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SOURCING STRATEGY FOR ASPHALT PRODUCTION FEEDSTOCK CONSIDERING MULTIMODAL TRANSPORT OPTIONS

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ABSTRACT
This paper examines the logistics and distribution channels for importing heavy crude oil, which is a source of bitumen. The study conducts a sensitivity analysis to assess the suitability of existing or new distillery locations based on the available transportation modes and carrier options. The model accommodates rate changes based on multimodal shipping rates, import taxes, and other factors to assess the effects on total cost, schedule, and risks. Although a strategic location near direct pipeline options using existing facilities could yield the least transportation cost, the lack of pipeline capacity with increasing demand and delays in building additional capacity weighs heavily against pipeline options. The analysis points to multimodal shipments via ocean vessels and pipelines as the least-cost solution for a proposed strategic location for the distillery, but other factors such as strained international relationships make them less attractive. Depending on the selected refinery location, the analysis found that railroad options present a viable alternative and could potentially lead to the best overall logistical solution for obtaining asphalt production feedstock.

Keywords: Asphalt Production, Bitumen, Crude Oil, Distillery Location, Supply Chain Logistics

INTRODUCTION

About 94% of the 4 million miles of paved roads in the United States contain asphalt material. The product also covers about 85% of the nation's airport runways and parking areas (EAPA & NAPA 2009). Asphalt mix consists of 4% to 6% *bitumen* by weight, depending on the application specifications. Bitumen functions as the glue that binds together the mineral aggregates. In the United States, the industry terminology for bitumen is *asphalt cement* or *liquid asphalt*. To minimize transportation costs, construction companies generally purchase asphalt material from mixing plants located relatively close to the work sites. There are more than 4,000 mixing plants distributed around the United States. Every congressional district has at least one. Collectively, these plants produce about 550 million tons of asphalt material each year (NAPA Working Group 2007). Refineries produce bitumen from the residual heavy oils of the distillation process where the primary target products are lighter petroleum such as propane, gasoline, diesel, and jet fuel.

Refineries have been upgrading distillation plants in recent years to process more of the residuum to meet growing demands for lighter and higher-value transportation fuel such as gasoline, diesel, and jet fuel (Platts 2012). Upgrades include technologies called cokers that can produce more heat to break down the residual bitumen further, producing greater yields of the lighter petroleum products. Hence, refineries are producing less bitumen from the residuals of the distillation process. However, companies may decide to increase bitumen production because of an anticipated increase in demand amidst a scarcity of supply. In particular, bitumen demand could increase drastically if governments approve long-term transportation bills and new construction projects proliferate across the country.

The conventional distillation of light crude leaves a smaller portion of heavy oils behind than the distillation of heavy crude. Traditionally, conventional refineries prefer lighter crude oil feedstock because of the higher yield of lighter petroleum for the same refining cost. However, light crude supply is at historic lows because of decades of extraction, political instability, and conflicts in major oil-producing countries (King, Deng and Metz 2012). In recent years, the acquisition cost for light crude has been as much as 20% higher than for heavy crude (Burkhard, Forrest and Beck 2011). Cokers can process the cheaper heavy crude oil, and as more units come online, competition for the domestic supply of heavy crude will increase. Bitumen producers anticipate that this growing demand for domestic heavy crude oil will lead to price increases. Given the overall decline in asphalt production, the anticipated demand increase for asphalt, and the growing competition for domestic heavy crude, companies are interested in understanding the import options for heavy crude oil to assess benefits of investing in the location of their existing refineries, or to identify potentially better locations for new refineries. This study, therefore, examines the logistics and distribution channel options for importing heavy crude oil for various refinery location scenarios.

This paper conducts a sensitivity analysis of the available transportation modes and carriers options, including a consideration of import taxes and regulations. The model will assess the effects on cost, schedule, and risks as a function of locating the distillery somewhere in the central U.S. As a case study, the scenario places a hypothetical company, called BIND (Bitumen National Distillers), at the banks of the Arkansas River near Tulsa, Oklahoma. In addition to being within proximity of Cushing, Oklahoma, which is the delivery, blending, and price settlement point for WTI on the New York Mercantile Exchange (NYME), the location choice provides the company with access to nearly all transportation modes, including river barges that can transport heated bitumen to mixing plant customers. Hence, the analysis incorporates actual transportation modes, carriers, and transfer points currently available to move purchased crude oil to the selected location for processing and distribution.

The organization of the remainder of this paper is as follows: Section 2 describes of the characteristics of the commodity, supply channel, demand, and transportation options. Section 3 proposes a multi-commodity multimodal model and discusses optimal solutions. Section 4 explores the sensitivity results and discusses the threats and opportunities of the import options for the location scenario. The final section provides concluding remarks and summarizes the study.

THE SUPPLY CHAIN

Four of the top 10 producers of crude oil are located in the western hemisphere including U.S., Canada, Mexico, and Venezuela (U.S. Census Bureau 2012). The United States is the second largest. Even so, the United States imports about half of the oil it consumes (Davis, Diegel and Boundy 2012). The combined reserve of Venezuela and Canada is the largest proven oil reserve in the world, and can be a stable source of supply for the western hemisphere for decades. Hence, this paper will focus on comparing the logistics of purchasing oil from the largest western hemisphere producers: Canada, Mexico, and Venezuela.

