Low Carbon Fuel Standard "Crude Shuffle" Greenhouse Gas Impacts Analysis

June 2010

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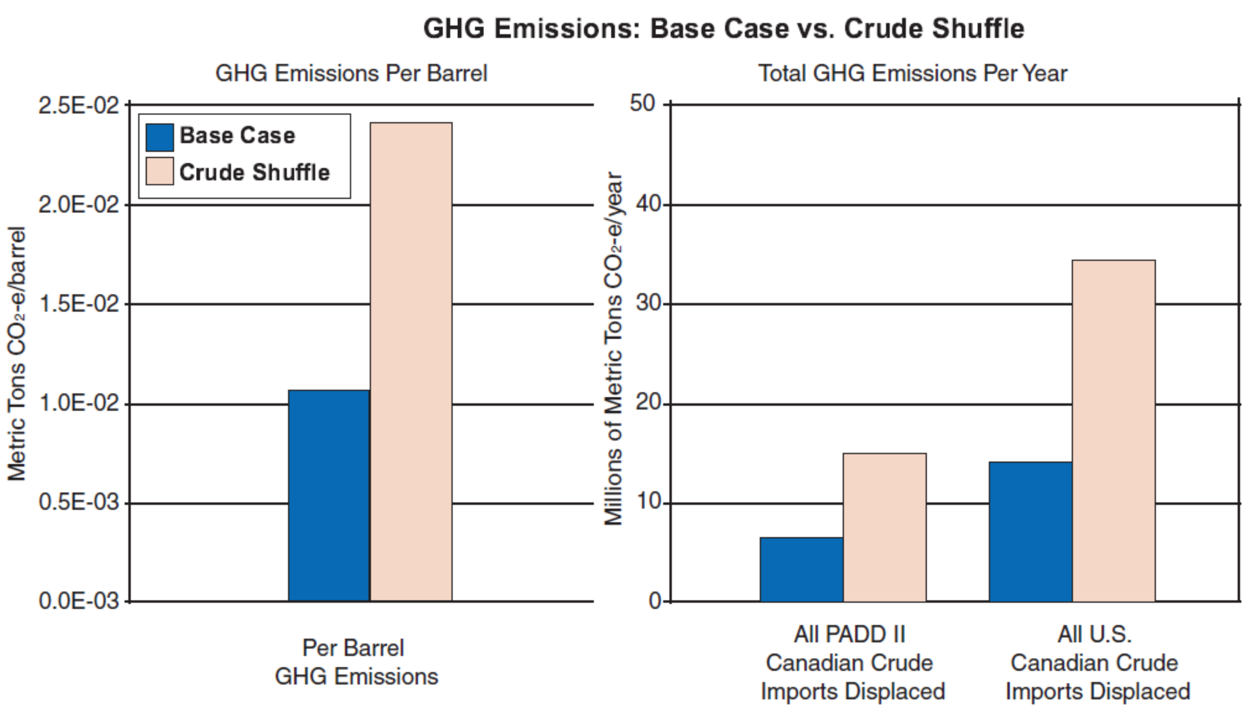
1.0 Executive Summary

A low carbon fuel standard (LCFS) policy requiring a reduction in the carbon content of transportation fuels is intended to reduce greenhouse gas (GHG) emissions from the transportation sector by setting a performance standard based on the total amount of carbon emitted per unit of fuel energy. A major challenge to the effectiveness of LCFS is the possibility of “shuffling” or “leakage.” The market will tend to promote solutions to meet LCFS that are the least costly, potentially shuffling production and sales in a manner that meets the requirements of LCFS but does not necessarily produce the desired outcomes for GHG emissions., This analysis illustrates that implementing LCFS in the U.S. could encourage “shuffling” that would double the greenhouse gas emissions associated with crude oil transport to and from regions directly and indirectly impacted by the policy, as shown in Figure 1.

Figure 1 LCFS Crude Shuffle GHG Impacts



Note: GHG impacts are shown for a “base case” developed to assess transport emissions associated with current crude import/export patterns between Canada and the U.S. and the Middle East and China, to a “crude shuffle case,” with Middle Eastern crude replacing Canadian imports to the U.S. and displaced Canadian Crude exports routed instead to China. GHG Emissions shown in this figure were calculated assuming transport by tanker includes a deadhead trip from delivery port back to the port of origin.

A LCFS implemented in the U.S. results in a notable increase in greenhouse gas emissions due to the displacement of Canadian crude imports to the U.S. and re-routing of crude imports and exports to accommodate this displacement. The policy is likely to discourage U.S. imports of Canadian crude produced from oil sands because of the higher-lifecycle GHG impacts[1], instead encouraging imports of crude from areas that produce light sweet crude, most notably from the Middle East. Nearby Canadian crude sources would be diverted to regions not affected by LCFS and replaced with supplies from distant parts of the world.

