Reducing GHG Emissions and Energy Input in the U.S. Supply Chain of Ethanol and Gasoline

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Abstract

The purpose of this study is to identify potential reductions of energy use and Green House Gases (GHG) emissions in the U.S. downstream (i.e., after production) supply chain of ethanol and gasoline fuels, by determining optimal transportation modes and routes. The analysis considers ethanol producers and fuel *blending* terminals, including consolidation and receiving hubs (Russell et al., 2009). Likewise transportation modes used for shipping ethanol are taken into account - rail, truck - in order to determine optimal delivery. Initial results support the need for construction of a new hub consolidation terminal or the expansion of the existing ones. This preliminary study leaves gasoline fuels, as well as shipments of ethanol via barge or vessel and of gasoline via pipeline, for a future extension.

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Overview

The U.S. has seen its energy use increase in extensive manner in the past decades in all sectors of the economy (Husar and Patterson, 1980; O'Brien and Woolverton, 2009). Moreover, it has long been in the interest of federal programs to strengthen and increase substitution of energy from non-renewable to renewable sources (Steiner, 2003; Babcock et al., 2010; Transportation Research Board of National Academies, 2011), and raise the efficiency of energy use. Likewise, policy makers seek to address the increasing emissions of GHGs in the past two decades, mainly due to CO_2 from fossil fuels which has risen by 21.8% in the U.S. from 1990 to 2007 (Fifth U.S. Climate Action Report, 2010). To address these challenges, on December 19, 2007, the Energy Independence and Security Act of 2007 (H.R. 6) was signed into law. This comprehensive energy legislation amends the Renewable Fuels Standard (RFS) signed into law in 2005, growing the RFS to 36 billion gallons in 2022 (Renewable Fuels Association website).

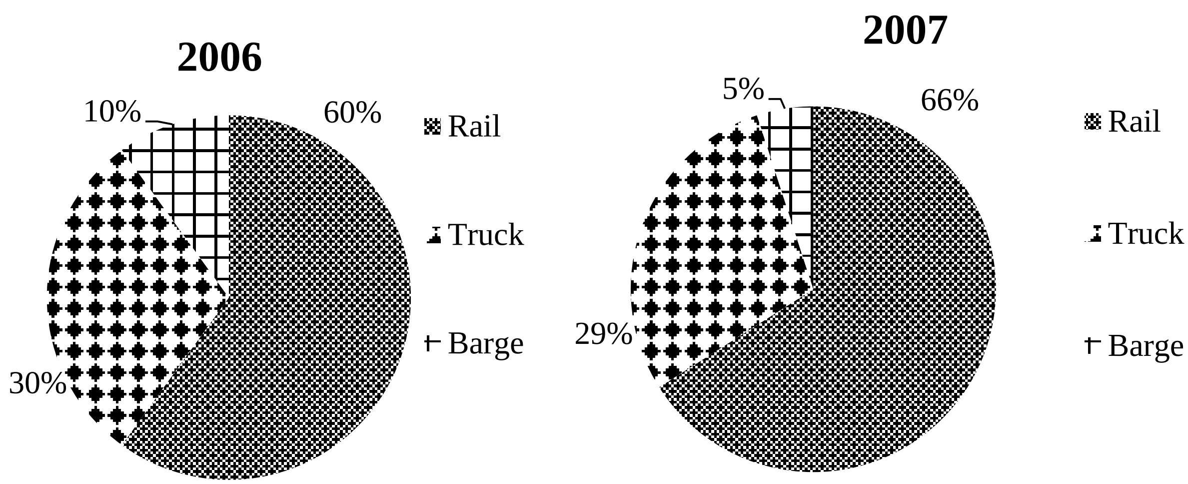
This paper specifically addresses 'downstream' distribution inefficiencies of both energy input and GHG emissions, and likewise considers transportations costs for ethanol fuel delivery between distant production origins to their refined fuel terminal and blending destinations. A main difficulty for incorporating ethanol shipments into the current petroleum 'downstream' supply chain is that petroleum is mostly shipped via pipelines. Yet potential contamination from water prevents ethanol from being shipped through these pipelines. i.e., water can be blended with ethanol, unlike the case of petroleum, and it is very difficult to subsequently separate them.

Despite a recent "specially-built" pipeline dedicated to ethanol shipment only ("An ethanol pipeline begins service"- NYT[2] July, 8, 2011), operating solely in Florida, the vast majority of ethanol shipments are made by rail, truck and barge. Statistics from 2007 (GTR, USDA 2008) have about 66% of all ethanol shipments being done by rail, followed by truck with

[2] New York Times

29% and barge at 5%. This is an increase in rail from the previous year 2006, where 60% of ethanol shipments were made by rail and 30% and 10% by truck and barge, respectively (ETB, USDA 2007), *as seen in Figure 1*. The latest USDA data (2010) indicates that rail has become almost 70% of ethanol transportation.

Figure 1: Transportation Modes for Ethanol Shipments



Background (Literature Review)

There is an extensive array of articles covering broad aspects of the biofuel industry and its optimal implementation. A recent paper by Ann et al. (2011) addresses a literature review on biofuel supply chain research, specifically operational research. The article partially arranges studies investigated as being either upstream (from farms of biomass to pre-processing plants), midstream (refineries of production plants), or downstream (after production to final consumer). The paper mentions very few studies of biofuel supply chain research addressing downstream operations. In this sense, Eksioglu et al. (2009) and Huang et al. (2010) conduct studies of optimal biofuel supply chain management covering stages from upstream to downstream by implementing multi-stage models.

A prior study by Tursun et al. (2008) concentrates in the future biofuels industry of Illinois by addressing the optimality of their bio-refineries location and transportation network. They implement a multi-year transshipment and facility location model to determine location and capacity of bio-fuel plants, amount of biomass required, and distribution of bioethanol and bio-energy. However, their linear mixed integer optimization program becomes computationally intractable, having to optimize by providing given biofuel plant locations.

