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The Logistics of Production and Supply of Ag Pellets for Industrial Applications in Canada

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Abstract

In this work we analyze the supply of biomass from field to an in-land or port destination. The biomass is pelletized to increase its bulk density to extend its storage period and for ease of its transport. The pellet may be used for conversion to chemicals and animal bedding or for straight combustion. We analyzed supply chain in Saskatchewan where there are plenty of crop residues but widely dispersed and harvest seasons are short. We envisioned that the farmer collects bales from field and transports the bales to farmstead during the harvest season. The bales are then processed into pellets using small scale pellet equipment. A custom operator with expertise in pelletization may engage in handling and densifying the biomass. The business case for the mobile mill will be similar to the well established custom grain and forage harvesting operations. The pellets are stored in hopper bottom grain bins at the farmstead. From this point, the handling of pellets would be similar to the handling and marketing of grain. The farmer trucks a specified volume of pellets from farmstead to the nearest elevator where the pellets are transferred to larger bins or silos. Pellets are extracted from silos and loaded onto the rail cars. The Canadian freight rail companies (mainly CN) currently transport over 3 million dry tonne (dt) of wood pellets in rail cars. The pellets are hauled to marine ports on the West Coast or East Coast for export. The cost of delivering ag pellets to biorefinery or to the shipping port is $86.09/dt. This cost does not include the equivalent value of removing biomass from the farm (e.g. fertilizer replacement) and return on investment. The GHG emissions to produce and transport ag pellets add up to 185.9 kg of CO_2 per dt of biomass. The cost of producing pellets without drying feedstock is $35.05/dt and the corresponding GHG for palletization amounts $146.30/dt.

Keywords

Canada, Pellets, Ag Pellets, Supply Chain, Logistics, Cost, GHG Emissions,

Infrastructure

1. Introduction

At present 40 pellet plants are operating in Canada, 19 of these plants are in BC scattered throughout the interior along the CN rail line. Prince George region has become a hub of wood pellet plants using mainly pine and Douglas fir as raw material [1]. Efforts are underway to use other soft wood variety like cedar, spruce and Hemlock. Pine is the preferred feedstock because of its abundant resin and easy to grind and dry. But the available pine for making wood products has diminished lately due to the destruction by Mountain Pine Beetle [2]. Pellet industry depends on the availability of mill residues from lumber operations.

Because of the low value of pellets compared to lumber, it is expensive for the pellet industry to harvest wood from the forest and trees, grind and transport that to the pellet plant. To alleviate this problem, new pellet plants are developed in vicinity of milling operations that may be far away from export ports. The transport cost for pellets becomes prohibitive. Wood except bark has a low ash content and is desired as fuel in boilers. Ag feedstock on the other hand is widely available but is not desirable for combustion in small scale stoves because of high ash and chlorine content. Crop residue is used in large co-firing with coal for power production.

In Canada around 90 million tonnes of grains are produced half of which are made up of corn and wheat [3]. The ratio of non-grain biomass to grain mass is assumed to be about 1 to 1. Not all biomass is harvestable. A fraction of biomass must be kept on the ground for soil conservation and fertility purposes. The amount depends on the yield of crop. In low yield not much biomass may be available for removal. We may assume that overall 20% of the biomass may be available and that amounts to 9 - 10 million tonnes of biomass can be harvested in Canada. The challenge is collection of these biomasses, and transports it to the end users.

Despite the abundance of lignocellulosic residues in Canada, they do not currently contribute to the production of biofuel in Canada and their use for bioenergy is limited to a sporadic non-commercial application. A primary barrier is a low and inconsistent quality and inefficient logistics of lignocellulosic residues, a pain point that was deeply felt by the cellulosic ethanol pioneers in the United States, resulted in the slowdown/shutdown of these facilities [4]. One of the lessons learned from these projects is that using straw bales directly as a feedstock in commercial biofuel projects is very challenging and inefficient. Turning bulky biomass with diverse properties to a uniform format, predictable properties and logistically advantageous pellets present a solution. Determining the cost of making pellets plus the logistics costs is one of the goals of this research.

