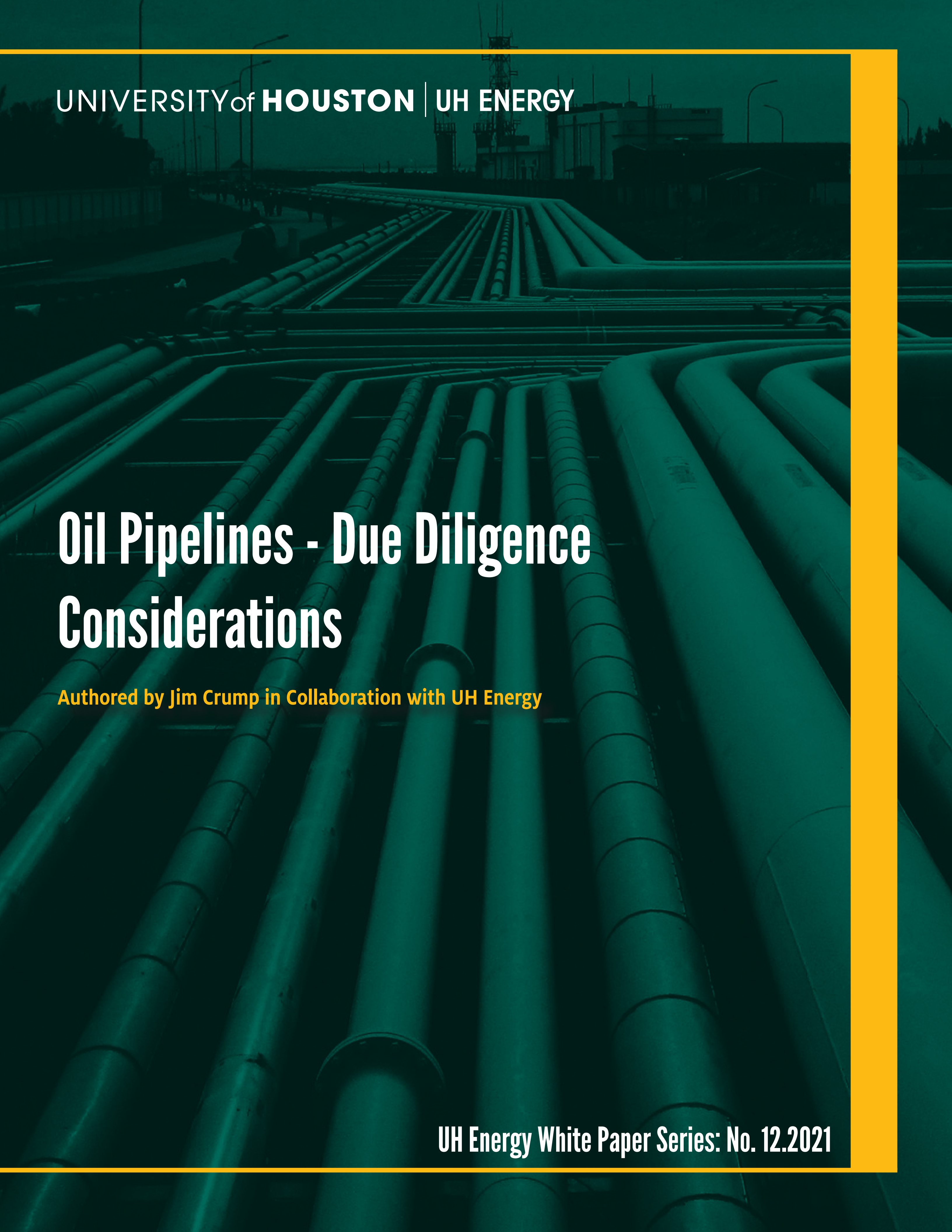

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Oil Pipelines - Due Diligence Considerations

Authored by Jim Crump in Collaboration with UH Energy

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About the Author

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Executive Summary

The U.S. crude oil pipeline network, a key component of energy infrastructure, has prompted vigorous public debate. Crude pipelines cross extensive land areas and waterways; environmentalists point to potential harm to land and water due to crude spills. Furthermore, refineries process crude to produce transportation fuels; these fuels produce greenhouse gases in transportation services, contributing to global warming. Hence environmentalists express concern that the construction of pipelines that extend the existing pipeline network, as well as the continued operation of existing pipelines, should be questioned on the basis of environmental harm to land and water as well as climate risk.

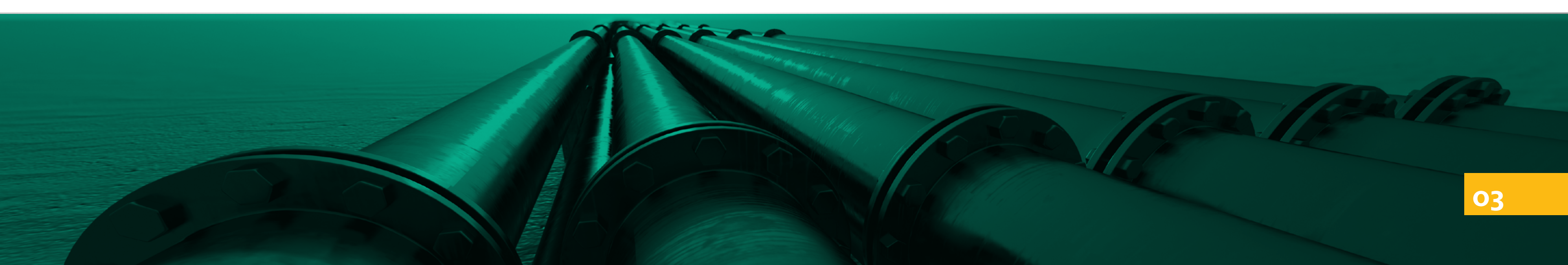
This study references a particular pipeline, the Dakota Access Pipeline (DAPL), to bring to light these environmental, climate, and safety concerns in specific terms. Made operational in 2017, the DAPL connects the Bakken basin to an oil terminal near Patoka, Illinois. The DAPL transits an extensive land route, about 1,170 miles, crossing waterways including the Missouri and Mississippi rivers. Operating steadily at capacity (750,000 barrels/day), the DAPL would deliver crude volume equivalent to roughly 3-4% of total crude and petroleum products supplied to the U.S. in 2019 (20.5 million barrels/day, with derived transportation fuels generating roughly 2.4 billion metric tons/year of greenhouse gas emissions – U.S. Energy Information Administration).

Elimination of this crude volume could be regarded as protecting environmental resources and mitigating safety and climate risks if indeed DAPL closure were to reduce crude transport volumes, crude refining, and petroleum fuel usage. Would halting the operation of the DAPL or other oil pipelines reduce crude oil consumption and avert these risks? Where does responsibility lie for due diligence efforts to investigate the environmental consequences, safety risks, and climate impact related to pipeline operation? This inquiry adopts a balanced viewpoint, offering a due diligence framework whose responsibilities lie with both industry participants and environmental interest groups, addressing these areas of focus:

• Pipeline and alternate modes of crude transport are reviewed; rail is the dominant alternative to pipe transport for crude produced in inland basins.
• Environmental risks and safety risks are evaluated for pipe and rail transport.
• Transport by pipe and rail from major producing basins, the Bakken, Permian, and Eagle Ford, is reviewed. These formations accounted for about 59% of US crude production in 2019.
• The cost of rail transport from these basins is analyzed. Rail transport costs exceed pipe transport costs; therefore, reduced crude consumption might be expected as a consequence of a shift from pipe to rail if pipeline transport is curtailed.
• However, an analysis of the elasticity of crude demand to refinery-delivered cost indicates very limited demand response to changes in crude transport costs. A statistical model indicates that the estimated cost increase would have slight impact on crude demand, with expected shift of crude transport from pipe to rail transport, almost barrel-for-barrel.