An early comprehensive study titled "The Oak Ridge National Laboratory Ethanol Project" (2000) - prior to the U.S. ethanol mandates of 2005 and 2007 - focuses on the required appropriate settings for petroleum refineries that consider entering the ethanol industry as well as their combined operational implementation. The increased operational interaction between petroleum and ethanol industries is based on the production locations and their distance, operational efficiencies and cost factors, as well as storage capacity of delivery terminals. The Renewable Fuels Standard (RFS) amended in 2007 has set mandatory blend levels for renewable fuels (Renewable Fuels Association website). Approximately 90% of ethanol production capacity in the USA is concentrated in the Mid-West, in an 8 state area comprising of Iowa, Nebraska, Minnesota, Illinois, South Dakota, Indiana, Kansas, and Wisconsin. Around 80% of the US population (and therefore the implied ethanol demand) lives along its coastlines (Ethanol Transportation Backgrounder, 2007). Therefore transportation of ethanol from the ethanol production plants to the petroleum storage and distribution facilities, where ethanol is blended into gasoline and transportation of reformulated gasoline from the petroleum storage and distribution facilities to the retail gas stations are critical components of the ethanol supply chain.

A recent study by Russell et al. (2009) describes five strategic plans of future integration between the supply chains of biofuels and petroleum. Given the proven lower costs of rail transportation over truck, the article addresses two key elements associated to increased rail use. These refer to rail access and shipment consolidation. The article proposes the use of large ethanol ‘hub receiving’ terminals with access to rail, given the considerable few storage terminals with rail access and the large costs of rail installation. In the same line, given that a large volume of ethanol is to be unloaded at these hubs – perhaps not enough to be supplied by particular ethanol plants - then ‘hub consolidating’ terminals are to be implemented for consolidation of shipments from Midwest producers. A few of these hub terminals are currently in use, and are to be incorporated in the biofuel supply chain structure.

A study by Wakeley et al. (2009) evaluates infrastructure requirements and transportation effects for light-duty vehicles using E-85 made of corn and cellulosic ethanol. A linear optimization model is applied for ethanol distribution and GHG emissions are computed from a Life-Cycle Analysis (LCA) perspective. Among the results found, are that long distance ethanol transport may negate any economic and environmental benefits compared to regular gasoline usage, thus emphasizing preference for regional distribution of ethanol. However, these results do not consider the use of hub terminals with rail access, mentioned in the previous study, that serve as intermediate storage sites for distant large geographical supply and demand areas. This paper empirically takes into account the existing consolidation and receiving hubs for computation of the optimal shipment routes and quantities delivered - from the ethanol plants to the blending/storage terminals.

Methodology and Analysis

As mentioned previously, this study accounts for the existing ethanol hub-consolidation and hub-receiving terminals, in addition to the regular ethanol and gasoline storage and blending terminals. Optimization results obtained are of volumes, transportation mode and routes of ethanol shipments between producers and final blending terminals. The study initially registers all ethanol plants and gasoline refineries in the continental U.S., leaving the incorporation of gasoline refineries for future study, as well as all refined fuel terminals and (ethanol) consolidation and receiving hubs. These sites have all been mapped-out with the Geographic Information Systems (GIS). Likewise, all available transportation shipment modes from production sites, through hubs or directly to terminals are computed with distance, energy used, GHG emissions and transportation costs.

A linear optimization model is applied using supply from U.S. ethanol production and demand from blending terminals as initial constraints. The tool takes into account supply chain constraints, e.g.; plant capacities, hub throughputs, volume per transportation mode and likewise considers (major) demand destinations. The output consists of the optimal transportation mode regarding energy use, lowest GHG emissions and transportation costs, as well as the volume being shipped.

The model applied seeks to minimize the following:

(1) $\sum_j \sum_k (F_{jk} d_{jk}) q_{jk}$

Such that:

(2) $F_{jk} = \begin{cases} T \ if \ d_{jk} < 300 \ mi \\ R \ if \ d_{jk} \geq 300 \ mi \end{cases},$

and initially subject to the following constraints:

(3) $\sum_k q_{jk} \leq Q_j, \quad \sum_j q_{jk} = D_k,$

where:

F_{jk} = Mode of transportation that ships from Ethanol plant j to Terminal k.

T = Cost of truck transport ($/mmg-mile) or truck emission (CO2 lbs./mmg-mile)

R = Cost of rail or truck transport ($/mmg-mile) or rail emission (CO2 lbs./mmg-mile). This cost incorporates shipping through a Consolidation and Receiving Hub, and subsequently shipping via truck from Receiving Hub to Terminal.

d_{jk} = Distance (rail or truck, per terminal) from ethanol plant j to terminal k (mi.)

q_{jk} = Quantity of ethanol transported from Ethanol plant j to Terminal k (mmg)

Q_j = Annual Ethanol production at facility j (mmgy)

D_k = Ethanol demand at Terminal k (mmgy)

i.e., initial constraints consider terminal demand being fully supplied.

Subsequently for the second optimization model, the hub consolidation thru-put constraint condition is incorporated into the model. The second optimization model is then executed in two stages. The first stage considers only the thru-put condition, and the second stage takes the remaining ethanol plants and terminals for direct supply.

Finally for the third optimization model, a new third hub consolidation is taken into account, and the optimization is computed in a similar manner to the first model. Thus, based on the optimization method above, three scenarios were estimated with different constraints and numbers of Hubs. Results from all three scenarios are compared and discussed in the results section.

Model 1

In model 1, both supply and demand constraints are satisfied and there are two consolidation hubs, Manly (IA) and Sauget (IL). Formally, the optimization problem is set as follows:

$$\textbf{(4)}\ Min \sum_j \sum_k (F_{jk} d_{jk}) q_{jk}$$

Subject to:

$$\textbf{(5)}\ \sum_k q_{jk} \leq Q_j, \quad \sum_j q_{jk} = D_k$$

Model 2

Model 2 has two stages. The first stage considers three constraints given by demand, supply, as well as the consolidation hubs' through-put constraint. Both demand and supply constraints are not bounded, while the through-put constraints of the two consolidation hubs are bounded. The second stage is optimized for the remaining routes of plant capacities and terminal demands that are partially not used or still remain fully not used. Cost is calculated according to linear distances of routes.

Stage 1

$$\textbf{(6)}\ Min \sum_j \sum_k (F_{jk} d_{jk}) q_{jk}$$

Subject to:

$$\textbf{(7)}\ \sum_k q_{jk} \leq Q_j, \quad \sum_j q_{jk} \leq D_k, \sum_{j \in hubc1} q_{jk} = 1000, \sum_{j \in hubc2} q_{jk} = 750,$$

where 1000 and 750 are in million gallons. These are the thru-put capacities for Manly, IA and for Sauget, IL, respectively.