Commodity Background

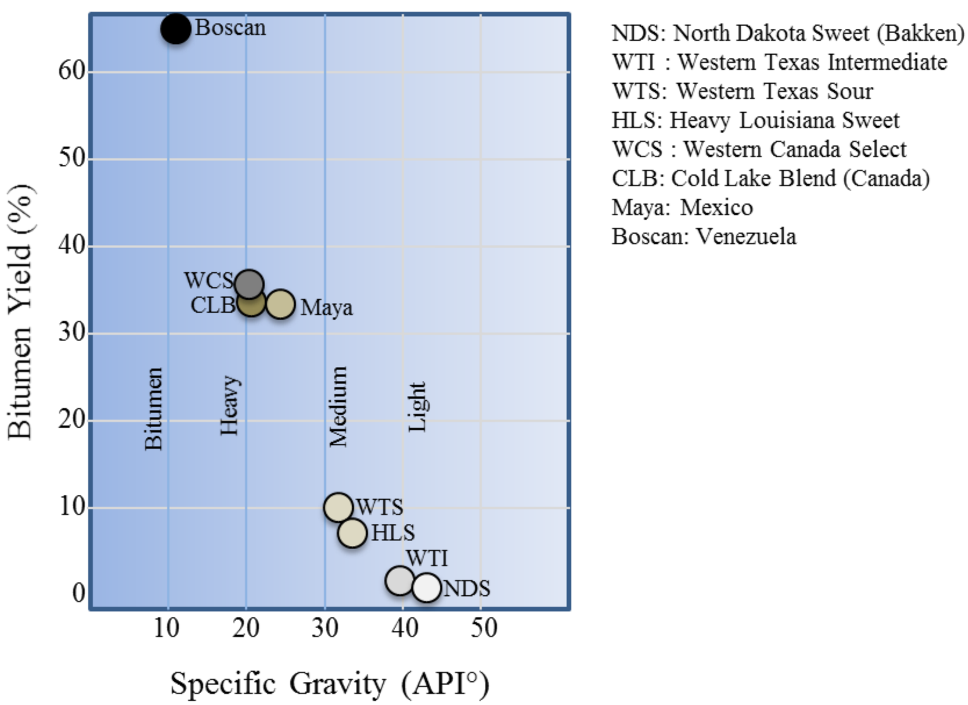


FIGURE 1 Crude oil classification.

Bitumen is a hydrocarbon material that is insoluble in water. It is a natural byproduct of organic material from bacterial decomposition. There are large deposits in “tar lakes” and “tar sands,” but crude oil contains most of the bitumen currently extracted. The bitumen content in crude oil varies with its specific gravity. The American Petroleum Institute (API) developed a measure of the specific gravity of oil in units of API degrees (Schenk, Pollastro and Hill 2006). A value greater than 10° indicates that the product will float on water, and below that indicates that it will sink. Higher numbers represent less dense oils that yield greater volumes of lighter, higher-value products for the same amount of processing. The industry classifies oil with an API gravity of less than 10° as bitumen, of 10° to 20° as heavy crude and above 33° as light crude (Figure 1).

Conventional oil has low viscosity and pumps can extract it from wells drilled into underground reservoirs. Unconventional oil is more difficult to extract because either the hydrocarbons are bound to sand particles, or rocks that trap them block the oil from flowing upwards. Analyst refers to unconventional oil as "tight oil" because it is more difficult to extract. However, improvements in horizontal drilling and rock fracturing technologies have led to tight oil booms in the Bakken (North Dakota) and Eagle Ford (Texas) shale formations. Both North Dakota Sweet (NDS) and Western Texas Intermediate (WTI) produce relatively low bitumen yields. Hydrocarbons extracted from the Canadian oil sands produce greater yields of bitumen.

Supplier Options

Numerous pipeline carriers are available in the area to deliver purchased crude oil to the BIND facilities located at Catoosa, which is about 65 miles east of Cushing. At that location, BIND Inc. can purchase crude oil feedstock from trading markets in Cushing, Oklahoma, which has the largest oil storage facilities in the United States (Philips 2012). Two varieties of heavy crude are generally available: Western Texas Sour (WTS) with API 31.7° and Heavy Louisiana Sweet (HLS) with API 32.9° (Table 1). When demand for bitumen weakens, or the price of oil is relatively low due to oversupply in Cushing, BIND can purchase Western Texas Intermediate (WTI), which has an API 39.6°. Western hemisphere sources involve a tradeoff in the API gravity and bitumen yield (Figure 1).

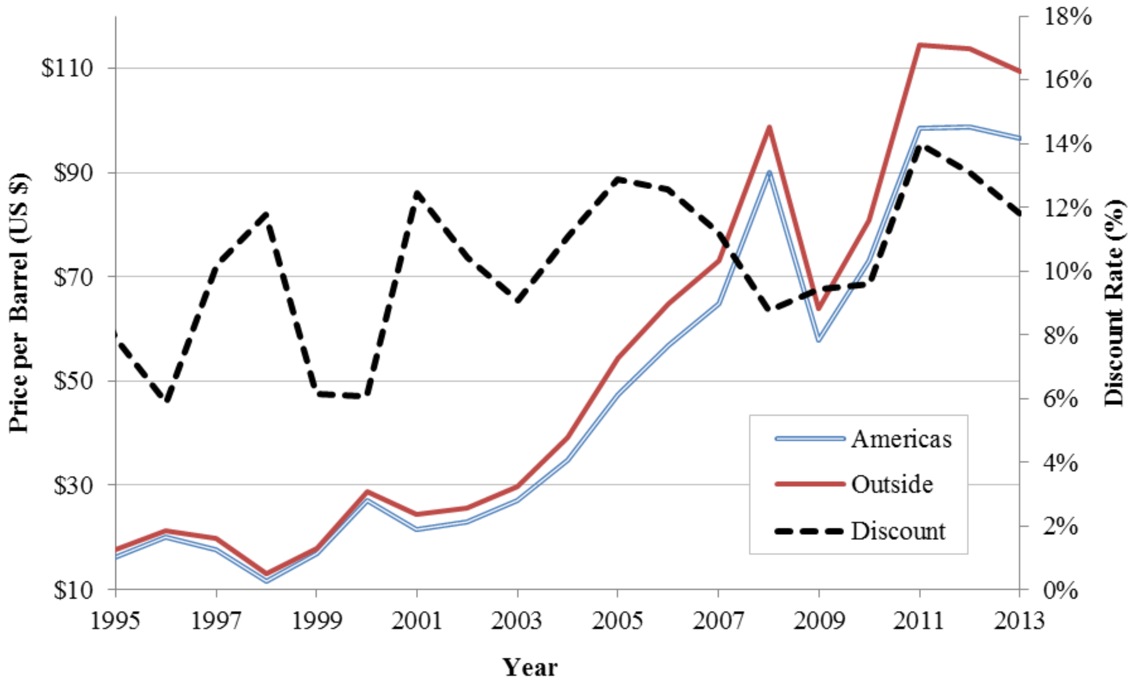


FIGURE 2 Annual average discount rate for crude from the Americas.

