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Rail vs Truck Transport of Biomass

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Abstract

This study analyzes the economics of transshipping biomass from truck to train in a North American setting. Transshipment will only be economic when the cost per unit distance of a second transportation mode is less than the original mode. There is an optimum number of transshipment terminals which is related to biomass yield. Transshipment incurs incremental fixed costs, and hence there is a minimum shipping distance for rail transport above which lower costs/km offset the incremental fixed costs. For transport by dedicated unit train with an optimum number of terminals, the minimum economic rail shipping distance for straw is 170 km, and for boreal forest harvest residue wood chips is 145 km. The minimum economic shipping distance for straw exceeds the biomass draw distance for economically sized centrally located power plants, and hence the prospects for rail transport are limited to cases in which traffic congestion from truck transport would otherwise preclude project development. Ideally, wood chip transport costs would be lowered by rail transshipment for an economically sized centrally located power plant, but in a specific case in Alberta, Canada, the layout of existing rail lines precludes a centrally located plant supplied by rail, whereas a more versatile road system enables it by truck. Hence for wood chips as well as straw the economic incentive for rail transport to centrally located processing plants is limited. Rail transshipment may still be preferred in cases in which road congestion precludes truck delivery, for example as result of community objections.

Index Entries: Biomass transportation; transportation economics; rail transport; truck transport; straw.

Introduction

In comparision with solid and liquid fossil fuels, biomass is lower in energy density and physical density. Because field harvested biomass has a low energy yield/unit area in comparision with solid fossil fuel sources such as a coal, its initial transport is typically in a transport truck with a 20–40 t capacity. Each of these factors contributes to biomass having a significantly higher cost of transportation per unit of available energy than fossil fuels.

When biomass is transported all the way to its final destination by a transport truck, a further problem with road congestion may arise. Many studies have shown that the optimum size of biomass projects is large

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when abundant biomass is available *(1–3)*. A detailed study of three field biomass sources in western Canada showed that optimum power plant size was 900 MW for biomass drawn from harvesting the whole boreal forest, 450 MW for straw, and 130 MW for forest harvest residues (FHR, the branches, tops, and possibly stumps of trees harvested for pulp or lumber); 450 MW is the largest assumed single unit size for boiler and steam turbo-generator in this study *(1)*. At 450 MW, biomass requirements are 2.1 M dry t of biomass per year, equivalent to one truck delivery of straw every 4 min if truck capacity is 17 t of straw per load (typical straw trucks have a nominal capacity of 20 t but are constrained by volume to carry about 17 t/load). This intensity of truck traffic could lead to community resistance in site selection for biomass processing plants.

One alternative to try to reduce transportation costs of field harvested biomass and alleviate truck congestion is to offload biomass from trucks to an alternative transportation mode before delivery to the processing plant. Previous studies have evaluated pipeline transport of biomass in detail *(4,5)*, slurry pipelining of biomass in water has a feasible cost structure for aqueous based processing, such as fermentation or supercritical gasification. Biomass is not amenable to pipeline transport if the end usage is combustion, because uptake of carrier fluid by the biomass is too high.

In this work, we evaluate offloading field harvested biomass onto dedicated unit trains for delivery to large scale power plants. The cost of delivering straw and wood chips from FHR by trucks to rail terminals for further transport by unit train is in comparision with previous studies of power plants supplied by truck alone. We develop an idealized case to explore the critical factors in transshipment of biomass, and then analyze two specific cases in the Province of Alberta, Canada, using existing rail lines. A previous European study looked at transportation costs in Europe by truck, rail, and ship *(6)*, and concluded that higher distances favored first rail, then ship transport. This study did not distinguish fixed and variable costs, a focus of this study, because recovery of incremental fixed costs of transshipment determine the distance at which it is economic.

Shipment of Biomass by a Single Transportation Mode

Many modes of transportation have a similarly shaped profile of cost vs distance shipped, as shown in Fig. 1. The intercept of the line at zero distance, "a," is the fixed cost of shipping a ton biomass regardless of distance; we call this the distance fixed cost (DFC). For example, for trucking in North America a typical cost of loading and unloading a straw or wood chip truck is approx \$5/t *(7)*. The slope of the line in Fig. 1, "b," is the distance variable cost (DVC). Most transportation modes have a linear DVC because the distance variable cost components, for example wages, fuel, and capital recovery for the transportation equipment, are directly proportional to the distance traveled.

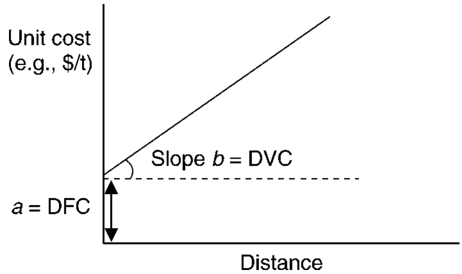

Fig. 1. General plot of unit transportation cost vs distance showing distance fixed and distance variable cost.