The objective of this research is to analyze a possible solution to the complex handling of ag biomass [5]. The paper discusses steps in harvesting, collection, storage and densification of ag biomass and supply of biomass to the point of its use. To this end the entire supply chain for ag biomass is divided into three distinct sub-activities: 1) baling and transferring bales to the farm yard during the harvest season, preferably the bales will be stored under cover; 2) crushing and grinding bales and pressing biomass to make pellets, and storing pellets in hopper bottom bins during the year, and 3) trucking pellets to a central elevators for bulk storage and shipping pellets to destinations by using rail infrastructure. Pelletization requires experience and skills in operating pellet mill equipment that may not be available at the farmstead. A custom operator may engage in pelletization using mobile equipment. This research estimates costs and CO_2 emissions associated with the proposed supply chain.

2. Collection and Baling

The Agriculture and Agri-Food's Biomass Inventory Mapping and Analysis Tool (BIMAT) provides internet-based GIS functionality to query and visualize biomass inventory data in Canada [6]. The data consists of crop locations, types, historical yield, and a number of other useful information. The Integrated Biomass Supply Analysis and Logistics (IBSAL) model is a modularized simulation of biomass supply chain that includes biomass collection, storage and transportation. In this study, IBSAL modules are assembled to simulate harvesting of straw, stover, and switchgrass yields [7]. The operations in this study started from combining for grain crop residues followed by baling and ended in stacking bales on the field side. **Figure 1** shows a baler producing large square bales from wheat straw. Crop residue is baled and stacked at the corner of the field. The stack size and location usually depend on the grid road, that serves a quarter section 160 acres (~65 ha). Chaining the sequence of harvest operations require training in Agricultural mechanization.

Figure 1. A large square biomass baler (Photo Courtesy of Krone).

The equation $C = aR^bY^c$ was fitted to the BIMAT data on yield Y and rate of biomass recovery R to estimate constants a, b, and c for cost in \$/dt (dry tonne), energy input in MJ/dt, and carbon emissions in kg CO_2/dt (**Table 1**). Variable R is the fraction of above ground biomass removed during harvest and Y is the yield defined as biomass above ground (dt/ha). The farm gate cost for the stacked bales ranged from \$20 per dt for high yielding regions of southwest Edmonton and Ontario to \$27 per dt for the eastern Ottawa region, and \$31 per dt for low yielding regions of central Saskatchewan [8]. The costs are validated with published custom rates.

3. Size Reduction and Pelletization

The preprocessing steps consist of breaking up bales to a size that can be fed to hammer mill for grinding bales to a size about 2 mm in order to make pellets as shown in **Figure 2**.

The equipment required consists of a loader to transfer bales from the stack to bale processor. The bale processor cuts the bale to sizes less than 100 mm. A feed processor that cuts the material to pieces for animal feeding can also be used as shown in **Figure 3**. The chopped biomass is fed to a hammermill for fine grinding. The hammer mill that is an integral part of the pellet mill shown in **Figure 4** grinds the material to around 2 mm. The suspended ground biomass is pushed up to a cyclone to separate the particles from air. The ground material is metered

Table 1. Estimated coefficients for straw, stover, and switchgrass to calculate C for cost \$/tonne, energy input MJ/tonne, or emission kg CO_2/dt.

Crop	Parameter	a	b	c
	Cost	25.65	−0.397	−0.507
Straw	Energy input	148.00	−0.692	−0.464
	CO_2 emission	10.30	−0.665	−0.447
	Cost	52.40	−0.679	−0.654
Stover	Energy input	405.00	−0.817	−0.740
	CO_2 emission	28.70	−0.797	−0.750
	Cost	33.90	−0.000	−0.300
Switchgrass	Energy input	302.40	−0.000	−0.460
	CO_2 emission	20.73	−0.000	−0.460

$C = aR^bY^c$, *a*, *b*, and *c* are tabulated values, *R* is rate of recovery of biomass (decimal fraction) Y is above ground yield (dry tonne/ha).

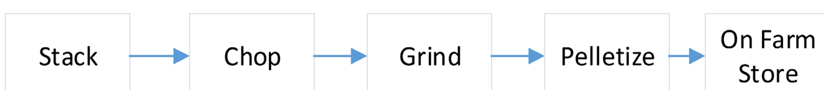

Figure 2. Flow chart showing the sequence of operation involved in preprocessing of biomass.