As observed, there is a diminishing return in yield as the API gravity increases beyond the threshold for the light crude category. Hence, the analysis accounts for bitumen yield differences by adjusting the number of barrels needed to produce the same amount of bitumen. In general, the southern trading partners can provide crude with the greatest bitumen yield but require non-pipeline transport modes.

Price Trends

Data from the U.S. Energy Information Administration (EIA) indicates that the average annual landed cost per barrel of crude oil from select countries in the Americas is, on average, less than from sources outside of the Americas (Figure 2). The average price discount for oil from the Americas has approached 14% in recent years. Bitumen producers expect that with increasing oil production levels in North America, this discount trend will sustain.

MODEL DEVELOPMENT

Transportation

Imports from Latin American countries will move north before arriving at U.S. Gulf Coast ports whereas imports from Canada will cross the border and then move south (Figure 2).

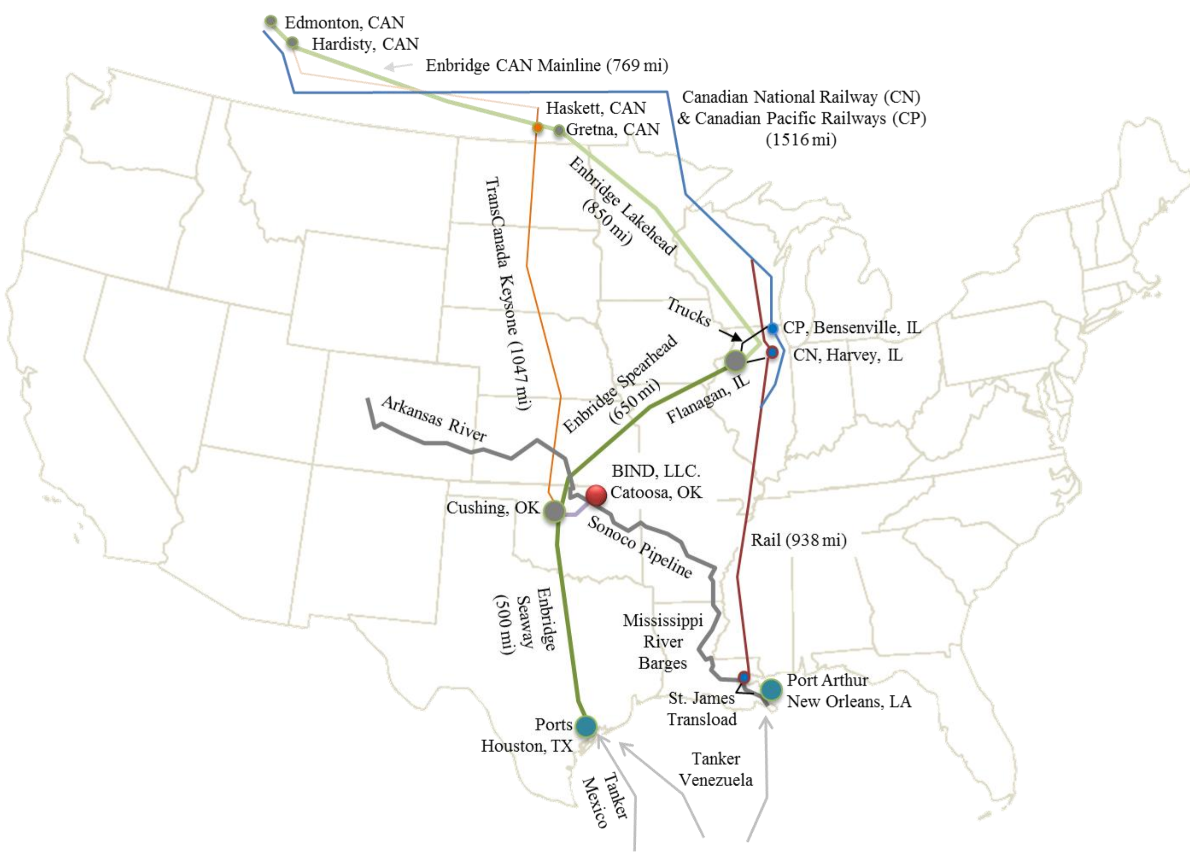


FIGURE 3 Transportation mode options for north-south crude oil movements.

The figure indicates the line-haul distances in miles. The four northbound route options from Venezuela or Mexico are oil tanker vessels-to-barge (Sea-Barge), oil tanker vessels-to-

Canadian Pacific Railway-to-trucks-to-pipeline (Sea-CP-TR-PL), oil tanker vessels-to-Canadian National Railway-to-trucks-to-pipeline (Sea-CN-TR-PL), and oil tanker vessels-to-pipeline (Sea-Pipeline). The five southbound route options from Canada are pipeline direct (Pipe-Direct), pipeline connection from Edmonton, Canada (E-Pipe-Pipe), pipeline connection from Hardisty, Canada (H-Pipe-Pipe), Canadian Pacific Railway-to-trucks-to-pipeline (CP-TR-PL), and Canadian National Railway-to-trucks-to-pipeline (CN-TR-PL). The logistics to obtain domestic oil from the Western Texas Intermediate (WTI) sources provide the baseline for comparison. Transporters must dilute the heavy crude oil to move it through long haul pipelines. Diluents consist of naphtha, gas condensates, or light oils that reduce viscosity. The typical mix reduces the actual feedstock content to 70% of a barrel (WEC 2010). It is not necessary to add dilutes for mode options such as rail, truck, and barge. However, if any of the intermediate movements involve pipelines, then the carrier must add a dilute and will increase the tariff based on the additional volume of material transported. The analysis accounts for these changes in payload weight or volume where appropriate.

The Class I railroad companies, Canadian National Railway (CN) and Canadian Pacific Railway (CP), both provide services northbound from transloading facilities in St. James, Louisiana, to their respective terminals near Chicago, Illinois. CN operates in Louisiana through subsidiary Illinois Central Railroad. CP also negotiated track rights to provide service in the region (AAR 2009). The CP terminal is located in Bensenville, Illinois, which is 106 miles east of the nearest pipeline injection point in Flanagan. The CN terminal is located in Harvey, Illinois, which is 98 miles east of the same pipeline injection point. CP provides service to Chicago from Hardisty while CN provides service from either the Edmonton or the Hardisty terminals near the Canada oil sands region.

