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Strategic Freight Transportation Analysis

Review of Transportation Costs for Alternative Fuels

Mark Holmgren
Graduate Research Assistant
Washington State University

Ken Casavant
SFTA Co-Principal Investigator
Washington State University

Eric L. Jessup
SFTA Co-Principal Investigator
Washington State University

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BORDER POLICY RESEARCH INSTITUTE
WESTERN WASHINGTON UNIVERSITY

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Mark Holmgren
Graduate Research Assistant

Ken Casavant
SFTA Co-Principal Investigator

Eric Jessup
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December 2007**

Washington State University
School of Economic Sciences
101 Hulbert Hall
Pullman, WA 99164-6210

SFTA Research Reports:
Background and Purpose
This is the **XX** report in a series of research studies prepared as part of the Strategic Freight Transportation Analysis (SFTA) study. SFTA is a six year comprehensive research and implementation analysis that will provide information (data and direction) for local, state and national investments and decisions designed to achieve the goal of efficient and seamless freight transportation.

The overall SFTA scope includes the following goals and objectives:
• Improving knowledge about freight corridors.
• Assessing the operations of roadways, rail systems, ports and barges – freight choke points.
• Analyze modal cost structures and competitive mode shares.
• Assess potential economic development opportunities.
• Conduct case studies of public/private transportation costs.
• Evaluate the opportunity for public/private partnerships.

The five specific work tasks identified for SFTA are:
• Work Task 1 - Scoping of Full Project
• Work Task 2 - Statewide Origin and Destination Truck Survey
• Work Task 3 - Short Line Railroad Economic Analysis
• Work Task 4 - Strategic Resources Access Road Network (Critical State and Local Integrated Network)
• Work Task 5 - Adaptive Research Management

For additional information about the SFTA or this report, please contact Eric Jessup or Ken Casavant at the following address:

Washington State University
School of Economic Sciences
301 Hulbert Hall
Pullman, Washington 99164-6210

Or go to the following Web Address:
www.sfta.wsu.edu

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Report 1
SFTA Full Scope of Work
by Eric L. Jessup
Report 2
Freight Truck Origin and Destination Study: Methods, Procedures, and Data Dictionary
by Michael L. Clark
Report 3
Value of Modal Competition for Transportation of Washington Fresh Fruits and Vegetables
by Ken L. Casavant & Eric L. Jessup
Report 4
Transportation Usage of the Washington Wine Industry
by Ken L. Casavant & Eric L. Jessup
Report 5
Dynamics of Wheat and Barley Shipments on Haul Roads to and from Grain Warehouses in Washington State
by Michael L. Clark, Eric L. Jessup & Ken L. Casavant
Report 6
An Assessment of the Current Situation of the Palouse River and Coulee City Railroad and the Future Role of the Port of Whitman County
by Ken L. Casavant, Eric L. Jessup, & Joe Poire
Report 7
New Techniques for Estimating Impacts of Rail Line Abandonment on Highways in Washington
by Denver Tolliver, Eric L. Jessup & Ken L. Casavant
Report 8
Implications of Rail-Line Abandonment on Shipper Costs in Eastern Washington
by Denver Tolliver, Eric L. Jessup & Ken L. Casavant
Report 9
Rail Line Investment Alternatives Resulting from Abandonment: A Case Study of Moses Lake, Washington
by Eric L. Jessup & Ken L. Casavant
Report 10
Freight Movements on Washington State Highways: Results of the 2003-2004 Origin and Destination Study
by Steve Peterson, Eric L. Jessup & Ken L. Casavant

Report 11
Transportation Characteristics and Needs of the Washington Hay Industry: Producers and Processors
by Stephanie Meenach, Eric L. Jessup & Ken L. Casavant

Report 12
Transportation and Marketing Needs for the Washington State Livestock Industry
by Stephanie Meenach, Eric L. Jessup & Ken L. Casavant

Report 13
Washington Warehouse/Distribution Center Industry: Operations & Transportation Usage
by Quinton D. Pike, Eric L. Jessup & Ken L. Casavant

Report 14
Waterborne Commerce on the Columbia/Snake Waterway: Commodity Movements Up/Down River 1995-2003
by Shushanik Makaryan, Marie Drews, Eric L. Jessup & Ken L. Casavant

Report 15
Profile of Washington Rail Shipments: Commodity Origin-Destination Analysis 1985-2002
by Jessica Stenger, Marie Drews, Eric L. Jessup & Ken L. Casavant

Report 16
Washington State Grain Cooperatives: History, Functions, and Regulations
by Jason W. Monson, Eric L. Jessup & Ken Casavant

Report 17
Evaluation and Estimation of Port Security Measures and Impacts Due to Catastrophic Events
by Grant Monson, Eric Jessup, & Ken Casavant

Report 18
2003 Eastern Washington Transportation Input-Output Study
by Robert Chase, Eric Jessup, & Ken Casavant

Report 19
2003 Washington Statewide Transportation Input-Output Study
by Robert Chase, Eric Jessup, & Ken Casavant

Report 20
Freight Movements on Washington State Highways: Comparison of Results of 1993 to 2003
by Steven Peterson & Eric Jessup

Report 21
2005 Transportation of Mining/Mineral Survey Summary Report
by Hayk Khachatryan, Eric Jessup, and Ken Casavant

Report 22
Projections of Washington-British Columbia Trade and Traffic, by Commodity, Route and Border Crossings
by Hamilton Galloway, Ken Casavant, & Eric Jessup

Report 23
All Weather Road Projects for the State of Washington: A GIS Application/Analysis
by Eric Jessup, Kelley Cullen, Jerry Lenzi, Ken Casavant
Report 24
A Framework for Modeling Rail Transport Vulnerability
by Steven K. Peterson and Richard L. Church
Report 25
Review of Transportation Costs for Alternative Fuels
by Mark Holmgren, Ken Casavant, and Eric Jessup

Table of Contents

List of Tables

List of Figures

Abstract

The increase in oil prices has caused a concern on the dependence for fossil fuels. Different alternative fuels are being analyzed to determine whether they are feasible. Many avenues need to be searched for each alternative fuel before deciding whether the benefits outweigh the costs. One such problem that needs to be addressed is whether the transportation sector can handle such a change. A synopsis of the transportation costs are examined in this report for different types of commodities which can be used for alternative fuels.

Introduction

The number of uncertainties has been growing regarding how to satisfy ever-growing demands for energy in the US. Historically, fossil fuels have provided the cheapest method in powering automobiles, but with declining known fuel sources, increasing prices and the evolving technology for alternative sources, other options may be more optimal. Several earlier studies have investigated different aspects of the feasibility of alternative fuels, to help determine whether this course of action is a worthwhile endeavor or not. There are many factors to consider when determining whether this path is realistic, primarily the transportation logistic and supply chain effects of these alternatives.

A collection of concerns arise when thinking about the use of alternative fuels. The use of alternative fuels may have a negative impact on the environment. Ecosystems may be destroyed in fragile areas where it would be more profitable to grow crops suitable for biofuels. Many goods that are used for alternative fuels are goods that individuals consume, which may lead to competition between fuel and food.

Since the price of traditional fossil fuels is increasing, the biggest concern is whether alternative fuels will be affordable and accessible while also less environmentally polluting. If the US were to transition to using alternative fuels there is a large setup cost as investment in fuel processing plants and infrastructures will have to be built. An increase in the demand for ethanol will result in price increases for inputs that are used to grow the intermediate goods. This will cause the price of the intermediate goods that will be used for ethanol fuel to also rise. Additionally, there will be an increase in the demand for vehicles to transport the biofuels, and at a reasonable

price. The purpose of this paper is to address issues relating to the transportation.

Logistics and supply chain efficiencies of moving biofuel feedstock and finished

products. This will also include evaluation of previous studies estimating transportation

costs.

One of the most important aspects of the emerging biofuel industry is the

relationship between production, processing, and distribution and the critical role that

transportation plays in providing access to different markets. Without transportation,

producers and consumers cannot exist. Moreover, if transportation is available and the

delivered cost of shipping is too high then alternative fuels consumption is impeded in the

market. The transportation cost has a significant influence on price of biofuels when all

costs are combined.

Background

The different alternatives for fossil fuel are ever increasing. Environmental

concerns with using fossil fuels have created an additional incentive for other options and

alternatives. An increase in traditional fuel prices has simulated further research on this

matter. As mentioned before, it is requisite that transportation be considered for this

issue. The transportation of these alternatives is examined for ethanol, biodiesel, and

hydrogen.

The shipment of the intermediate good to the ethanol plant, and hauling from the

ethanol plant to the distributor will be discussed. Ethanol can be created from several

goods, but this paper will examine transporting corn stover, switchgrass, straw, wood

chips, manure, energy cane (sugarcane), sorghum, and poplar trees. The goods that were

mentioned that can be used for ethanol have different physical properties and therefore require different transportation equipment and vehicles for shipment. Some goods are heavier than others, thus this implies that each of these goods are going to have different transportation costs on various modes. Not all of the papers introduced make this distinction, but it is important to find the methods they used to calculate the transportation costs. Three main modes of transport in which these goods can be shipped are truck, rail, ship, or pipeline. Some of the papers will cover each of these modes, but some of them will focus on the differences in cost between these different moves and vehicles.