Table 1
Values of DFC and DVC Used in this Study

	Truck		Rail		
	DFC ($/dry t)	DVC ($/dry t-km)	DFC ($/dry t)		DVC ($/dry t-km)
			Shipper components	Carrier components	
Straw	4.76	0.1309	6.74	10.27	0.0277
Wood chips	4.98	0.1114	6.35	3.62	0.0306

Truck transport of biomass often requires little or no investment by the shipper, because trucks are owned by the carrier, not the shipper. Straw bales located at the roadside can be loaded on a straw transport truck by equipment located on the truck, and conveying of wood chips into chip trucks has a low fixed cost per ton of wood chips. The situation is different for rail transport in North America, the rail carrier typically owns the main tracks but the shipper owns the siding and all equipment located there, i.e., the shipper is responsible for loading the railcars. In addition, for any long term project such as a power plant supplied by dedicated unit trains the shipper typically owns the railcars. Thus for rail transport of straw or wood chips, DFC has two components to it, the fixed cost charged by the rail carrier and the costs incurred by the shipper for loading the rail cars, including the rail siding and the railcars themselves.

Table 1 shows the values of DFC and DVC used in this study (all costs in this study are reported in 2004 in USD). Truck costs are midrange values drawn from a detailed analysis of previous studies of trucking costs *(7)*. The estimate of rail carrier costs were drawn from an analysis of estimates for moving straw and wood chips in western Canada provided by a carrier active throughout North America *(8)*. Wood chips have an assumed moisture level of 45%, and straw an assumed moisture level of 16% *(1)*.

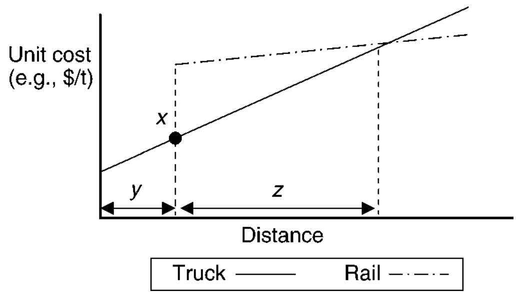

Fig. 2. Unit transportation cost vs distance for truck only and truck plus rail.

Truck and rail carrier DFC is independent of scale, but the shipper component of DFC in Table 1 is calculated based on the "specific case" sizes in this study. The specific wood chip case is a 130 MW power plant burning chipped biomass from FHR; the size of this plant was determined to be optimal from a previous study *(1)*. The specific straw case is a 250 MW power plant burning straw chopped from delivered large round or square bales with a weight of approx 0.6–1 t/bale. The straw power plant size is less than optimal, but the power cost vs size profile is relatively flat between 250 and 450 MW and hence the impact of the smaller plant size is small *(1)*. The wood chip power plant requires 3.8 unit trains/wk, and the comparable figures for straw are 10.1 unit trains/wk. For each of these cases a detailed scope of equipment required by the shipper is developed in order to estimate the shipper's component of DFC. In addition, we study a range of idealized straw and wood chip power plant sizes to estimate the size of power plant at which train transport is justified.

By inspection, rail shipment of biomass has a lower variable cost but a higher fixed cost, this is why most short haul of bulk goods is by truck and long haul by rail. However, the dispersed nature of biomass requires that it start its transportation to a processing plant on a truck. The critical issue for biomass therefore is under what circumstances it is economic to offload truck transported biomass to a train.

Transshipment: Using Two Transportation Modes

Because field sourced biomass must be hauled to a transshipment depot by truck, the total cost of shipment by truck and train is illustrated by Fig. 2. At the point at which biomass is unloaded from the truck, point *x* in Fig. 2, incremental DFC is incurred. This incremental fixed cost can only be justified if the DVC of the second transportation mode, in this case rail, is lower than that of the first mode, truck. The critical question for transshipment then becomes at what distance, *z* in Fig. 2, does the lower DVC of the second transportation mode offset the incremental DFC? If the distance for rail shipment of biomass is shorter than z, trans-shipment is not economic. Put another way, is the rail shipment distance far enough so that one can afford to offload biomass to a second transportation mode? In this study we refer to the distance z as the crossover distance, i.e., the minimum rail distance for which transshipment is economic.

Note that the distance y in Fig. 2 is the average truck haul distance to the rail site. This is influenced by the number of transshipment points (in this study, rail sidings) that can offload the biomass. This is discussed later.

