for dedicated crop production. The data also suggests that cool-season grasses may be better suited for biomass production in Saskatchewan than warm-season grasses, which are generally used for dedicated energy crop production.

Table 1. Summary of dedicated energy crop yield potential in Saskatchewan and Canada.

Crop	Typical Yield in Saskatchewan (dry tonne/ha)	Maximum Yield Reported in Canada (dry tonne/ha)
Switchgrass	1 to 2	12 (Quebec)
Miscanthus	4 to 10[1]	33 (Ontario)
Forage Sorghum	2 to 9	11 (Ontario)
Reed Canarygrass	1 to 5	11(Quebec)
Forage Pearl Millet	5 to 8	12 (Ontario)
Wheatgrasses	1 to 5	n/a

(1) Data from Edmonton, Alberta

Potential for Biomass Utilization in Saskatchewan

Coal combustion provides 48% of the electrical power generated by SaskPower and 41% of the electricity used by Saskatchewan residents (SaskPower, 2011). Cofiring biomass with coal is a common way to reduce the negative environmental impacts of coal combustion. Cofiring is common in Europe and many systems are reported to handle 15% biomass (on an energy basis) without significant equipment modifications or influence on the properties of the fly ash. If 15% (representing 252 MW) of the coal burned by SaskPower is offset by biomass, approximately 624,000 tonnes of biomass would be required (assuming an energy content of 17 GJ/dry tonne and a 75% conversion efficiency). According to the Biomass Inventory Analysis and Mapping Tool (BIMAT) developed by Agriculture and Agri-Food Canada, the cereal straw required to offset 15% of the coal burned by SaskPower would be available within a 150 km radius of the coal-fired plants in Saskatchewan.

Biomass Supply Chain Costs

The main components of the biomass supply chain are production, processing, and transportation. In this study, harvesting (collecting) was included in the cost of production. The main assumptions for each stage of the supply chain used in PAMI's logistics model are outlined here.

Production

In this study, production costs represented the cost to produce, collect and deliver the biomass to field-side in bale or chopped form. Because crops like wheat, barley, oats and flax are produced primarily for food production, the cost of producing agricultural residue was limited to the cost for collecting the straw and for replacing the nutrients contained in the removed straw.

As the primary use for dedicated energy crops is for energy, the entire production cost (seeding, fertility, land use, collection, delivery, etc.) were included. In this study, production costs also included a margin to provide the farmer an incentive to produce and harvest biomass crops (5% of production costs for agricultural residues and $247/ha for production of dedicated energy crops were used for the margin in the study).

Processing

Biomass material is bulky and difficult to handle with traditional material handling equipment. Densification (producing briquettes or pellets) is an energy intensive process because it can require drying, size reduction, extrusion, and cooling. The end product is uniform and can typically be conveyed with traditional handling equipment. Densification can also reduce transportation costs over long distances because dense material requires fewer loads to deliver the product to the user (refer to next section). Torrefaction (char production) is another processing option suitable for biomass that will be cofired with coal. Torrefied material has a higher heating value than raw biomass, is easier to grind and has superior storage characteristics. Ultimately, the end use and costs for processing and transporting biomass dictates the preferred form of biomass (baled, densified, torrefied, shredded, etc.).

In this study, the processing costs included the capital, ownership and operating costs associated with small-scale (for field-side processing) and large-scale (for centralized processing) equipment. The processing costs included the cost to dry and grind material to a suitable level for processing. It was assumed that all agricultural residues and crops were collected at 15% moisture content.

Transportation

Transport distances in Saskatchewan are less than 500 km so only truck transport costs were investigated in detail. In this study, it was assumed that the trucks and trailers would be owned and operated by the biorefinery so the costs included capital and operating costs but not a margin. Unlike other logistics studies, this study took into account the cost and weight of dry bulk and flat deck trailers. Flat deck trailers are suitable for hauling biomass bales, while higher cost, heavier dry bulk trailers are required for hauling densified biomass. The capacities and allowable loads (assuming no overweight or over width permits) for flat deck and bulk trailers are shown in Table 2. Hauling bales is limited by volume and hauling pellets is limited by weight. To ensure the payload doesn't exceed that allowed on Saskatchewan's primary highways, a bulk trailer can only be filled approximately three quarters full.

Table 2. Effect of volume and load restrictions for several trailer types.