This paper will first look at the costs of transporting goods to the ethanol plant by looking at corn stover, switchgrass, straw, woodchips, and manure in that order. An article will be introduced that analyzes the shipment of sorghum, switch grass, hybrid poplar, and energy cane that exist in the same model. Once the ethanol has been produced the transportation aspects of moving ethanol from the processing plant to the consumer will be analyzed. Next, the markets for canola oil and soybean are analyzed for the transportation costs for biodiesel. The methods of transporting hydrogen and the optimal methods will be shown. The paper will then conclude.

Corn Stover

Corn stover is everything that is left over in the field when the corn has been harvested. The models described here are studies that were performed in the Midwest since they have a comparative advantage in growing corn. The first study that will be analyzed is a rail linked plant site in Illinois that was modeled for the transportation costs

for corn stover (Atchison & Hettenhaus, 2003). The plant site is located near El Paso, IL between two collection sites one hundred miles apart, one in Chatsworth which is to the East, and the other is Farmington to the West where both sites are connected to the plant via rail. It is assumed for each collection location there is a 15 mile collection radius, and the stover is collected from 40% of the land. Here are the estimates and results of the model.

Table 1: Estimated Rail Transport Cost for 30 MPH Farm Rail Line

	Units	Annual $(000)	
Rail Track, miles		100 mi	200 mi
Cars	200	$600	$600
Engines	2	$180	$180
Fuel	110 gal/hr	$590	$1,780
Crew	4	$960	$2,880
Track Lease	$100/mile/month	$120	$240
Annual Cost		$2,460	$5,680
Cargo	dt annually, 000	700	2,000
$/dt		$3.50	$2.80
Car utilization	8,000 hrs/yr	25%	90%

The third column represents the original model, and the forth represents if the equipment is used to the limit which requires two more collection sites, two additional crews, and doubling the leased track. Converting $/dt gives $0.02($0.021)/dry tonne/km for the 100 mile case, and $0.02($0.017)/dry tonne/km for the 200 mile case. This shows as the number of collection sites increase around a processing plant the transportation cost per dry tonne per km decreases but the change is negligible.

There are four primary collection options when harvesting corn stover, which include large round bales, large rectangular bales, silage collection, and unprocessed pickup. Once the stover has been collected it is hauled to the storage unit. From the

12

storage unit the stover is hauled to a conversion facility where the ethanol is produced.

Perlack & Turhollow (2002) analyze the collection, handling, and transport for each

method. Large round bales and large rectangular bales can either be baled then placed on

the edge of the road by tractors for trucks with flatbed trailers to pick up or they can be

baled then hauled by high speed tractors (e.g., JCB 1385) and bale wagons to the storage

facility. The silage collection systems chop the stover into short billets that can be

thrown onto wagons. Once the wagons are loaded, there are two options to get the stover

to the storage facility. The wagon can be pulled to the edge of the field, where they are

dumped into silage trailers and hauled to storage. The other option is to pull the loaded

wagon to storage using a high speed tractor. The unprocessed pickup method is the same

as the silage collection, but has a lower packing density.

The transportation cost functions depends on a number of assumptions which are

found in Appendix A. The farmer needs to be compensated for hauling the crop because

the corn stover adds nutrients for next year's crop. This value is estimated at $10.00 per

dry ton based on a number of papers in the literature. An operation cost has been added

to the model to cover the cost of planning the collection operations, selecting operators,

and coordinating the project which has been estimated to be 5% of the cost of collection,

transporting, and the farmer's compensation. Each transportation cost was calculated for

the four different hauling methods for four different facility sizes (500 dry ton/day, 1,000

dry ton/day, 2,000 dry ton/day, and 4,000 dry ton/day).

Delivering stover from the field to the storage facility showed no dominant

method. For large round bales, using a high speed tractor with a bale wagon is cheaper

than loading the bales on flatbed trailers and hauling them by truck to storage. Large

rectangular bales would be cheaper to haul by loading the bales on a flatbed trailer and pulled by a truck, but except when the facility is small then it would be more optimal to haul with a high speed tractor and bale wagon. The silage harvest and unprocessed pickup is best to use high-speed tractors and wagons for the 500 dry ton/day and 1,000 dry ton/day facilities. For the larger facilities 2,000 dry ton/day and 4,000 dry ton/day, the cheaper method is using a truck and flatbed trailer. For every case, transporting the bales from storage to the facility is cheaper using a flatbed trailer and truck rather than the high speed tractor and wagon.

The transportation costs of the cheapest delivered method for each collection type are shown in the paper. The size of the processing facility affected the distance of delivery from the farm to storage and the distance of hauling from storage to the processing facility. Here are the assumptions for distances.

Table 2: Assumed Distance and Area for Varying Facility Sizes

Facility Size (dry tons/day)	Stover Collection Area (km^2)	Avg. One-way Haul Dist. (km)
500	4,610	35
1,000	9,220	50
2,000	18,441	71
4,000	36,907	100

The paper measured the results in $/dry ton, but for consistency in this report the results shown here have been converted to $/dry tonne/km.

Table 3: Costs for Different Types of Bale Systems

Bale System	Facility Size			
	500	1,000	2,000	4,000
Large Round Bales				
Delivered Cost in Storage	$0.69	$0.49	$0.35	$0.25
Transport Cost	$0.20	$0.15	$0.12	$0.10
Farmer Payments	$0.10	$0.10	$0.10	$0.10
Operation Expenses (5%)	$0.05	$0.04	$0.03	$0.01
Total delivered at conversion facility	$1.04	$0.78	$0.60	$0.46
Large Rectangular Bales				
Delivered Cost in Storage	$0.70	$0.50	$0.36	$0.23
Transport Cost	$0.20	$0.16	$0.13	$0.10
Farmer Payments	$0.10	$0.10	$0.10	$0.10
Operation Expenses (5%)	$0.05	$0.04	$0.03	$0.02
Total delivered at conversion facility	$1.05	$0.80	$0.62	$0.45
Unprocessed Pickup				
Delivered Cost in Storage	$0.58	$0.48	$0.36	$0.27
Transport Cost	$0.12	$0.10	$0.08	$0.07
Farmer Payments	$0.10	$0.10	$0.10	$0.10
Operation Expenses (5%)	$0.04	$0.03	$0.03	$0.02
Total delivered at conversion facility	$0.84	$0.71	$0.57	$0.46
Silage Collection				
Delivered Cost in Storage	$0.46	$0.36	$0.28	$0.22
Transport Cost	$0.12	$0.10	$0.08	$0.07
Farmer Payments	$0.10	$0.10	$0.10	$0.10
Operation Expenses (5%)	$0.03	$0.03	$0.02	$0.02
Total delivered at conversion facility	$0.71	$0.59	$0.48	$0.41

Unprocessed pickup and silage collection are both non-conventional systems. The results show that additional research needs to be done on wagon design and compaction may be warranted.

When goods are transported an important insight is to look at the fixed and variable costs of shipping goods. Kumar et al. (2005) show the fixed and variable costs of transporting different commodities in Year 2000 USD[1]. Using the paper, Perlack & Turhollow which was just analyzed, Kumar et al. (2005) are able to determine the components of the fixed costs for round bales and rectangular bales and find they are $7.05 and $6.97 per dry tonne, respectively. The variable costs are computed from the

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[1] All papers are converted into 2007 USD.

transport function for round bales and rectangular bales and discover they are $0.06 and $0.07 per dry tonne per km, respectively. The point at which these two cost curves cross is 14.5 dry tonnes, which is likely that the farm will produce at least this amount.

Kumar et al. (2005) also find from the Jose & Brown (2001) study that is based on a series of assumptions find the variable cost. They first assume that stalks are harvested from a 130 acre irrigated field that yields 150 bushels per acre. The weight of the stalk is based on collection. If the stalks are shredded and raked the weight is 3.5 tons per acre. Stalks that are raked weigh 2.75 tons per acre, and the stalks baled directly after combining weigh 2.0 tons per acre. Each bale weighs 1,100 lbs. Thirty bales are loaded on a truck. It is assumed that the transportation cost is $2.50 per mile per load for a minimum of ten miles, or $2.50/16.5 = $0.152 per ton per mile. Converting the value into kilometers and 2007 USD gives $0.12 per dry tonne per km. This meager report repeatedly shows up in the literature.

Another study by Glassner et al. (1998) analyzed a corn stover collection operation in Harlan, IA. In the 97 and 98 crop years, a custom-harvesting contractor made contracts with 440 different farmers to bring haul their stover to a collection facility in Harlan. The contractor received the costs for baling, baling collection, and delivery to the processor from each of the farmers. From this study Kumar et al. (2005) find the fixed and variable costs to be $8.07 per dry tonne and $0.14 per dry tonne per km, respectively.

Switchgrass

Various methods are used in determining the transport costs of shipping
switchgrass. One of the most basic models is one in which Cundiff & Harris used in
1995. They visualized a hauling contractor with a loader and three trucks. The loading
cost is $3.58/dry tonne assuming $47.19/hr to loader and one hour to load a truck which
holds 13.2 dry tonnes. Based on a 64.37 kilometer round trip, each 12.2 metre flatbed
truck averages 2 loads a day; the truck cost will be $169.90/load, or $0.02/dry tonne/km.
The total transport cost function becomes $3.58 + $0.02*d where d represents the
distance.

The more common method for finding the transportation costs for shipping
switchgrass is to look at the fixed and variable costs. Kumar et al. (2005) find the
distance variable cost for shipping switchgrass is $0.24/dry tonne/km, and the fixed cost
is $3.95/dry tonne. These figures are based on the paper by Marrison & Larson (1995),
which assume a one way trip. The variable costs were found by an earlier paper
(Johnson, 1989), which performs an intensive review of equipment costs for wood
residue recovery and collection.