Given the risks of oil transport by both pipe and rail, this due diligence framework recommends investigative tasks for both the pipeline industry and environmental groups. Balanced due diligence, with participation by both industry and environmentalists, can lead to more disciplined and therefore more effective outcomes with respect to the environment, public safety, and climate risk.

This study deals with the transport of crude from the three major U.S. basins. Conclusions are therefore limited to crude transport within the U.S. from these inland sources. An expanded scope of information would be needed to draw reliable conclusions concerning crude transported to the U.S. from other sources in Canada, Latin American, or other global regions.



A. Oil Transported by Pipe and Rail

A crude oil pipeline network of about 84,000 miles serves the U.S. (lower 48 states), delivering about 95% of the 12.3 million barrels per day of U. S. production in 2019. A rail network of about 140,000 miles serves the U.S., more extensive in regional coverage than oil pipelines. At its peak in 2014, rail shipment accounted for about 11% of U.S. production, declining to about 5% in 2019 because of the commissioning of new oil pipelines, mainly for ex-Permian production. Rail operations typically rely on road transport by tanker trucks for limited, short-haul movements to deliver crude to rail loading locations.

Rail is the dominant alternative to pipe transport from inland sources. Rail is of particular importance if crude supply cannot be served by available pipeline infrastructure and if the matching of crude quality to that of a U.S. producing basin is required, if contractual or other business considerations motivate crude purchase from a U.S. basin, or if anticipated crude supply is transient.

Of course, rail is not the only alternative in the management of the crude supply chain. Supply analysis may lead to marine delivery, from offshore sources, as the economically favored, least-cost alternative for coastal refiners. A significant proportion of U.S. refineries are coastal facilities that can accept marine delivery. Thus, rail delivery stands as an available alternate mode for crude transport, dominant for inland sources, but not an exclusive supply alternative.

B. Overview of Findings

Available information indicates that both pipe transport and rail transport create risks. Two reports published by U.S. government agencies provide information on environmental risks due to transport-related oil spills: U.S. Rail Transportation of Crude Oil (Congressional Research Service, December 2014) and a Report on Shipping Crude Oil by Truck, Rail, and Pipeline (Pipeline and Hazardous Materials Safety Administration – PHMSA, March 2019).

The 2014 report reviewed spill volumes during 1990 – 2007, segmenting the study into three six-year sub-periods. The authors found that the normalized rail-related spill volume (normalized volume spilled by volume transported) was greater than pipe-related spill volume during 1990 – 1995 while pipe-related spill volume was greater during 1996 - 2001 and during 2002 – 2007. The report acknowledged a degree of ambiguity in the interpretation of these statistics with respect to environmental harm, citing the importance of spill location and noting that significant harm can result from “a minor spill in a populated area or sensitive ecosystem.”

The PHMSA report explained that rail-related spill volume was higher than pipe-related spill volume due in part to “high-impact incidents” in certain years, notably in 2008 and 2013. For example, in 2008 a significant spill occurred due to the derailment of oil-bearing railcars near Oklahoma City; in 2013 major rail spills occurred near Aliceville, Alabama and Casselton, North Dakota. The proximity of these derailments to population centers substantiates the importance of location, as highlighted in the 2014 study.

The PHMSA report of 2019 also compared transport modes with respect to public safety, noting that, “If incident rate is used as a proxy for safety, shipping by pipeline would be considered safer than by rail . . .” Relating safety incident counts to shipped crude during the study period, the report noted, “For pipeline transport, an incident occurred approximately once every 720 million gallons (17.1 million barrels) of crude oil shipped; for rail, an incident occurred approximately once every 50 million gallons (1.2 million barrels) of crude oil shipped.”

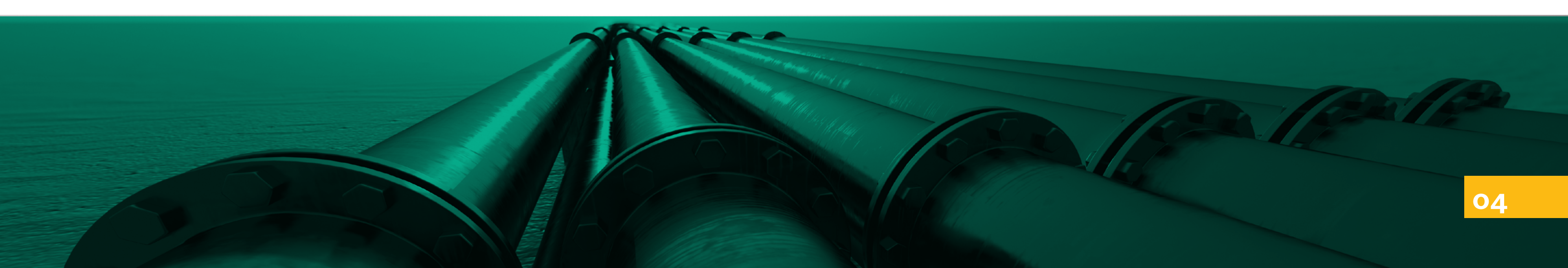
Crude Spill Rates

	Pipeline	***Rail***
% Spilled, 2007-2016 average (percentage of volume shipped)	0.0010%	0.0076%
Projected Spill Volume (in gallons) in 2019 based on total production of 12.3 MM barrels/day and exclusive transport by pipe or rail.	1,870,000	14,200,000

Figure 1. In 2019 PHMSA presented data for the period 2007 – 2017, with oil spill statistics indicating decisively smaller spill volumes for pipe compared to rail transport.

The PHMSA study also recognized ambiguity in the interpretation of “incident count”, citing the need for a clearer definition of incident severity and more consistent data gathering. The PHMSA authors recommended “additional study of modal comparisons using composite consequence metrics including spill data, incidents, and human consequences.”

Studies by private organizations have asserted the relative safety of pipeline transport with greater certainty. From a 2013 Manhattan Institute study that examined safety incidents during 2004 – 2009, “This paper compares the record of transport via pipeline to that of road and rail. . . pipelines are the safest option, (resulting in) fewer injuries than road or rail.” US News & World Report concluded, from a review of safety incidents during 2007 – 2016, that “Alternate modes (rail and truck) will continue to be part of the energy infrastructure but from a safety perspective they both have higher incident rates than pipelines.”



These studies indicate that both transport modes, pipe and rail, create environmental and safety risks. The weight of evidence in the more recent reports might suggest that pipeline transport is the lower-risk mode. However, thoughtful review of these reports leads to two more substantive conclusions. First, statistics that simply state spill rates in terms of oil volume or safety risks in terms of event count may be misleading because neither measure captures incident severity.

Second, the importance of the location of environmental or safety incidents implies that the chosen route of transport for either pipe or rail significantly influences transport risks. Routing decisions will be critical in our assessment of due diligence tasks for pipeline proposals.

C. Rail Costs

Rail costs are key to this study. Rail rates were provided by Escalation Consultants, rail transport advisors, using Escalation's Rail Cost Control (RCC) program. Operating railroads submit rates to the Surface Transportation Board (STB), the U.S. government agency that oversees railroads; the STB compiles this data and publicizes rail rates in the Public Use Waybill Sample; Escalation's proprietary RCC program draws data from the Waybill Sample and summarizes cost information in useful formats. Public information concerning rail rates is limited for proprietary reasons; Escalation utilizes a public source (the Waybill Sample) to access extensive cost data.