Scope of Equipment

Specific Straw Case

For truck only movement of straw, this study assumes that farmers place round or large square bales at roadside and cover them with tarps. The power company contracts with trucking firms to bring straw to the power plant, removing the tarps and leaving them at the roadside for reuse by the farmer. Trucks have self-loading equipment and are contracted year round, so that the annual harvest of straw is primarily stored on public road allowances at the sides of farmer's fields; in western North America road allowances are large and could store all of the straw harvest from adjacent fields. The power plant has at least 1–2 wk of straw storage, and more if seasonal road access is an issue. Trucks are weighed on entry and exit from the plant, and straw moisture is measured; payments to the farmer are calculated on this basis. Straw is removed from trucks by fork lifts; a fleet of 18 is required (including one spare) for the specific case described earlier.

For transshipment of straw to trains, trucks arrive at existing designated grain elevator terminals and are weighed on entry and exit; straw moisture is measured at this time. Rental fees for land usage at grain terminals are based on discussions with industry *(9)*. Straw is stored until 2650 t, an amount sufficient for a 100 rail car unit train, is amassed. Unit trains are dedicated to a single use, and not used for backhaul. Note that 100 car unit trains are standard for carrying grain and supplying coal to some power plants in North America, and that many (but not all) grain elevators have the capability to load 100 car unit trains; rates charged by rail carriers are lowest for 100 car unit trains with short turnaround times, i.e., loading times less than 9 h. Rail cars would be owned by the power plant through purchase or committed long term lease. Straw is loaded on the railcars in 9 h or less by a fleet of 18 forklifts located at each transshipment terminal. The operating crew for the forklifts rotates between the transshipment sites at grain elevators. When unit trains arrive at the power plant they are unloaded by forklifts; there is minimal difference in the requirement for forklifts and other equipment at the power plant between truck and truck plus train delivery of straw.

Specific Wood Chip Case

In western Canada, most trees that are harvested for pulp or lumber are skidded to the side of a logging road whole, delimbed and topped at the roadside. Hence, FHR accumulates at roadsides as long windrows of material. A modified forwarder equipped with a pushing blade and a grapple would consolidate the residues and load the chipper. For truck only delivery of chips, trucks would normally be directly loaded from the chipper, but could also self load from wood chip piles. (Note that an alternative scheme would see residues rolled and bound and transported as "logs," a system developed in Finland for coniferous trees and applied to a variety of species in subsequent trials *[10]*. This system would require testing to determine its suitability for mixed hardwood and softwood stands found in western Canada.) Trucks would dump chips in the vicinity of dump pockets linked to a conveyor belts at the power plant. A bulldozer and front end loader would consolidate material at the power plant, and would move chips from long term plant site storage to the dump pockets if needed.

For transshipment of chips to trains, specialized sidings on existing rail lines in northern Alberta would be built, equipped with dump pockets and conveyor belts. Trucks would dump chips over the dump pockets; each siding would require a bulldozer and front end loader to consolidate chips. Chips would be accumulated until a full unit train could be loaded from multiple conveyors in 9 h or less. At the power plant rail cars would be rotated over dump pockets, a process currently in use with unit coal trains using gondola cars. There is minimal difference in the requirement for equipment at the power plant between truck and truck plus train delivery of wood chips.

Full equipment and staffing requirements were developed for each case and, capital and operating cost estimates were then calculated. Critical values for each "specific" case are shown in Table 2. Biomass yields are per gross hectare, which allows for uses of land in an area for purposes other than that associated with the biomass, such as communities, roads, and alternate crops. (Details are in ref. *[1]*). For straw we assume the power plant is able to purchase 80–85% of the available straw in the area in a poor harvest year (lowest quartile) and 60–65% in an average harvest year; note that a study has shown that recovery of straw does not reduce soil carbon in Canadian prairie black soils *(11)*.

Idealized Straw and Wood Chip Cases

In evaluating truck only vs truck plus rail shipment of biomass, we start with an idealized "best" case for straw and wood chips, in which rail sidings are assumed to be located exactly as needed in the center of contiguous sources of biomass, and rail lines direct from the sidings to the power plant are available. An idealized case defines a value of the crossover distance below which transshipment from truck to rail is not economic. If the number of transshipment terminals is optimized to give lowest overall

Table 2
Cost Factors for Biomass Transportation[a]