Stage 2

$$\textbf{(8)}\ Min \sum_j \sum_k (F_{jk} d_{jk}) q_{jk},$$

where d_{jk} is calculated based on direct distance without considering hubs subject to:

$$\textbf{(9)}\ \sum_k q_{jk} \leq Q_j, \quad \sum_j q_{jk} = D_k,$$

The criteria applied for the computation of costs of model 1, of the 1st stage of model 2, and of model 3 (presented below) are based on the Table 1:

Table 1: Transportation Mode Choice Criterion

	Plant Access	**Terminal Access**	**Transportation Mode**
	Rail truck	Rail truck	
1	yes	yes	Rail
2	yes	no	>300 miles Hub RRT except if truck from hub is more than truck from plant. ,<300miles direct distance Truck
3	no	no	>300 miles Hub Truck,<300 miles direct distance Truck
4			Direct distance

Note: RRT is plant to hub consolidation via rail, hub consolidation to hub receiving via rail and hub receiving to terminal via truck.

For the computation of the cost F_{jk} of stage 2 from model 2, only two criteria are considered for the transportation modes used, as can be seen in Table 2.

Table 2: Transportation Mode Choice Criterion for Model 2 Stage 2

Cost	Direct Distance more than 300 miles	Direct Distance less than 300 miles
Plant &Terminal with rail access	Rail_Cost*Direct_Distance	Rail_Cost*Direct_Distance
All other possibilities	Rail_Cost*Direct_Distance	Truck_Cost*Direct_Distance

Model 3

For model 3, in addition to constraints and hubs of model 1, there is one more consolidation hub located at the state of Nebraska. The new consolidation hub location responds to Nebraska being the 2nd largest state producer of ethanol, having 25 ethanol plants and with a production capacity of about 2 billion gallons of ethanol per year.

Data and Variables Used

In the above model, 218 ethanol plants (mostly located in Midwest—Figure 4 in the Appendix) shipped ethanol to 2 hub consolidation terminals (Manly, IA and Sauget, IL—Figure 5 in the Appendix), 14 hub receiving terminals (FL, CA, LA, GA, MD, NJ, RI, TX, NY—Figure 5 in the Appendix) and 1260 regular terminals, i.e., blending or storage and distribution facilities (mostly located across the coasts). First, the highway and rail distances were both directly calculated from the ethanol plants to the terminals, as well as including via hub consolidation and receiving terminals. For the driving distances (mi.), a macro in SAS was created to access Google Maps multiple times in order to obtain different pairs of longitude and latitude. With respect to the rail distances (mi.), it was assumed that these equal the highway miles multiplied by a factor of 1.1.

This resulted from our observation that a substantial random sample of rail miles from Carbon Fund Amtrak was equal to the driving distance from Google Maps times 1.1.

The costs were based on a mileage-based rate following the analysis of Parker et al. (2008). In this analysis, the focus is on the distance-dependent component and excluded is the fixed cost, as well as the loading/unloading component. For truck capacity of 8,000 gallons of ethanol and a distance dependent cost of 1.3$/mile/truckload, the truck cost utilized in the estimation was 0.0001625$/mile/gallon. For a rail car capacity of 33,000 gallons of ethanol and a distance dependent cost of 0.0075$/mile/100 gallons, the rail cost utilized in the optimization model was 0.000075$/mile/gallon. The latter was based on the rate schedule for agricultural products provided by Union Pacific. Regarding the energy input by mode, the estimate for truck is 0.1619 gallons of diesel fuel/vehicle (containing ethanol) per mile, whereas for freight rail is 0.002230 gallons of diesel fuel/ton (ethanol) per mile. These numbers were computed with data obtained from the Transportation Energy Data Book available at the Center for Transportation Analysis in the Oak Ridge National Laboratory. (http://cta.ornl.gov/data/index.shtml). Note that the energy consumption is defined as the Energy Intensity (Btu/ton per mile) divided by Energy Conversion (Btu/gallon). Last, the CO2 emission factors for truck and rail are: 0.654 lbs. of CO2 per ton (of ethanol) -mile and 0.055 lbs. of CO2 per ton (of ethanol)-mile, respectively. These values are obtained from Carbonfund.org, a non-profit organization.

With respect to the mode access for ethanol plants, all have truck access for inbound feedstock as well as outbound ethanol. Moreover, less than 5% of plants do not have rail access for outbound products. These latter without direct rail accesses were mostly bio-refineries of smaller capacity. The majorities of ethanol plants are located next to railway lines, and in some cases, have dual rail access (e.g., ABE-Huron plant delivers both via DM&E as well as BNSF railroad. There was not a unique source from where to acquire information about ethanol plants' rail access. Most bio-refineries either did not have a website or they did not provide any information about their transportation options. Thus, summarized information of whether a plant had rail access or not was obtained from sources such as the [1] Ethanol Magazine (used to search for plants' websites), [2] the Energy Supply Logistics website along with Google maps, and [3] articles/papers. As for the terminals' inbound rail and truck access - contrary to the ethanol plants - most terminals receive their products by pipeline and truck. Much fewer terminals have waterborne and/or railroad access. Information was collected regarding the inbound rail and truck access from the Energy Supply Logistics website, IRS, and from the subsidiary of CSX transportation, TRANSFLO shipping company.

In order to find the ethanol quantity a terminal was capable of receiving, information about terminal storage capacities was obtained from various websites (see detailed sources in the Appendix). However, for the vast majority of terminals, this data was not publicly available. Hence, the approach used to construct demand estimates for the terminal destinations could be summarized as follows: 1) for each state, the capacities were summed for the terminals from which actual data could be obtained 2) this sum was then subtracted from the total motor gasoline state demand (EIA, 2009), which included fuel ethanol blended into motor gasoline, 3) the result (i.e., rest from total demand) was divided or split by the number of terminals within that particular state for which no information was available, 4) a ratio of state ethanol demand (which did not include denaturant fuel) over the state motor gasoline demand was created, 5) finally, this ratio was multiplied with the resulting value found in step 3, and the output was considered the ethanol demand for each terminal from that state for which capacity information was not available. Hence, the ethanol demand for terminals in each state considers the product of the ratio of un-denatured ethanol consumption over motor gasoline fuel ratio times the particular terminal's capacity being considered. This serves as a close proxy for the volume/capacity of ethanol that is consumed by each blending terminal from each state.