The lack of pipeline capacity has enticed railroads to increase their proportion of crude oil transport by double-digit figures (AAR 2015). In addition to providing a viable alternative to pipelines, moving crude oil by rail has a few advantages. Diluents otherwise needed for pipeline transport are unnecessary for tank car transloading, thereby reducing transport and refining costs. Another advantage is that carriers can assure refineries of crude oil purity because, unlike pipeline batch processing, there is less chance for cross-contamination with other products during rail transport.

The number of modes involved in a specific route might offset their variations. Generally, the route with more than two different modes of transportation has fewer variations than one with a single transportation mode, and that leads to less vulnerability. On average, modes that use rail and trucks have the least variation. However, transshipments and longer transit time often adds to the overall cost, so future studies will explore the sensitivities of mode transfer factors.

Model for Multi-Commodity Multimodal Transportation

The virtual network can be described as $G = (N, L)$ where N and L denote nodes and links, respectively. For each route $R(O, D)$ from origin O to destination D, which consists of a set of links, there is K commodities indexed k, and M modes indexed m. The node moving commodity k is n_l^k and the link l_{ij} represents a specific mode between two connected nodes. The entire network for this scenario analysis has 43 nodes and 38 links. The National Transportation Atlas database provides the geographic data for the distances between node pairs.

Numerous researchers explored various methods to solve the multimodal transportation optimization problem (Sitek and Wikarek 2012) (Chen, et al. 2011). The objective of this study is to determine the least-cost solution for crude oil imports from various supply points to the selected location for BIND Inc. The generalized transportation costs for moving one unit of commodity *k* over a set of links $l_q^m \in R(O,D)$ is:

$$\min_{l \in R(O,D)} \sum_{l(i,j)} \sum_{k \in K} \sum_{m \in M} x_{l(i,j)}^{mk} \, c_{l(i,j)}^{k} \tag{1}$$

where

$c_{l(i,j)}^{k}$ = the unit mode-related costs to move commodity k from origin *i* to destination *j* through links *l*

$x_{l(i,j)}^{mk}$ = the number of barrels moved from origin *i* to destination *j* through links *l*

k = type of crude oil, *k* = {Boscan, Maya, Boscan-diluted, Maya-diluted, WSI}

m = mode of transporting crude oil {pipeline, rail, truck, barge, seaway}

l(*i*,*j*) = a directional link from node *i* to node *j*

R(O,D) = a route from origin O to destination D comprised of a set of links

The distance related costs between the origin and the destination includes the trans-loading/transshipment cost for rail, truck, and barge. The model converts the number of barrels moved across a link to ton-mile, and adds those to the cost of transportation by sea and pipeline. The model constrains the total shipment from all origins to be at most the total amount of crude oil supply available for each product type *k* such that:

$$\sum_{j} x_{l(i=O,j)}^{k} \leq SUPPLY_O \; \forall k = \{1,2,\dots,K\} \tag{2}$$

The total demand constraint is the capacity of a refinery such that:

$$\sum_{i} x_{l(i,j=D)}^{k} \geq DEMAND_D \; \forall k = \{1,2,\dots,K\} \tag{3}$$

The sensitivity analysis will use several demand levels $DEMAND_D$. Conservation of flows constrains the transshipment nodes such that:

$$\sum_{j} x_{l(i,j)}^{k} = \sum_{i} x_{l(i,j)}^{k} \tag{4}$$

That is, the total inbound shipments to the transshipment nodes must be identical to the total outbound shipments for all mode types and links. The least-cost solution for the ideal scenario does not account for issues such as node accessibility and any capacity constraints. The analysis varies the demand while maintaining the mode rates constant to determine the sensitivity of the total transportation cost for each commodity type, from each source.

Analysis Results

The scenario analysis used rates posted for each option in the first half of 2012 (Table 1). The diluted Boscan oil from Venezuela minimizes the total transportation costs for BIND Inc. to produce 325,000 barrels of asphalt. Shippers will move the crude oil from Venezuela through a connection of ocean going vessels, the Seaway pipeline from the Port of Houston to Cushing, OK, and local pipelines from Cushing, OK to BIND Inc. in Oklahoma, resulting in $3.36 million in costs.

SCENARIO-BASED SENSITIVITY ANALYSIS

The sensitivity analysis uses three scenarios by sourcing crude oil from Venezuela, Mexico, and Canada. The first scenario is a multimodal transportation option that combines ocean vessels (i.e. oil tanker) and pipelines. The second scenario combines ocean vessels, and barges that use an inland waterway, namely the Mississippi River. The final scenario uses an all pipeline transportation option from Canada.

Ocean Vessels and Pipeline Considerations

Shippers negotiate rates in the open market based on contract length, shipment frequency, and shipment volume. Draft restrictions in the Gulf of Mexico limit ocean vessel sizes and their capacities to Aframax class tankers, which carry a maximum of 70,000 tons. About 464,286 barrels of Boscan crude equates to 69,452 tons. Based on the API density, the calculations equate one ton of crude oil to 6.7 and 7.1 barrels of Boscan and Maya blends, respectively. To produce the same amount of asphalt with lower density Maya crude, BIND Inc. must purchase 973,054 barrels, which weighs 137,437 tons, and require two Aframax tankers from southern Mexico. The average charter rate for Aframax tankers operating the so-called "TD9" route in the Gulf of Mexico was $13,250 per day (Weber 2012). The average total trip time, including transloading for Venezuelan and Mexican tanker trips, respectively, were 15 and 11 days (CRSL 2012). These equated to tanker transport costs of 43¢ and 30¢ per barrel for Bocan and Maya crude, respectively. Adding diluents for long-haul pipeline transport swells the volumes for Boscan and Maya crude to 663,265 and 1,390,077 barrels, respectively. The pipeline cost from the U.S. Gulf Coast to northern destinations must include the necessary dilutes to allow the oil to move at speeds between two to eight miles per hour. Incidentally, the transloading operation that pumps oil from one storage tank to another does not require diluents.