This study provides an evaluation of the net GHG impacts of implementing LCFS in the United States by focusing on resulting shifts in crude oil transport to isolate the net change in GHG emissions. The analysis compares a "base case," developed to assess transport emissions associated with current crude import/export patterns between Canada and the U.S. and the Middle East and China, to a "crude shuffle case," with Middle Eastern crude replacing Canadian imports to the U.S. and with Canadian crude exports routed instead to China (Figure 2).

Changes in transportation energy use and greenhouse gas emissions between the base case and crude shuffle case were evaluated on a per-barrel basis and on a total basis to provide two metrics for assessing LCFS impacts. Calculating the net change in transportation energy use per barrel requires identifying energy inputs for each segment of transport and linking energy usage with the amount of crude transported as a result of the calculated energy usage. Evaluation of total energy use and GHG impacts requires linking per-barrel values with expected quantities of crude displaced under LCFS. This study evaluated a range of assumptions about total crude displacement to bracket potential LCFS impacts in terms of total change in energy use and GHG emissions. Total change in energy use and GHG emissions has been calculated for the displacement of all crude currently imported to the U.S. from Canada and all crude currently imported to the PADD II region of the U.S. from Canada.

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[1] [1] A Low-Carbon Fuel Standard for California Part 1: Technical Analysis, Project Directors: Alexander E. Farrell, UC Berkeley and Daniel Sperling, UC Davis, 2007 (http://www.energy.ca.gov/low_carbon_fuel_standard/UC_LCFS_study_Part_1-FINAL.pdf)

Table 1 Summary of GHG Impacts of the LCFS Crude Shuffle (Change in GHG emissions)

Scenario	Change from base case to crude shuffle case in Metric tons CO_2-e per barrel of crude transported (including tanker transport—one way)	Change from base case to crude shuffle case in Metric tons CO_2-e per barrel of crude transported (including tanker transport—roundtrip/deadhead)
Average of potential pipeline routes	7.21E-03	1.27E-02
Scenario	**Change in Metric tons CO_2-e total per year (tanker transport—one way)**	**Change in Metric tons CO_2-e total per year (tanker transport—roundtrip/ deadhead)**
All Canadian Imports to U.S. displaced	15,081,322	18,975,585
All Canadian Imports to U.S. PADD II displaced	7,142,118	8,986,339

This analysis of the change in crude-transport-related emissions accompanying implementation of a LCFS indicates that the net effect will be a doubling of GHG emissions associated with changes in crude-transport patterns. It indicates an increase in global GHG emissions by 7.1 to 19.0 million metric tons per year (Table 1), depending on the extent of resulting Canadian crude displacement. Modeling results show a doubling of GHG emissions on a per-barrel basis and on a total basis. Implementing an LCFS has the effect of shifting crude import/export patterns in a manner that requires a change in the mix of transport methods and requires that crude be transported over much greater distances.

2.0 LCFS Crude Shuffle

A low carbon fuel standard (LCFS) is a policy requiring a reduction in the carbon content of transportation fuels. LCFS is intended to reduce greenhouse gas (GHG) emissions from the transportation sector by setting a performance standard based on the total amount of carbon emitted per unit of fuel energy. The standard is based on a life-cycle evaluation of carbon emissions, including all the carbon emitted in the production, transportation, refining, and use of the fuel. A major challenge to the effectiveness of LCFS is the potential for “shuffling” or “leakage.” The market will tend to promote solutions to meet LCFS that are the least costly, potentially shuffling production and sales in a manner that meets the requirements of LCFS but does not necessarily produce the desired change in GHG emissions. For example, a producer of lower-carbon fuels could divert its LCFS-compliant supplies to areas where LCFS is in effect and simply shift its higher-carbon fuel supplies to areas with no LCFS. In this scenario, LCFS is ineffective in bringing about a decrease in the GHG emissions associated with fuel consumption.

LCFS implemented in the United States is likely to discourage imports of Canadian crude produced from oil sands. Canada is currently the largest single exporter of oil into the United States, and it serves most refineries in the northern part of the U.S. Even refiners in the southern part of the United States are beginning to refine heavier Canadian crudes. Because more energy is required to recover heavy Canadian crude oil than lighter, sweeter crudes, Canadian crude generates more GHG on a lifecycle basis[2]. Because of the higher-lifecycle GHG impacts, LCFS would tend to discourage the use of Canadian crude in the U.S. and encourage imports of crude from areas that produce light sweet crude, most notably the Middle East. LCFS would support the replacement of nearby Canadian crude sources with crude supplies from other parts of the world, and supplies of Canadian oil sands would be diverted to regions not affected by LCFS.