Results & Discussion

The initial model applied (Model 1) does not take into account the thru-put capacity constraint from both consolidation terminals (Manly, IA and Sauget, IL). This first model does however consider particular distance conditions (i.e. trucking between plant and terminal for less than 300 mi. – in case of terminals not having rail access) and the demand from all storage/blending terminals being fully supplied, as mentioned previously in Table 1 of the methodology section. Summary statistics of the optimal computations obtained from the prior constraints imposed on model 1 are in Table 3.a. and Table 3.b. *The volume being shipped is referred to as q.* Columns noted as Transportation, Energy Input and Emission refer to results obtained by taking into account the conditions set by transportation costs ($), energy used (gals of diesel fuel) and emission costs (lbs. of CO_2) , respectively.

From table 3.b., it can be seen that the annual thru-put volumes to be shipped through each consolidation terminal are higher than their initial capacity. The thru-put capacity for Manly, IA is about 1 mmgy, i.e. 1 billion gallons of ethanol per year (Blanchard, Trains Magazine, Aug. 2007) and for Sauget, IL is about 750 million gallons of ethanol per year (Melcer, St. Louis Post-Dispatch, April 2, 2007). However, the thru-put volume results under transportation costs are about 2.01 billion gals/yr. and 2.14 billion gals/yr. for Sauget and Manly, respectively. These results increase when taking into account energy used, obtaining 2.2 and 2.21

gals./yr for Sauget and Manly, respectively; and further augmented when considering emission conditions, resulting at 2.56 billion gals./yr. and 2.54 billion gals./yr., respectively.

Model 1

Table 3.a.: Summary Statistics of Model 1

	Transportation		Energy Input		Emission	
Model 1	**#**	**%**	**#**	**%**	**#**	**%**
# of optimal possible routes	260,615	---				---
Routes with non-zero q	12,369	4.75%	13,712	5.26%	16,851	6.47%
Routes pass hubs and non-zero qs	11,214	90.66%	12,596	91.86%	15,973	94.79%
# of plants	213	---	213	---	213	---
# of terminals	1224	---	1224	---	1224	---
Total volume (mmgy)	10,576	---	10,568	---	10,574	---
Total cost ($, gals Diesel, lb. CO_2)	749,605,913	---	77,860,297	---	4,479,481,302	---

Table 3.b.: Thru-Put Volumes of Consolidation Hubs for Model 1

Model 1	**Transportation**	**Energy Input**	**Emission**
Sauget, IL (mmgy)	2,012.94	2,205.85	2,556.28
Manly, IA (mmgy)	2,136.22	2,211.32	2,537.33

Given the results obtained with model 1, a model 2 that specifically takes into account the thru-put constraints from each hub consolidation terminal is applied.

Model 2

In model 2, of the first stage, 1000 million gallons and 750 million gallons are used as through-put for hub consolidation Manly and Sauget. The summary statistics of 1st stage are summarized in Table 4.a. *This model was not applied under energy input conditions*.

For the 2nd stage, in the case that the demand of a terminal is filled or capacity of a plant is fully used as a result of computation of the prior 1st stage, then all the routes to or from this terminal or plant are not considered. Therefore, there are 22,906 (8.79%) routes that are dropped because of plants being fully used and 41,069 (15.76%) routes dropped because terminals are filled[3] in 1st stage.

Summary statistics from applying model 2 are in table 4.a and table 4.b, by considering conditions of transportation costs and emission costs, respectively. These results include volumes being shipped - q - (mmg), costs per mmg, and total costs.

Table 4.a.: Summary Statistics of Model 2

	Transportation		**Emission**	
	#	**%**	**#**	**%**
1st stage optimization				
routes pass hubs	207,479	79.61%	207,479	79.61%
routes with non-zero q	1,875	0.72%	2,073	0.80%

[3] There are 260,615 routes in the data set.

routes pass hubs and non-zero qs	1,875	0.72%	2,073	0.80%
# of routes 1st stage	260,615	---	260,615	---
# of plants 1st stage	213	---	213	---
# of terminals 1st stage	1224	---	1224	---
Total cost of 1st stage ($ or lb. CO2)	160,566,972			
2nd stage optimization				
routes with non-zero q	4,645	2.36%	4,657	2.15%
# of routes 2nd stage	196,640	---	216422	---
# of plants 2nd stage	194	---	199	---
# of terminals 2nd stage	1,014	---	1088	---
total volume (mmg)	1750	---	8824.26	---
Total cost of 2nd stage ($ or lb.CO2)	142,207,791	---	828,281,000.82	---
Total cost ($ or lb. CO2) 2nd stage dropped route because plant is fully used	22,906	8.79%	17,136	---
2nd stage dropped route because terminal is filled	41,069	15.76%	27,057	10.38%
1st stage fully used plants	17	7.98%	14	6.57%
1st stage filled terminals	175	14.30%	136	11.11%

Model 3

This model considers the optimized shipments when taking into account the installation of a new hub consolidation terminal in Nebraska. This new terminal seeks to decrease the excess optimal thru-put volume that is shipped through existing Manly, IA and Sauget, IL consolidation terminals. This new terminal lowers the transportation costs, energy input costs and GHG emission costs that result from having a thru-put constraint at current consolidation terminals – which substantially increase these costs – by incorporating more rail shipment capabilities between consolidation and receiving hubs. Results from the addition of this new terminal are in Tables 5.a and 5.b, below. Table 5a considers the results for shipments having access to three consolidation hubs, without thru-put constraints in any of them (No Hubc). In addition, Table 5a includes results for shipments considering the thru-put constraint of the current existing two hubs – Manly and Sauget (Yes Hubc). Table 5b shows summary statistics for annual shipments (q) and their costs in terms of transportation ($), energy input used (gals. of diesel fuel) or GHG emissions (lbs. of CO_2). These are shipments from ethanol plants to terminals which may be sent either through consolidation and receiving hubs, or directly from plant to terminal. These summary statistics likewise consider the case of not having a thru-put constraint at the existing consolidation terminals, and also the case of applying the thru-put condition to current consolidation terminals.