Time is an important variable to look at when determining transportation costs.
Zhan et al. (2005) incorporate time into their estimated transportation cost function for
switchgrass which is

$$c_{ij} = K_1 * DIST(i, j) + K_2 * TIME(i, j) + K_3 \qquad (1)$$

where c is the transportation cost, DIST(i,j) is the distance from cell i to j, and TIME(i,j)
is the amount of time it takes to ship from cell i to j. K1 is a distance-dependent cost
parameter that reflects distance-related costs (measured in dollars per kilometer per dry

tonne) including fuel, repairs, tires, trailer costs, maintenance, and lubrication. K2 is a time-dependent parameter that measures time-dependent costs (measured in dollars per hour per dry tonne) related to labor as well as truck and trailer time costs, which includes depreciation, insurance, interest, and fees. K3 is related to regional labor costs (measured in dollars per dry tonne) and is the per unit terminal costs such as costs associated with loading/unloading and transaction costs.

The data that is used comes from Graham et al. (2000). They use a model (RIBATRANS.xls) which contains the size of the truck, characteristics of biomass (bale size), hourly labor rates, and assumptions about the number of trailers and forklifts needed per-truck. Using this information they calculate the fixed cost, the per-hour cost, and the per-kilometer cost of transporting a tonne of biomass. Estimates of K1, K2, and K3 are then determined which are found to be $3.48 per km per tonne, $0.06 per hour per tonne, and $4.38 per tonne, respectively.

These results show the weights for distance, time, and the regional labor costs. The first term (K1) of equation (1) is the distance-dependent cost parameter, which is $3.48, and is multiplied by the distance. This implies that for every kilometer traveled it will cost approximately $3.48 per tonne for fuel, repairs, tires, trailer costs, maintenance, and lubrication. The second term (K2) is the time-dependent parameter, which is $0.06, and this is multiplied by the time it takes to travel. In other words, for every hour traveled it will cost around $0.06 per hour per tonne for the driver, depreciation of the truck, insurance, interest, and fees. The third term is the cost for loading/unloading, and transaction cost which was $4.38 per tonne. Adding these three components, assuming distance and time are known, gives the value for the total transportation cost.

Another important aspect of transporting biofuels is to include specific values for fixed and variable costs and then look at the marginal effects of changing those values. Tiffany et al. (2006) incorporates repairs, cleaning, transport, and tires into the variable costs, and depreciation and licenses into the fixed costs. These assumptions, which can be found in Appendix B, are applied to Conservation Reserve Program lands that are in North Dakota. Varying the radius of the switchgrass field, the model finds the average cost of transporting the switchgrass to the center. Here are the results of the model.

Table 4: Costs of Transporting Switchgrass when Distance Changes

Radius (km)	Number of trips	Number of bales	Tonnes of Switchgrass	Total kilometers traveled	Total Travel Expenses	Average cost per tonne	Marginal cost per tonne	Expense per tonne km
16.09	1,589	57,195	29,057	88,680	115,751	3.28	3.99	0.07
24.14	2,819	101,492	51,561	222,703	268,926	4.18	5.22	0.05
32.19	4,368	157,246	79,886	470,949	539,071	5.08	6.75	0.04
40.23	5,808	209,093	106,226	765,905	852,609	5.90	8.02	0.04
48.28	8,125	292,499	148,598	1,347,483	1,461,108	6.89	9.83	0.04
56.33	10,756	387,201	196,711	2,136,773	2,277,386	7.86	11.57	0.04
64.37	14,216	511,786	260,004	3,326,735	3,498,642	8.97	13.45	0.04
72.42	18,257	657,243	333,900	4,888,321	5,091,984	10.07	15.25	0.04
80.47	24,097	867,488	440,712	7,411,119	7,653,302	11.35	17.37	0.04

Once this is found the marginal effects of wages paid to drivers, waiting time to pickup, diesel price, driving speed, bale weight, number of acres, yield, and crow mile to road mile multiplier are shown. There are no real marginal effects to average cost per ton when diesel fuel price is varied, all other marginal effects change the average cost per ton significantly.

One model uses aggregated data to find the transportation costs. It is assumed that shippers charge transporting goods by weight and not by commodity type. From the

Commodity Flow Survey, Murrow et al. (2006) used the "Shipments by Destination and Mode of Transportation" table for each state-to-state transport, the metric ton-km shipped between individual states which were divided by the total metric ton-km shipped nationwide. This gives a matrix of ratios that captures each state-to-state transportation flow's fraction of the national total of transportation. The ratio is then used to divide the national aggregate dollars spent on rail and truck transport into cost estimates for each respective state-to-state transport. Each state-to-state cost was divided by the metric tons shipped between states which produced a matrix of costs per metric ton shipped. Using the distances between state center points, a linear regression was used to produce an equation for cost per metric ton as a function of distance where the slope equals the average cost per metric ton-km. The results of this model show that freight rates for truck was $0.15 per tonne-km, and the freight rates for rail was $0.05 per tonne-km. These results are consistent with the truck freight estimates in *Transportation in America* which is published by the Eno Transportation Foundation, and the rail freights estimates at Association of American Railroads (AAR).

Different methods are used when collecting switchgrass, and there are diverse ways to transport switchgrass. Kumar & Sokhansanj (2007) examine five different collection options that are square bale, round bale, loaf, dry chop, and wet chop. The collected switchgrass are stored on the side of the road until they are shipped by bale transport, grind transport, or chop transport to the biorefinery.

The harvest schedule for switchgrass in Nebraska and Iowa was decided to be one cut per year. The commercial yield was assumed to be 11 dry tonnes/ha. The weather was incorporated to determine the moisture content. Once the switchgrass is grown then

it is collected either by square bales, round bales, loafs, dry chops, or wet chops. For

square bales, switchgrass is mowed, raked, baled into squares and moved to the side of

the road. The method for the round bale is similar but they are round. Loafing is picked

up by a loafer and is made into large stacks. For dry chop, a forage harvester picks up the

dry biomass, chops it into small pieces, and is blown into a forage wagon. Once the

forage wagon is full, it is hauled to the side of the road and is unloaded. Wet chop has

the same process but is hauled to a silage pit where the biomass is compacted to produce

silage. No storage costs exist since the collected biomass is transported to the side of the

road.

The specifications of the equipment used for collection were found from the

American Society of Agricultural Engineers (ASAE). The collection costs are listed

here.

Table 5: Switchgrass Collection Costs for Different Scenarios

Scenarios	Collection Cost ($/dry tonne)	Scenarios	Collection Cost ($/dry tonne)
Square Bales		**Loafing**	
Swathing	$3.18	Swathing	$3.18
Raking	$1.53	Raking	$1.51
Baling (square)	$6.18	Loafing	$8.91
Roadsiding & Stacking	$10.16	*Total*	$13.67
Tarping	$2.99	**Chopping – Piling**	
Total	$24.10	Swathing	$3.18
Round Bales		Raking	$1.51
Swathing	$3.18	Harvesting	$7.92
Raking	$1.51	Piling	$2.28
Baling (round)	$7.05	*Total*	$14.81
Roadsiding	$5.40	**Chopping – Ensiling**	
Stacking	$1.19	Harvesting	$8.20
Tarping	$4.23	Ensiling	$14.72
Total	$22.62	*Total*	$22.63

Square baling cost has the highest collection cost at $24.10/dry tonne. The lowest collection cost is loafing which is $13.67. The loafer is the cheapest since the number of operations is lower.

It is assumed that the biorefinery where the switchgrass will be hauled to have a capacity of 1814 dry tonnes per day, and the maximum distance to the biorefinery is 77 km and the minimum distance is 3 km. Bale transport for square and round bales are loaded onto trucks to the biorefinery. Grind transport for bales and loafs are shredded and loaded onto trucks to the biorefinery. Chop transport for dry chop and wet silage are loaded onto the truck and hauled to the biorefinery. Each of the transport methods were estimated using data from the ASAE. The transportation costs for the three different shipping methods are shown.

Table 6: Switchgrass Transportation Costs for Different Scenarios

Scenarios	Transportation Cost ($/dry tonne)
Scenario T1 – Load Bale – truck	
Loading	$1.61
Trucking	$8.60
Unloading	$1.46
Stacking	$0.67
Grinding	$8.66
Total	$21.19
Scenario T2 – Bale or loaf is ground – truck	
Grinding	$8.66
Trucking	$13.59
Unloading	$0.62
Total	$23.19
Scenario T3 – Ground biomass – truck	
Loading	$3.62
Trucking	$20.50
Unloading	$0.93
Total	$25.32

Grinding is a major cost for scenarios T1 and T2. Scenario T1 is the cheapest, and scenario T3 is the most expensive.

The total cost of transportation is calculated by estimating the loading, traveling, and unloading time by each truck for each day. The transportation cost will be the average cost over one year. These are the results that were found.

Table 7: Switchgrass Fixed & Variable Costs for Different Scenarios

Scenario	Fixed Costs ($/dry tonne)	Variable Costs ($/dry tonne/km)
T1	$12.38	$0.1111
T2	$9.84	$0.1733
T3	$5.66	$0.2580

The fixed costs vary from the different unit operations. T1 fixed costs include loading, unloading, stacking, and grinding costs. T2 fixed costs are unloading and grinding costs. T3 fixed costs are only loading and unloading. The variable cost varies across scenarios since each one has a different density.