Escalation provided 2019 rail costs for three major shale formations: Bakken, Permian, and Eagle Ford, producing approximately 1.4, 4.4, and 1.4 million barrels/day respectively, a total of 7.2 million barrels/day, about 59% of the 12.3 million barrels/day of 2019 U.S. crude production. Other formations including the Barnett, Haynesville, and Marcellus are notable fossil sources but overwhelmingly produce gas, little oil.

"Class 1" railroads with annual revenues above $490 million generate the bulk of cost data; 'short line' railroads, a smaller proportion. Seven Class 1 railroads serve the U.S.: Burlington Northern & Santa Fe and Union Pacific (serving mainly western U.S.); CSX Transportation and Norfolk Southern (eastern U.S.); Kansas City Southern (mid-continent); and two Canadian railroads, Northern and Pacific.

The importance of this cost information? Transport of crude by rail rather than pipelines increases the cost of transport of crude oil to refineries; our later cost analysis indicates that average rail rates from the three major basins (about $7.40/barrel – Escalation Consultants) are about 12% of average crude costs for the January 2000 – December 2019 period (about $62/barrel, WTI). Further analysis examines the relationship between crude transport cost and fuel demand.

D. Rail Costs – Crude From the Major Producing Basins

The graphs that follow present 2019 rail rates provided by Escalation Consultants, specialists in rail transport cost analysis, first ex-Bakken, then ex-Permian and Eagle Ford combined.

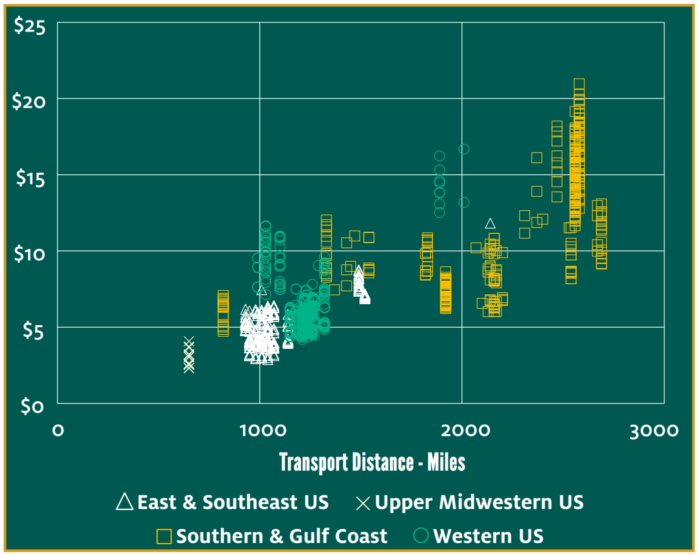


Figure 2. Rail Transport Costs, ex-Bakken ($ per barrel)
Data generated using Escalation Consultants' Rail Cost Control (RCC) program.

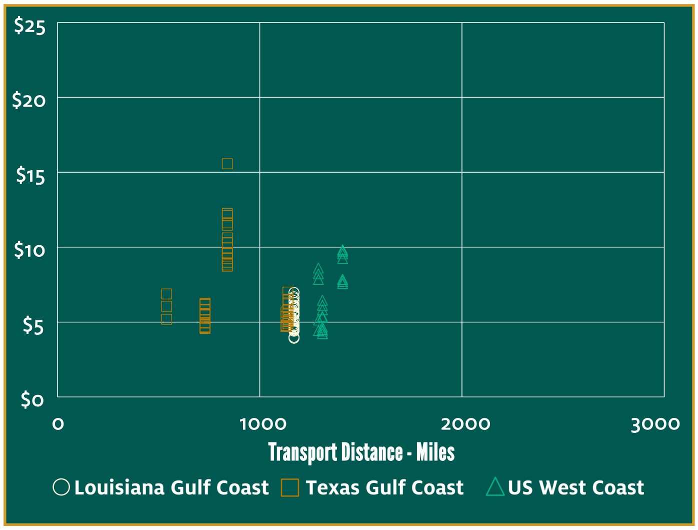


Figure 3. Rail Transport Costs, ex-Permian and Eagle Ford ($ per barrel).

The table below indicates a high proportion of ex-Bakken crude transported by rail (about 22%); a much smaller proportion of Permian plus Eagle Ford crude; average rail rate, about $7.40 per barrel.

To summarize delivery of crude from the major basins, reference to the Petroleum Administrative Districts for Defense (PADDs) is useful: PADD 1 (East Coast), PADD 2 (Midwest), PADD 3 (Gulf Coast), PADD 4 (Rocky Mountains), PADD 5 (West Coast); the Bakken is located in PADD 2 and the Permian and Eagle Ford are located in PADD 3. Using PADD designations to visualize crude movements, 34% of PADD 2 crude (Bakken region) was shipped to PADDs 1, 3, and 5 in 2019. Placements outside of PADD 2 were of this magnitude owing largely to competition in PADD 2 from Canadian crude.

In contrast, only about 17% of crude sourced in PADD 3 (Permian and Eagle Ford region) was shipped to other PADD regions given relatively modest, short-haul pipeline distances to coastal refining and export facilities as well as the large share of U.S. refining capacity (more than 50%) on the Gulf Coast. Appendix I presents 2019 estimates of crude shipments from the three major formations based on movements by PADD.

The smaller proportion of rail-transported Permian and Eagle Ford crude compared to Bakken crude follows extensive development of pipelines for crude takeaway. The Permian and Eagle Ford are 'heavily piped' compared to the Bakken due to the recent construction of pipelines supplying gulf coast crude markets. Significant pipeline buildout for the Eagle Ford basin began with the startup of the Eagle Ford Pipeline (2012, with 2015 expansion), The Kinder Morgan Crude and Condensate Pipeline (2012), and the Double Eagle Pipeline (2015), providing aggregate capacity of about 1 million barrels/day, primarily for destinations in the Corpus Christi and Houston areas.

Pipeline buildout for Permian crude has included the Longhorn Pipeline (2013), the BridgeTex (2014), Midland-to-Sealy (2018), Gray Oak and Cactus II Pipelines (2019). The EPIC, Midland-to-Echo, and very large Wink-to-Webster Pipeline (1.5 million barrels/day) began operation in 2020. Principal destinations for Permian crude are in the Houston area, with some deliveries to Corpus Christi and Louisiana. The total capacity for the above pipelines carrying Eagle Ford and Permian crude is roughly 6 million barrels/day. Appendix II offers further detail, including pipeline developers, startup years, transit miles, destinations, and pipeline capacities. Returning to the graphic presentation of 2019 rail rates by Escalation Consultants, the "vertical alignment" of costs at specific transport distances is notable. Cost "spreads" at equivalent distances are due to different outcomes of negotiations between shippers and railroads for the same transport routes. In some cases, shippers bargain through intermediaries rather than directly. Direct bargaining is normally the lowest-cost alternative, routine for large shippers.