Trailer Type	Volumetric Capacity (m^3)	Allowable Load (tonnes)	Bulk Density of Payload (kg/m^3)	Volume of Load if Maximum Weight is Used (m^3)	Weight of Load if Maximum Volume is Used (tonnes)	Optimal Bulk Density of Payload (kg/m^3)
Eight-axle flat deck (bales)	130	37	150 to 255[(1)]	145 to 247	20 to 33	284
Eight-axle dry bulk (pellets)	85	35[(2)]	550 to 700	50 to 64	47 to 60	412

(1) Assuming that literature values represent bulk density of several bales stacked together. Range includes both large round and large square bales.

(2) Lighter weight dry bulk trailers can have payload capacities as high as 42 tonnes. However, light weight (aluminum) trailers are more costly.

Delivered Cost of Biomass

A summary of the cost to deliver 408,000 tonnes of cereal straw an average distance of 110 km to the largest of three SaskPower coal-fired plants is shown in Table 3. Processing for briquettes, pellets and torrefied pellets was assumed to be field-side while torrefaction and grinding was assumed to occur on-site at the biorefinery. The processing cost for straw bales ($3.32/t) refers to the cost to shred bales on-site at the biorefinery.

Table 3. Cost to deliver 408,000 dry tonnes of biomass to offset 15% of the coal used at a single SaskPower coal combustion facility.

	Feedstock Cost ($/t)	Processing Cost ($/t)	Transportation Cost ($/t)	Total Cost ($/t)	Total Cost ($/GJ)
Straw Bales	$38.80	$3.32	$19.41	$61.52	$3.62
Briquettes	$38.80	$70.27	$19.27	$128.34	$7.35
Pellets	$38.80	$69.39	$17.93	$126.11	$7.42
Torrefied pellets	$38.80	$113.47	$21.01	$189.91	$9.71
Torrefaction and Grinding On-site	$38.80	$38.70	$19.41	$96.91	$4.84

The lowest cost option (based on $/GJ) was straw bales. However, the value of shredded straw bales is relatively low due to the need for further processing. Field-side processing helps reduce the transportation cost a small amount, but the low capacity and inefficient power systems of field side processing equipment makes processing cost per tonne very high. Torrefaction and grinding (but not pelleting) on site results in a low total cost ($/GJ) while providing a high value product for combustion. However, nondensified torrefied material is difficult to handle and poses a dust and explosion hazard. The costs associated with storage and handling torrefied material should be assessed to ensure that torrefaction and grinding on-site represents an economically viable option for cocombustion with coal. As coal can be delivered to combustion facilities for approximately $1/GJ to $5/GJ, the cost of delivered biomass is comparable to coal.

Fieldside Versus Centralized Processing

Although densification and processing was shown to not significantly reduce transportation cost, processing may add value to the biomass feedstock and, in some cases, is required for improved handling, conveying, and conversion to useful energy. Field-side processing means the normally bulky material does not need to be transported very far before it can be processed. However, field-side units tend to have lower capacity and lower efficiency and rely on fossil (diesel) fuel to process feedstock for renewable fuel. On the other hand, centralized processing requires transporting the bulk material over longer distance and requires more handling (loading and unloading).

Based on the assumptions used to develop PAMI's logistics model, it was more economical to transport bulk residue to a centralized facility even for very short transport distances (refer to Table 4). Better estimates of the costs of operating field-side units might make field side processing more cost effective for short distances. The total transport distance for centralized processing was assumed to be 20% higher than the distance for field-side processing. More accurate transport distances for centralized processing (via GIS or similar software) might lower the transportation cost associated with centralized processing. The transportation cost for centralized processing also includes added loading and unloading costs.

In all cases, transporting round bales was more economical than field-side or centralized processing. The value of round bales is less than that of pellets as bales require specialized handling. However, the cost of processing round bales on site can be as high as $50/t and the delivery of round bales would still be more economical than field side or centralized pelleting.

Table 4. Summary of processing, transportation and total costs ($/t) for field-side versus centralized processing for a variety of transport distances.