Figure 3. Bale loading and processor. Bales are loaded into a tub grinder and shredded (photo Courtesy of authors).

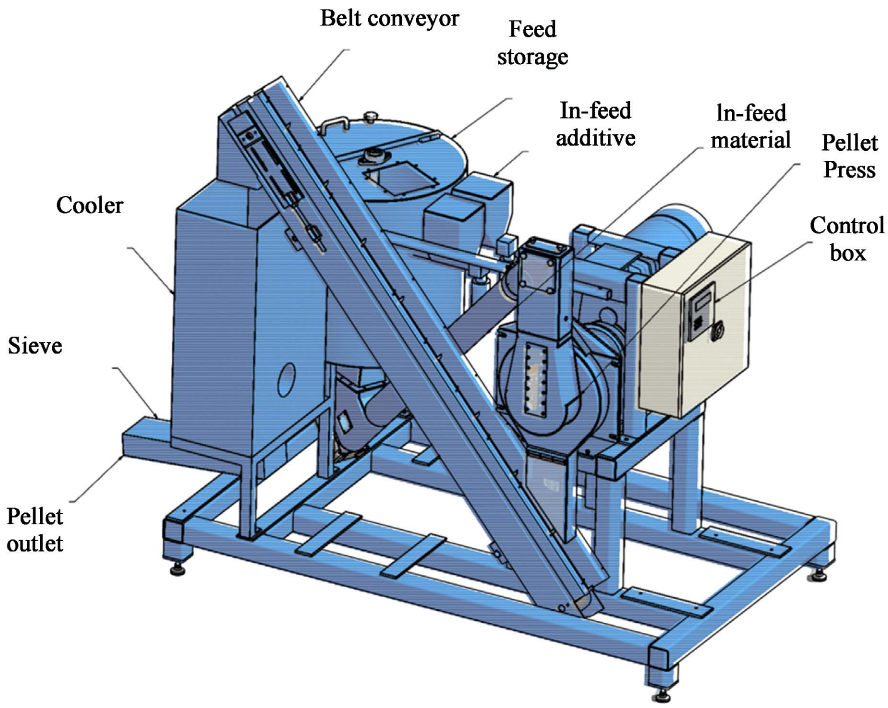

Figure 4. Small scale self-contained pelletization system in a container (Photo courtesy of authors).

to the pellet press to form dense pellets. The pellets (6.3 mm in diameter and 12 mm length) are cooled and sifted and stored in the hopper bottom bin that are used for grain storage on the farm. The pellets remain in the bin until their trucked to the main elevator that is a central storage to hold large volumes of pellets [9].

Table A1 (Appendix) lists equipment for preparing biomass for preparing and pressing the biomass into pellets, and storing pellets in storage bin. The Table also lists the prices and the year associated with the prices. We used equation 1 to calculate the price in $2019 using an annual rate of inflation at 2.5%.

$$\$2019 = \$\, year\left(1+0.025\right)^{(2019-year)} \tag{1}$$

For example, the price of bale handler in 2017 at $66,900 is used in Equation (1) to arrive at the price of $70,287 in 2019. The remaining data in **Table A1** are conventional values for number of years of life, estimated number of hours per year and rated power for the equipment. **Table A2** lists input for the calculation of preprocessing equipment for densification of biomass. For CO_2 emissions per kWh electricity use, we used 0.70 kg between long term USA emission factor at 0.5 kg and a high value of 0.85 kg for Saskatchewan, Canada.

Table A3 lists output of calculations for emissions and the unit cost of producing pellets on the farm. To calculate cost per hour, we divide the calculated $/h by t/h for each unit operation and then multiplied by the tonnage of the pellet press. The pellet press had the lowest throughput (1.2 t/h) and the lowest throughput determines the overall throughput of the entire system. The total cost of producing pellets and placing pellets in storage on the farm was $42.06/h and CO_2 emissions were 146.3 kg/hr. These values divided by the overall throughput of the system yielded cost and emissions per unit mass. The final $35.05 is close to $31.98 that Ref [10] obtained from field testing of a small scale pelletization process.