Combining the collection costs and transportation costs gives the total delivery costs. There are seven cases for the total delivered costs and are summarized here.

Table 8: Descriptions of Various Methods for Collecting Switchgrass

| Cases	Description
Case 1 (C1, T1)	Switchgrass collected as square bales, loaded on to the truck, transported to the biorefinery by truck and ground at the biorefinery
Case 2 (C1, T2)	Switchgrass collected as square bales, ground in the field using a mobile grinder and transported to the biorefinery by truck
Case 3 (C2, T1)	Switchgrass collected as round bales, loaded on to the truck, transported to the biorefinery by truck and ground at the biorefinery
Case 4 (C2, T2)	Switchgrass collected as round bales, ground in the field using a mobile grinder and transported to the biorefinery by truck
Case 5 (C3, T2)	Switchgrass collected as loafs, ground in the field using a mobile grinder and transported to the biorefinery by truck
Case 6 (C4, T3)	Switchgrass chopped and piled, and is transported to the biorefinery by truck
Case 7 (C5, T3)	Switchgrass chopped and ensiled, and is transported to the biorefinery by truck

The total delivered cost is then shown.

Table 9: Switchgrass Fixed & Variable Costs for Different Cases

Cases	Fixed Costs ($/dry tonne)	Variable Costs ($/dry tonne/km)
Case 1	$36.48	$0.1111
Case 2	$33.94	$0.1733
Case 3	$40.00	$0.1111
Case 4	$37.46	$0.1733
Case 5	$23.51	$0.1733
Case 6	$20.47	$0.258
Case 7	$28.29	$0.258

The results are shown graphically.

Figure 1: Switchgrass Delivered Costs for Different Cases
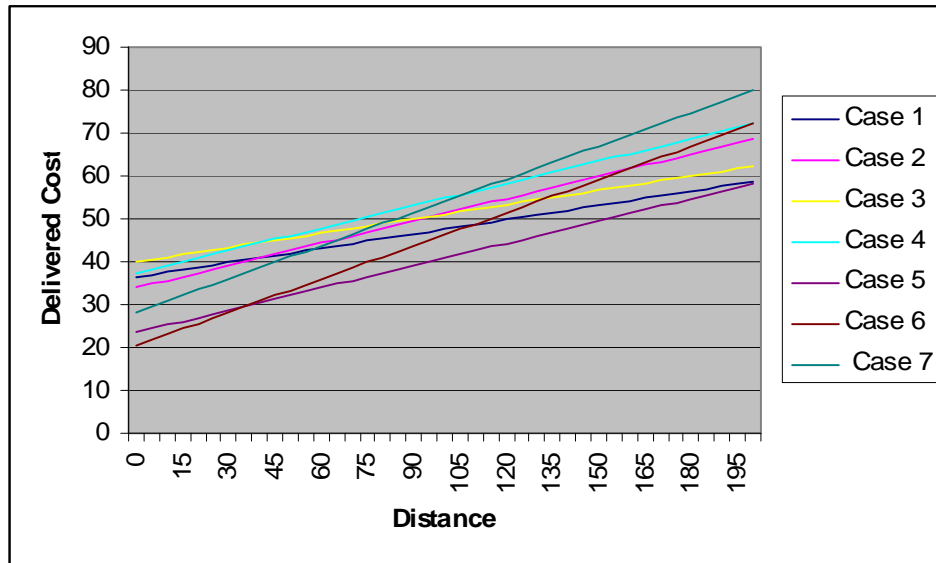
Based on the graph no dominant case exists. Depending on the distance the switchgrass needs to be hauled will determine which case is the cheapest to ship.

Straw

Straw is another source for ethanol. Jenkins et al. (2000) discuss how straw in California is disposed by open burning. This causes serious health effects among residents living in the area. A solution to the problem is to haul the straw to an ethanol plant which would create a solution to the problem. To determine whether this is a solution in California, eighty-four farmers were surveyed, and twenty-nine operations were observed. The farmers gave information regarding the capacities and costs for raking, swathing, bailing, roadsiding, and transportation for three different interval distances. Operations gave moisture, average speed, and capacity for raking, swathing, baling, and roadsiding. From the operations they were also able to find the averages for load/unload time, travel distance, travel time, travel speed, and capacities. Each of the

operations were analyzed assuming costs for labor, fuel, repair and maintenance, depreciation, interest on capital, and taxes and insurance. Harvesting costs are then found from the operations for raking, swathing, baling, and roadsiding. The costs for raking, swathing, roadsiding, and loading and unloading from the farm surveys are similar to the operations estimates. The baling costs and transportation costs are higher for the operations estimates because of the equipment that was being used. Kumar et al. (2005) do not report whether their results are from the farmer surveys or the operations estimates, but find that the distance variable cost is $0.16/dry tonne/km, and the fixed cost is $5.29/dry tonne.

Wood Chips

Wood chips are being investigated to be transported via pipeline. The wood chips would be transported through the pipeline in a slurry form. At this time shipping wood chips via pipeline could only work for current pipeline since the cost of constructing one mile of pipeline is roughly $1 million (GAO). Kumar et al. (2004) compare the cost of transporting wood chips by truck and pipeline. The transportation costs by truck are in terms of fixed and variable costs. Two estimates of truck transport are discussed, a lower bound and a higher bound. The lower bound cost comes from a study that was done by the Forest Engineering Research Institute of Canada (FERIC) which finds that

$$\text{Trans. Cost} = 0.13*d + 5.94$$

where d is the distance. The upper bound truck transport cost was found using current short-term contract hauling rates. The result is

$$\text{Trans. Cost} = 0.18*d + 4.55$$

26

The transportation costs shipping via pipeline were found for both one-way and two-way, where the two-way is shipping the slurry to the processing facility and then only the carrier fluid is shipped back. The results are based on a study done in 1967 and personal communication with a Canadian engineering contractor. The following information was found.

Table 10: Costs & Distances for Shipping Wood Chips via Pipeline

Cases	Cost ($/dry t)	Distance between slurry pumping stations
Two-way pipeline transport cost of water wood chip slurry		
2 million dry t/yr capacity	0.1023*d + 1.47	51
1 million dry t/yr capacity	0.1355*d + 2.65	44
0.5 million dry t/yr capacity	0.1858*d + 4.80	36
0.25 million dry t/yr capacity	0.2571*d + 9.05	29
One-way pipeline transport cost of water wood chip slurry		
2 million dry t/yr capacity	0.0630*d + 1.50	51
1 million dry t/yr capacity	0.0819*d + 2.63	44
0.5 million dry t/yr capacity	0.1088*d + 4.80	36
0.25 million dry t/yr capacity	0.1473*d + 9.07	29

The results show that for a carrier fluid return pipeline (two-way), and without a carrier fluid return pipeline (one-way) the 2 million dry t/yr capacity is the cheapest. Truck transport is cheaper than 0.25 million dry t/yr capacity for both scenarios. This implies that if the capacity of the pipeline is too low, shipping the wood chips via truck is more optimal.

Manure

Manure is unlike the other goods mentioned earlier since it can be used in other markets and increases the productivity of growing any of the aforementioned goods. If it

is not used as a fertilizer it still needs to be moved where profits can be made. Fleming et al. (1998) analyzes the cost-benefit analysis of shipping manure. The total cost of delivering manure is DC and is denoted by

$$DC = BC + AMC = r_B QH + r_A QH * Mileage = QH(r_B + r_A Mileage) \quad (2)$$

where BC is the base charge, AMC is the additional mileage charge, r_B is unit cost of hauling manure, Q is the quantity of manure hauled per finished hog, H is the number of hogs finished, r_A is the unit mileage charge, and Mileage is the total number of miles that quantity of manure is hauled. The equation for required acreage (RA) is introduced which is

$$RA = \frac{N_M QH}{N_C} \quad (3)$$

Here N_M is the nutrient content of manure, and N_C is the need of a specific crop for that nutrient. Search acreage (SA) is defined as

$$SA = \frac{RA}{\alpha\beta\gamma} = \frac{N_M QH}{\alpha\beta\gamma N_C} \quad (4)$$

Here α is proportion of cropland, β is the proportion of suitable cropland, and γ is the proportion of crop acres where manure is accepted. It is assumed that the maximum one way mileage is two times the square root of SA divided by 640 acres in a square mile. Using this assumption, with eq. (4), equation (2) becomes

$$DC = QH\left[r_B + Zr_A\left(\frac{N_M QH}{640\alpha\beta\gamma N_C}\right)^{\frac{1}{2}}\right] \quad (5)$$

where Z represents trips.

28

The total benefit (TB) from manure is denoted by

$$TB = \left(\sum_{i=n,p,k} P_{M,i} N_{M,i} + A \right) QH \qquad (6)$$

Here $P_{M,i}$ is the commercial price of fertilizer ($/lb) for nitrogen (n), phosphate (p), or

potash (k). $N_{M,i}$ is the quantity of a nutrient in manure. A is the application cost of

commercial fertilizer expressed in $/gal of manure. Differentiating equations (5) and (6)

with respect to H and setting the difference to zero gives

$$\left[\left(\sum_{i=n,p,k} P_{M,i} N_{M,i} \right) + A - r_B - \frac{3Zr_A}{2} \left(\frac{N_{M,T} QH}{640 \alpha \beta \gamma N_{C,T}} \right)^{\frac{1}{2}} \right] Q = 0 \qquad (8)$$

Solving for H, plugging into equations (5) and (6), and then subtract (5) from (6). If this

value is positive then the manure should be shipped, but if it is negative then it would not

be beneficial to ship.