Summary: ex-Bakken, Permian & Eagle Ford (2019)

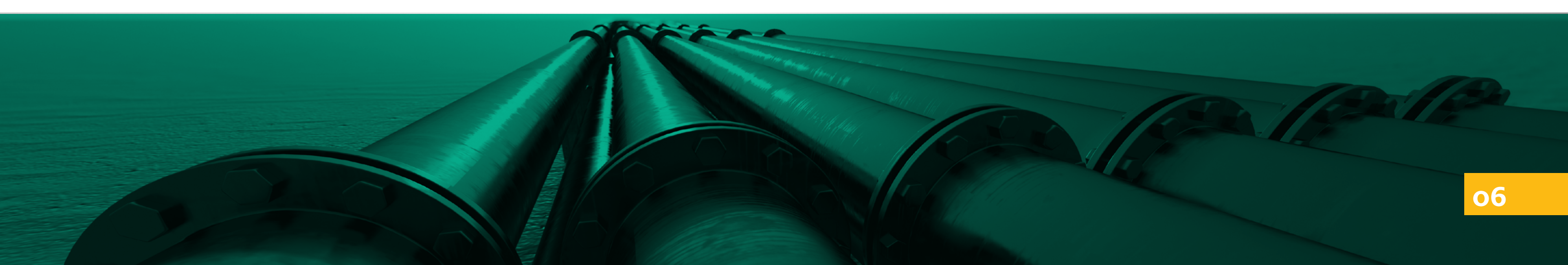
	Bakken	Permian + Eagle Ford	Total
Crude Transport by Rail (thousand bbl/day)	314	48	362
Production (thousand bbl/day)	1,440	5,740	7,200
Fraction of production shipped by rail	22%	1%	5%
Avg rail transport cost ($ per barrel)	7.58	6.39	7.42

Figure 4. Data sourced from Escalation Consultants' Rail Cost Control (RCC) program.

Differences in rail shippers' negotiation strategies matter as well. The size of negotiated spend is a significant factor. Shippers may differ in the size of spend due to differences in the degree of commodity consolidation for bargaining. It is normally advantageous to maximize negotiated spend by consolidation across crude sources and destinations and also across liquid commodities, including chemicals, that move by rail. Two offsetting considerations must be addressed if crude oil is displaced from pipe to rail. First, pipeline transport cost is avoided; second, avoided pipeline cost is offset by rail-related charges that are not included in reported Waybill Sample transactions and that normally are not replicated in pipeline operations. The 2014 Congressional Study cited earlier, U.S. Rail Transportation of Crude Oil, followed by a 2017 Strada study, Economic, Environmental, and Safety Impacts of U.S. Oil and Gas Transport, estimated ex-Bakken pipeline costs averaging approximately $5/barrel, and interestingly, estimated total rail costs at $10-15/barrel, with a difference (total rail cost in excess of pipeline cost) of approximately $7.50, comparable to the rail cost average of $7.40 for the three major basins provided by Escalation Consultants.

If crude moves by rail, a sequence of transport steps and labor-intensive activities add to the rail rates reported by Escalation Consultants that are drawn from the STB Waybill Sample. An approximation of these costs, not available publicly, is outlined in Appendix III based on information provided by industry consultants, as referenced in the Appendix. Summarizing these activities for unit trains (typically 80-120 railcars), which dominate crude rail movements:

Rail loading:
• Crude is shipped from lease sites to rail loading tankage (typically by truck, some movements are by pipeline);
• A unit train is positioned for loading via a (top-loading) manifold, then manifold connections are attached manually, with progressive railcar re-positioning by a rail



locomotive;
• The loaded unit train is moved to a main rail line (typically a rail line for a Class I railroad).
Rail off-loading after transit to rail destination:
• Again, railcar positioning, for off-loading;
• Manifold connections are manually connected for bottom off-loading of each railcar, top manways opened for vacuum break; again, progressive repositioning by a rail locomotive is normally required;
• After off-loading, the empty train is transferred back to the main rail line for return to the rail loading facility in the producing basin.

Appendix III provides further explanation and offers an estimate of these rail-related loading/off-loading costs at about $3-4.5 /barrel, largely offsetting (as an approximation) the $5/barrel pipeline cost referenced above. This information is not publicly available for proprietary reasons; the Appendix also references the industry consultants who outlined the above activities and costs.

Pipeline transport typically provides facilities and services that significantly limit such costs. For example, large-scale systems feature gathering lines to transport crude to long-haul pipeline tankage, making truck movement unnecessary. Destination activities and costs are minimized when pipeline systems deliver to large 'liquidity hubs' (such as the Enterprise-owned ECHO terminal noted above and in Appendix II) with routine, high-volume and low-cost pipe transfer to refinery destinations. Direct rail delivery to such refinery destinations is difficult due to spatial design considerations alone.

Tankage and track installation for rail off-load typically require more than 150 acres, with pipeline connections to other terminals and to consuming refineries that often require staff-managed transfer.
Costs associated with the above rail activities are approximate and region-specific (given variations in costs including trucking and labor costs). In our estimate of the "spread' of rail costs over pipeline costs (the cost increment for rail over pipe transport), pipeline costs and the rail loading/off-loading costs noted above are offsetting, and comparable in magnitude.

Therefore, rail costs reported by Escalation Consultants (averaging $7.40/barrel) will stand as the approximate cost excess for rail over pipe costs of crude movement.
Of course, other economic considerations affect a crude shipper's planning basis for rail versus pipe transport. In both cases, facility abandonment prior to the end of useful life imposes a capital cost. In the case of rail, facility investments including tankage at loading and off-loading facilities, crude manifolds, rail track, and piping from off-load sites to terminals and consuming refineries are abandoned if producing basin performance falls; pipelines would face abandonment in such cases as well.

Other differences between rail and pipe would influence shippers' planning processes depending on specific business strategies. Railcar lease terms (typically seven years duration) offer flexibility compared to pipeline capacity participation; flexibility is favored when near-term business restructuring is anticipated.

Longer-term pipeline capacity interests would be advantageous for companies that rely on ratable operation of long-lived refining assets, offering increased certainty with respect to future supply costs. Refiners, particularly those that rely on long-range operational stability, speak of "dating" rail carriers but "marrying" pipelines. For such refiners, highly marriageable pipelines would be those delivering to proximate liquidity hubs and offering competitive long-term rates.

In addition, financial risk-management instruments of six- to eighteen-month duration are available to hedge forward pipeline rates for ex-Permian and ex-Cushing pipeline supply. Such financial tools offer refiners a further opportunity to manage future cost uncertainties.

As a further consideration, refinery operation is affected when storms interrupt rail service; pipeline operations are typically unaffected unless severe weather affects operations at a crude source or refinery destination. The expectation that severe weather could interrupt rail transfer is influenced by regional sourcing and refining conditions; rail interruption may occur when either gulf coast storms or extreme Midwest weather events affect rail routes.

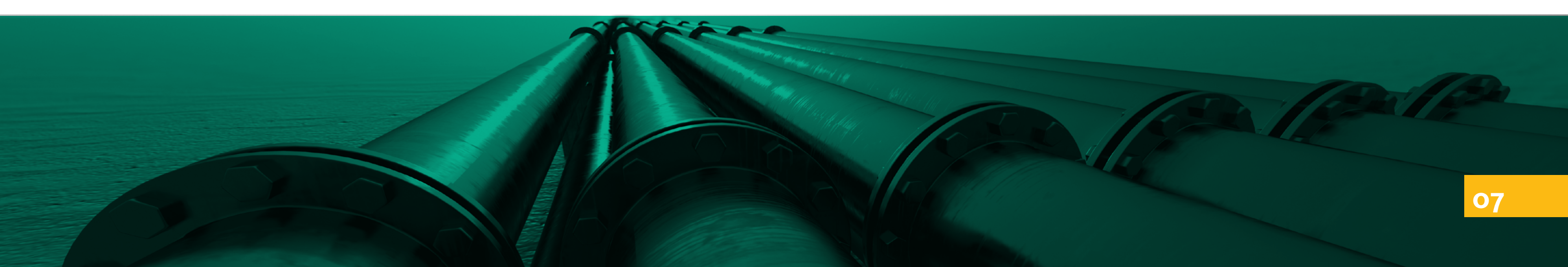
These issues - abandonment risk, short-term supply flexibility (or long-term supply certainty), pipeline tariff hedging, and weather effects - are influenced by regional factors and, within regions, by business-specific strategic plans.
Returning to a previous comment, the total operational cost difference between pipe and rail are estimated at $7.40/barrel for the statistical analysis of fuel demand response to crude supply cost that follows.