In terms of generalized equation to calculate cost as a function of initial price and throughput of the pellet press, we developed the following equation for cost of pelletization vs. throughput and initial purchase price by running IBSAL form a range of scenarios.

$$Cp = \frac{0.3\times 10^{-4}\, Pi + 40.58}{Y} \tag{2}$$

Cp is the cost of pelletization in $/dt, *Pi* is the initial price of pellet press (excluding axillary equipment). *Y* is the throughput of the press mill in dt/h. We should caution against generalization of Equation (2). The equation is only applicable for a narrow range of throughput and the initial price of the pellet mill used in this example.

4. Transport from Farm Bin to Elevator

We applied engineering economics to calculate the cost of transporting biomass from farm to the central storage (hub) (**Table A4**). We selected three size trucks, small (29.5 m^3 truck box, 185 kW engine), medium (44 m^3 truck box, 222 kW engine), and large (85.2 m^3 truck box, 259 kW engine) capacity and power. The sizes and prices were taken from Doepker trailer (**Figure 5**). The prices were adjusted to 2019 by applying a rate of inflation (2.5% per year). Values for years of life, hours of work per year and kilometers driven in a year were within the range of expected operation of the transport equipment.

To calculate fixed and operating costs, we used ASABE Standards EP496 and D497 costing method. The methods were outlined in a special report prepared for AAFC [8]. **Table A5** lists the input values to the engineering economic equations. We assumed annual 6% for interest rate and annual 2.5% for rate of inflation.

Figure 5. Grain truck that is also suitable for transporting biomass pellets from farm to a central storage site.

The rate of insurance, housing, and taxes on annual basis was 2% of the purchase price of equipment. ASABE specifies the conversion of engine power to average hourly fuel consumption (0.223 L/kW engine power), equivalent of carbon dioxide emissions from burning each L of fuel (2.64 kg CO_2/L of fuel). For these calculations we assumed 50 km one way and average speed of 50 km/h. The effective distance travel is 2/3 of the supply radius for a circular supply area with the hub at the center of the circle.

Table A6 lists the output cost and emissions from the three size trucks with the inputs listed in Table A5. The fuel cost is a major cost item, 60% to 66% of the hourly cost of the truck. Fixed costs are a small portion of the total hourly cost of the equipment [11]. Tire cost is another operating cost that must be calculated carefully. For example we may assume a new tire lasts 100,000 km. Each tire may cost $400 to replace. The truck is driven 12,500 km/year. Therefore to replace tires in a 10 wheel truck is calculated by [12]

$$Tire\frac{\$}{\mathrm{h}}=\frac{12500/100000*10}{2560}=0.20 \quad (3)$$

Table A6 lists the hourly cost of transport ranges from $90.89 to 117.48 per dt depending on the size of transport equipment. The corresponding CO_2 emission ranges from 108 to 152 kg per dt of biomass mostly depending on the fuel consumption of the transport equipment.

Conventionally, cost of transportation has been calculated using an equation similar to the following [13]

$$C_{Tr}=7.67+0.18d \quad (4)$$

C_{Tr} is $/dt and d is distance travelled (km). Equation (4) has been widely reported in the literature for calculating the cost per tonne given a distance. The model is described as fixed cost $7.67/dt for loading and unloading; the coefficient $0.18 accounts for $ per dt per km. The problem with Equation (4) is that it does not consider variable fuel prices as well as the load carrying volume of the truck and fuel surcharges.

We further conducted a detailed engineering economics on three size of commercial trucks for handling pellets and included fuel use and its price. The following empirical equation described the data best,

$$C_{Tr} = (15.24G + 4.08)Ln(Q) - 9.48G + 17.84 \tag{5}$$

C is transport cost ($/h), G is fuel price ($/L) and Q is volume load capacity of the truck (m^3). The travel time for the truck is calculated as,

$$t = \frac{2d}{V} \tag{6}$$

t is travel time (h), d is the distance (km) one way, and V is the average speed (km/h). For a circle around the supply region, the distance D is equal to $2/3R$, where R is the radius of the supply region. The dry tonne capacity of the truck is calculated from volume and load density,

$$w = \rho Q \tag{7}$$

w is the volume mass capacity of the truck (dt), Q is load volume of the truck (m^3), and ρ is the density of the load (dt/m^3). The cost $/dt is then calculated from the following equation,

$$C_{Tr} = \frac{[C][t]}{W} \tag{8}$$

C_{Tr} is ($/dt) for transport.