The decision variables of Volume (Ton) in Table 1 indicate the amount of crude oil shipped as 663,265.3 barrels for the least cost solution. Until May 2012, the Enbridge Seaway pipeline was the only option for northbound crude oil transport from Houston, Texas to distribution markets in Cushing, Oklahoma. The company reversed this pipeline direction to move a glut of crude stored in Cushing to refineries in the south (Daniel, Monaco and Bird 2012). The steady increase in Bakken and Canadian oilfield production contributed to this buildup in Cushing. Although this option is no longer available, it serves as a reference for the sensitivity analysis. The average published tariff was $27.17 per cubic-meter, which equated to about $4.32 per barrel (Figure 4a). Local pipelines are the only routes available to move crude oil from Cushing to the facilities near Tulsa, Oklahoma. The average tariff was 22 cents per barrel. Adding dilutes to move heavy oil transported by rail or truck increased the effective cost per barrel to 32 cents. Moving the lighter grade Western Texas Intermediate (WTI) from domestic sources does not require dilute, hence the cost was 22 cents per barrel (Figure 3).

TABLE 1 Decision variables for the scenario analysis

	Type	Mode	Volume (Ton)	Objective Coefficient ($)
Venezuela	Boscan	Sea*	0	0.43
		Barge**	0	12.10
		Rail-CP*	0	19.92
		Rail-CN*	0	19.29
		Truck**	0	12.46
		Truck**	0	11.52
		Pipeline + Dilute*	0	3.08
		Local Pipeline*	0	0.32
	Boscan-Diluted	Sea*	663265.3	0.43
		Seaway Pipeline*	663265.3	4.32
		Local Pipeline*	663265.3	0.32
Mexico	Maya	Sea*	0	0.3
		Barge*	0	11.423
		Rail-CP**	0	18.81
		Rail-CN**	0	18.21
		Truck**	0	11.77
		Truck**	0	10.89
		Pipeline + Dilute*	0	3.08
		Local Pipeline*	0	0.32
	Maya-Diluted	Sea*	0	0.3
		Seaway Pipeline*	0	4.32
		Local Pipeline*	0	0.32
Canada	WCS-Dilbit	Keystone Pipeline*	0	4.36
		Local Pipeline*	0	0.32
		Mainline-Lakehead*	0	3.97
		Spearhead Pipeline*	0	2.15
		Local Pipeline*	0	0.32
	WCS	Rail-CP**	0	14.77
		Truck**	0	11.60
		Spearhead Pipeline*	0	3.08
		Local Pipeline*	0	0.32
	CLB-Dilbit	Mainline-Lakehead*	0	4.26
		Spearhead Pipeline*	0	2.15
		Local Pipeline*	0	0.32
	CLB	Rail-CN**	0	14.90
		Truck**	0	10.73
		Spearhead Pipeline*	0	3.08
		Local Pipeline*	0	0.32
U.S.	WTI	Local Pipeline*	0	0.22

* Transportation unit cost per barrel
** Transportation unit cost per ton-mile.

By inspection (Figure 4a), Seaway Pipeline dominates the total transportation cost of the shipment of Boscan-Diluted from Venezuela. However, the cost of using the Seaway Pipeline becomes almost flat after reaching the required demand at 3.2 million barrels per day. At around two million barrels, the cost via the Seaway Pipeline exceeds the cost by multimodal transport via local pipelines and ocean shipping from Venezuela. The Seaway pipeline from Houston, TX is the most price sensitive mode in this route (Figure 4a), which means that any small disruption on the link will result in substantial cost increases for shipments.

Ocean Vessel (Tanker) and Inland Waterway (Barge) Considerations

The ports of entry for southern sources depend on the mode options available at the time to haul products north. Vessels will deliver crude oil to ports in Houston, Texas, for injection into northbound pipelines. When gathering or local pipeline capacity is not available or too expensive, tankers can also deliver crude oil to ports in New Orleans, Louisiana for line-haul north by barge or rail. This scenario analysis incorporates the possibility that growing demand for specialty oil transport such as heavy crude and asphalt products will encourage large barge companies on the Mississippi to consolidate or collaborate to increase their capacity for transporting liquid products. Barges enter the Mississippi waterway system at Harvey Lock and must then travel about 930 miles north to the BIND transloading facilities located on the Arkansas River. From the river entrance, barges navigate 130 miles north to Baton Rouge, 72 miles to Old River, 280 miles north on the Mississippi, then 448 miles west on the Arkansas River. The last leg is on the McClellan-Kerr Arkansas River System, which is accessible to ocean commerce all year round. The average posted charter price for crude oil tank barge transport on the Mississippi River in 2012 was 8.7 cents per ton-mile (Kirby 2012). At this rate, the equivalent transport cost per barrel was between $11 and $13 for Latin American Crude (indicated as Sea-CP-TR-PL for Venezuela and Sea-CP-TK-PL for Mexico). The transport times are between 14 and 20 days, based on the length of the journey and the transloading duration.

The sensitivity analysis (Figure 4b) indicates that barge cost is sensitive to demand increases because of high variable cost. Conversely, economies of scale and the availability of large port or offshore docking accommodations reduce the rate of variable cost increases for ocean vessels. Once the demand arrives at about 8.5 million barrels, the barge costs begin to dominate the total transportation cost. Because of the limited capacity of barges relative to tankers, the freight rate per barrel (ton-mile equivalent) is much higher than for sea, and shows a greater degree of variations. Barge options are still vulnerable for shipments from Venezuela and Mexico. They do not contribute significantly to the total cost until the demand reaches 8 million barrels. However, their degree of variations needs more attention because of the potential for service disruption due to river spills, water levels, and weather conditions.

Keystone and Local Pipelines Considerations

The posted rate for the TransCanada direct pipeline service was $4.36 per barrel to move diluted heavy crude from the Hardisty terminal in Canada to the Cushing terminal. It is currently the only direct pipeline service available, and may no longer be an option for additional shipments because competing Bakken oilfield shippers has already contracted nearly all of its capacity for several years. The posted rate was $4.26 per barrel for the Enbridge connecting service to move diluted heavy crude from the Edmonton Cold Lake Blend (CLB) terminal with a connection through Flanagan to Cushing, arriving 12 days later. The posted rate for purchasing Western Canada Select (WCS) from the Hardisty terminal was $3.97 per barrel, and it arrives 3 days sooner because the distance is about 128 miles shorter.

