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Technoeconomic analysis of wheat straw densification in the Canadian Prairie Province of Manitoba

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ABSTRACT

This study presents a technoeconomic analysis of wheat straw densification in Canada's prairie province of Manitoba as an integral part of biomass-to-cellulosic-ethanol infrastructure. Costs of wheat straw bale and pellet transportation and densification are analysed, including densification plant profitability. Wheat straw collection radius increases nonlinearly with pellet plant capacity, from 9.2 to 37 km for a 2–35 tonnes h^{-1} plant. Bales are cheaper under 250 km, beyond which the cheapest feedstocks are pellets from the largest pellet plant that can be built to exploit economies of scale. Feedstocks account for the largest percentage of variable costs. Marginal and average cost curves suggest Manitoba could support a pellet plant up to 35 tonnes h^{-1}. Operating below capacity (75–50%) significantly erodes a plant's net present value (*NPV*). Smaller plants require higher *NPV* break-even prices. Very large plants have considerable risk under low pellet prices and increased processing costs.

1. Introduction

Canada's ethanol mandate of 5% renewable fuel content in gasoline requires the annual production of approximately 2 billion litres of renewable fuel across Canada (Environment Canada, 2011). This has generated interest in second-generation technologies using feedstocks such as agricultural residues. Residue-based feedstocks could significantly extend the potential of Canada's bioethanol industry and provide up to 50% of the country's transportation fuel demand (Mabee and Saddler, 2010). This is especially pertinent given that most Canadian ethanol plants use first-generation starch-based feedstocks (Table 1). This huge investment occurs at a time when the use of food grains as feedstocks is raising environmental sustainability concerns and ethical issues related to food versus fuel.

Manitoba, one of Canada's three Prairie Provinces, is a key player in supporting the attainment of these national ethanol targets. The province's ethanol program is enabled by its 2007 *Biofuels Amendment Act* which came into effect on January 1, 2008 and requires fuel suppliers in Manitoba to replace at least 8.5% of their gasoline sale in Manitoba with ethanol (Government of Manitoba, 2011). This provincial mandate will require about 143 million litres of ethanol generated from approximately 380,000 tonnes of wheat annually. Manitoba can supply 5–7 million tonnes of agricultural residues, especially wheat straw. Canadian Prairie Provinces account for 93% of total wheat production (Statistics Canada, 2010), making wheat straw the most abundant crop residue, hence the focus of this study.

However, the development of a lignocellulosic feedstock-based ethanol plant in Manitoba requires investment in logistics and infrastructure. Developing an integrated biomass-to-ethanol supply chain is constrained by the economics and logistics of transporting low bulk density agricultural biomass to central cellulosic ethanol biorefineries without expensive densification systems to increase density. It is also not known whether wheat straw densification can attract equity investment and evolve as a viable enterprise to support the development of a lignocellulosic ethanol biorefinery concept in rural Manitoba.

The overall objective of this study is to assess the economics and business case for establishing a biomass densification system in Manitoba. Specifically, the study: (i) compares wheat straw bales versus wheat straw pellets in terms of their feedstock cost to an ethanol biorefinery; (ii) assesses the financial viability of a pellet plant. All costs used in this paper are based on US dollar values for 2009.

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Table 1
Canadian ethanol plants, capacity, and location (Canadian Renewable Fuels Association, 2011).

Plant name	City	Province	Feedstock	Capacity million litres	Status
Alberta Ethanol & Biodiesel GP Ltd.	Innisfail	Alberta	Wheat	150	Proposed
Amaizelingly Green Products L.P.	Collingwood	Ontario	Corn	58	Operational
Atlantic Bioenergy Corporation	Milford	Nova Scotia	Energy beets	–	Demonstration
Enerkem Alberta Biofuels	Edmonton	Alberta	Municipal (landfill) solid waste	36	Construction
Enerkem Inc.	Sherbrooke	Quebec	Various feedstocks	0.475	Demonstration
Enerkem Inc.	Westbury	Quebec	Wood waste	5	Demonstration
GreenField Ethanol Inc.	Chatham	Ontario	Corn	195	Operational
GreenField Ethanol Inc.	Johnstown	Ontario	Corn	230	Operational
GreenField Ethanol Inc.	Tiverton	Ontario	Corn	27	Operational
GreenField Ethanol Inc.	Varennes	Quebec	Corn	155	Operational
Growing Power Hairy Hill	Hairy Hill	Alberta	Wheat	40	Proposed
Husky Energy Inc.	Lloydminster	Saskatchewan	Wheat	130	Operational
Husky Energy Inc.	Minnedosa	Manitoba	Wheat and corn	130	Operational
IGPC Ethanol Inc.	Aylmer	Ontario	Corn	162	Operational
Iogen Corporation	Ottawa	Ontario	Wheat, barley, and oats	2	Demonstration
Kawartha Ethanol	Havelock	Ontario	Corn	80	Operational
NorAmera BioEnergy Corporation	Weyburn	Saskatchewan	Wheat	25	Operational
North West Terminal Ltd.	Unity	Saskatchewan	Wheat	25	Operational
Permolex International, L.P.	Red Deer	Alberta	Wheat, corn, barley, rye, triticale	42	Operational
Pound-Maker Agventures Ltd.	Lanigan	Saskatchewan	Wheat	12	Operational
Suncor St. Clair Ethanol Plant	Sarnia	Ontario	Corn	400	Operational
Terra Grain Fuels Inc.	Belle Plaine	Saskatchewan	Wheat	150	Operational