Combining Equations (5)-(8) results in a single equation to calculate $/dt for transport

$$C_{Tr} = \frac{2d\left[(15.24G + 4.08)Ln(Q) - 9.48G + 17.84\right]}{\rho VQ} \tag{9}$$

For pellets with a density of 0.65 dt/m^3 and a distance of 2/3 of 50 km, and average speed of 50 km/h, Equation (9) reduces to

$$C_{Tr} = \frac{1}{Q}\left[(31.24G + 8.32)Ln(Q) - 19.43G + 36.57\right] \tag{10}$$

C_{Tr} is unit transport cost ($/dt), Q is the load volume capacity of the truck, G is fuel price ($/L). For a truck 29.5 m^3 truck volume, and $1.35/L for the price of diesel, the transport cost is calculated to be $6.14/dt.

5. Receiving, Handling and Storage at the Elevator

Our major assumption for this project is that the biomass takes a logistical route similar to grain. The material is transported by grain-type trucks shown in **Figure 5** to elevators (the hub) where the pellets are stored in silos. The Canadian Grain Commission published tariffs for elevating grain, storing, and out loading the grain. **Table A7** lists the average cost of elevation ranges between $13.90/t to

$17.44/t. Note that t is tonne representing the mass of grain as is with respect to the standard moisture content. The standard moisture content ranges from 9% for canola to 15.5% for corn. Most of the small grain cereals are designated at a standard moisture content of 14%, all in wet mass basis.

The average cost increases to $22.3/t. for other grain and grain screening category. The cost for elevating corn appears to be cheaper than other crops. The minimum cost of storage is recorded at $8/t to a maximum of $40/t for grains and $66/t for grain screening. The reason for this large variation among different grains and elevators is not known to the author at this time. The cost of storage per day ranges from $0.09/t to $0.12/t. The variability among primary elevators for storage ranges from $0.02/t to $0.20/t per day. The variability in storage cost is higher than the variability in elevation.

Currently there are 206 primary grain elevators in Saskatchewan enumerated in **Figure 6** based on their capacity. A handful of these elevators are designated as processing elevators engaged in processing activities like flour milling and grain cleaning. Primary elevators are mainly engaged in receiving grain from grain trucks, loading grain into the silos, storing grain for a period, and loading the grain into the rail cars when an order for transport comes in. The elevators may be equipped with grain dryers and grain screening facilities. The capacity of primary elevators ranges from few hundred tonnes to the largest in Moosejaw (Vittera Inc.) at 160,670 t. Roughly 55% of the elevators have a capacity less than 20,000 t, 43% have a capacity between 20,000 to 40,000 t.

6. Outbound Transport from Elevator

Grains is dispatched from elevators to in-land or seaport destinations by using rail cars. The two major railway companies CN and CP cover the entire country

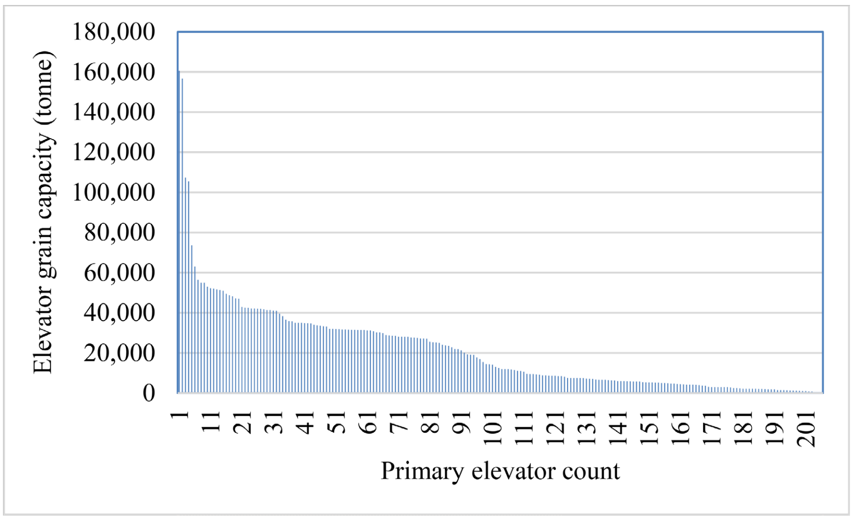

Figure 6. Distribution of grain elevators in Saskatchewan. Only four grain elevators have a capacity larger than 100 thousand t. 43% have a capacity between 20 to 60 thousands t. The remaining 55% have a capacity less than 20 thousands t. (Source: https://www.grainscanada.gc.ca/en/grain-research/statistics/elevator-charge-summaries/)