TransCanada offers direct pipeline service from Hardisty, Alberta in Canada to Cushing via its existing 1816-mile *Keystone* pipeline. However, takeaway demand from the Bakken region has already contracted its available capacity of 591,000 barrel-per-day for 18 years (CAPP 2012). The company proposed to build a shorter 1,700-mile pipeline with a capacity of 830,000 barrel-per-day from Hardisty, Canada to Steele City, Nebraska, connecting to the existing leg that moves crude oil to Cushing. The U.S. State Department rejected this proposal in January 2012 because of environmental issues (Platts 2012). The posted rate was $4.36 per barrel to move diluted crude oil to Cushing when capacity is available on the existing TransCanada pipeline. The final distribution channels to the BIND facilities near Tulsa are via the local pipelines as described previously.

The 650-mile Enbridge Spearhead pipeline is the only option available for long-haul crude oil transport from the Chicago area to markets in Cushing (Figure 3). The pipeline injection point is at Flanagan, which is about 100 miles west of the Class I railroad company terminals near Chicago. This pipeline has a capacity of 190,000 barrels per day. The average posted rate was $2.15 per barrel. Adding diluents at the injection point to move undiluted crude transported by rail or truck increased the effective cost per barrel to $3.08. Enbridge announced plans to build another pipeline in parallel to the Spearhead to increase its route capacity by another 585,000 barrels per day by 2014.

Heavy crude oil is available for purchase and shipment from one of two terminals in western Canada. The Cold Lake Blend (CLB) is available at the Edmonton terminal. The Hardisty terminal sells a slightly heavier blend, the Western Canada Select (WCS), which is preferable for bitumen production. Options for shipment across the border to the United States are two pipeline and two rail carriers. Moving crude by pipeline requires diluents, which increases the volume, weight, and processing costs as previously described. One pipeline company provides direct service to Cushing but its capacity is constrained due to increasing take-away demand from the Bakken oilfields.

The other pipeline carrier has similar capacity but provides service via a connection in Flanagan. However, with the growing U.S. demand for lower cost crude from Canada, this capacity is already committed for 10 years into the future (CAPP 2012). Therefore, CN and CP elected to fill the growing demands by providing tank car service that moves undiluted heavy crude from Canadian terminals to markets near Chicago. Trucks may then provide connecting services to the pipeline injection point in Flanagan as previously described for rail movements that originated in the south.

Enbridge offers connecting pipeline service from terminals in Edmonton or Hardisty, Alberta, in Canada to Flanagan via its Mainline and Lakehead systems, and then to its Spearhead system that terminates in Cushing. The bottleneck is the Spearhead capacity of 193,000 barrels per day (CAPP 2012). The recent direction reversal of their *Seaway* pipeline to move oil from Cushing to refinery distribution pipes in Houston has essentially created long-haul pipeline service from Canada and the Bakken to U.S. Gulf Coast refineries. The Spearhead system is the bottleneck for that route. The owner recently announced proposals to build new pipelines parallel to both the Spearhead and Seaway systems to increase capacity for southbound oil movements. The current Seaway capacity of 150,000 barrels-per-day is a bottleneck that will likely remain until additional options, such as the TransCanada XL pipeline, becomes available.

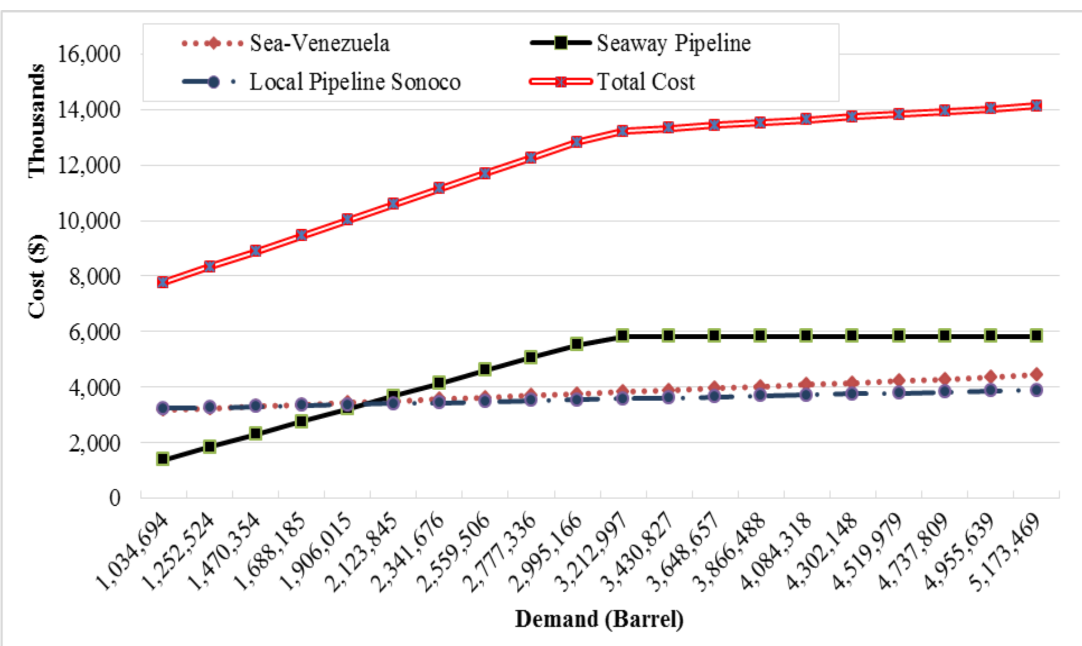
Meanwhile, railroad companies are alleviating these bottlenecks by hauling crude oil from terminals near the Canadian oil sands to their Chicago terminals, and then potentially through to Gulf Coast refineries. The analysis indicates that the existing pipeline options limit the shipment capacity to BIND to approximately 5.3 million barrels per day, based on the cost sensitivity for the selected period (Figure 3c).