Fuel type	Straw	Wood chips
Power plant size (MW)	250	130
Biomass yield (dry t/gross ha)[b]	0.416	0.247
Biomass demand (M dry t/yr)	1180	635
Hectares required/yr	2830	77,100
Average driving distance (km)	67.2	350.3
Capital cost at the power plant ($ 000)		
Train cars *(12,13)*	28,500	16,000
Forklifts	418	–
Trailer buildings	45	15
Front end loader	–	30
Bulldozer	–	100
Building tracks at the plant	–	1200
Operating cost for the power plant ($ 000)		
Salaries	1400	500
Maintenance	318	170
Capital cost per rail transshipment terminal ($ 000)		
Forklifts	418	–
Trailer buildings	45	15
Front end loader	–	30
Bulldozer	–	100
Land for storage	–	23
Building tracks at the terminals	–	1200
Mechanisms (Including conveyor belt, dumping system, and dump pocket)	–	450
Operating cost per rail transshipment terminal ($ 000)		
Salaries	1250	400
Maintenance	318	170
Rent for usage of facilities at terminals (Including land for storage)	150	–
Total capital cost ($ 000)[c]	29,700	22,700
Annual return on capital at 10%	3210	2410
Total operating cost ($ 000)[c]	4730	1410
Shipper component for rail DFC ($/dry t)	6.74	6.35

[a]All costs in 2004 in $ US.
[b]Gross hectares includes all land, including land used for other crops/species, and for non-agricultural or forestry purposes such as roads, communities, and industry.
[c]The capital and operating cost calculations are based on three rail transshipment terminals.

biomass transportation cost, we call this crossover distance the minimum economic rail shipping distance (MERSD).

The first task is to determine the optimum number of transshipment points, i.e., railroad sidings that transfer biomass from truck to storage to train. There is an optimum, because a decrease in transshipment points

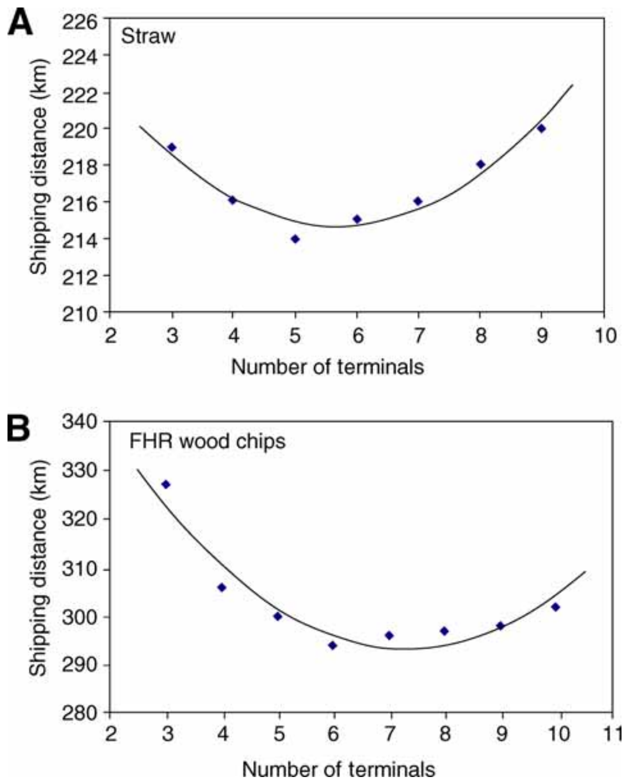

Fig. 3. (A) Total shipping distance vs number of rail transshipment terminals for a 250 MW straw power plant **(B)** and for a 130 MW wood chip power plant.

increases the distance over which biomass is carried at the higher "per km" rate (DVC), i.e., it increases the distance y in Fig. 2, whereas an increase in transshipment points increases the total DFC, because each siding requires a land payment and investment in loading and unloading equipment. The optimum number of terminal is that which gives a minimum total shipping distance, $y + z$ in Fig. 2, which corresponds to the minimum shipping cost. Figure 3 shows the calculated total shipping distance as a function of the number of terminals delivering straw and wood chips. From this we concluded that the optimum biomass shipment per rail terminal was approx 255,000 dry t/yr. We tested this assumption with a larger straw fired power plant, 450 MW, and found a comparable result, shipping 225,000 dry t of straw per terminal is the optimum tradeoff between truck DVC and rail DFC. A value of 255,000 dry t of straw per year per terminal was used in the analysis of the idealized case.