E. Crude Cost, Fuel Consumption

What would be the consequence of an increase in the average cost of crude oil delivered to U.S. refineries due to a shift of transported crude volume from pipe to rail? The graph below presents crude price (monthly WTI - $/barrel) and fuel usage (gasoline, diesel, jet, fuel oil – thousands of barrels per month) during the 20-year period beginning in January, 2000. Cursory inspection suggests that crude price can change (increase or decrease) by magnitudes far in excess of $7.40 per barrel without producing a significant change (decrease or increase, respectively) in fuel demand. For example:

• During June 2002 – June 2006, a crude price increase of about $30 per barrel was accompanied by a small but measurable increase in fuel demand; a price increase of comparable level during January 2010 – January 2014 coincided with a period of relatively stagnant, unchanged fuel demand.

• Periods of a dramatic decrease in crude price with only a slight response in demand are also apparent. Between January 2014



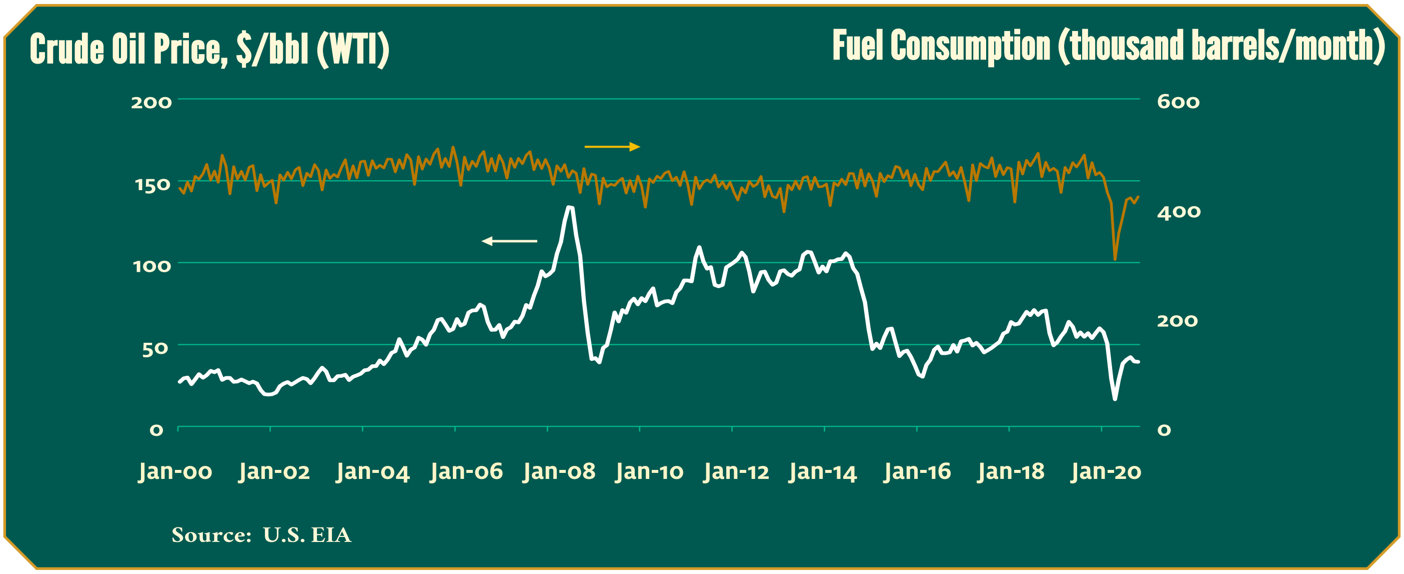


Figure 4. Data sourced from Escalation Consultants' Rail Cost Control (RCC) program.

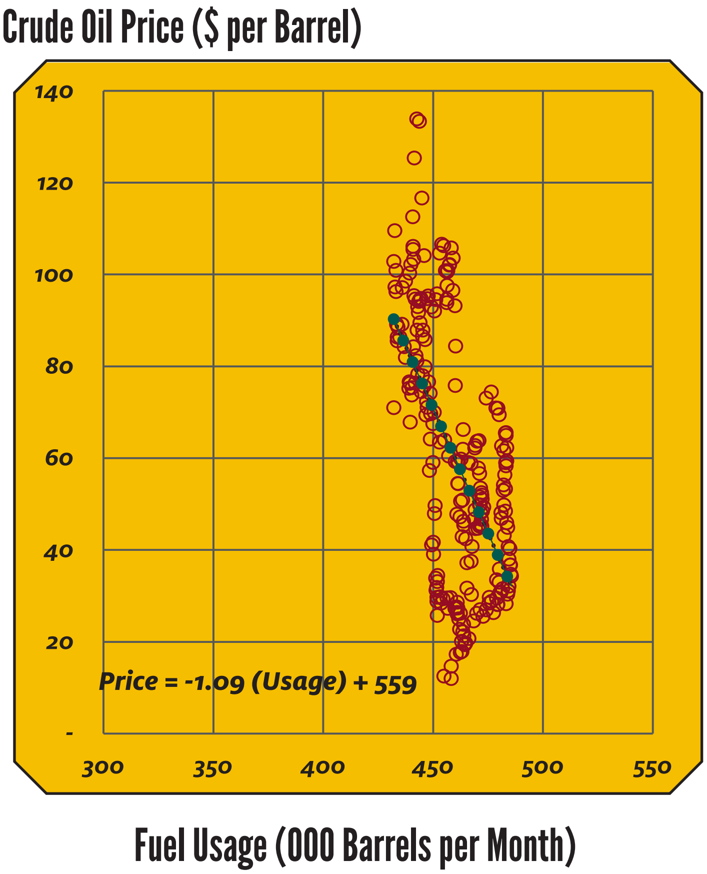


Figure 5. Crude and Fuel – Statistical Relationship

and January 2020, crude prices fell by about $40 per barrel; fuel demand rose during this period to a slight degree.

This analysis must advance beyond a cursory review. Statistical analysis provides a deeper explanation. The 20-year scatter plot that follows supports this analysis. The slope (change in price/change in fuel) is negative, as expected – a price increase results in a reduction, though slight, in fuel usage over time. Testing a price change of $7.40/barrel, given average 2000 - 2019 fuel usage of 470 million barrels/month, with fuel – price dependence of -1.1 (change in crude price/change in fuel consumption):

7.40 $/barrel of crude x 1/ (-1.1 $/barrel / thousand fuel barrels/month) = About 7.0 thousand fuel barrels/month, Less than 2% of fuel consumption (470 thousand barrels/month, 2000-2019 average).

The importance of this result lies in its approximate magnitude rather than its precise value. The point of emphasis is the small degree of change in fuel demand in response to crude price. An estimate of the error associated with the above-calculated result (-1.1 $/barrel) is based on the standard deviation for the calculated fuel response, 0.32 $/barrel. Application of the simple "two-sigma rule" stating that approximately 95% of expected outcomes lie within two standard deviations (0.64 $/barrel) of the mean value (here, -1.1 $/barrel) and assuming a normal distribution of fuel response to price:

7.40 $/barrel of crude x 1/ (- 0.46 $/barrel / thousand fuel barrels/month = About 16 thousand fuel barrels/month, About 3-4% of fuel consumption (470 thousand barrels/month, 2000-2019 average).

increased in 2021, and may exceed 2019 levels in 2022.