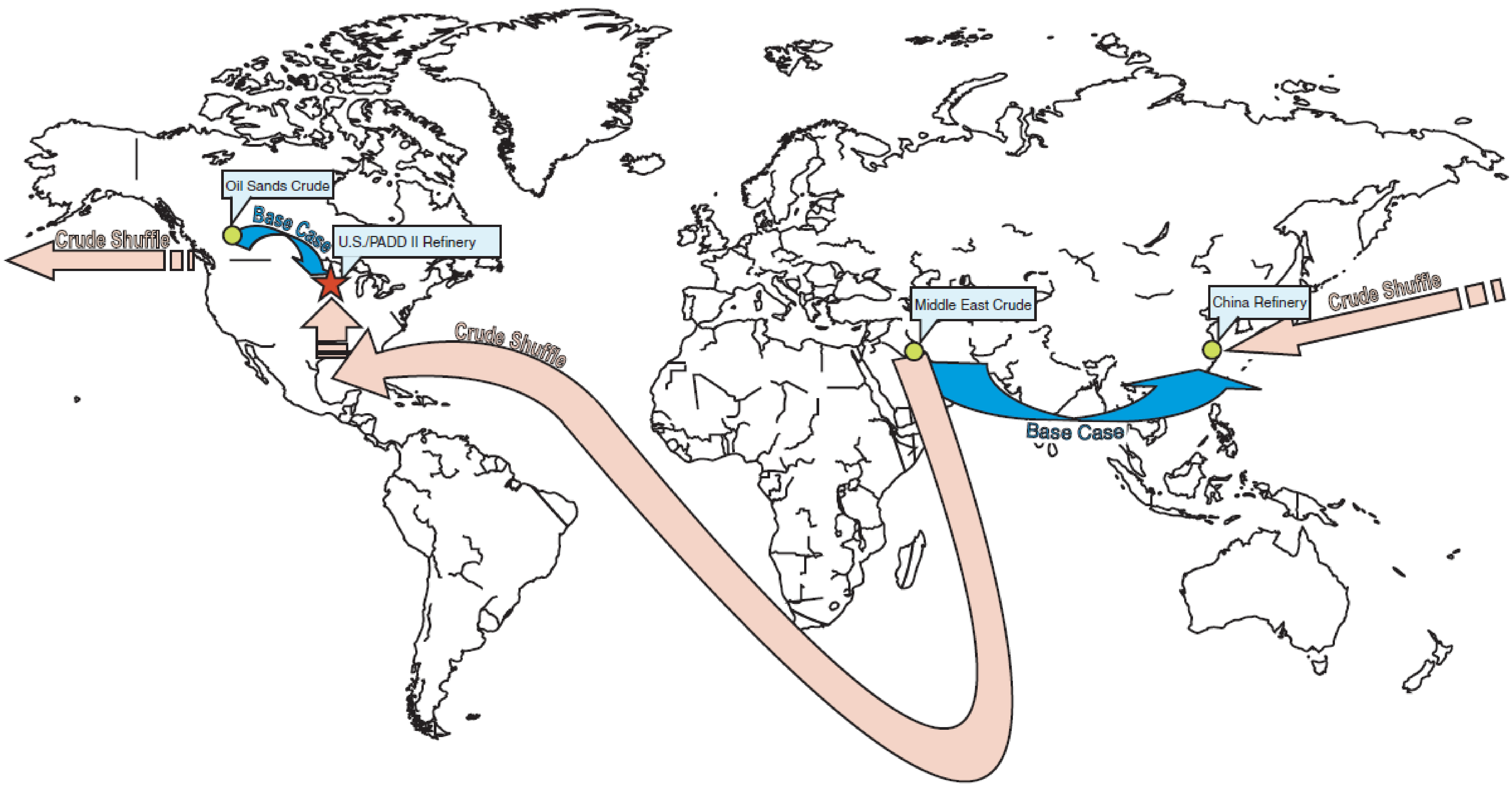
While it is likely that LCFS would change the mix of crude imports to the United States, LCFS implemented in the United States is not expected to change overall trends in energy use and demand for crude resources throughout the rest of the world. A shift in U.S. crude-supply preferences will simply cause redirection of crude supplies elsewhere. Canadian crude exports to U.S. will be diverted to former recipients of Middle East crude supplies. Market analysis indicates that one

[2] A Low-Carbon Fuel Standard for California Part 1: Technical Analysis, Project Directors: Alexander E. Farrell, UC Berkeley and Daniel Sperling, UC Davis, 2007 (http://www.energy.ca.gov/low_carbon_fuel_standard/UC_LCFS_study_Part_1-FINAL.pdf)

plausible shift corresponding to the U.S.'s substitution of Middle Eastern crude for Canadian crude would be the replacement of Middle Eastern crude imports to China with Canadian crude. With no net impact on the amount or type of oil consumed worldwide, U.S. implementation of LCFS would simply modify transportation patterns associated with crude imports and exports (Figure 1). The net impact of LCFS on global GHG emissions, therefore, can be isolated by focusing on the resulting shift in crude transport patterns. Because the negative impacts attributed to greenhouse gas emissions occur at a global scale, the effectiveness of an LCFS policy in modifying anthropogenic GHG forcing on the climate should be evaluated relative to these net global impacts on GHG emissions.