2. Rationale for biomass densification

Lignocellulosic agricultural biomass like wheat straw constitutes a low value and renewable energy feedstock. However, it is too bulky for efficient transportation, storage, and handling without expensive material transformation systems to increase bulk density (Adapa et al., 2009). Stephen et al. (2010) elaborated the significance of biomass logistics as a determinant of second-generation biofuel plant scale, location, and technology selection. Sokhansanj et al. (2010) showed that the cost of transporting a tonne of corn stover over 50 km is 10 times higher relative to pelletised stover. According to Mani et al. (2004, 2006), raw cellulosic biomass possesses a low bulk density of 30 kg m^{-3} and moisture content of 10–70% (weight basis). Densification via pelletisation increases specific biomass density to over 1000 kg m^{-3} (Adapa et al., 2007, 2009; Mani et al., 2004; Lehtikangas, 2001), thereby rendering itself more amenable for efficient and cost-effective handling and storage, an important operation in the economic viability of cellulosic ethanol (Sokhansanj and Turhollow, 2004; Mani et al., 2006; Sokhansanj et al., 2010).

In spite of these attributes, it is useful to understand how competitive wheat straw pellets would be as feedstocks, relative to wheat straw bales. There are efforts to understand the viability of pellet plant capacity, differences in the electricity price, and raw material cost (Thek and Obernberger, 2004; Mani et al., 2006; Sokhansanj et al., 2010). However, some researchers such as Krishnakumar and Ileleji (2010) are not convinced that densification is required. They investigated five feedstocks: corn grain, bales of corn stover and switchgrass, corn stover pellets, and switchgrass pellets. Their analysis showed that the cost of transporting a tonne of switchgrass pellets was the least for bigger ethanol plants; for smaller plants, corn stover bales had the lowest cost. However, the total cost per litre of corn stover and switchgrass pellets before conversion to ethanol was higher than that of corn grain for all plant sizes. It is understood that biomass feedstock was not economically beneficial to ethanol plants compared with cereal grain because of lower ethanol conversion rate and higher capital cost. However, regarding ethanol derived from second generation technologies, it is useful to throw more light on how densification changes the logistics and economics of bioethanol feedstocks.

3. Methods

3.1. Study region

Biomass Inventory Mapping and Analysis Tool (BIMAT) developed by AAFC (2010) was used to identify high wheat producing areas in Manitoba. A further analysis of wheat hectares by Census Consolidated Subdivisions, using Statistics Canada Census of Agriculture (Statistics Canada, 2007) shows that wheat production is concentrated in several Manitoba regions mainly in the south-west. As a result, Carman, Manitoba was selected as the densification plant location (Fig. 1). Biomass availability is based on a 50% farmer participation rate, and takes into account tillage type and competing uses of straw for livestock and soil conservation. Apart from the concentration of wheat production in this region, the location of densification and ethanol production in rural locations is influenced by economic development objective of both federal and provincial governments of Canada. Therefore, the scope of this study is limited to a business case for southern Manitoba, and the entire biomass-to-densification-to-ethanol infrastructure is intended to support this local rural biorefinery concept.

3.2. Transportation mode

In most Prairie cases, short line rail lines are not available near farms that would be contracted to supply straw. In farmer-owned processing plants, trucks could offer more flexibility and responsiveness to move the product as the market dictates, thereby reducing the need for storage at the ethanol plant. Mahmudi and Flynn (2006) estimated the cost of biomass transport by truck only and truck-plus-train for straw and wood chip at $25.60 and $33.70 per tonne respectively, suggesting that rail shipment is manifestly less cost efficient for the second generation biofuel industry in its present configuration, until the industry becomes more diversified, based on a greater number of feedstocks and bioproducts. Therefore, this study assumes that trucks will be the primary mode of transportation for moving biomass from the farm to the densification plant in Carman and to ethanol plants within the region.