Two important statistical effects were tested in the above analysis. First, the timing of usage versus price. Unsurprisingly, correlation is strongest if fuel usage lags price; the correlation was found to be strongest if fuel usage lags price by about 18 months, the lag interval used in the above analysis. While the prices of transportation fuels respond rapidly to crude prices (in less than two months), consumers require time to adjust to fuel prices. For example, individual motorists respond quickly if fuel prices rise by adjusting driving patterns or by "carpool" practices to reduce miles driven, and later by vehicle purchase choices. Commercial fleet operators respond quickly if fuel prices rise by altering freight routes as well as haulage quantities per vehicle where feasible, and later by fleet conversion to improve fuel efficiency.

Second, averaging of the demand across several months results in 'smoothing' of the price/crude relationship to more accurately assess the change in correlation with lag time. Here, averaging over 12-month periods (commencing 12 months after the prompt pricing month) is used. Little change in calculated dependence (the price/usage "slope") results from 6-month or 3-month averaging or single-month treatment.

Our analysis supports the view that if proposed pipelines are canceled, or if operating pipelines are decommissioned, then crude from onshore basins will move by rail, on an almost barrel-for-barrel basis. This conclusion suggests that environmentalists should accept due diligence tasks. After all, crude displaced from pipe transport will find its way to refineries, then to fuel consumers, by an alternate mode, rail transport. As we shall see, environmental interest groups should indeed take on a due diligence role in the review of pipeline proposals.

F. Statistical Conclusions and Limitations

The error analysis as shown in Figure 5 indicates that on the basis of cost, pipe-displaced crude would move by rail under typical conditions given the statistically low response of fuel demand to crude transport cost. However, if the error range is extended by three standard deviations (0.96 $/barrel), embracing almost all expected outcomes (more than 99%), again based on normally distributed values, then the error-bound fuel response rises to about 50-55 thousand fuel barrels/month, or about 11-12% of average fuel consumption. Some reviewers might take the position that this fuel response (reduction in fuel use) is no longer negligible. Thus a cautionary note: The above statistical model appears to provide reasonable, directional guidance under typical conditions but not precise guidance under all conceivable circumstances.

This statistical framework deals only with modest changes in fuel demand. The dependence of fuel on price presented here would apply to relatively small changes in demand (say, 20% or less); methods used here cannot be extended to a "fuel-less" world by an "extrapolation to zero" in the demand for petroleum fuels.

Escalation Consultants report that rail tariffs have varied within a 10-12% range during the last 6 years, with 2% per year increases during 2015-2019. Their analysis, again using Escalation's Rail Cost Control (RCC) program, showed a decrease in U.S. rail rates of about 5-6% from the highest rate levels in 2019 to the period lowest rail rates in 2020 (third and fourth quarters) – again, pandemic conditions were at issue. Given the substantial decrease in rail rates during 2020, the 20-year period ending in December, 2019 was adopted here as the appropriate time interval for evaluating the expected impact of rail-based changes on crude delivery cost. Rail rates have

G. Due Diligence - the Role of Industry

Our due diligence review begins with pipeline companies, whose plans establish the conceptual origins of pipeline designs. We again refer to the Dakota Access Pipeline (DAPL), mentioned earlier, carrying crude from the Bakken to southern Illinois. Pipeline design is considered, along with routing alternatives.

A design feature of subsea pipelines transporting oil from offshore wells can reduce spill risk when pipelines cross bodies of water or ecologically sensitive land areas. As noted by TechnipFMC PLC, a technology advisor to energy companies with specific expertise in subsea design, "pipe-in-pipe" installations provide an inner "flowline" pipe, carrying crude, with an outer "carrier" pipe that protects the flowline. For offshore production, the carrier also protects flowline insulation, often needed to prevent the cooling of crude that is transiting the seafloor at relatively low temperatures; wax formation at low temperatures can cause pipeline blockage. For onshore pipelines, the pipe-in-pipe design would make sense for selective pipeline segments where leakage would pose the greatest environmental risk.

Double-pipe design offers two important advantages for waterways and other environmentally sensitive crossings. The carrier pipe adds a second layer of protection against leakage to the environment and protects against severe loading conditions or external shocks. Also, the annulus between the two pipe layers can be pressurized; a loss of pressure would indicate a leak in either the flowline or carrier. Pressure transmitters would report the pressure loss to pipeline monitoring stations for investigation and repair. Leakage to the environment could occur only in the unlikely event of leakage in both pipe layers. The author could not identify public information referencing double-pipe performance in contrast to single-pipe subsea installations. The superior performance of double-piping with respect to leakage is based on private discussion with an industry consultant (William

Taggart, Taggart Engineering).

Double-pipe installation would of course affect pipeline project costs. Precise estimation is difficult and would depend on specific routing and other conditions affecting construction, as for subsea installations. The flowline (typically 30 or 36 inches in diameter) must be inserted within the carrier (illustratively 48 inches in diameter) along with annular spacers that maintain concentric stability. Nitrogen facilities with pressure sensing would add further costs. Pipe-in-pipe design would likely result in a doubling of mile-to-mile pipeline installation cost (again, a privately communicated estimate – Taggart Engineering). From the same consultant source, operating costs would rise as well for an inland pipe-in-pipe segment.

What construction cost increment is likely for a large U.S. crude oil pipeline? Reuters (2015) and RBN Energy (2020) reviewed more than fifty pipelines with startups during 2014-2021. Of these, large pipeline projects form a useful subset for the present review: crude capacity of 500,000 to 1,000,000 barrels per day; diameter 30 or 36 inches; pipeline length about 500 to 1,200 miles; construction cost in the range \$2.0–3.8 billion, approximately \$3–5 million per mile. With the DAPL as an example: 30-inch diameter, roughly 1,170 miles in length, project cost about \$3.8 billion, and per-mile cost about \$3.2 million.

Environmental protection would require double-piping on a limited basis for pipe segments spanning sensitive transit zones. If 5% of an onshore pipeline route crosses areas where double-piping is prudent, then project cost could rise by about 5%; if 10%, then by about 10%. If for example the DAPL cost increment were about \$0.2 – 0.4 billion, such an increment could not be dismissed in project economic review. However, such costs may be pragmatically regarded as a form of insurance against the loss of "license to operate", against the potential loss of pipeline operating rights (with risk of loss of investment) in case of a severe environmental incident.

A further, very simple design consideration: alternate routing. Why are pipeline routes almost always "straight", or nearly so? For a sound financial reason, cost reduction. But why not evaluate the avoidance of communities and environmentally sensitive areas? A balancing of costs arises - financial, and social or environmental. For a pipeline delivering crude across 500 – 1,200 miles, selective diversions and double-pipe segments would appear reasonable for avoidance of future risks, including liability risks.

Segment-based pipeline review might add social and environmental protections and might help to preserve long-range value in view of "stranded asset" risks. Such risks might mature if crude production falls in a source basin or if demand declines in a delivery market. Could a crude pipeline, or pipeline segment, find future value for water transport? Could a pipeline serve for future transport of carbon dioxide supporting carbon capture and sequestration (CCS)? Such re-purposing opportunities would involve the evaluation of materials of construction and metallurgical properties.

As for double-piping, these design and routing alternatives could increase construction costs, reducing the economic attractiveness of pipe relative to rail. As a result, pipeline construction may be marginally favored over rail transport or conceivably disfavored. However, our environmentally and socially conscious world is likely to require these due diligence steps. Such prior investigation could enhance the public positioning of pipelines, limit risks of after-the-fact opposition, and provide design enhancements to preempt mandated pipeline shutdown.