This study evaluates the net GHG impacts of implementing LCFS in the United States by focusing on resulting shifts in crude-oil transport. The analysis compares a "base case," developed to assess transport emissions associated with current crude import/export between Canada and the U.S. and the Middle East and China, to a "crude shuffle case," with Middle Eastern crude replacing Canadian imports to the U.S. and displaced Canadian crude exports being routed to China (Figure 2).

Figure 2 LCFS Crude Shuffle redistribution of oil imports/exports



3.0 Crude-Shuffle Scenarios

To evaluate the net greenhouse-gas impacts of the LCFS crude shuffle, this analysis quantifies the difference in energy consumed for the transportation of crude in the "base case" and the "crude shuffle case" discussed above. It assumes that, prior to implementation of LCFS, oil sands crude from Canada is imported to the U.S. via pipeline and crude from the Middle East is transported to China via tanker. Implementation of LCFS results in crude transport from Canada to China via pipeline and tanker, and from the Middle East to U.S. via tanker and pipeline. Pipeline routes and shipping ports were chosen based on a general assessment of current and planned pipeline-transport routes and frequently used ports capable of accommodating a typical crude tanker (very large crude carriers, or VLCCs).

Because this analysis focuses on isolating the net change in transportation energy use, it considers only transportation routes, modes, and distances expected to change as a result of LCFS. Segments of the relevant transport paths that we expect to remain unchanged are not evaluated. For example, pipeline transport from the point of extraction in the Middle East to the tanker at a Middle Eastern port would be required whether the crude was destined for China (under the base case) or the U.S. (under the crude shuffle case). In contrast, pipeline transport of Canadian crude follows an entirely different route, via different pipelines and over a different distance, under the base case (transport to U.S.) and the crude shuffle case (transport to port for shipment to China), so energy usage associated with the different pipeline routes across Canada was evaluated.

Changes in transportation energy use and greenhouse gas emissions between the base case and crude shuffle case were evaluated on a per-barrel basis and on a total basis to provide two metrics to assess LCFS impacts. Calculating the net change in transportation energy use per barrel requires identifying energy inputs for each segment of transport and linking energy usage with the amount of crude transported as a result of the calculated energy usage. Pipeline energy use per barrel was calculated by evaluating total energy use associated with known throughput rates for each segment of pipeline. Tanker energy use per barrel was calculated by evaluating total energy use over a known trip distance for a given tanker capacity. Specific methods for calculating energy usage on a per-barrel basis for pipeline transport and for tanker transport are discussed further in Section 4.3. To calculate overall per-barrel energy use and GHG emissions for each case, per-barrel energy usage was summed across each leg of transport associated with each case.

Evaluation of total energy use and GHG impacts requires linking per-barrel values with expected quantities of crude displaced under LCFS. To allow a direct comparison between the base case and the crude shuffle case, this analysis identifies a specific quantity of crude transported from Canada to the U.S. under the base case and evaluates the transport of this amount of crude across both cases. Under the base case, total energy use is calculated for moving a specific amount of crude from Canada to the U.S. and for moving a corresponding amount of crude from the Middle East to China. This allows a direct comparison to the crude shuffle case, in which the same quantities of crude are assumed to be shifted from Canada to China and from the Middle East to U.S. For the purposes of this study, we have used a range of assumptions about total crude displacement to bracket potential LCFS impacts in terms of total change in energy use and GHG emissions. Total change in energy use and GHG emissions has been calculated for the displacement of all crude currently imported to the U.S. from Canada and all crude currently imported to the PADD II region of the U.S. from Canada.

Figure 3 provides an overview of start and end points and transportation modes associated with the base case and the crude shuffle case.

Figure 3 Base Case and LCFS Crude Shuffle Pathways

3.1 Base Case

In the base-case scenario, no LCFS is in place and crude movement reflects current market dynamics. Canadian crude imports to the U.S. are not inhibited, and Canadian crude bound for the U.S is not diverted to China. A variety of assumptions have been made in defining routes, modes of transport, and other relevant inputs for the base case. These assumptions and inputs are discussed below. Table 2 provides a general overview of the transportation modes and routes that comprise the base-case scenario.

Table 2 Base-Case Modes and Routes

General Transport Route	Start/End Points	Transport Mode
Crude transport from Canada to U.S.	Edmonton/Chicago	Pipeline
Crude transport from Middle East to China	Basrah/Ningbo	Tanker

3.1.1 Canadian Crude to U.S.

Under the base case, crude is transported from Canada (Edmonton) to the U.S. (Chicago) via one of two potential pipeline routes, the existing Enbridge Chicago pathway or the Express Chicago pathway (see Appendix A). All transport from Canada to the U.S. is assumed to occur over land routes and no tanker transport is included in this analysis.

3.1.1.1 Pipeline Transport

A number of specific characteristics vary by pipeline and are critical in calculating energy usage. These key characteristics for each route are detailed in Table 3, in which pipeline transport is broken into segments from Edmonton to Chicago. Section 4.2 further details how these inputs were used in modeling total energy use and GHG emissions for this leg of the base case.