The state of Iowa was used to estimate this model. The values for (8) were found

by a number of studies done by different Iowa State University Extension programs,

personal communications, and data from the USDA. The results showed that slurry

manure should be incorporated rather than wasted. Furthermore, producer profits will be

higher and will improve the air quality.

This model does not directly apply to shipping manure for ethanol, but it does

however show whether it is optimal to ship it or not for fertilizer purposes and determines

the transportation costs. In the ethanol market eq. (6) would have to be changed to

account for the difference. Some recommendations would be to change the commercial

price of fertilizer to the commercial price of ethanol. The quantity of a nutrient in

manure could be the same or could be changed to the yield the ethanol (manure) gives. Further investigation is required to make appropriate changes to the model.

One popular way to model the transportation cost is to gather data on transportation costs by contacting different shipping companies. This data estimates how much it will cost to ship. Whittington et al. (2007) contacted different shipping firms from a set of nine counties in Mississippi and estimated the costs of transporting poultry litter to those respective counties. Based on the data they find the transportation cost function to be

$$C_M = 0.1 + 0.002 * D \qquad (9)$$

C_M is the costs per ton mile of transportation, and D is the distance traveled. 0.1 is the fixed costs associated with shipping poultry litter, and 0.002*D represents the variable costs that are incurred with the shipment.

Manure may be shipped with varying moisture contents. Aillery et al. (2005) and Ribaudo et al. (2003) find the transportation costs for shipping different moisture contents of manure. This was done by using data from the USDA and applying the model used by Fleming et al. (1998) that was documented earlier. Ghafoori et al. (2007) compare the fixed and variable costs from these two studies. The results are shown here.

Table 11: Variable & Fixed Costs for Hauling Manure

Manure	Moisture Content (%)	Variable Cost ($ per tonne per km)	Fixed Cost ($ per tonne)
Lagoon Manure	99	0.22	2.31
Slurry Manure	95	0.22	2.31
Dry Manure	50	0.08	11.57
Solid Manure	n/a	0.09	6.94
Liquid Manure	n/a	0.22	2.31

The method to ship the manure will depend on the distance. For transporting short distances the moister manures should be used. As the distance increases the less moisture manure is cheaper.

Multiple Goods

Bhat et al. (1992), widely cited, use an empirical model that aggregates different goods that can be used for ethanol. The data comes from the US Department of Agriculture's Agricultural Marketing Service (AMS). This study used the truck rate information for four weeks in December 1991 that comprises trucking rates for 176 combinations of routes and crops. The estimated model is

$$TC = 51.42 + 0.94*d + 145.68*MIXVEG + 110.78*GRAPFRT + 532.05*ORANG$$
$$+382.05*TOMAT + 533.05*APPLE + 281.65*POTAT - 45.91*SRWC \qquad (10)$$

where d is in km; MIXVEG, ONION, GRAPFRT, ORANG, TOMAT, APPLE, POTAT, and SWRC are the crop dummy variables for mixed vegetables, onions, grapefruits, oranges, tomatoes, apples, potatoes, and short-rotation woody crop, respectively. Each dummy variable is a value of one if the observation pertains to that crop and zero otherwise. Ignoring all the other dummy variables the transportation costs for herbaceous crops and woody chop are

$$TC = 51.42 + 0.94*d \qquad \text{(herbaceous crops)} \qquad (11)$$

$$TC = 5.51 + 0.94*d \qquad \text{(woody chop)} \qquad (12)$$

From these functions the cost of transporting sorghum, switchgrass, hybrid poplar, and energy cane are found in different parts of the US using mean round-trip distances between farm and processing plants.

In the literature some have compared the transportation costs of various goods used for producing ethanol. Borjesson and Gustavsson (1996) not only compare various goods, but also relate the different methods of shipping in Sweden. The sources are in Swedish and are not currently in English, so the methods of how the transportation costs are computed are unknown. The results of the different transportation costs are shown here.
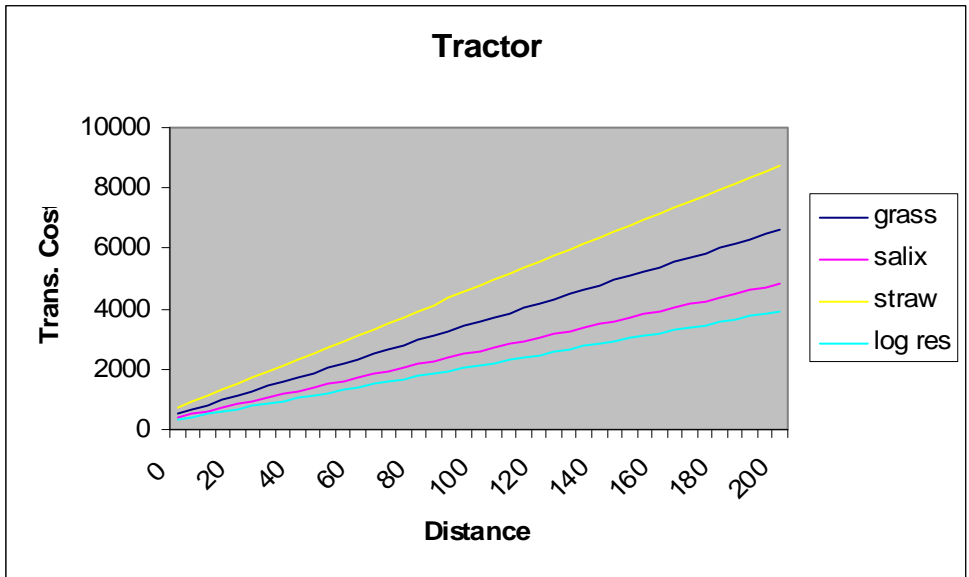
Table 12: Transportation Costs for Hauling Various Fuels

Fuel	Tractor US$/TJ	Truck US$/TJ	Train US$/TJ	Boat US$/TJ
Reed Canary Grass	513.06 + 30.51*d	1,220.24+ 6.52*d	2,634.62 + 1.25*d	1,941.30 + 0.43*d
Salix	388.26 + 22.19*d	582.39 + 13.03*d	1,192.51 + 1.94*d	1,386.64 + 0.87*d
Straw	721.05 + 40.21*d	1,663.97 + 8.74*d	3,743.93 + 1.25*d	2,911.94 + 0.54*d
Logging Residues	318.93 + 18.03*d	485.32 + 10.95*d	1026.11 + 1.53*d	1178.64 + 0.62*d
Methanol	-	194.13 + 4.30*d	596.26 + 0.93*d	651.72 + 0.21*d
Petrol	-	97.06 + 2.08*d	277.33 + 0.43*d	332.79 + 0.11*d
Coal	-	180.26 + 4.02*d	360.53 + 0.53*d	471.46 + 0.18*d

In general tractor and truck are better for transporting short distances, and train and boat are better for longer distances. The transportation costs are the lowest for logging residues, followed by salix, reed canary grass, and straw when the transportation distance is less than 100 km. For distances over 200 km, shipping methanol, petrol, and coal are the cheapest.

When using a tractor to transport, logging residues are the cheapest and straw is the most expensive and is independent of distance. The results are shown graphically below.
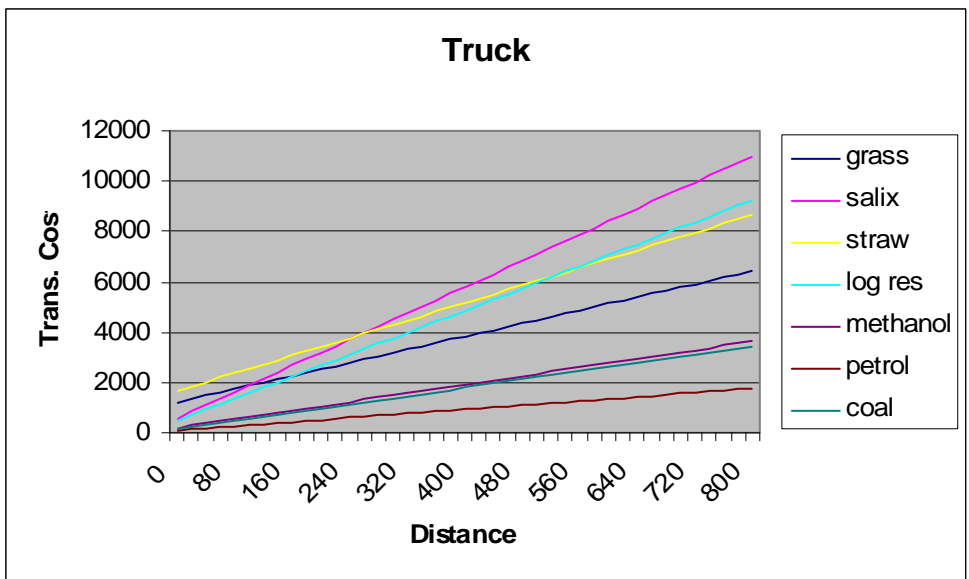
Figure 2: Transportation Costs for Shipping Various Fuels by Tractor

For truck transport, petrol is always the cheapest followed by coal and methanol.

The transportation cost for the four other goods depends on distance.