A similar analysis was done for an idealized wood chip case, and the minimum crossover distance corresponds to 100,000 t of wood chips per terminal. This value was used in the subsequent development of the idealized case. Note that the optimum ton per year per terminal is lower for wood chips than for straw; this arises because the gross yield, i.e., the tons

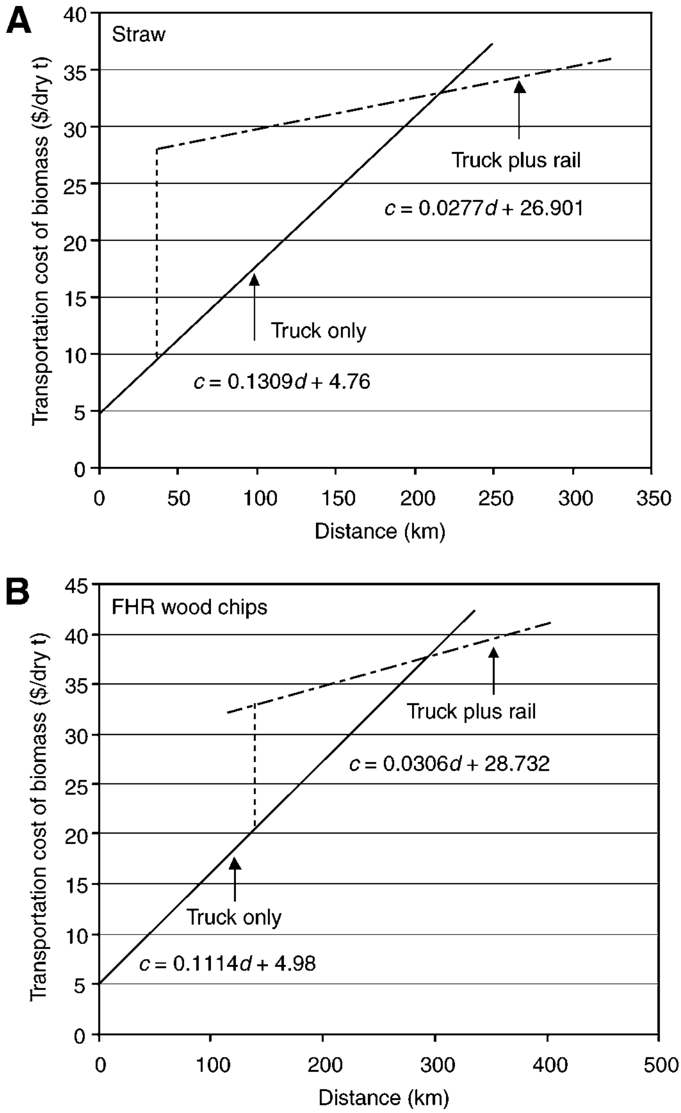

Fig. 4. The cost of delivered biomass for truck only and truck plus rail shipment as a function of distance.

of biomass per gross hectare, is lower for FHR than for straw. Boreal forests have a long rotation cycle, typically 100 yr in Alberta, Canada, and it is this low cutting frequency that gives a low net yield of FHR per gross hectare of forest. Hence to aggregate the same amount of biomass from chipped FHR a longer driving distance is required than for straw, and the optimum configuration of a two mode transportation system is less tonnage per rail terminal for a biomass source with lower gross yield.

Figure 4 shows the cost of delivered biomass in $/t for truck only and truck plus rail shipment for the two cases. Note that the total shipping distance is 215 km for straw and the MERSD distance is 170 km for straw, and yet if centrally located a 250 MW straw power plant would draw from an area of radius of less than 100 km (the biomass draw distance) with an average driving distance of 70 km. The shipping and MERSD distances for straw are so much greater than the biomass draw distance that transshipment to rail is not economic at 250 MW for a centrally located straw power plant; there is not enough haul distance on rail to recover the incremental fixed costs of transshipment. Note that the calculated MERSD distance is consistent with current shipping practice in the grain industry: in discussion an Alberta based grain terminal manager noted that for single rail car quantities of grain (not a unit train) trucks are used to haul grain for distances up to 300 km, even if the truck route parallels existing train tracks *(14)*. Shipment of biomass to a plant that is not centrally located to the draw area is discussed later.

For wood chips from boreal FHR the total shipping distance is 295 km and the MERSD distance is 145 km, whereas the biomass draw distance is 480 km, which gives an average driving distance of 340 km. Hence in an idealized case in which abundant rail lines are available it is more economic to transport boreal FHR wood chips by a combination of truck plus rail; the impact of the lower gross yield of biomass from FHR is to shift the optimum transportation mode to truck plus rail.

DVC for rail transport of straw is slightly less than DVC for rail transport of wood chips, because rail lines for forested areas of Alberta are more remote and presumably have higher maintenance cost. Despite this, the MERSD distance for hauling straw by rail is higher than for hauling wood chips, because the DFC for straw is higher. There is a larger cost in loading straw onto rail cars than wood chips, and a longer distance is required to recover this fixed cost. In general, determination of the minimum economic distance for transshipment requires a specific determination of DVC for both modes of transportation and DFC for switching from one mode to the other.