Table 3 Base Case Canada to U.S. Pipeline Transport Route Inputs and Assumptions

Route	Origin	Destination	Pipeline	Distance (mi.)**	Diameter (in.)	100% Capacity Flow Rate*** (thousands of barrels per day)	Change in Elevation (ft)	Notes
Oil Sands Enbridge Chicago Pathway								
Segment 1	Fort McMurray	Cheecham	Athabasca	62	30	390	203	[8]
Segment 2	Cheecham	Edmonton	Waupisoo	236	30	350	775	[7]
Segment 3	Edmonton	Hardisty	Enbridge	85/15	36/48	880		[1]
Segment 4	Hardisty	Superior	Clipper	1070	36	450	1409	[2]
Segment 5	Superior	Chicago	Line 6A	467	34	670	63	[3]
Oil Sands Express Chicago Pathway								
Segment 1	Fort McMurray	Cheecham	Athabasca	62	30	390	203	[8]
Segment 2	Cheecham	Edmonton	Waupisoo	236	30	350	775	[1]
Segment 3	Edmonton	Hardisty	Enbridge	85/15	36/48	880		[1]
Segment 4	Hardisty	Casper	Express	785	24	280	-3072	[4]
Segment 5	Casper	Wood River	Platte	932	20	164	4693	[4]
Segment 6	Wood River	Patoka	Woodpat	58		309	-75	[5]
Segment 7	Patoka	Chicago	Chicap	203	26	360	-74	[6]

* Assume Western Canadian Select crude or a crude with similar characteristics

** Distances derived from http://www.mvs.usace.army.mil/permits/pn/p-2303.htm

*** 100% Capacity flow rate assumed initially, see Section 6.1 for discussion of sensitivity analysis. Capacities from page 77 of http://www.neb.gc.ca/clfnsi/rnrgynfmtn/nrgyrprt/lsnd/pprtntsndchllngs20152004/pprtntsndchllngs20152004-eng.pdf

[1] 517 Gw-hr per year at capacity per "Line 4 Buildback" settlement filed at NEB

[2] http://www.enbridge.com/about/enbridgeCompanies/pdf/preliminary-information-package-enbridge_pipelines_inc.pdf

[3] Enbridge 2008 Refiner and Customer Update

Route	Origin	Destination	Pipeline	Distance (mi.)**	Diameter (in.)	100% Capacity Flow Rate*** (thousands of barrels per day)	Change in Elevation (ft)	Notes
[4] http://www.kne.com/business/canada/Express_Platte.cfm								
[5] no information available								
[6] http://www.bppipelines.com/asset_chicap.html								
(7) http://www.enbridge.com/waupisoo/about-project/proposed-facilities.php								
(8) http://www.enbridge.com/ar2008/management-discussion-analysis/liquids-pipelines/enbridge-system-and-athabasca-system/								

3.1.2 Middle-East Crude to China

Under the base case, crude is transported from the Middle East (Basrah) to China (Ningbo) via crude oil tanker. In this analysis, pipeline transport from the point of extraction to port in the Middle East is expected to occur regardless of destination (U.S. or China) and transport from port to refinery in China is expected to occur regardless of origin (Middle East or Canada). Since neither of these pipeline segments represents a change in transport from base case to crude shuffle case, they are not evaluated.

3.1.2.1 Tanker Transport

The key route characteristic that impacts total energy use associated with tanker transport is total trip distance. British Petroleum (BP) distance tables were used to derive a total trip distance of 6,020 nautical miles from Basrah to Ningbo.

3.2 Crude Shuffle Case

Under the crude shuffle case, LCFS is in effect in the U.S., and imports of Canadian crude are replaced with imports from the Middle East, with Canadian crude diverted to China. A variety of assumptions made in defining routes, modes of transport, and other relevant inputs are discussed below. Table 4 provides a general overview of the transportation modes and routes for the crude-shuffle scenario.

Table 4 Crude Shuffle Modes and Routes

General Transport Route	Start/End Points	Transport Mode
Crude transport from Canada to China	Edmonton-Kitimat/ Kitimat-Ningbo	Pipeline/Tanker
Crude transport from Middle East to U.S.	Basrah-Galveston/ Galveston-Chicago	Tanker/Pipeline

3.2.1 Canadian Crude to China

Under the crude shuffle case, crude is transported from Canada (Edmonton) to China (Ningbo). Pipeline transport moves this crude from the point of extraction (Edmonton) to a Canadian port (Kitimat), where it is transferred to a tanker and shipped to a Chinese port (Ningbo). Pipeline transport through Canada is assumed to occur via one of two pipelines, the TMPL China Pathway or the Gateway China Pathway (see Appendix A). For this analysis, pipeline transport from a port in China to a refinery in China is expected to occur regardless of origin (Middle East or Canada). Since this particular pipeline segment does not represent a change in transport from base case to crude shuffle case, it is not evaluated.