and is connected to the US railway system as is shown in Figure 7. Both companies carry grains from inland terminals to the ports in Eastern, Central, and Western Canada. CN has current presence in the U.S. and CP will be active in the U.S. as well. At the present CN Railways is the sole carrier of wood pellets. The gravity flow of pellets allows pellets to be loaded into rail cars similar to those used for carrying grain. A railcar typically holds 85 to 100 t. In Canada, the average load is about 80 t/carload [14]. Average number of rail cars in a freight train (sometimes called unit train) ranges from 80 to 108 cars. Figure 8 shows a unit train is standing by a modern elevator. Average length of the haul for class 1

Figure 7. The network of CN Railways extending from Halifax on the East coast to Vancouver on the West coast. Major grain elevators are strategically located along the rail line, a number of smaller elevators are connected to major elevators on branch rail lines (Source).

Figure 8. Specially designed grain transport rail cars are used to transport grain in Canada is suitable to transport biomass pellets. Photo Courtesy of Authors.

trains in Canada (CP and CN) was 1500 km in 2016 while the average haul for short line ranged from 128 to 306 km. The bottom of a car consists of three or more divided hoppers with doors hinged lengthwise of car and dumping between rails when unloading.

We developed the following generalize equation to describe the transport of pellets from an elevator to a destination,

$$C_R = 4.50 + 0.0336d \quad (11)$$

C_R is \$/dt, d is distance travelled in km. We included the BC surtax in anticipation that such a tax will be instituted nationally under the Clean Fuel Standards. Using a distance of 200 km will make the cost of transporting pellets at \$4.57 d/t.

7. Concluding Remarks

The analysis in this research offers a pathway for commercialization of ag pellets in Canada. One of the major hurdles in supplying ag pellets to market place is the lack of infrastructure for post production handling of pellets. In this article, we demonstrated that it would be feasible to view handling of pellets similar to handling of grains. Once pellets are made at the farmstead, the pellets are stored in hopper bottom bins. The delivery of biomass from the farm to a point of use will take a route similar to that of the grain.

Table 2 and Table 3 summarize the costs and GHG emissions associated with handling of biomass bales, pelletization, small and large scale storage and transport. The costs do not include drying that would be a major expense and source of emissions. Small grains not including corn grown on the Prairies are dry at

Table 2. Overview of cost functions for supplying biomass from farm to biorefinery in Saskatchewan.

Supply chain main operations	\$/dt	Generalized cost equation C = \$/dt
Harvest and stack bales	23.70	$C = 25.65R^{-0.397}Y^{-0.507}$ R = fraction removed, Y = yield (dt/ha)
Preprocessing (size reduction, densification, on farm storage)	35.06	$C = \frac{0.3\times10^{-4}Pi + 40.58}{Y}$ Y is throughput of the pelletizer (dt/h)
Biomass transport from farm to the hub (grain truck)	6.14	$C = \frac{0.06D\left[(15.24G + 4.08)Ln(Q) - 9.48G + 17.84\right]}{Q}$ D = distance (km); G is diesel price (\$/L) Q is volume of the truck (m^3), Assumptions: bulk density 0.65 tonne/m^3, average speed 50 km/h
Receiving, elevating, and load out at the hub	16.53	\$13.79/dt for corn to \$22.23/dt for screenings
Storage at the hub	0.10	\$0.09/dt for corn to \$0.12/dt for screenings
Rail transport from hub to biorefinery	4.56	$C = 4.50 + 0.0336L$ L is in km
Total logistics cost (\$/dt)	86.09	

Table 3. Overview of GHG emission functions for supplying biomass from farm to biorefinery in Saskatchewan.