We return to the DAPL, a remarkably straight pipeline connecting the Bakken to Patoka, Illinois. The DAPL crosses several bodies of water, notably Lake Oahe, a reservoir on the path of the Missouri River, and the Mississippi River. Could pipe-in-pipe designs afford protection for such selective segments? Could routing deviations reduce the likelihood of spills or safety incidents in or near communities? Could pipeline planners identify carbon-emitting industrial facilities for future CO_2 transport to geological formations for sequestration?

H. Due Diligence - the Role of Environmental Interest Groups

To begin, environmental advocates must recognize the inelasticity of fuel demand to oil price. Environmental stakeholders have often acted on the implied belief that cancellation of pipelines (or decommissioning of operating pipelines) would result in reduction of crude transport and fossil fuel consumption with consequent mitigation of environmental, safety, and climate risks. The statistical analysis presented here leads to the conclusion that crude will move to market without pipe transport.

What tasks lie within the due diligence framework for environmentalists? Environmental impact assessment must take into account environmental risks to land and water due to movement of crude by rail if pipeline transport is foreclosed. Climate-concerned citizens have often focused on greenhouse gases emissions from transportation fuels; environmental risks caused by oil spills must be analyzed as well.

Recalling the reports by the Congressional Research Service (2014) and the Pipeline Hazardous Material Safety Administration (2019), the potential mode shift from pipe to rail for the transport of crude calls for careful review of the likelihood and consequences of oil spills. If an oil pipeline project is terminated (or a functioning pipeline is decommissioned), where will rail-transported crude find refining homes? Would these rail routes transit waterways or ecologically sensitive areas where oil spills could cause serious environmental harm?

Alternatively, can the reviewers of potential rail transport point

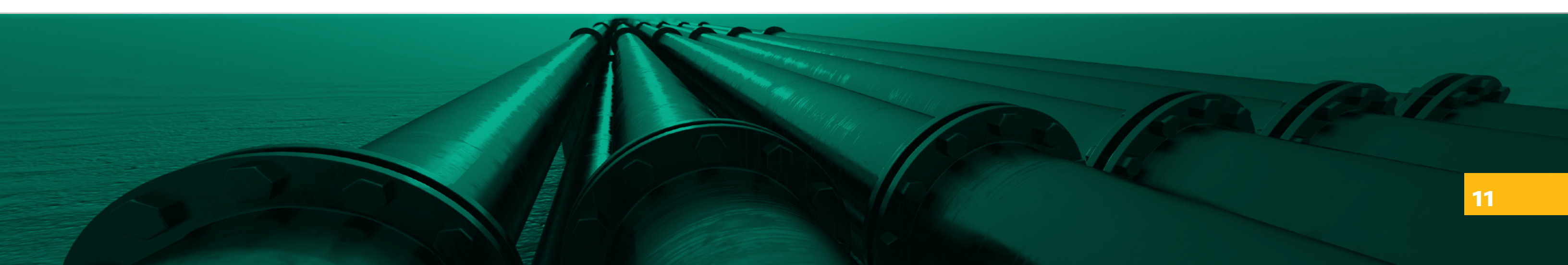
to factors that would mitigate the environmental consequences of rail transport in contrast to pipe transport? If not, then the review must deal with the likelihood of environmental harm from rail delivery.

Public safety merits careful attention as well. Again, the conclusions of the 2014 and 2019 reports by the Congressional Research Service and PHMSA are relevant, as are the reports by the Manhattan Institute and U.S. News and World Report. All indicate that safety risks are an important factor if supply shifts from pipe to rail. Again specific comparative review is necessary, as for environmental risk. What are the likely refining destinations for rail-transported crude? What routing is anticipated – for example, via existing rail lines that transit communities? If so, are there factors that would mitigate safety consequences for the anticipated rail routes?

As before let us call to mind the Dakota Access Pipeline. What environmental and safety risks would result from rail delivery following the DAPL supply route, from North Dakota through South Dakota, Iowa, and Illinois? Recognizing the environmental and safety risks of crude transport by rail, are there opportunities to mitigate these risks for the movement of crude by rail from the Bakken formation following the route of the DAPL?

I. Concluding Remarks - Due Diligence Framework

The guardians of public interest should insist on a well-structured due diligence framework for the evaluation of crude oil pipelines; both industry participants and environmental advocates can usefully engage in this due diligence process. The process outlined here would lend discipline to public discourse regarding pipelines and alternate modes of crude transport. A more disciplined viewpoint is a more effective and persuasive one.



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The statistical model addresses a limited scope of investigation, focusing on the apparent claim of environmentalists that oil pipeline closure is certain to reduce oil product usage. A more complex model would be needed to fully explore the influence of crude cost on fuel demand. For example: Fuel demand shifts may "feed back" to influence oil pricing; regional dynamics may be statistically different; societal viewpoints concerning oil product usage may exert an influence. The present study deals with a specific, restricted inquiry.

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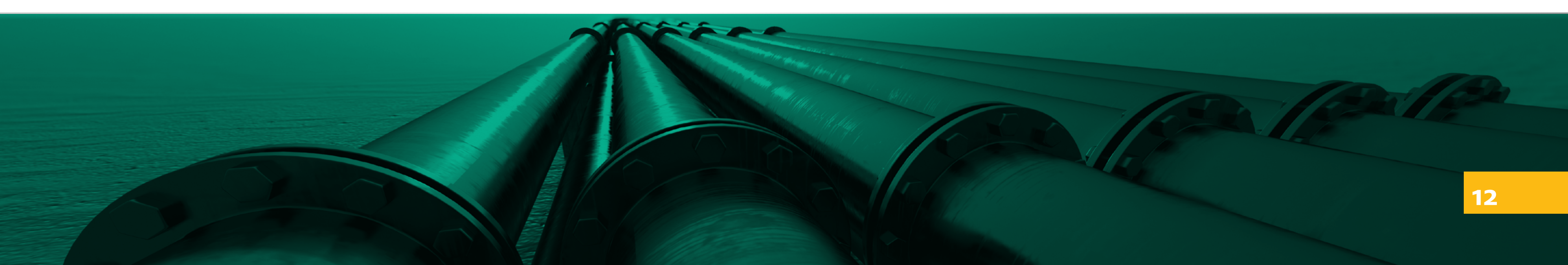

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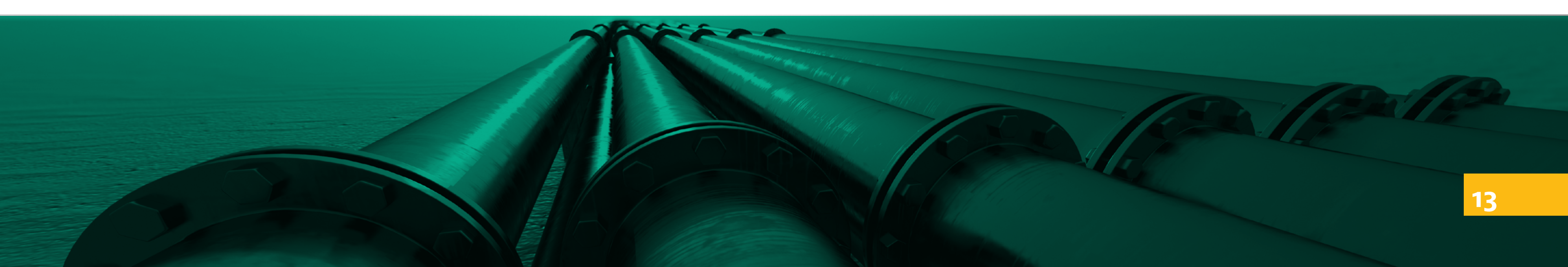