Figure 3: Transportation Costs for Shipping Various Fuels by Truck

From the graph when transporting by truck, for shorter distances logging residues are the cheapest to ship and then salix. After 180 km grass becomes the cheapest to ship, and after 540 km straw becomes the second cheapest to ship.

In the train transport industry, petrol is the cheapest to ship followed by coal and methanol. For goods that can be transformed into ethanol, logging residues is the cheapest to ship by train unless the distance is more than 5745 km which the cheapest becomes grass. The graph below shows the specifics of the industry.

Figure 4: Transportation Costs for Shipping Various Fuels by Train
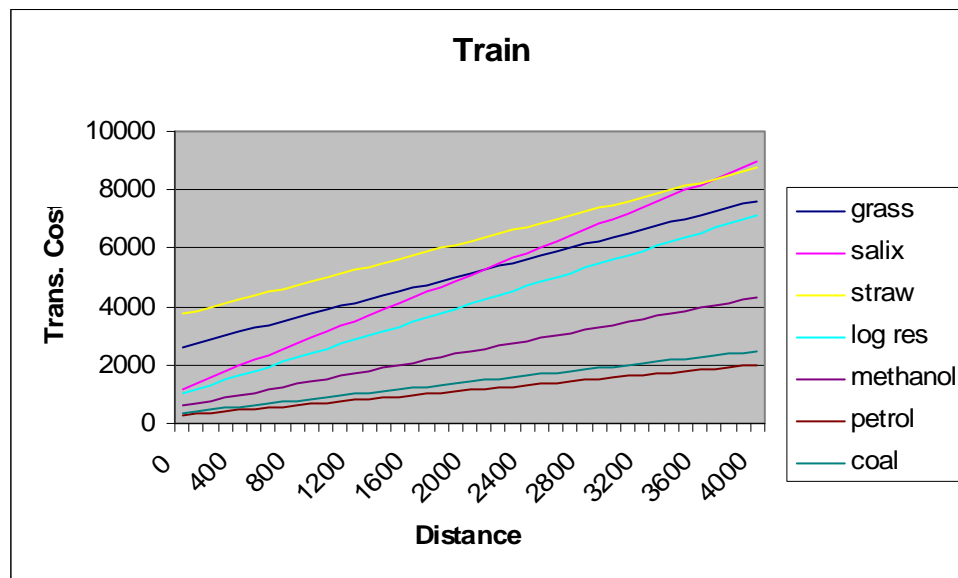
Once again in the boat industry, petrol is the cheapest good to ship. After petrol, coal and methanol are the next cheapest. Logging residues is the next cheapest until it needs to be shipped over 4,014 km, and then grass becomes cheaper. Salix is cheaper to ship for shorter distances until 1,261 km, and then grass is cheaper. The complete results are shown here.

Figure 5: Transportation Costs for Shipping Various Fuels by Boat
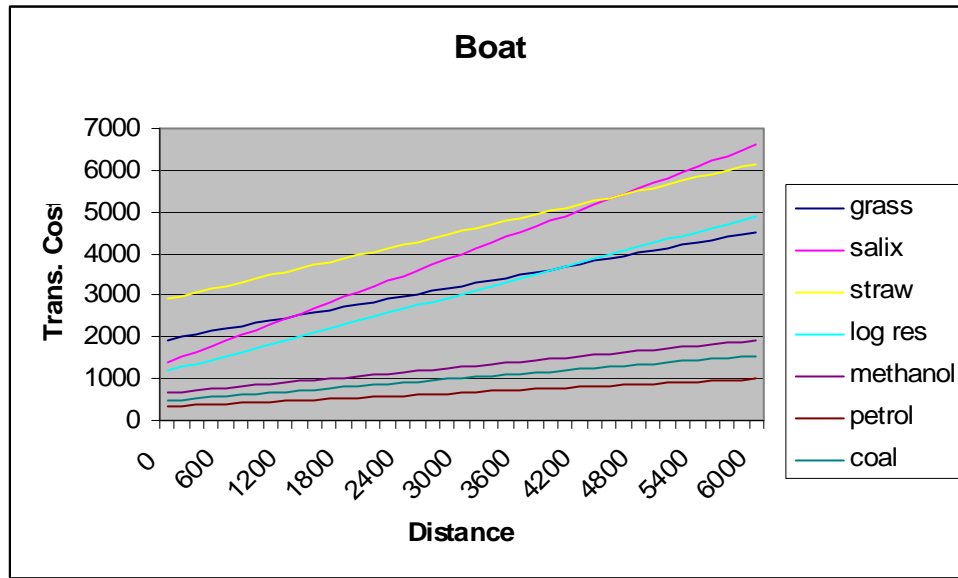
Furthermore, based on discussions between shippers Borjesson and Gustavsson (1996) believe the future transportation cost should decrease. The motor fuel and electricity costs are expected to decrease due to improvements in transportation technology where motor fuel and electricity costs account for 25% of transportation costs. This means according to the researchers that the transportation costs will be reduced between 2-7%. Conversely, when electricity that is used to power trains is produced from biomass instead of fossil fuels the transportation costs increase 3-4%.

Ethanol

Schlatter (2006) finds the transportation costs from Brazil and Chicago to New York City and San Francisco by rail and/or water. The author uses costs and rates interchangeably. To determine the transportation costs from Brazil to New York City

and San Francisco he takes the average CIF (Costs, Insurance, and Freight[2]) price of

Brazilian ethanol at US ports and subtracts the FOB (Free On Board[3]) price of ethanol at

Brazilian ports. The rail costs (rates) from Chicago to New York City and San Francisco

were found from the CSX railway and Burlington Northern Santa Fe railway websites.

The barge costs (rates) were found by Reynolds (2000) which heard them at the

Sacramento DOE Workshop by Dan Penovich who works for GATX. The results of the

transportation costs (rates) are shown below and are in terms of dollars per gallon.

Table 13: Ethanol Transportation Costs (Rates) from Brazil

	New York	California
Brazil	$0.14	$0.14
Chicago by rail	$0.13	$0.17
Chicago by water	$0.12	$0.17-0.18e

where e denotes an estimate

The complexity of the methodology is minimal. The model is introduced to show

a simple procedure for calculating transportation costs (rates).

Robert Reynolds, president of Downstream Alternatives, Inc. has written a few

papers on transporting ethanol to the consumer. In his earlier work in order to get the

transportation costs he would contact ethanol producers. More recently he used the

information that comes from *Ethanol Monitor* which is a magazine put out by Oil Intel.

Ethanol Monitor has information on prices that relate to ethanol and the cost of

transportation. More specifically rail rates through CSX and BNSF, and truck rates

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[2] Costs, Insurance, and Freight implies that the price includes the costs of the good, how much it will be to insure, and the freight costs once the buyer receives the goods shipped. (Source: unstats.un.org)
[3] Free on Board implies that the seller pays for the shipping costs and usually the insurance costs. (Source: www.investorwords.com)

which are from the EIA (Energy Information Administration). Hence, this magazine

offers a rich source of data for the researcher.

Furthermore, Reynolds (2002) has looked at the transportation costs of ship/barge,

rail, and truck for shipments within and between PADDs (Petroleum Administration for

Defense Districts[4]). All ethanol plant locations and key ethanol markets in the US were

analyzed to determine the total amount of ethanol production and consumption in each

PADD. More production of ethanol exists in PADD II (Midwest) and shows how much

it will cost to ship to the other PADDs. The model incorporates not only current ethanol

production plants, but the ones that are under construction and that are proposed. Two

case studies were performed where the first one assumes 5.1 billion gallons per year

(Case B1) and the second assumes 10 billion gallons per year (Case C).

The production of ethanol, feedstock type, and how much is imported and

exported by each PADD for Case B1 is shown in the following table.

Table 14: Ethanol Production, Imported, & Exported by PADD

PADD	Grain	Cellulosic	Tot. Produced	Exported	Imported	Used
I		0.2	0.2		1.1	1.3
II	4.0	0.5	4.5	2.3		2.2
III		0.2	0.2		0.5	0.7
IV			0.0		0.1	0.1
V		0.2	0.2		0.6	0.8
Total		1.1	5.1	2.3	2.3	5.1

Listed in the paper are all the current ethanol plants, plants that are under

construction and plants that are being proposed with how much each plant produces. The

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[4] PADD's separate the US into five regions and were created during WWII to facilitate oil allocation.
(Source: www.eia.doe.gov)

population for each PADD was developed to determine the demand for gasoline, and how much was needed in each PADD. The next step taken was to find all the terminals in all of the PADDs that could access ethanol. The total amount of exports and imports of ethanol were determined between the PADDs and by which method (truck, rail, boat, or barge). The transportation costs between PADDs were determined by a composite freight rate for each mode of transportation. The composite freight rate was calculated by how much freight shipped to the other PADD and by which mode. The freight rates for rail, ship, and ocean barge are determined by a specific location in each PADD and the results are shown below.

Table 15: Composite Freight Rates Imported from PADD

PADD	Ship	Ocean/barge	Rail
I	$0.11/gal	$0.07/gal	$0.125/gal
III	N/A	$0.03/gal	$0.085/gal
IV	N/A	N/A	$0.045/gal
V	$0.14/gal	N/A	$0.14/gal

The truck freight rates were assumed in each location.