3.2.1.1 Pipeline Transport

Specific characteristics that vary by pipeline are critical in calculating energy usage associated with this mode of transport. These are detailed in Table 5, which also shows pipeline transport broken into segments along each pathway. Section 4.2 further details how these inputs were used in modeling total energy use and GHG emissions for this leg of the crude shuffle case.

Table 5 Crude Shuffle Case Canada to China Pipeline Transport Route Inputs and Assumptions

Route	Origin	Destination	Pipeline	Distance (mi.)	Diameter (in.)	100% Capacity Flow Rate (thousands of barrels per day)	Change in Elevation (ft)	Notes
Oil Sands TMPL China Pathway								
Segment 1	Fort McMurray	Edmonton	AOSPL	270	22	275	853	[3]
Segment 2	Edmonton	Vancouver	TMPL	716	24	260	2044	[1]
Oil Sands Gateway China Pathway								
Segment 1	Fort McMurray	Edmonton	AOSPL	270	22	275	853	[3]
Segment 2	Edmonton	Kitimat	Gateway	738	36	525	2061	[2]
* Assume Western Canadian Select crude or a crude with similar characteristics								
[1] Transit time - 7 to Kamloops, 9 to Burnaby http://www.kindermorgan.com/business/canada/data/2/rec_docs/KMinCanada_web.pdf								
[2] //www.northerngateway.ca/project-info/northern-gateway-at-a-glance								
(3) http://phx.corporate-ir.net/phoenix.zhtml?c=63581&p=irol-pipelines								

3.2.1.2 Tanker Transport

The key route characteristic that impacts total energy use associated with tanker transport is total trip distance. BP distance tables were used to derive a total trip distance of 4,903 nautical miles from Kitimat to Ningbo.

3.2.2 Middle-East Crude to U.S.

Under the crude shuffle case, crude is transported from the Middle East (Basrah) to the U.S. (Chicago). Tankers transport this crude from the Middle Eastern port to the U.S. Gulf Coast (Galveston), where the crude is transferred via pipeline to Chicago via the Freeport Chicago Pathway or the St. James Chicago Pathway (see Appendix A). Forthis analysis, pipeline transport from the point of extraction in the Middle East to port is expected to occur regardless of destination (U.S. or China). Since this particular pipeline segment does not represent a change in transport from base case to crude shuffle case, it is not evaluated as part of this analysis.

3.2.2.1 Pipeline Transport

Specific characteristics that vary by pipeline are critical in calculating energy usage associated with this mode of transport. These are detailed in Table 6, which shows pipeline transport broken into segments along each pathway. Section 4.2 further details how these inputs were used in modeling total energy use and GHG emissions for this leg of the crude shuffle case.

Table 6 Base Case Middle East to U.S. Pipeline Transport Route Inputs and Assumptions

Route	Origin	Destination	Pipeline	Distance (mi.)	Diameter (in.)	100% Capacity Flow Rate (thousands of barrels per day)	Change in Elevation (ft)	Notes
Middle East/ St. James–Chicago Pathway								
Segment 1	St. James	Patoka	Capline	632	40	1200	-489	[1]
Segment 2	Patoka	Chicago	Chicap	203	26	360	0	[2]
Middle East/ Freeport–Chicago Pathway								
Segment 1	Freeport	Cushing	Seaway	530	30	350	-935	[3]
Segment 2	Cushing	Wood River	Ozark	440	22	239	505	[4]
Segment 3	Wood River	Patoka	Woodpat	58		309	-74	[5]
Segment 4	Patoka	Chicago	Chicap	203	26	360	0	[6]
* Assume Western Canadian Select crude or a crude with similar characteristics								
[1] http://www.bppipelines.com/asset_capline.html (today does less than 400thousands of barrels per day)								
[2] http://www.bppipelines.com/asset_chicap.html								
[3] http://www.teppco.com/operations/onshoreCrudeOilPipelinesServices.htm								
[4] http://www.enbridgeus.com/Main.aspx?id=2374&tmi=138&tmt=4								
[5] no information available								
[6] http://www.bppipelines.com/asset_chicap.html								

3.2.2.2 Tanker Transport

The key route characteristic that impacts total energy use associated with tanker transport is total trip distance. BP distance tables were used to derive a total trip distance of 13,102 nautical miles from Basrah to Galveston.

4.0 Greenhouse-Gas Emissions: Modeling Methodology and Assumptions

This analysis depends on a variety of assumptions that were made based on best available, publicly accessible data sources. Critical assumptions and the modeling framework for estimating transport energy use and emissions are discussed below.