The size of the power plant determines the biomass draw distance, we analyze a range of plant sizes to determine the point at which, in an ideal case, transshipment to rail is more economic than truck only transport. Figure 5A shows the total delivered cost of straw by truck only and by truck plus rail as a function of power plant size, assuming the plant is centrally located. Not until total plant size reaches 2700 MW does transshipment of straw to rail result in a lower delivered cost of biomass. Previous studies *(1)* have shown that the optimum size of a straw power plant is in the range of 250–750 MW, and hence the practical potential for transshipment to give a lower biomass cost to centrally located power plants appears to be negligible. Even if straw yield is reduced by a factor of three, say because farmers are willing to sell less than 33% of recoverable straw to a power plant, transport by truck to a 250 MW centrally located power plant is more economic than truck plus rail transport. Figure 5B shows the comparable data for wood chips from boreal FHR. In

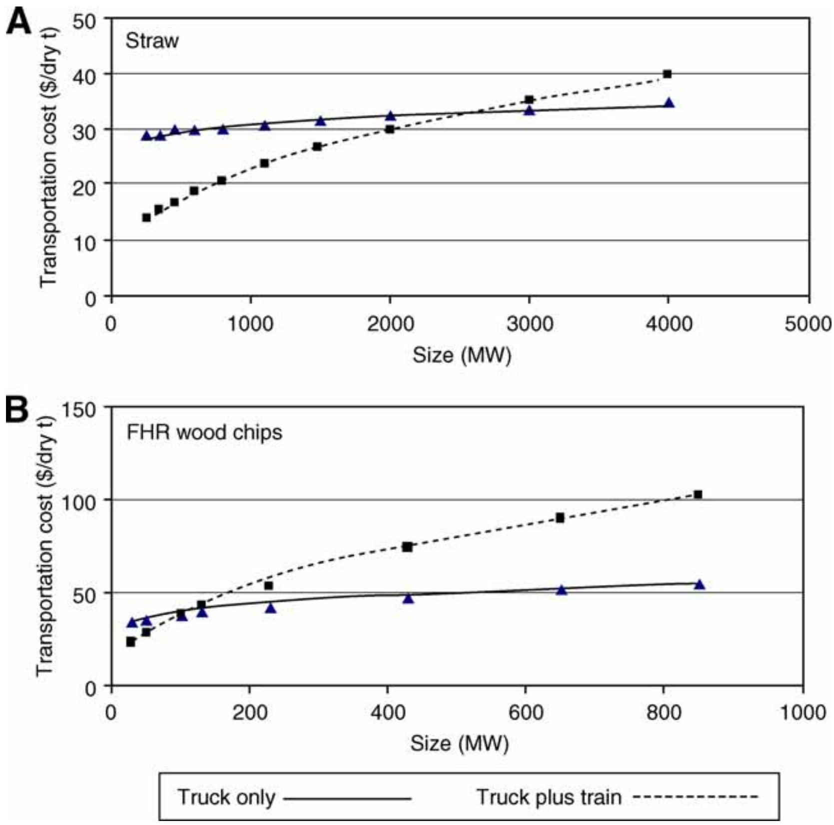

Fig. 5. Delivered cost of biomass as a function of power plant size.

an idealized case, transshipment to train gives a lower delivered cost of biomass to a centrally located plant above 100 MW.

Two Actual Cases in Alberta

The idealized cases assumed that rail lines and sidings were available exactly where needed, and hence from an economic perspective are "best case" analyses. In reality rail lines are well established, and impose their own geographical limitations on plant location. We explore this impact by looking at two specific cases in the Province of Alberta, Canada. Figure 6 shows a map of Alberta, showing existing rail lines. The circles drawn around the straw (S) and wood chip (WC) terminals show the area from which we assume that biomass is drawn. The radius is calculated based on the biomass yield and the size of the plant. For the 250 MW straw plant with three terminals the radius of each draw area is 55 km; for the 130 MW wood chip plant with three terminals it is 270 km.

For the straw case, rail lines in the area of grain growing use Edmonton as a hub. Straw terminals assumed in the specific case are labeled S1–S3 in Fig. 6, and the power plant location at Camrose is labeled