In Table 6, there is a sample of states that have their shipment statistics details presented from applying model 1 (i.e. existing two consolidation hubs, without thru-put constraints). These include number of plants and terminals involved in the shipping process, the demand from terminals, the average shipment size (mmgy), and the average distance involving shipments that use both rail and truck, as well as shipments only by truck for the case of direct shipments.

Table 5.a.: Summary Statistics of Model 3

	No Hubc Constr_Trans	**No Hubc Cnst_EnrgyIn**	**No Hubc Constr_Emis**	**Yes Hubc Constr_Trans**	**Yes Hubc Const_EnrgyIn**	**Yes Hubc Constr_Emis**
#Non-Zero q routes	11,841	12,944	15,726	10,917	10,973	12,994
# q routes thru hubs	10,823	11,959	14,868	9,835	9,897	12,067
# q direct delivery	1,018	985	858	1,082	1.076	927
# Total Cost		72,933,390			80,119,366	
($, gals Diesel, lb. CO_2)	715,024,916		4,040,965,485	780,317,060		4,532,120,071
HubC1 thru-put (mmgy)	1,206	1,233	1,290	1,000	1,000	1,000
HubC2 thru-put (mmgy)	2,013	2,117	2,267	750	750	750
HubC3 thru-put (mmgy)	1,462	1,470	1,608	2,819	2,868	3,224

Note: This table is based on 261,916 observations

Table 5.b.: Summary Statistics of Volume and Unit Cost of Model 3

	Without Hub ConsolidationConstraint						**With Hub Consolidation Constraint**					
	Transportation Cost		**Energy Input Cost**		**Emission Cost**		**Transportation Cost**		**Energy Input Cost**		**Emission Cost**	
	q (mmgy)	cost ($/mmgy)	q (mmgy)	(Gals. Dsl / mmgy)	q (mmgy)	lbs. (CO_2/mmg)	q (mmgy)	cost ($/mmgy)	q (mmgy)	(Gals. Dsl / mmgy)	q (mmgy)	lbs. (CO_2/mmgy)
Mean	0.89309	60,391	0.81682	10,649	0.67223	256,977	0.96864	71,84	0.96413	12,133	0.81378	348,812
Median	0.30	32,665	0.29	10,458	0.24	106,310	0.32787	38,341	0.32	11,840	0.29543	168,252
Max	19.61	2,290,627	19.61	28,757	19.61	16,014,520	19.61	3,225,377	19.61	28,898	19.61	20,377,836
Min	0.01	166	0.01	2.02	0.01	2,244	0.01	187	0.01	2.02	0.01	756
Std.	1.95084	109,457.95	1.86081	4,096	1.67790	646,257	2.04356	126,746	2.02688	5,026	1.84902	728,411

Table 6: Shipment Statistics for a Sample of States

State	Shipments	# Terminals	Terminal Demand (mmgy)	# Plants	# Shipments	mean shipment (q) size (mmgy)	mean distance - Truck (mi)	mean distance - Rail (mi)
NC	Direct	14	9.702	5	14	8.442	364.46	-
	Thru-hubs	47	9.702	24	392	0.639	292.89	854.38
	via Manly				0			
	via Sauget				392			
FL	Direct	6	16.212	2	6	16.210	635.67	-
	Thru-hubs	76	16.212	23	602	1.024	452.85	856.82
	via Manly				0			
	via Sauget				602			
IA	Direct	24	4.2	14	24	3.850	32.72	-
	Thru-hubs	0	0	0	0	0	0	0
IL	Direct	54	9.216	16	55	8.208	63.83	-
	Thru-hubs	0	0	0	0	0	0	0
NE	Direct	14	3.654	9	15	3.407	24.54	-
	Thru-hubs	0	0	0	0	0	0	0
NY	Direct	48	7.098	14	60	4.260	558.85	-
	Thru-hubs	67	7.098	47	1018	0.244	86.94	1378.58
	via Manly				980			
	via Sauget				38			
NJ	Direct	17	11.844	13	21	5.076	634.43	-
	Thru-hubs	47	11.844	47	767	0.371	83.35	1341.80
	via Manly				672			
	via Sauget				95			
CA	Direct	39	11.508	10	53	5.992	262.71	-
	Thru-hubs	108	11.508	46	1426	0.439	48.75	2069.79
	via Manly				1354			
	via Sauget				72			
TX	Direct	49	7.308	7	56	4.622	410.95	-
	Thru-hubs	141	7.308	29	1848	0.284	260.92	1055.81
	via Manly				1847			
	via Sauget				1			

Summary Statistics regarding volumes of annual shipment (q), unit cost and total costs under transportation-cost conditions, for all three models described earlier, are in table 7.a. Summary statistics for shipment volumes, unit costs, and total costs under ‘energy input – cost conditions’, for the 1st and 3rd model are in Table 7.b. Finally, Table 7.c, includes summary statistics for shipment volumes, unit costs, and total costs under ‘GHG emissions – cost conditions’, for all three models.

From Table 7.a – the increase, in an average sized shipment, of total transportation cost due to having thru-put constraints at both consolidation terminals, is about 159%. This is obtained from the costs considered at both stages of model 2 in comparison to the cost obtained from model 1. However, the decrease in an average sized shipment of total transportation costs from having a 3rd consolidation hub (model 3), instead of two consolidation terminals without thru-put (model 1), is only of 0.35%. From Table 7.b, for an average sized shipment the decrease in energy input total costs by having the 3rd consolidation hub over two hubs that do not have thru-put constraint, is of 0.76%.

Likewise, from Table 7.c for an averaged sized shipment, the emission total cost increases incurred by having thru-put constraints at both consolidation terminals, are of about 43% in terms of lbs. of CO2. Once again this is obtained from the costs considered at both stages of model 2 in comparison to the cost obtained from model 1. In addition, there is a decrease of 3.33% in the average sized shipment’s emission total costs when incorporating the 3rd hub (model 3) with respect to the two existing consolidation hubs without thru-put (model 1), as anticipated.