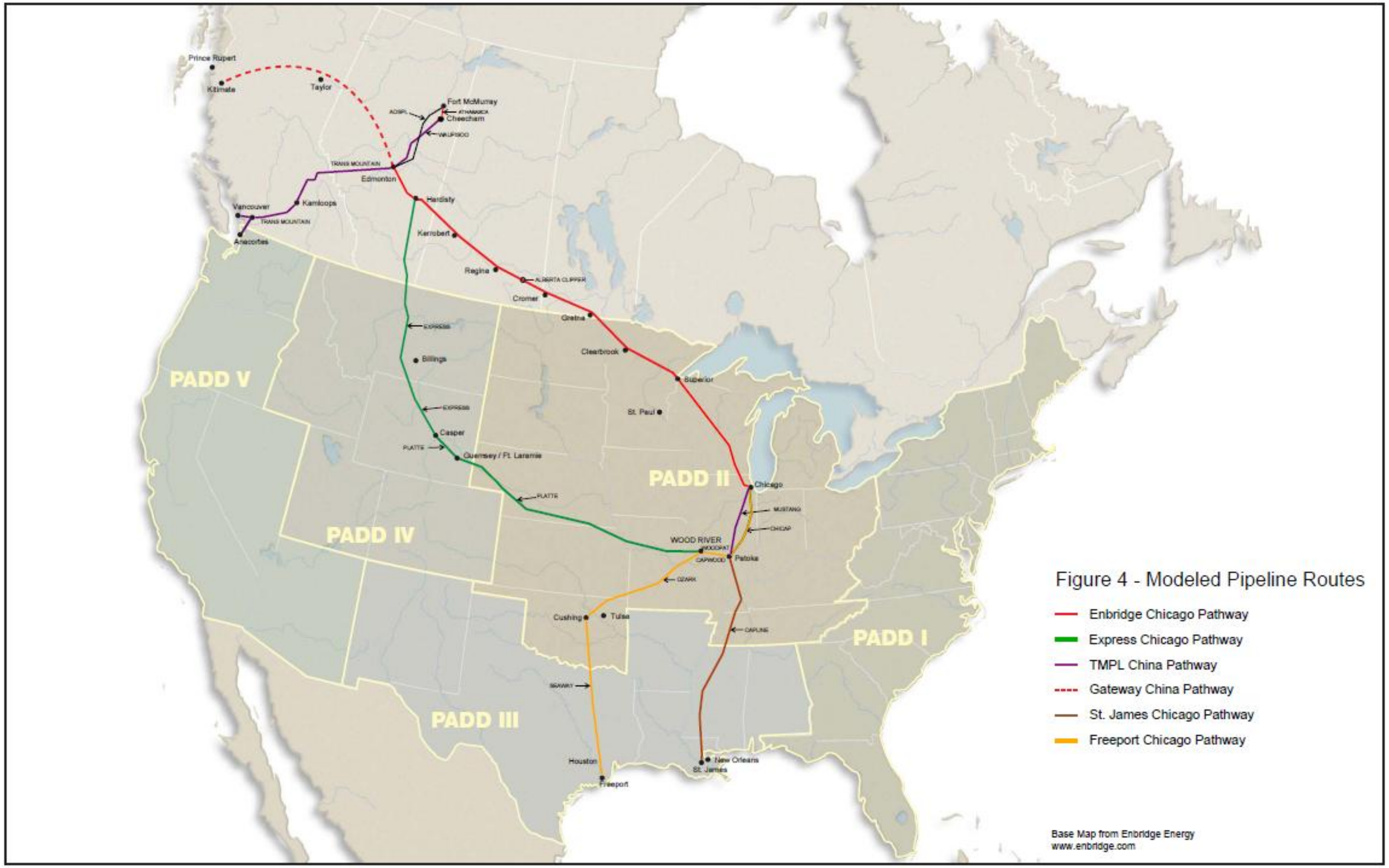
4.1 "A Barrel Is a Barrel"

For the purpose of this analysis, it has been assumed that transport of one barrel of crude, regardless of origin or characteristics, is comparable to transport of one barrel of any other type of crude. It follows from this assumption that importing one barrel of Canadian crude, for example, to the U.S. satisfies the same amount of end-use demand as one barrel of Middle Eastern crude. Thus, under the crude shuffle case, it makes sense to conclude that each barrel of displaced Canadian crude is replaced with a barrel of Middle Eastern crude on a 1:1 basis.

4.2 Pipeline Transport: Methodology and Assumptions

Energy requirements for pipeline transport were calculated by using the Applied Fluid Technologies (AFT) Fathom software to model energy usage at pump stations along each pipeline pathway discussed in Section 3. Modeled energy usage was then coupled with region-specific energy-use emission factors to calculate greenhouse-gas emissions. Emissions were calculated on a per-barrel basis by dividing total greenhouse gas emissions per day by total barrels of crude transported per day over the pipeline of interest. A map of specific pipeline routes is provided in Figure 4.

Figure 4 Base Case and LCFS Crude Shuffle Pathways



4.2.1 Fathom Modeling: Pipeline Energy Use

AFT Fathom modeling was conducted to estimate the power required to pump crude oil along the six different pipeline routes discussed in Section 3.0. Calculations and detailed model assumptions for each pipeline segment are provided in Appendix A.