Comparison of Scenarios

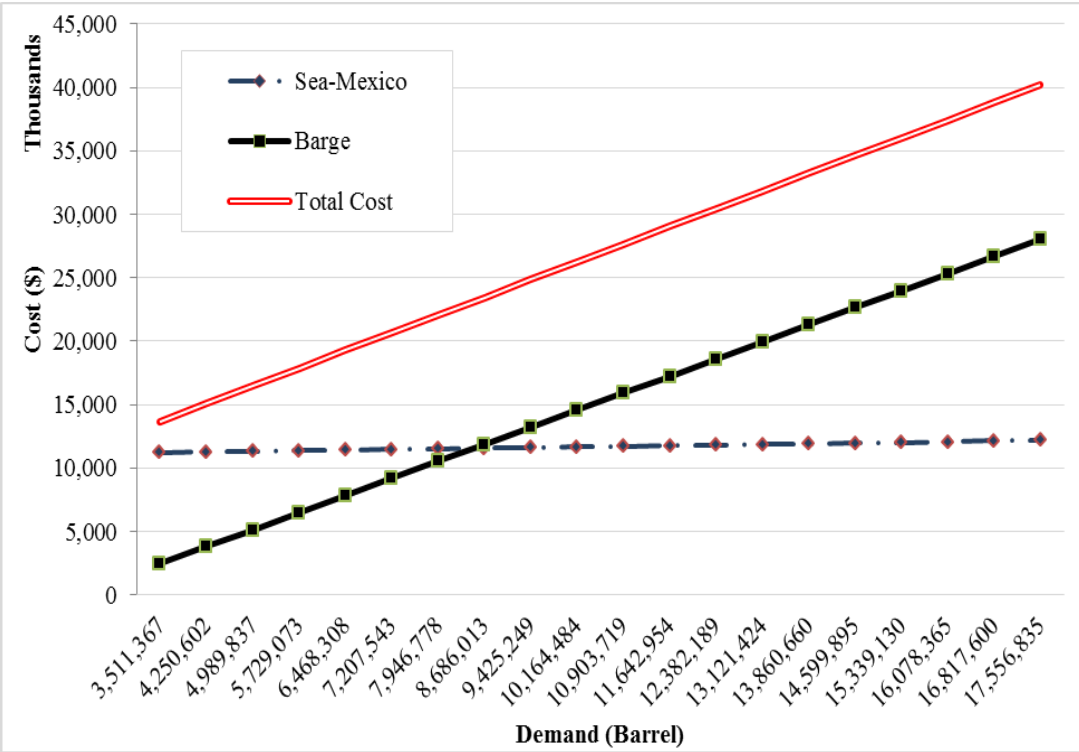
The high bitumen yield from Boscan crude makes it the least cost option for asphalt feedstock import. In spite of diluting the crude oil for shipping through pipelines, the total cost of importing Boscan crude oil from Venezuela remains lowest. However, indirect factors such as a strained political relation, the fear of corruption, and the risk of price increases from weather related delays, decreases the attractiveness of that option. The sensitivity analysis for this scenario indicates that when the demand surpasses one million barrels, the total transportation cost from Venezuela will exceed the Canadian options that use pipelines (Figure 4d). The scenario analysis also indicates that Mexican oil would be the least expensive option.

When the demand for asphalt feedstock exceeds one million barrels of crude oil per year, then the direct pipeline option via the existing TransCanada XL facilities becomes the least cost option. However, when the demand reaches five million barrels, the lack of pipeline capacity and delays in building additional capacity begins to weigh heavily against this option. The next lowest cost options become pipeline transfers using the Enbridge facilities. However, the heavy competition for this capacity to move Canadian and Bakken oil to southern markets may also present risks of price increases and delays. Rail options from Canada become the third lowest in transportation cost per barrel. A potential advantage of selecting rail under these circumstances would be the possibility that railroads would be more likely to negotiate lower prices in order to fill their excess capacity and to continue growing that portion of their business.

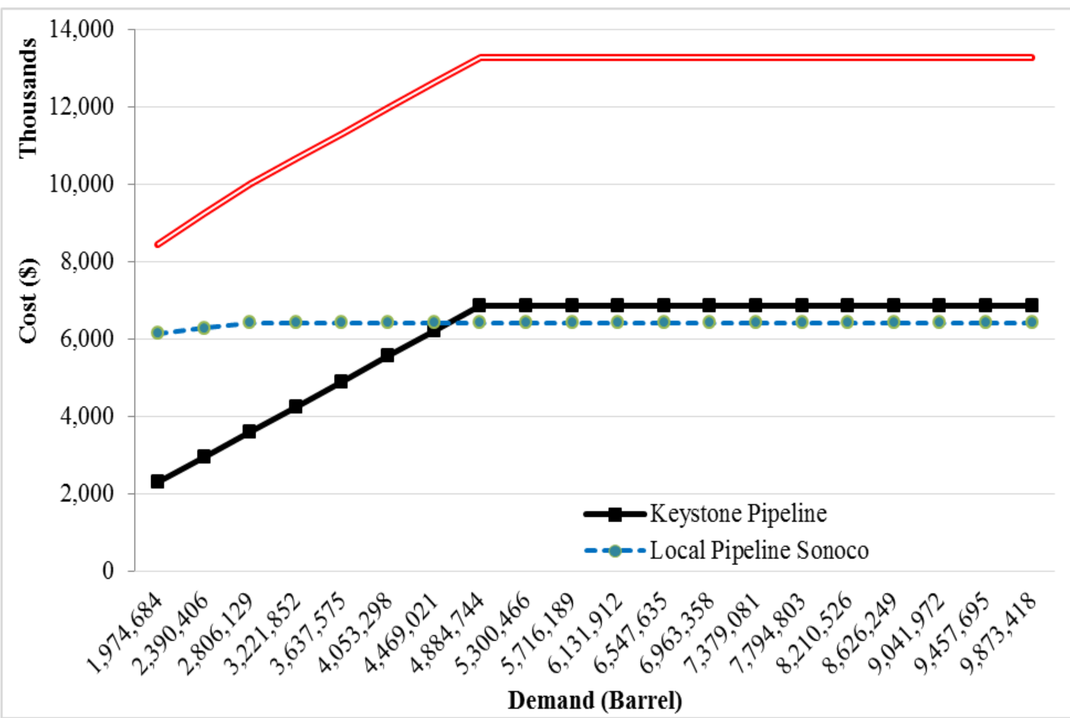
Upon arrival in the U.S., BIND Inc. must contract with trucking companies to transload the oil from a rail terminal near Chicago, and move it to the Enbridge pipeline injection facilities in Flanagan. Enbridge must then add the appropriate amount of diluent needed to move the heavy oil from Flanagan via pipelines to their storage facilities in Cushing. In this scenario, local pipelines must then move the diluted heavy oil to its final destination for storage in tanks located in Catoosa, Oklahoma. A significant disadvantage of this option is that the oil must utilize the Enbridge Spearhead pipelines that represent a bottleneck for the last long-haul leg. The hybrid rail-pipeline option involves transloading to trucks for a short-haul connection, thereby increasing risks. Another major disadvantage is that tri-modal movements by rail, truck, and pipeline will more than double the transport time relative to pipeline-only options.