Supply chain main operations	kg CO_2/dt (typical)	Generalized cost equation *GHG* = kg/dt
Harvest and stack bales	25.0	$GHG = 10.30 R^{-0.665} Y^{-0.447}$ R = fraction removed (decimal) Y = yield (dt/ha)
Preprocessing (size reduction, densification, on farm storage)	146	$GHG = 146/Y$ Y is throughput of the pelletizer (dt/h)
Biomass transport from farm to the hub (grain truck)	5.78	$GHG = 0.087L$ L is distance travelled (km) Assuming 50 km radius of truck travel
Rail transport from hub to biorefinery	9.10	$GHG = 0.046L$ L is in km Assuming 200 km travel for typical

the time of harvest [15]. Drying of straw may not be needed for these locations.

A few unknowns need to be worked out to realize the proposed pathway from making ag pellets and transporting the pellets to market. A demand is created for ag pellets, the quality of pellet with respect to durability and ash content meets the acceptable standards, there must be adequate storage capacity both on the farm and at the elevator to hold the additional volumes of pellets, the rail companies like CN and CP are willing to enter in transporting ag pellets similar to wood pellets.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix A

Table A1. List of equipment and economic parameters for the on-farm grinding and pelletization of biomass (1 ton per day).

Equipment	Price ($)	Year	Price 2019 ($)	Years of life	Hours/year	Power (HP, kW)	Fuel/elect.	Units
Bale handler	66,900	2017	70,287	10	5120	125	20.6	L/h
Bale processor	33,500	2017	35,196	10	5120	125	20.6	L/h
Conveyor	4282	2018	4389	10	5120	5	5.0	kW/h
Hammer-mill	14,152	2018	14,506	10	5120	37	37.0	kW/h
Cyclone	9748	2018	9992	10	5120	15	15.0	kW/h
Magnet	3477	2018	3564	10	5120	2	5.0	kW/h
Hopper	3721	2018	3814	25	5120	2	2.0	kW/h
Pellet press	49,788	2018	51,033	10	5120	90	90.0	kW/h
Cooler + screen	12,407	2018	12,717	15	5120	10	10.0	kW/h
Containers + Installation	32,141	2018	32,945	25	5120	0.0	0.0	0.0
Hopper bin	40,734	2018	41,752	35	4800	0.0	0.0	0.0
Auger loading	24,995	2017	26,260	10	4800	24	24.1	kW/h
Controls & automation	59,169	2017	61,291	10	5120	10	10.0	kW/h

Table A2. Cost input parameters to calculate fixed and operation costs and emissions for pelletization equipment.

Interest rate	Inflation rate	Insurance, housing, taxes	kg CO_2 per L/h diesel	kg CO_2 per kWh electricity	Diesel $/L	Electricity kW/h	Repair & Maintenance
0.06	0.025	0.02	2.64	0.70	1.35	0.08	0.02

Table A3. Engineering output for calculating CO_2 emissions and the unit cost of producing and storing pellets on the farm.

Operations	Energy unit cost ($/h)	Repair & Maint ($/h)	Labor cost ($/h)	Op cost ($/h)	Salvage value factor	Fixed cost ($/h)	Total cost ($/h)	t/h	Emissions kg CO_2/h	Total cost ($/h)
Raw material preparation										
Bale handler	27.85	0.27	0	28.12	0.284	1.36	29.49	5	13.07	7.08
Bale processor	27.85	0.14	0	27.98	0.284	0.68	28.67	12	54.46	2.87
Conveyor	0.40	0.02	0	0.42	0.284	0.09	0.50	20	0.21	0.03
Hammer-mill	2.96	0.06	0	3.02	0.284	0.28	3.30	1.2	25.90	3.30
Cyclone	1.20	0.04	0	1.24	0.284	0.19	1.43	5	2.52	0.34
Magnet	0.40	0.01	0	0.41	0.284	0.07	0.48	20	0.21	0.03
Labor			15				15.00			15.00
Pellet press										
Hopper	0.16	0.01	0	0.17	0.120	0.04	0.22	1.2	1.40	0.22
Pellet press	7.20	0.20	0	7.40	0.284	0.99	8.39	1.2	63.00	8.39