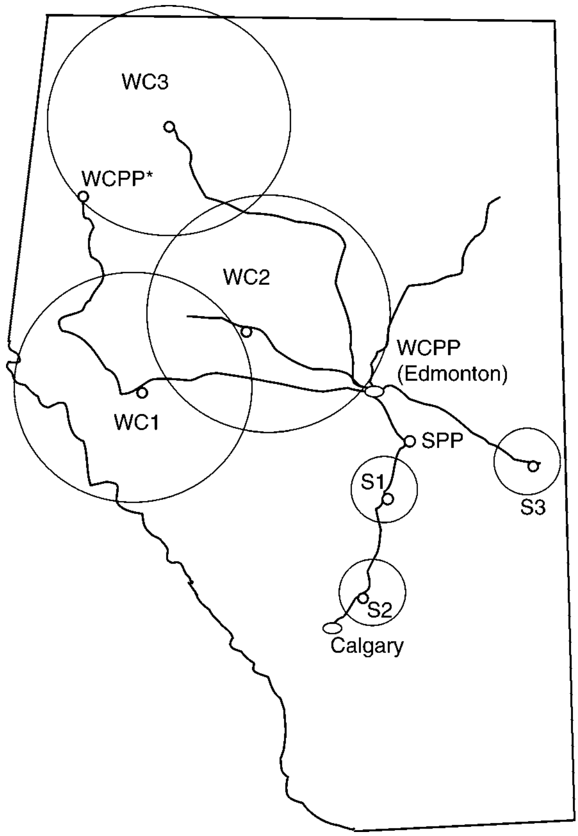

Fig. 6. Map of Alberta showing existing rail lines related to two specific prospective biomass power plants.

SPP. Rail haul distances range from 95 to 215 km. Truck haul distances are far higher than in the ideal case because the straw source is not adjacent to the power plant.

For the wood chip case a large draw area uses three rail lines that also converge on Edmonton. In this case, the only practical location for a wood chip power plant supplied by rail is adjacent to the city of Edmonton. Rail distances are high, and range from 160 to 410 km. The wood chip terminal locations and power plant location are labeled WC and WCPP in Fig. 6. Because roads are more prevalent than rail lines in northern Alberta, a wood chip power plant supplied by truck could have a more central location; WCPP* in Fig. 6 shows the alternate location of a truck supplied wood chip power plant, in Grande Prairie. This is a critical difference between the two transportation alternatives, a more extensive road network allows a more centrally located power plant in comparision with the restrictions imposed by the layout of the rail system.

Table 3 shows the delivered cost of biomass by truck only and truck plus train for the straw and wood chip power plants. Truck only delivery

Table 3
Cost of Biomass Transport by Truck Only and Truck Plus Train for the Straw and Wood Chip Power Plant ($/t)

	Truck only	Truck plus train
Straw plant in Camrose	25.6	33.7
Wood chip plant in Edmonton (rail) or Grande Prairie (truck)	43	44

is less expensive than truck plus train for the straw power plant, even though the straw is being drawn from further away than in the ideal case. Truck only delivery is also less expensive than truck plus train for wood chips, because truck transport enables a more centrally located plant. Thus, although in an ideal case transshipment of boreal FHR wood chips to train gives a lower cost, the geographic constraints of rail line layout shift the balance in favor of truck transport.

Discussion

Field sourced biomass, in comparision with other energy forms, has a low physical and energy density and starts its journey to a processing plant on a truck. For these reasons transportation of biomass is a significant cost, and as biomass processing grows, project developers will place an emphasis on reducing these costs.

Transshipment from truck to any other mode of transportation only makes sense if the second mode has a lower cost per km (DVC) than the originating mode. Train transport has a DVC significantly lower than truck transport. However there is a minimum shipping distance required for transshipment to be economic, because transshipment has incremental fixed costs independent of distance shipped (DFC). Only when the savings in DVC are large enough to offset the incremental DFC is transshipment economic.

DVC and DFC are case specific. DVC depends on the transportation mode and the specific location, and DFC depends on the specific biomass being transported. The values for truck transport cited in this study are representative of North America *(7)*, but would not necessarily apply to Europe, for example, DFC reflects the specific equipment and contractual arrangements involved. For example, truck transport in North America is typically through third party carriers who charge for loading and unloading time, whereas for rail transport in North America it is the shipper, not the carrier, that leases or owns the rail cars and constructs the rail siding and the loading equipment. Thus any analysis of transshipment would have to factor in specific values to determine the minimum economic shipping distance.

There is an optimum number of transshipment terminals for any two mode transportation scheme. A higher number of terminals increases the fixed costs of transshipment, for example, the investment in land and equipment to move biomass from truck to train, but reduces the truck transport distance and thus reduces the overall DVC incurred. In the ideal analysis we assume that the optimum number of terminals is in place, and calculate MERSD based on that number of terminals. The ideal number of terminals and the biomass moved per terminal depends on the biomass gross yield, i.e., the amount of biomass per total hectares in the draw area. A lower biomass gross yield reduces the value of the optimum amount of biomass moved through each terminal, because truck haul distances increase as biomass yield decreases.