Table 7.a.: Volume and Cost Summary Statistics of Model 1, Model 2 and Model 3 of Transportation Cost

	Q (mmgy)				Cost ($/mmgy)				Total Cost($)			
	model1	model2_1st	model2_2nd	model3	model1	model2_1st	model2_2nd	model3	model1	model2_1st	model2_2nd	model3
mean	0.8551	0.9333	1.9005	0.89309	113,149	85,640	54,488	108,203	60,604	75,844	81,101	60,391
median	0.2500	0.4928	0.6990	0.30	113,060	88,391	53,700	108,250	29,257	43,775	35,601	32,665
max	19.6100	11.5080	16.2120	19.61	219,420	106,650	123,080	263,070	2,267,047	1,090,993	1,139,297	2,290,627
min	0.0100	0.0549	0.0050	0.01	65	45,880	65	16	287	31,887	221	166
std.	2.0245	1.4594	2.8155	1.95084	37,870	14,666	23,342	39,358	133,768	112,233	129,987	109,458
# of obs.	12,369	1,875	4,645	15,726	12,369	1,875	4,645	15,726	12,369	1,875	4,645	15,726

Note: This summary statistics is based on non-zeros q observations.

Table 7.b.: Volume and Cost Summary Statistics of Model 1 and Model 3 of Emission Input

	Q (mmgy)		Cost (gals Diesel/mmgy)		Total Cost (gals Diesel)	
	model1	model3	model1	model3	model1	model3
mean	0.77070	0.81682	11,119	10,649	5,678	5,635
median	0.2400	0.2900	10,923	10,458	2,747	3,049
max	19.6100	19.6100	25,621	28,757	294,464	265,686
min	0.0100	0.0100	8.1	2.0	8.1	23.3
std.	1.9212	1.8608	3,791	4,096	13,555	10,631
# of obs.	13,713	12,944	13,713	12,944	13,713	12,944

Note: This summary statistics is based on non-zeros q observations.

Table 7.c.: Volume and Cost Summary Statistics of Model 1, Model 2 and Model 3 of Emission Cost

	Q (mmgy)				Cost (lb. CO_2/mmg)				Total Cost(lb. CO_2)			
	model1	model2_1st	model2_2nd	model3	model1	model2_1st	model2_2nd	model3	model1	model2_1st	model2_2nd	model3
mean	0.6275	0.8445	1.8948	0.81378	571,045	253,396	115,470	517,725	265,829	201,831	177,857	256,977
median	0.2100	0.5000	0.5631	0.29543	485,700	258,000	112,740	424,190	102,443	124,440	64,892	106,310
max	19.6140	11.5100	16.2120	19.61	2,152,500	365,000	253,910	2,009,900	28,440,300	3,738,320	3,133,890	16,014,520
min	0.0100	0.0200	0.0050	0.01	782	101,000	782	195	3,447	79.790	70	2,244
std.	1.7042	1.3513	2.8214	1.84902	354,307	69,798	48,001	334,851	828,371	352,470	302,452	256,977
# of obs.	16,853	2,074	4,657	15,726	16,853	2,074	4,657	15,726	16,853	2,074	4,657	15,726

Note: The summary statistics is based on non-zeros q observations.

Recommendations & Conclusions

–Ideas for Project Expansion and Future Work

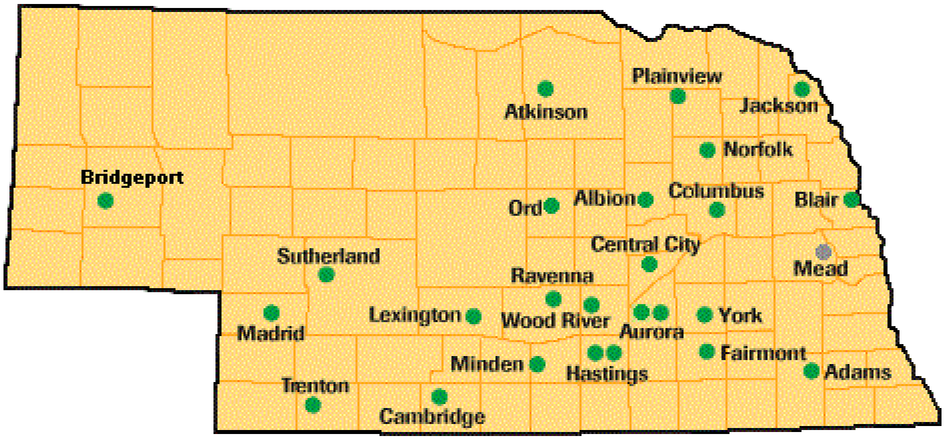
The hub receiving terminals are served by unit trains and this suggests that a unit-train volume of ethanol needs to be consolidated at the ethanol plant origins (Russell, 2009). However, the U.S. ethanol supply market is characterized by medium-production-capacity plants scattered across the Midwest (Kotrba 2007). An ethanol plant faces the challenge to achieve unit train volume on its own and thus makes use of existing consolidation hubs in Iowa and Illinois.

Taking into account that Iowa has 42 plants with total state capacity of 3655 mil gallons, and Illinois has 13 plants with a capacity of 1446 mil gallons (see Table 8), another potential candidate for the location of a consolidation hub would be the state of Nebraska. Nebraska has 25 plants and is the second producing state after Iowa with a total production capacity of 1950 mil gallons. Furthermore, Nebraska also has large-production capacity plants. The hub consolidation terminal would be located ideally next to rail lines, at a close proximity to ethanol plants and close to a river (to achieve transportation via barges). Based on the above criteria (see Figures 2 and 3), we suggest a hub consolidation terminal at the Southwestern region of Nebraska, closer to the Kansas border (40.739, -98.741).