The intra-PADD movements were then determined, and the costs were based off of freight rates within each PADD. The same methods were used to determine the intra-PADD movements. Case C is then calculated the same way which case B1 was which gave the same freight rates for both cases. In order for Case B1 to be plausible, an additional 254 tractor trailers, 2,549 rail cars, and 21 river barges will be needed. For Case C it would need the amount for Case B1 plus 309 tractor trailers, 923 rail cars, and 21 river barges.

Biodiesel

Biodiesel is another option for fuel, but is limited to engines that run on diesel fuel. This limitation reduces the current literature on transporting costs for biodiesel. However, one study examines the transportation of canola oil to a Portland Biodiesel Plant. Using the number of miles from major cities in Oregon to Portland, O'Brien (2006) estimates the transportation costs. Using a range of truck costs in $/hr ($60 to $85 in $5 increments), the cost per truck load is constructed from eight cities in Oregon to Portland for a round trip[5]. The average truck cost per tonne-km for all of the different truck costs and locations gives a value of less than one penny. This value seems low and a possible explanation is that only the price of the truck is included, and would be beneficial to include loading/unloading costs, labor, depreciation, etc.

A one-way cost per load is established from varying cost per mile and the eight cities. The cost per mile ranges from $1.25 to $2.50 ($0.78/km to $1.55/km) in $0.25 increments. It is assumed that 90,000 gallons of canola oil is hauled for each truck which is 313.8048 tonnes (www.gourmetsleuth.com & www.taylormade.com.au/billspages/conversion_table.html). The average for the cost per km-tonne is $0.51. The conclusion from these results show that as the press plant is built closer to the seed source and end user of the canola meal will result in lower transport costs.

The transportation costs for soybeans and its byproducts were investigated for a number of locations in Tennessee. One of the objectives of the study by English et al. (2002) was to determine an optimal location for a biodiesel plant in Tennessee. To examine this endeavor, data was gathered from a study by Chris Dager which gives

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[5] It is assumed that canola oil is delivered with an empty return.

transportation costs for soybeans from various locations to eight different locations in Tennessee. The data also consists of the costs for shipping biodiesel from these eight locations to particular places across the US. Dager contacted truck, rail, and barge shipping companies to determine the linehaul costs, and unloading/loading costs for shipping soybeans and biodiesel to the respective locations.

It is assumed that the loading cost for soybeans is $1.67/tonne irrespective of transportation mode. Furthermore, the unloading cost for soybeans is $0.49/tonne for truck, $1.72/tonne for rail, and $2.46/tonne for barge. This implies based on this model that the fixed costs for shipping soybeans is $2.16/tonne for truck, $3.39/tonne for rail, and $4.13/tonne for barge. The loading cost for biodiesel is assumed to be $1.48/tonne and the unloading cost is $1.57/tonne regardless of transportation mode which implies the fixed cost is $3.05/tonne for all three different modes. Based on the data the average linehaul cost (variable cost) for shipping soybean by truck is $0.05/tonne/km, by rail is $0.02/tonne/km, and by barge is $0.01/tonne/km. For biodiesel the average linehaul cost (variable cost) for shipping is $0.001137/tonne/km by truck, $0.000811/tonne/km by rail, and $0.001568/tonne/km by barge. At first glance it appears that the linehaul costs may be low, and there might be some information that is not accounted for in the data. Additionally, it does not seem reasonable to assume that the loading costs for soybeans and the loading/unloading costs for biodiesel are the same across all different types of modes.

Hydrogen

Currently most of the hydrogen for transportation comes from methane which is a natural gas. Hydrogen is shipped two different ways, either by liquid or compressed gas. Similar to ethanol, hydrogen can be transported by truck, rail, and pipeline. The shipping infrastructure is limited because most hydrogen is absorbed at the production site. At this time there are 16 pilot hydrogen refueling stations in the US, but this number could very well increase in the next few years (Wakeley et al., 2007).

The cheapest and most common method to produce hydrogen is steam methane reforming (SMR) (Wakeley et al., 2007). After the natural gas has been reformed it can be shipped either as a liquid or a gas. Wakeley et al. (2007) examine the production, distribution, and fueling costs for ethanol and hydrogen. The transportation costs for hydrogen delivery were documented from the analysis of Simbeck and Chang (2002). Simbeck and Chang (2002) receive the transportation costs from Amos (1998).

Amos (1998) applies a number of assumptions, which can be found in Appendix C, to determine the transportation costs for shipping hydrogen using truck, rail, water transport, and pipeline. When determining transportation costs for truck haul, the truck may take several trips or it may sit around awhile. From this it may be incorrect to use per truck basis to estimate delivered cost of hydrogen. Amos (1998) accounts for the difference when estimating the transportation costs of transporting hydrogen.

The following steps were taken to compute the transportation costs by truck:

First the production rate is multiplied by the operating days to calculate the annual production rate. This annual production rate is divided by the truck capacity to find the number of trips. (It is possible to have less than one trip per day for small production rates.) The total number of miles traveled is calculated using the two-way drive distance times the number of trips per year. The travel time per trip is calculated by dividing the two-way distance by the average truck speed and rounding up to the next

whole hour. The per trip travel time is multiplied by the total number of trips per year to get the total driving time per year. The total time for loading and unloading is calculated by multiplying the load/unload time by the number of trips per year. Adding the drive time and loading/unloading time gives the total delivery time.

The total delivery time is divided by the truck availability per year to determine the number of trucks needed (One truck may be used for several trips using this method). Dividing the total delivery time by the yearly driver availability determines the number of drivers needed (One driver may make multiple trips, or multiple drivers may be needed for long trips). Fuel use is based on the distance driven divided by the mileage. Fuel cost is then calculated based on usage.

Trip frequency is calculated by dividing the trips per year by the number of operating days. Trip length was based on the total delivery time divided by the number of trips (or drive time per trip plus the delivery time). A utilization rate is calculated by dividing the trip frequency by the number of trucks.

A fixed price was assumed for all trailers. Metal hydride costs were calculated using a metal hydride storage price, but the capacity of the metal hydride truck was kept constant. For liquid hydrogen, boiloff losses were taken into account by assuming some hydrogen was lost during transit. No transfer losses during loading and unloading were included.

The capital costs include the price of the truck cab, undercarriage, and intermodal storage unit. Depreciation is straight-lined separately for the cab and trailer since they have different Internal Revenue Service class lives. The labor costs are based on total driving hours. (Whether the driver wages were paid for time on the road or time driving was unclear. In the case of trips longer than 12 hours, two drivers are needed, but in these calculations, the wages were paid for time driving only.) Total cost consists of capital depreciation, labor, and fuel costs.

Rail was computed in like manner with some changes.

For rail transport, similar procedures were used to calculate the delivery time and number of railcars required, but there are no fuel or labor costs. Instead, a flat rate freight charge is assumed. The transit times were rounded up to the next whole day, and the loading/unloading time was changed to 24 hours, assuming one rail switch per day. The hydrogen producer was assumed to own the rail cars, so no demurrage or rental fees were included.

For the rail case, higher storage capacities were used. For the metal hydride, a higher railroad weight allowance allowed the storage capacity to be raised to 910 kg (2,000 lb). At 3% storage density, this would result in a total hydride alloy weight of 30 tonnes (33 tons). The liquid hydrogen capacity was based on values for a jumbo liquid hydrogen railcar.

Capital costs for the rail case consist of the rail car storage unit and undercarriage. The only operating cost is the railroad freight charge. Hydrogen boil-off is accounted for in the liquid hydrogen case.

Water transport was determined by synonymous methods with a few changes.

The cost calculations for shipping hydrogen by ship or barge are very similar to the calculations for shipping by rail, except the average speed is lower and the load/unload time is extended to 48 hours, assuming a shipping container must be there the day before the ship leaves and can't be picked up until the day after the ship arrives. Again, a flat rate is assumed for calculating shipping charges and the travel time is rounded up to the next whole day.

The storage capacities used for transport by ship are the same as for truck transport, because intermodal transport units are assumed to be used. In this case, no undercarriage charge was used. The costs of getting the intermodal units from the hydrogen plant to the shipyard were not included.

The following methods were used for pipeline delivery cost.

For pipelines, the costs considered included the installed pipeline costs, the compressor cost to overcome the friction losses in the pipe, and the electricity requirements for the compressor.

The pressure loss through the pipe was calculated assuming the roughness of steel pipe and a compressible gas flow equation. The gas being pumped was assumed to be coming out of storage at pressure, and the only compression needed was to provide motive force to overcome friction losses in the pipe. The compressor size and energy requirements were based on the same ratio of logs used to calculate the incremental increase in storage pressures. In most cases the pipeline losses, and therefore compressor size, were small.

Capital costs for the pipeline include all costs associated with purchasing the pipe, installing it and obtaining any required right-of-ways. The total cost for pipeline delivery includes the compressor, pipeline, and electricity costs.

The study examines the hydrogen as compressed gas, liquid form or metal hydrides[6] and is transported by truck, rail, ship, or pipeline. Eight methods of delivery are used which are: compressed gas by truck, compressed gas by rail, liquid hydrogen by truck, liquid hydrogen by rail, liquid hydrogen by ship, metal hydride transport by truck, metal hydride transport by rail, and pipeline delivery. There are five different production rates (5 kg/hr, 45 kg/hr, 454 kg/hr, 4,536 kg/hr, and 45,359 kg/hr) for each method of delivery. Each production rate has seven different one-way delivery distances (16 km, 32

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[6] Hydride is a compound of hydrogen with another, more electropositive element or group. Source: American Heritage Dictionary.

km, 80 km, 161 km, 322 km, 805 km, and 1,609 km). Total costs are computed for each

possible combination of production rates and delivery costs. Kilograms were converted

to metric tons (tonnes). The total costs for each distance was divided by the respective

distance to get the total cost in terms of $/tonne/km. Since the total costs showed no real

change when the delivery distance increases, but except when the hydrogen is delivered

by truck, the average across distances was found for each production rate. This gives one

transportation cost for each transport method in terms of $/tonne/km for each of the five

production rates with the results shown here.