		1 km	10 km	50 km	100 km	500 km
Field-side Pellets	Processing	69.38	69.38	69.38	69.38	69.38
	Transportation	9.75	10.42	13.43	17.19	47.25
	Total[(a)]	**117.93**	**118.6**	**121.61**	**125.37**	**155.43**
Centralized Pellets	Processing	44.83	44.83	44.83	44.83	44.83
	Transportation[(b)]	19.09	19.98	23.91	28.83	68.16
	Total[(a)]	**102.72**	**103.61**	**107.54**	**112.46**	**151.79**
Round Bales	Processing[(c)]	3.32	3.32	3.32	3.32	3.32
	Transportation	9.44	10.49	15.12	20.91	67.25
	Total[(a)]	**51.56**	**52.61**	**57.24**	**63.03**	**109.37**

[a] Total includes production cost of $38.80/t

[b] Transportation distance for centralized processing was 20% higher than listed

[c] Round bale processing refers to bale shredding on site

Implications of Results

The results of this and other case studies outlined in the full report suggested that densification does not significantly reduce the transportation costs when biomass is transported by truck. In fact, when the processing and transportation costs are added together, the delivered cost for densified material is significantly higher than the cost for delivering biomass bales. The number of loads required for densified material is lower than the loads required for bales. However, to meet the payload restrictions of highways in most of Canada, the bulk trailers required to haul densified biomass can only be filled three quarters full making bulk trailer transport inefficient. In most biomass logistics studies, it is unclear if the costs and capacities of different trailer types are considered (The Research Park, 2009; Suh et al., 2011; Sokhansanj and Fenton, 2006).

However, processing (torrefaction and/or densification) adds value to the biomass, making it easier to incorporate biomass fuel into existing infrastructure. The PAMI logistics model allowed comparisons of the total cost (processing and transportation) of field-side and centralized processing. The results indicated that centralized processing was more cost-effective than field-side processing. This was due to the inefficient power system and low capacity of field-side equipment. Improving the efficiency, reliability and capacity of field-side processing equipment may make field-side processing more cost-effective.

Conclusions

This study focused on the agricultural practices and costs associated with production, collection, processing, and transportation of agricultural residues and dedicated energy crops. The report's main conclusions for each component of the supply chain are summarized here in point form.

Production and Collection

- Dedicated energy crops are costly to produce given that all costs associated with production (seed, fertilizer, chemical, equipment, land use, etc.) must be recovered to be economical for the producer.
- The yield potential in Saskatchewan for the most common dedicated energy crops (switchgrass and miscanthus) is much lower than in the US or eastern Canada, therefore, in Saskatchewan the per tonne field-side cost is high for dedicated energy crops. However, more research is required to determine the suitable type and species of energy crops for Saskatchewan.
- The farm gate cost (including nutrient value of straw, collection, and margin) for spring wheat straw was approximately $38/t ($13.18/t for nutrients, $23.77/t for baling and $1.85/t for profit margin).
- Markets for biomass are not well defined, which increases the risk associated with biomass production.

Processing

- Biomass processing can include densification alone (production of briquettes, cubes, or pellets), torrefaction alone, or torrefaction combined with densification.
- Depending on the end-use, biomass processing adds value to the feedstock, but is costly. Costs for densification alone ranged from $40 to $70/t while costs of combined torrefaction and densification ranged from $90 to $113/t.
- Centralized processing is generally more efficient than field-side processing and the results of this study suggest that, even for short transport distances, it is less costly to process material at a centralized facility. Improving the efficiency of field-side equipment will reduce the costs associated with field-side processing. However, field-side processing relies on less efficient and mobile energy sources (fossil based), often negating the benefit of generating renewable fuels.
- More studies are required to assess the total energy requirements and capacity of field-side and centralized processing equipment.

Transportation

- Transporting biomass feedstock can be done by truck, ship, rail, or pipeline. The transportation distance and end use will dictate the most suitable form of transportation. The distances traveled within Saskatchewan are relatively small (<500 km) so a detailed analysis of transportation costs was completed for truck transport only.
- Contrary to most other logistics studies, the results in this study showed that densification did not significantly reduce transportation costs. This is partially due to the capital cost of dry bulk trailers needed for hauling densified material being higher than the capital cost for flat deck trailers needed to haul bales. Also, the allowable payload of dry bulk trailers on Saskatchewan highways meant they are used inefficiently being only three quarters full when at maximum allowable weight.
- The cost of truck transportation of bales ranged from $10/t to $20/t for distances less than 100 km.

General Information on Biomass Utilization

- The “value” of biomass feedstock will be dependent on the end use. For combustion, the “value” will be based on higher heating value, nutrient and moisture content, ease of size reduction, and conveying and storage characteristics.
- Full energy balances of the supply chain need to be assessed to ensure that no more fossil fuel is being used than green fuel being generated from the biomass.
- The cost of delivered agricultural residue is comparable to the delivered cost of coal in Saskatchewan (on a $/GJ basis). However, costs to change infrastructure to handle biomass feedstock need to be defined. It has been suggested that 15% of coal can be offset by

biomass without requiring significant changes to the combustion equipment, but handling and conveying equipment might need to be altered.

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