APPENDIX I: Crude Production of Major Basins, Estimated Movements by PADD

Basin	PADD Location of Producing Basin	Crude Production of the Basin (bbl/day, 2019)	Estimated % Volume from Producing Basin			
			to PADD 3	to PADD 2	to PADD 5	to PADD 1
Permian	PADD 3	4.4	78%	21%	1%	-
Eagle Ford	PADD 3	1.4	99.8%	-	0.2%	-
Permian + Eagle Ford	PADD 3	5.7	83%	16%	1%	-
Bakken	PADD 2	1.4	15%	66%	11%	8%

Notes: 2019 Basin Production Volumes from EIA *"Drilling Productivity Report "*,
https://www.eia.gov/petroleum/drilling/
Additional sources providing inter-PADD crude movements:
https://www.eia.gov/dnav/pet/pet_move_pipe_dc_R20-R30_mbbl_m.htm
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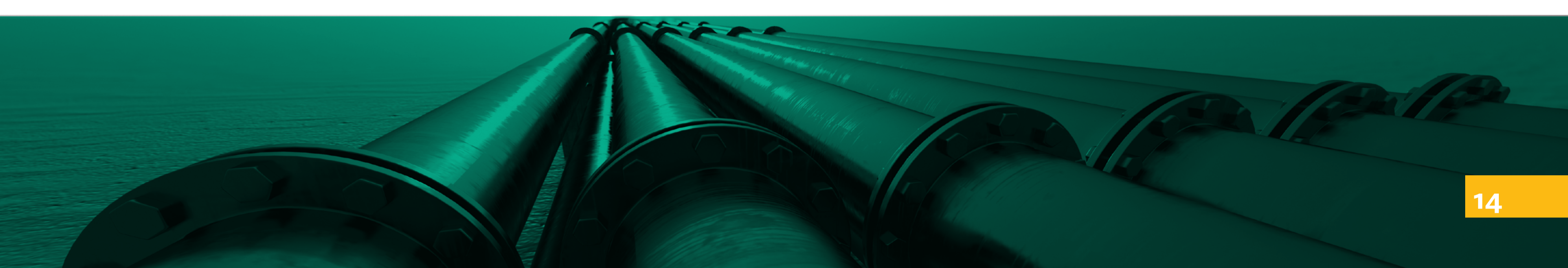

APPENDIX II: Major Crude Oil Pipelines - Eagle Ford, Permian

Basin Source: Eagle Ford

Project Name	Developer(s)	Year in Service	Transit Miles	Delivery Point(s)	Added Capacity
Eagle Ford Joint Venture Pipeline	Enterprise Products, Plains All American	2012	175	Houston (ECHO Terminal - Enterprise)	300,000
Kinder Morgan Crude & Condensate	Kinder Morgan	2012	264	Houston and Sweeney, TX	300,000
Double Eagle Pipeline	Magellan, Kinder Morgan	2013	194	Corpus Christi and vicinity	100,000
Eagle Ford Joint Venture Pipeline Expansion	Enterprise Products, Plains All American	2015	175	Added delivery to Corpus Christi & Wilson Cty, TX	300,000

Basin Source: Permian

Project Name	Developer(s)	Year in Service	Transit Miles	Delivery Point(s)	Added Capacity
Longhorn (with 2014	Magellan	2013	450	Houston	250,000
BridgeTex Pipeline	Magellan, Occidental	2014	400	Houston	300,000
Cactus I Pipeline	Plains All American	2015	298	Corpus Christi	250,000
Midland-to-Sealy Pipeline	Enterprise Products Partners	2018	410	Sealy, TX (on to Houston ECHO Terminal via Enterprise-owned	575,000
Cactus II Pipeline	Plains All American	2019	575	Corpus Christi and vicinity (Ingleside)	670,000
Gray Oak Pipeline	Andeavor, Phillips 66	2019	850	Corpus Christi, Sweeney, Freeport	900,000
Wink-to-Webster Pipeline (Wink: Midland, TX Area)	ExxonMobil, Lotus Midstream, Delek US,	2020	650	Houston area - ECHO Terminal (Enterprise), Webster, Baytown	1,000,000
Midland-to-ECHO 3 Pipeline	Enterprise Products	2020	416	Enterprise (ECHO) Terminal,	450,000
EPIC Crude Pipeline	EPIC Pipeline	2020	730	Corpus Christi and vicinity (Ingleside)	600,000

Notes

From U.S. Energy Information Agency (EIA), *Pipeline Projects,* **https://www.eia.gov/petroleum/data.php**

Wink-to-Webster and Midland-to-Echo 3 Pipeline capacities are consistent with undivided ownership interests, utilizing the same pipeline facility (Enterprise Products' interest corresponds to 450,000 bbl/day; total pipeline capacity about 1,450,000 bbl/day).

All above pipelines are long-haul, connecting producing basins to crude markets.

APPENDIX III: Rail Cost (Typically not Replicated in Shipments by Pipeline)

Estimated Costs apply to the operation of unit trains, Typically 100 railcars (660 bbl/railcar)

Activities and Order-of-Magnitude Costs for Loading Activities *(In the Producing Basin)*

Activity Description	Comment	Cost Approximation
Truck crude from lease-site tankage to tankage serving a loading facility	Semi tank-truck approximate operating cost $1.80/mile, transport volume 190 bbl (references below), assume 50-mile transport radius (100 mille truck range). In some cases transfer is by pipeline.	$1/bbl
Positioning of the unit train	Positioning (typically in several steps) by a rail locomotive for top-loading via manifold connections to all railcars.	Included in all-in loading facility estimate.
Crude loading at rail loading facility	All-in operating cost is estimated, including rail locomotive operation, manual removal of top manways, and manual attachment of manifold connections to all railcars.	$1.00-1.50/bbl
Position the unit train to ship to destination	The unit train is moved to the railroad main line for transit to destination, by either the loading facility's rail locomotive or the mainline railroad (typically Class I).	Included in all-in loading facility estimate.

Rail Transit to the Off-Load Facility Follows, Typically by a Class I Railroad;
(Estimated ex-Bakken, Permian and Eagle Ford Costs Provided by Escalation Consultants)

Activities and Order-of-Magnitude Costs for Off-Loading Activities *(At the Destination)*

Activity Description	Comment	Cost Approximation
Again, positioning of the unit train	Positioning by a rail locomotive for manifold connections to all railcars. (Again, sequential movements are typical.)	Included in all-in off-load facility estimate.
Crude loading at rail loading facility	All-in operating facility cost is estimated, including manual attachment of manifold connections to all railcars (bottom connections in this case - top manways are opened for vacuum break).	$1.00-1.50/bbl
Position the unit train to return the unit train to the producing basin	The unit train is moved to the railroad main line for transit back to the loading facility in the producing basin.	Included in all-in loading facility estimate.

Other Costs

Activity Description	Comment	Cost Approximation
Rail lease cost	Typically seven years, with cost for earlier exit. Estimated monthly lease cost, $675/railcar, with railcar capacity of 660 barrels.	$0.70 - 0.90/barrel
Railcar demurrage	Charged to destination owner (typically, shipper) if a car is held longer than a specified time, typically 7-14 days. Demurrage costs normally depends on plannng discipline by shipper and off-load staff.	Highly variable. Reasonably included in the above indicated estimate of rail lease cost.
Other railcar repair/movement costs	Cars stranded due to damage are typically moved/repaired with costs for the lessee's (shipper's) account.	
	Approximate Total	$3.5-5/barrel

NOTES

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