Table 16: Hydrogen Total Transportation Costs ($/tonne/km)

Production Rate (kg/hr)	Compressed Gas Delivery by Truck	Compressed Gas Delivery by Rail	Liquid Hydrogen Delivery by Truck	Liquid Hydrogen Delivery by Rail	Liquid Hydrogen by Ship	Metal Hydride Transport by Truck	Metal Hydride Transport by Rail	Pipeline Delivery of Hydrogen
5	$80.26	$38.46	$40.56	$16.27	$50.50	$315.06	$76.50	$654.25
45	$13.98	$36.59	$4.50	$3.02	$29.92	$13.70	$39.49	$74.29
454	$13.61	$35.92	$0.99	$2.01	$27.58	$7.90	$36.99	$7.45
4,536	$13.48	$35.92	$0.68	$2.01	$27.57	$7.90	$36.99	$0.80
45,359	$13.48	$35.92	$0.67	$2.01	$27.57	$7.90	$36.99	$0.83

For smaller quantities liquid hydrogen is the cheapest as long as it is shipped by

truck or rail. As the amount produced increases, pipeline delivery becomes more

competitive. Generally, rail costs have little change with production and distance. Water

shipment costs are higher, but are consistent as long as the production rates are higher.

Using this information, and combining the environmental cost and safety risk

from their study; Wakeley et al. (2007) find that there exists no dominant choice between

ethanol and hydrogen. The fuel costs are lower for hydrogen, but the capital costs,

environmental costs, and safety risks are lower for ethanol. Prices of the goods that are

used for ethanol as well as natural gas prices may increase which changes the outcome of this model. From this information, the final result is that areas such as Iowa where there is a strong support for ethanol production the market will produce ethanol. As the availability of biomass decreases it is more likely that hydrogen will be used.

Conclusion

The number of goods that can be used for alternative fuels is many. This report has specifically looked at the cost of transporting corn stover, switchgrass, straw, wood chips, manure, salix, and logging residues to be converted into ethanol. Once the ethanol has been created from these goods the transportation costs for distribution has been reported. It has also been shown the transportation costs for canola and soybeans to be turned into biodiesel. The transportation costs for biodiesel and hydrogen has been viewed.

A great variance arises in the transportation costs for each of the goods. The fixed cost for corn stover has varied from $6.97 to $8.07/tonne, and the variable cost is from $0.06 to $0.14/tonne/km. The variance for switchgrass is even greater with the fixed cost ranging from $3.58 to $40.00/tonne and variable cost $0.02 to $0.11/tonne/km. Wood chips vary from $1.47 to $9.07/tonne for fixed costs and $0.06 to 40.25/tonne/km for variable costs. The transportation costs for all types of manure seem to be significantly lower with a range of $0.08 to $0.22/tonne for fixed costs and $0.002 to $11.57/tonne/km. In the biodiesel market, it seems unreasonable that the variable cost is less than one penny to haul by truck, rail, or barge. One study the range of different scenarios to haul hydrogen is wide.

The discrepancy between these reports can very well possibly be based on the assumptions that are made. Some papers make many assumptions about the characteristics of the tractor and truck, while others make a general assumption. Others have analyzed the whole process of harvesting, collecting, and handling, while a number of papers take an easier approach by assuming this process as one cost.

Most of the papers reviewed use costs and rates interchangeably. The authors will contact different shipping companies to ask for their rates and use it as a guide to determine the transportation cost. This method does not account for the costs of shipping the good. The models that find the actual cost of using a truck, rail, or barge are more accurate and reliable.

None of the papers in this report discuss the issues dealing with the transportation costs. When one contacts a freight company to determine their shipping costs, the shipper is not locked into shipping that product. The shipper may haul the good, but no one knows how long and what price it could be. When the number of goods that needs to be shipped expands the price of transporting those goods will also increase. Not only will the price increase, but the amount of traffic on the roads, on the rails, and in the rivers and oceans will be impacted. Each processing plant believes that the freight company will haul their good, but this may not be so if there are other competitors.

The discrepancies in transportation costs for alternative fuels are prevalent. When the analysis is presented it should be done not only with explicit costs, but also implicit costs. The model does not need to stop when the freight rates are found, or when the collection, storing, and delivering costs are found. There are other markets affected besides the farming, processing, and hauling. Trafficking, substituting, and

sustainability are examples of others. Thus, when these and others are included this

creates a true picture of this puzzle.

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Appendix A – Perlack & Turhollow 2002 paper

Financial Assumptions	Value
Interest Rate	6.5%
Farm labor wage rate ($/hr)	$8.50
Farm labor benefits rate	0.1
Truck labor wage rate	$14.40
Truck labor benefits rate	0.2
Fuel ($/gal.)	$1.10
Fuel tax ($/gal.)	$0.35
Oil ($/gal.)	$5.30
Purchase price/list price ratio	0.9
Labor hours/machine hours ratio	1.2

Transport Assumptions	Bale Wagon	Flatbed Trailer
Speed of vehicle from field to storage	30 mph	40 mph
Number of bales loaded on each one	17	28
Loading/unloading time	0.5/min/bale	0.5/min/bale

Appendix B – Tiffany et al. 2006 paper

Transportation Assumptions	
Hourly wage (for one driver and ¼ loader)	$20
Waiting time to load (minutes)	45 min.
Number of additional pickups	0
Time added for an additional pickup	60 min.
Waiting time to unload (minutes)	8 min.
Diesel fuel cost ($/gal)	$1.50/gal.
Gas mileage of trucks (miles per gallon)	8 mpg
Non-fuel expenses for truck ($/mile)	$0.395/mile
Driving speed (miles per hour)	50 mph
Number of bales per truckload	36 bales
Distance conversion (constant for conversion from "crow miles" to road miles)	2.11
Tons per bale (typically .375 - .5)	0.5 tons/bale
Yield per acre (tons of Switchgrass)	4 tons/acre
Acreage multiplier	1

Appendix C – Amos 1998 paper

HYDROGEN TRANSPORTATION ASSUMPTIONS (Amos 1998)

Truck Tube Unit=	$100,000 per module
Truck Tube Capacity=	181 kg/truck 400 lb/truck
Truck Liquid Tank=	$350,000 per module
Truck Liquid Capacity=	4,082 kg/truck 9,000 lb/truck
Truck Hydride Container=	$2,205 per kg hydrogen $1,000 per lb hydrogen
Truck Hydride Capacity=	454 kg/truck 1,000 lb/truck
Truck Undercarriage=	$60,000 per trailer
Truck Cab=	$90,000 per cab
Truck Mileage=	6 mpg
Truck Average Speed=	80 km/hr 50 mph
Truck Load/Unload Time=	2 hr/trip
Truck Availability=	24 hr/day
Hours/Driver=	12 hr/driver
Driver Wage w/ Benefits=	$28.75 per hour
Diesel Price=	$1.00 per gal
Truck Boil-Off Rate=	0.30% /day
Rail Tube Unit=	$200,000 per module
Rail Tube Capacity=	454 kg/railcar 1,000 lb/railcar
Rail Liquid Tank=	$400,000 per tank
Rail Tank Capacity=	9,072 kg/railcar 20,000 lb/railcar
Rail Hydride Container=	$1,000 per lb hydrogen
Rail Hydride Capacity=	907 kg/railcar 2,000 lb/railcar
Rail Undercarriage=	$100,000 per railcar
Rail Average Speed=	40 km/hr 25 mph
Rail Load/Unload Time=	24 hr/trip
Rail Car Availability=	24 hr/day
Rail Freight=	$400 per rail car
Rail Boil-Off Rate=	0.30% per day
Ship Liquid Tank=	$350,000 per container
Ship Liquid Capacity=	4,082 lb/tank 9,000 lb/tank
Ship Average Speed=	16 km/hr 10 mph
Ship Load/Unload Time=	48 hr/trip
Ship Tank Availability=	24 hr/day
Shipping Charge=	$3,000 per container
Ship Boil-Off Rate=	0.30% per day
Pipeline Cost=	$621,504 per km $1,000,000 per mile
Steel Roughness=	4.6E-05 m
Pipe Diameter=	0.25 m
Temperaure=	283 K
Delivery Pressure=	2 MPa
Viscosity=	8.62E-06 kg/m*s
R (hydrogen)=	4124 N*m/kg K
Compressor Capital Cost=	$1,000 per kW
Compressor Size=	4,000 kW
Compressor Pressure=	20 MPa
Comp. Pressure Scale-Up=	0.18
Comp. Cost Scale-Up=	0.80
Compressor Power=	2.2 kWh/kg (20 MPa) 1.00 kWh/lb (20 MPa)
Electric Cost=	$0.05 per kWh
Operating Days/Year=	350 days/year
Trailer/Tank Depreciation=	6 years
Tractor Depreciation=	4 years
Railcar Depreciation=	15 years
Pipeline Depreciation=	22 years