Continued

Cooler screen	0.80	0.05	0	0.85	0.212	0.19	1.04	1.2	7.00	1.04
Containers +installation	0.00	0.10	0	0.10	0.120	0.29	0.39	1.2	0.00	0.50
On farm Storage										
Hopper bin	0.00	0.17	0	0.17	0.065	0.42	0.60	1.2	0.00	0.60
Auger	1.92	0.11	0	2.03	0.284	0.54	2.58	25	0.79	0.12
Controls & automation	0.80	0.24	0	1.04	0.000	1.51	2.55	1.2	7.00	2.55
Sum ($/h)								1.2	175.56	42.06
Per ton									146.30	35.05

Table A4. Selection of transport equipment and specifications and their initial purchase price: 4.8 m farm grain truck single axle with 6 tires, medium size 7.3 ft truck 2 axle with 10 tires and a tandem 14.6 ft truck with 3 axle and 18 tires.

Transport equipment	Cap. (m^3)	Engine power (kW)	Price ($)	Year	Price in 2019 ($)	Years of life	hrs/yr	Km/yr
Small (6 wheel)	29.5	185	79,900	2014	90,400	10	2560	12,500
Medium (10 wheel)	44.0	222	120,000	2014	135,769	10	2560	12,500
Large (18 wheel)	85.2	259	179,000	2014	202,522	10	2560	12,500

Table A5. Cost input parameters to calculate fixed and operation costs and emissions for transport equipment.

Interest rate	Inflation rate	Insurance, Housing, Taxes	Diesel $/L	kW (Engine) to L (ASABE EP 496)	kg CO_2 per L diesel	Travel distance (km)	Travel speed (km/h)	Load density (t/m^3)
0.06	0.025	0.02	1.35	0.223	2.64	50	50	0.65

Table A6. Engineering economic calculations for the three sizes of transport equipment.

Transport Equip	L/h	Fuel cost ($/h)	R & M per km	R & M ($/h)	Tires $/h	Labor cost ($/h)	Op cost ($/h)	Salvage value factor	Fixed cost ($/h)	Total cost ($/h)	CO_2 kg/h
Small (6 wheel)	41.0	55.69	1.39	6.79	0.12	25.00	87.93	0.35	3.29	90.89	108
Medium (10 wheel)	49.5	66.83	1.39	6.79	0.20	25.00	99.07	0.35	4.94	103.76	130
Large (18 wheel)	57.8	77.97	1.39	6.79	0.35	25.00	110.20	0.35	7.36	117.48	152

Table A7. Canadian Grain Commission Tariffs ($/t) for primary elevators for receiving storing and loading out of grains. Number of elevators 40 to 50 surveyed. The data is for crop year 2014.

Operation	Stats	Wheat	Oats	Barley	Canola	Corn	Soy/Peas	Other grains screenings.
Receiving, Elevation, Load out ($/t)	Average	16.33	14.99	17.44	15.63	13.79	15.29	22.23
	Std. dev.	4.35	2.50	4.61	3.58	5.00	3.13	14.84

Continued

	Coef. Var. (%)	26.6	16.7	26.5	22.88	36.2	20.5	66.8
	Minimum	8.00	8.00	8.00	8.00	8.00	5.00	8.00
	Maximum	26.00	18.78	26.00	30.00	40.00	20.00	66.00
Storage Daily after day 10 of storage ($/t per day)	Average	0.11	0.11	0.11	0.10	0.09	0.09	0.12
	Std. dev.	0.04	0.06	0.04	0.05	0.04	0.04	0.06
	Coef. Var (%)	42.2	49.5	39.6	51.2	49.3	44.2	51.7
	Minimum	0.02	0.03	0.03	0.03	0.03	0.03	0.03
	Maximum	0.20	0.22	0.18	0.22	0.15	0.15	0.25

Source: https://www.grainscanada.gc.ca/en/grain-research/statistics/elevator-charge-summaries/.

Table A8. Economic parameters for estimating the cost of rail transport of pellets.

Basic pull charge ($/railcar/km)	3.1920
Fuel surcharge ($/railcar/km)	0.0298
BC carbon tax ($/railcar/km)	0.1171
Railcar lease ($/dt)	4.50
Railcar capacity (dt)	99.5