Table 8: 6 Top States with the highest Ethanol Capacity

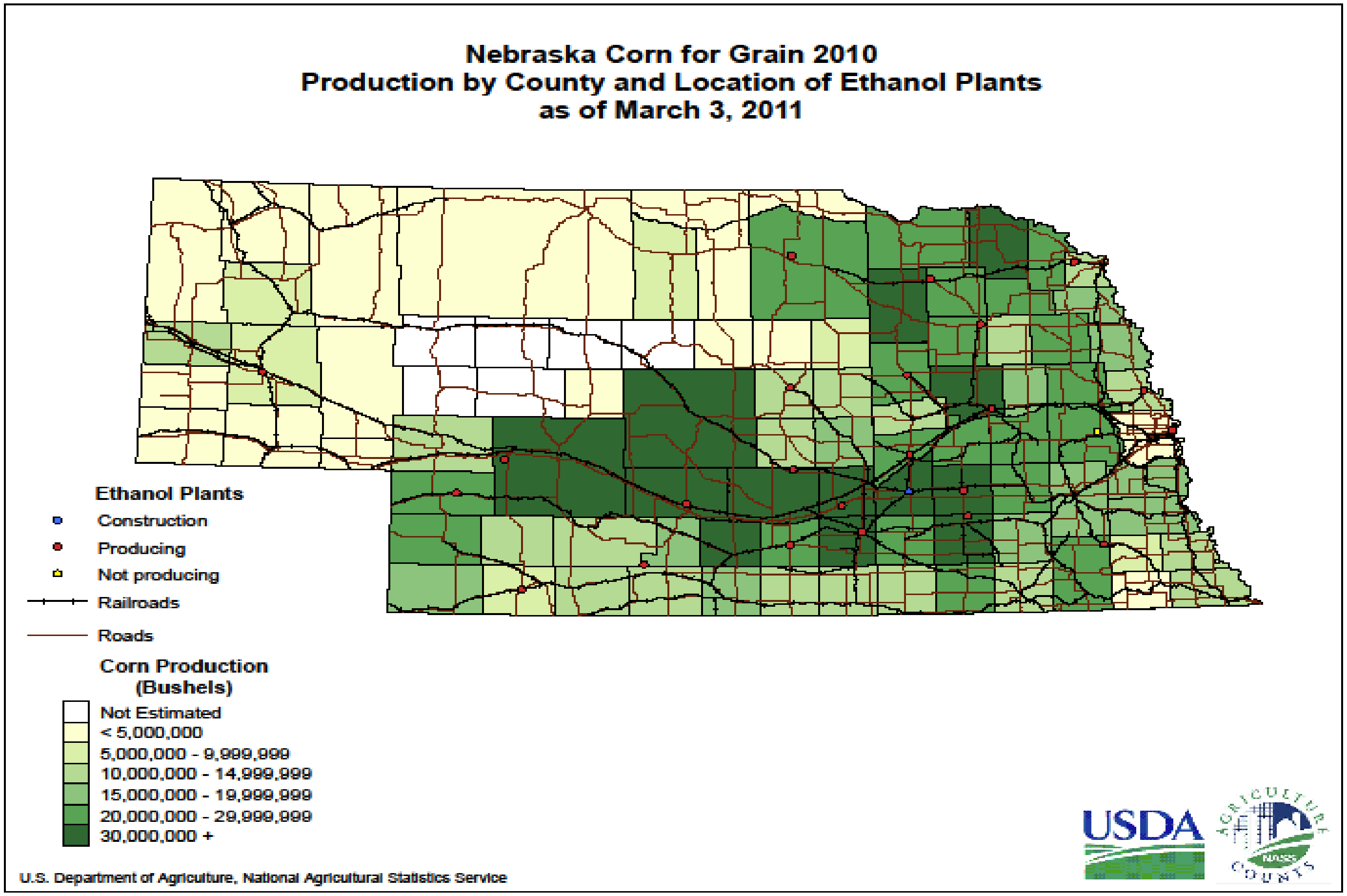
State	# Plants	Total Capacity (mil gallons)
SD	16	1020.3
IN	14	1168
MN	21	1170.5
IL	13	1446
NE	25	1950
IA	42	3655.5

Figure 2: Ethanol Plants in Nebraska



Source: 2011 Nebraska Ethanol Board

Figure 3: Location of Ethanol Plants along with Rail lines in Nebraska



Source: US Department of Agriculture, National Agricultural Statistics Service (NASS)

Ethanol production plants with less than 10 million gallons of annual capacity ship ethanol by truck only. It is assumed that these plants produce at a level rate of 340 days per year. Thus these ethanol plants produce up to 29.4 thousand gallons of ethanol every day. A single full truck can carry between 7800 to 8200 gallons of ethanol, and it will need to make four round trips per day to transport the ethanol produced to the hub consolidation terminal. It is necessary to look for ways to increase the amount of ethanol a truck can carry. Reducing the frequency of ethanol shipments will reduce the total distance travelled, reducing the Green House gas emissions as well. However, the recommendation should undergo more research in order to evaluate the extent to which the capacity of trucks can be increased without violating safety regulations by the US Department of Transportation and Highway Administration. There are special regulations for the maximum weight a truck may carry at any given point of time.

On the other hand, POET (privately held company based out of Sioux Falls, SD) is the largest producer of ethanol in the USA and in 2010 - along with pipeline-builder Magellan Midstream Partners - started conducting feasibility study to build a $4 million ethanol pipeline (CNN Money, Mar 2010). The pipeline under consideration would extend 1,800 miles, crossing seven state lines, carrying 240,000 barrels a day. If the pipeline is built, it would link cornfields and refineries in the upper Midwest to fuel-hungry markets on the East Coast, while boosting transport efficiency (equivalent to reducing the carbon footprint) by 30%, compared with rail, and nearly by 90% compared with trucks (CNN Money, Mar 2010). As a key provision of the Renewable Fuel Pipeline Act bill that was reintroduced in Feb 2010, Congressman Leonard Boswell has proposed to release loans amounting to 80% of the proposed cost of the pipeline. Nonetheless, as of January 2012, POET had postponed the plans for the pipeline. The company predicts that it would not be able to get the federal loan guarantee, without which the project will not be able to move forward. There should be more feasibility studies conducted to build similar pipelines across the USA to support the growing ethanol production in the USA.

A financial analysis was performed to compute the impact of adding a hub consolidation terminal in Nebraska, to the current distribution network of ethanol. The cost of building similar hub consolidation terminals in Manly (IA) and Sauget (IL) had been $13.0 million and $12.5 million, respectively. The cost constructing a hub consolidation terminal in Nebraska was estimated to be the average of the costs of building the above 2 consolidation terminals, at $12.75 million. The potential cost savings of the supply chain network were computed for the case of adding a new hub consolidation terminal to the network. The Model 1 results show that the total cost of the supply chain network in terms of transportation is $749.6 million. The Model 3 results show that the total cost of the supply chain network in terms of transportation is $715.02 million. Thus the total cost savings generated, if a third hub consolidation terminal were added to the supply chain network, is $34.58 million. The operating costs of the hub consolidation terminal were not accounted for in this analysis. The NPV of the project by applying different discount rates are in Table 8, and all results are of a positive NPV.