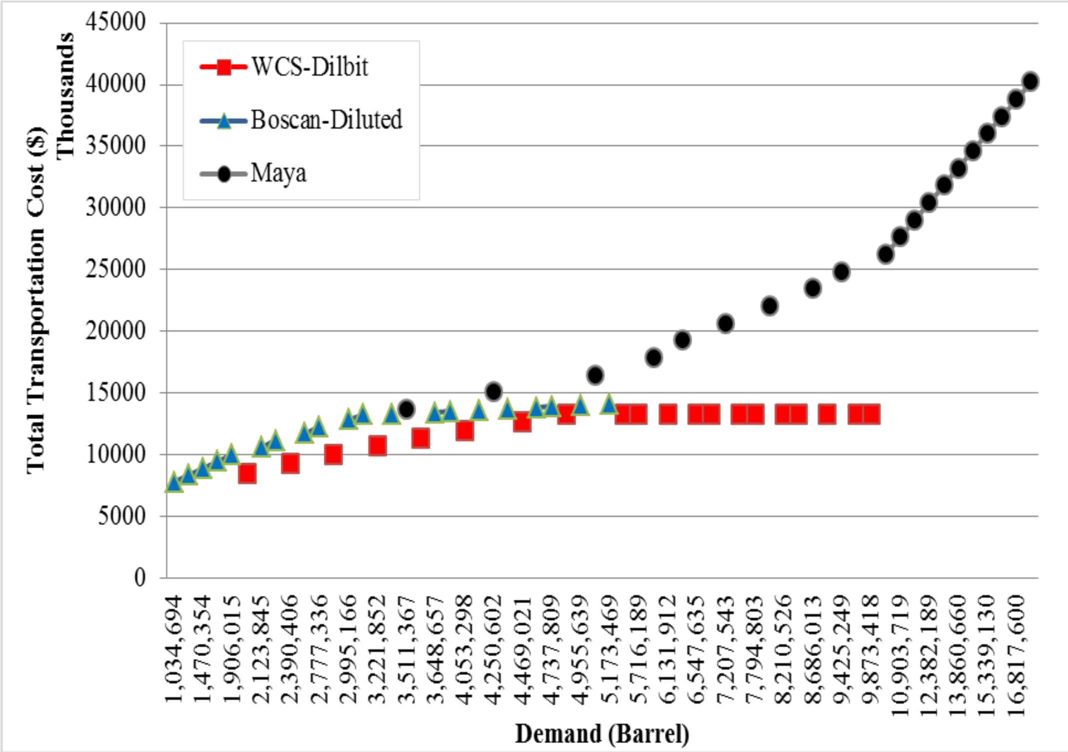
a) Sea-Pipeline from Venezuela; Sea-Pipeline (Boscan-Diluted from Venezuela) - total cost of transportation



b) Sea-Barge from Mexico; Sea-Barge (Maya from Mexico) - total cost of transportation



c) Direct pipeline connections from Canada through Keystone and local pipelines (WCS-Dilbit)



d) Comparison of the three scenarios: ocean-pipe for Boscan-Diluted, ocean-barge for Maya, and all pipeline for WEC-Dilbit

FIGURE 4 Scenario-based sensitivity analysis.

SUMMARY AND CONCLUSIONS

This paper presented a multimodal, multi-commodity, and multi-sourcing model to analyze and guide the shipment choices for crude oil to produce bitumen at an existing or a potentially new refinery location in the United States. The model utilizes simplified constraints to demonstrate the overall shipment cost sensitivity to changes in demand and multimodal options.

Numerous factors can cause changes in the demand and the availability of various mode options. Hence, the analysis highlights various potential issues as well as opportunities. The U.S. Gulf Coast currently accounts for more than half of the U.S. refining capacity (Nerurkar 2012). The growing demand to move crude oil from the Bakken oil fields to Gulf Coast refineries has used nearly all of the pipeline capacity currently available (Johnson 2012). The possibility of a new TransCanada XL pipeline promises to alleviate some of the capacity issues, but only for north-south product movements. In the meanwhile, railroads are attempting to fill the gap but shippers do typically pay a higher rate for such non-pipeline options.

Options that use tankers and barges are also vulnerable to supply chain disruptions. For instance, hurricanes in the Caribbean have periodically disrupted oil supplies to U.S. Gulf Coast refineries and caused significant price increases. The last major hurricane affected more than one million barrels per day of production capacity (OPEC 2012). Explosions at the Venezuela Amuay and Mexico Madero refineries spurred greater competition for oil from alternative sources. Extremely cold weather in the north may also disrupt supplies from Canadian sources.

Hence, the importer must account for these risks as well as for sudden price changes and transport delays due to other extreme events such as terrorist threats.

In addition to the supply and demand dynamics described, government actions may spur other changes. Given the complexity of such multimodal supply chain scenarios, this analysis provides researchers with a basic framework to analyze and model alternative mode choices for existing refinery locations, to evaluate the sensitivity of various factors involving the location of new production facilities, and to assess potential opportunities and threats.

Future research will develop a more detailed model to account for actual demands in the downstream supply chain at the state and national levels. The analysis will simulate other facility locations to assess the cost sensitivity under similar market conditions, and include the cost of other risk factors that are not necessarily a direct function of shipping rates.

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