For straw or corn stover in North America we estimate that the MERSD to recover fixed costs of loading dedicated unit trains is 170 km. An economically sized centrally located power plant would have a biomass draw area significantly less than the shipping distances associated with rail transshipment, hence using rail would increase, not decrease the overall power cost. For a more diffuse biomass source such as boreal FHR wood chips, we estimate the MERSD to recover fixed costs of loading dedicated unit trains is 145 km. In theory, if rail lines were conveniently located, it would make sense to transship wood chips to rail for transport to an economically sized centrally located power plant.

As this study has shown for one location, the Province of Alberta, Canada, rail lines are usually not ideally located for biomass processing as a fuel or feedstock. Road networks tend to be far more versatile than rail networks for aggregating biomass for processing near the point of origin. Road networks reach more locations than rail lines, reflecting that fact that there are far more motor vehicles than trains in operation at any point in time, and most use of roads is for the transportation of smaller quantities of people or goods than would be appropriate for rail. One consequence of this is that roads allow a more diverse pathway for the movement of goods, and hence give greater flexibility in the location of a power plant supplied by truck as in comparision with one supplied by rail. In this study, the wood chip power plant requires trains arriving from three different rail lines. The existing layout of rail lines in Alberta would dictate an Edmonton location for a rail-based wood chip power plant, because the three rail lines converge there. Locating the wood chip power plant in Northwestern Alberta and supplying it by rail would require much longer overall rail transport distances. However, a truck-based power plant could be located more centrally to the wood chip supply in northwestern Alberta, and the wide availability of roads means that longer transportation distances are not required for this location. This difference in location between a rail supplied and truck supplied plant is enough to shift the economics in favor of truck transport. In general, we conclude from this study that the economic incentive for rail transshipment of biomass to centrally located processing plants is limited at best.

Unit trains provide the least expensive form of rail transport for bulk commodities because the processing of rail cars by the carrier is minimal.

If biomass is being shipped in smaller quantities, and especially if it uses rail cars provided by the carrier, charges will be higher, which would increase the MERSD distance.

Long distance shipment of biomass to a noncentrally located processing plant would justify rail transport at distances above the MERSD distance identified in this study. However, economics will likely favor processing close to the biomass source unless the cost of transporting the products of processing biomass, for example, power or ethanol, are higher than the cost of transporting the biomass itself. Hence, biomass transshipment is theoretically economic but in practical terms we expect it to be cost effective only in limited cases in which long distance transport is required.

The analysis in this study has focused on the cost of truck vs rail delivery of biomass. However, social issues may create a situation in which a higher cost alternative, rail transport, is selected to provide a social good. One potential reason to use rail shipment of biomass even when not lower cost than truck delivery is to avoid a traffic congestion issue that would otherwise preclude the development of a biomass processing plant. Rail shipment by unit train has less impact on communities because rail lines are well established and the additional usage for one or two unit trains/d has a lower impact on people near the transportation corridor than a steady stream of trucks. Truck traffic for economically sized biomass power plants could exceed community tolerance. In this case, a small difference in cost would be offset by the potential failure to receive approval for a truck-supplied project.

Conclusions

The key conclusions from this study are:

- Transshipment of biomass from truck to a second mode of transportation will only be economic if the cost/distance traveled is lower for the second transportation mode. It also requires additional fixed costs independent of the distance (DFC), the investment in land and facilities to transship the biomass. Hence there will always be a minimum economic shipping distance for the second transportation mode, because the savings in DVC must offset the incremental DFC.
- For any two mode transportation scheme there is an optimum number of transshipment terminals that minimizes overall shipping costs. There is a tradeoff between higher DFC and lower DVC as the number of terminals increases. In this study, 255,000 dry t of straw per year and 100,000 dry t of boreal FHR wood chips are the optimal rates of biomass per terminal.
- Alberta, Canada, rail and truck rates are typical of North America. If dedicated unit trains are used for rail transport and the number of terminals is optimized, the MERSD for straw is 170 km, and for boreal FHR wood chips is 145 km.

- A centrally located straw power plant of economic size (250 MW) has a biomass draw area lower than the minimum economic rail distance, and hence transshipment to rail will not be economic for such a plant. It might be warranted if community resistance to truck traffic is a major factor in plant sizing.
- A centrally located boreal FHR wood chip power plant of economic size (130 MW) has a biomass draw area larger than the minimum economic rail distance and associated truck travel, and hence transshipment to rail would be economic if rail lines existed that went to a central location.
- The actual layout of rail lines frequently precludes central location of an economically sized biomass processing plant supplied by rail. Road networks frequently allow more flexible location of processing plants than rail lines. In a specific case analyzed in Alberta, the difference in location for a boreal FHR wood chip power plant tips the balance in favor of truck transport.

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