Table 8: Net Present Values under different discount rates

Discount Rate	**Net Present Value (Million $)**
9 %	$121.75
10 %	$118.34
11 %	$115.05
12 %	$111.90
13 %	$108.88
14 %	$105.97
15 %	$103.17

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Appendix

Figure 4: Locations of Ethanol Plants and Gasoline Refineries in the US

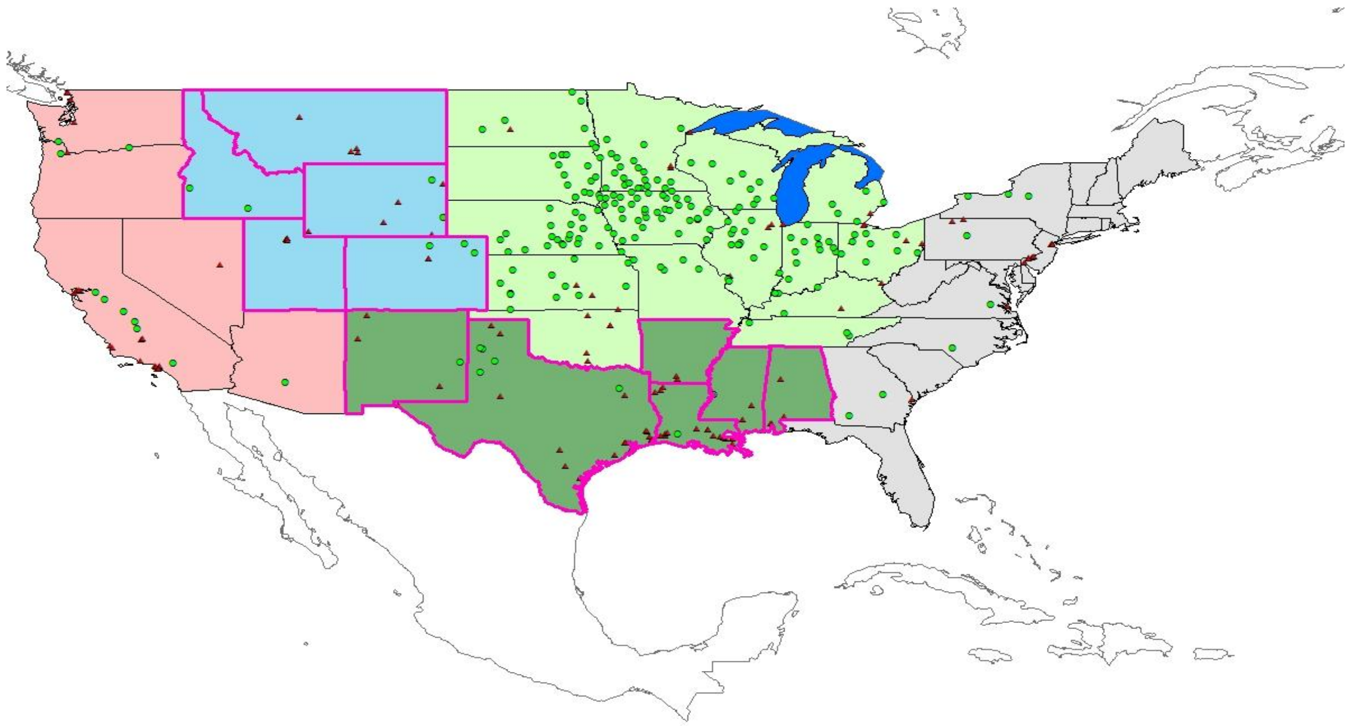
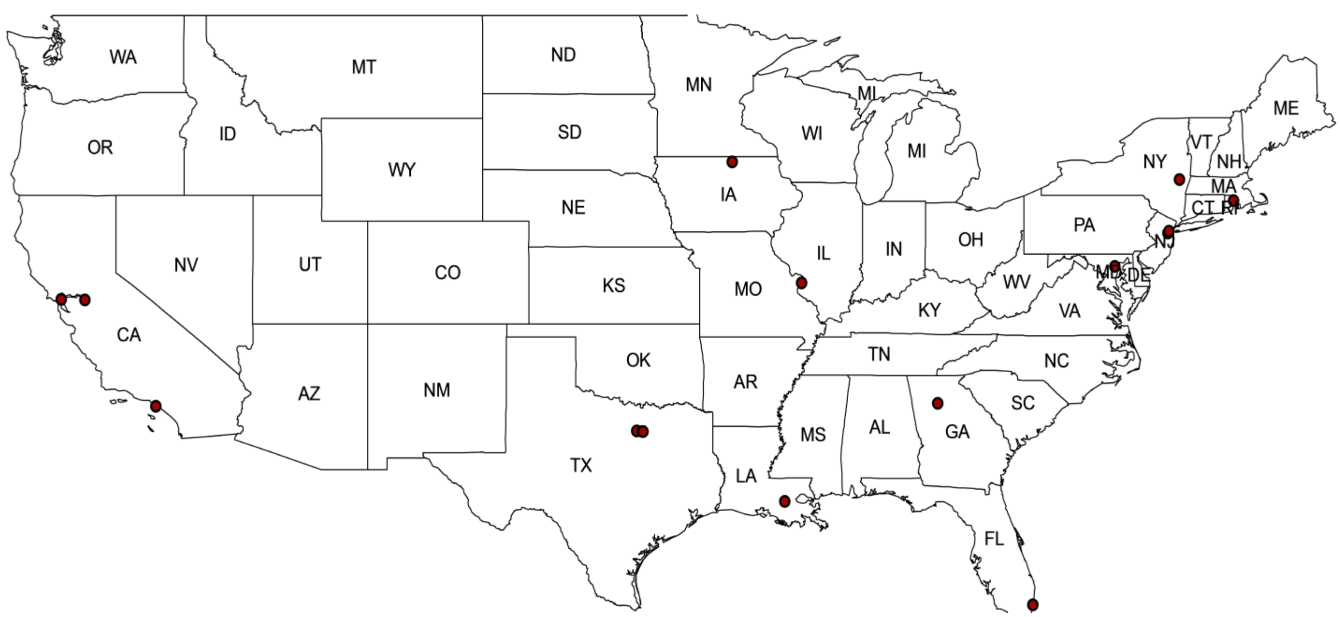


Figure 5: Locations of Hub Consolidation (2) and Hub Receiving (14) Terminals in the US



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