- Calculation 001 Pump Energy Requirements and Usage – Enbridge Chicago Pathway
- Calculation 002 Pump Energy Requirements and Usage – Express Chicago Pathway
- Calculation 003 Pump Energy Requirements and Usage – TMPL China Pathway
- Calculation 004 Pump Energy Requirements and Usage – Gateway China Pathway
- Calculation 005 Pump Energy Requirements and Usage – Saint James Chicago Pathway
- Calculation 006 Pump Energy Requirements and Usage – Freeport Chicago Pathway

All of the calculations were performed using publicly available information for the following inputs: pipe sizes, pathway piping length, pump stations, changes in pipeline pathway elevations, crude oil properties, and crude flow rates. The pump stations were modeled as close to existing pump stations on each pathway as possible given publicly available information. The total pressure drops between each pumping station and for the entire pathway were determined by using the AFT model. The resulting pump horsepower requirements were then calculated by using the pump-flow and pump-head requirements.

The following general assumptions underlie the power usage estimates for all pipeline segments:

1. Crude has the characteristics of Western Canadian Select (WCS) as shown on the Enbridge 2009 Crude Characteristics table.
2. Crude is transported at 10°C and the temperature remains constant for the entire distance of transportation.
3. Piping is steel with a wall thickness of 0.5 inches
4. Piping lengths indicated in Section 3 of this report include required fitting lengths.
5. Pumps are 70- 80% efficient
6. Pump motor is 95% efficient.
7. WCS viscosity is 350cST
8. Working pressure in pipeline is 800psig – 1200psig
9. Change is elevation from station to station is at a constant slope.

The following equations were used to calculate the pump power required to transport the crude oil.

$$\text{Hyd hp} = \frac{\text{lb of liquid per minute x H(in feet)}}{33{,}000}$$

$$\text{Brake hp} = \frac{\text{Hyd hp}}{\text{Pump efficiency}}$$

$$\text{KW input to motor} = \frac{\text{Brake hp} \times 0.7457}{\text{Motor efficiency}}$$

$$H\ (\text{feet}) = \frac{\text{psi} \times 2.31}{\text{Specific Gravity}}$$

$$\text{kWh} = \text{Pump Power Required (kW)} \times \text{running time (h)}$$

Each calculation contains the references used to determine the required pumping power. The calculations also include the AFT model input and output. The results of the calculations are an estimate of the required pumping power; detailed pump layout and sizing calculations were not performed.

Table 7 summarizes the results of each of the calculations.

Table 7 Summary of Pumping Power Requirements

Pathway	Pipe length (miles)	Total pressure loss in piping (psid)	Head loss (ft)	kWh
Enbridge Chicago Pathway	1,935	25,241	62,695	2.25E+09
Express Chicago Pathway	2,376	47,981	119,179	2.20E+09
TMPL Pathway	986	19,274	47,874	1.03E+09
Gateway China Pathway	1008	14,186	35,236	1.20E+09
St. James–Chicago Pathway	835	24,170	60,035	3.89E+09
Freeport–Chicago Pathway	1,231	25,209	62,616	1.18E+09

4.2.1.1 Calculation 001, Pump Energy Requirements and Usage—Enbridge Chicago Pathway

Calculation 001 modeled the power requirements to pump crude oil from Fort McMurray to Chicago along the Enbridge Chicago Pathway. It modeled 33 pumps stations over 1,935 miles of pipe ranging from 30 to 48 inches in diameter. Modeling indicates that the total kWh required for transporting crude oil from Edmonton to Chicago 365 days a year, 24 hours a day, is 2.25 x 10^9 kWh. Calculation details and references are provided in Appendix A.

4.2.1.2 **Calculation 002, Pump Energy Requirements and Usage—Express Chicago Pathway**

Calculation 002 modeled the power requirements to pump crude oil from Fort McMurray to Chicago along the Express Chicago Pathway. It modeled 54 pumps stations over 2,376 miles of pipe ranging from 20 to 48 inches in diameter. Modeling indicates that the total kWh required for transporting crude oil from Edmonton to Chicago 365 days a year, 24 hours a day, is 2.20 x 10^9 kWh. Calculation details are provided in Appendix A.

4.2.1.3 **Calculation 003, Pump Energy Requirements and Usage—TMPL China Pathway**

Calculation 003 modeled the power requirements to pump crude oil from Fort McMurray to Vancouver along the TMPL China Pathway. It modeled 36 pump stations over 986 miles of pipe ranging from 22 to 24 inches in diameter. Modeling indicates that the total kWh required for transporting crude oil from Fort McMurray to Vancouver 365 days a year, 24 hours a day, is 1.03 x 10^9kWh. Calculation details are provided in Appendix A.

4.2.1.4 **Calculation 004, Pump Energy Requirements and Usage—Gateway China Pathway**

Calculation 004 modeled the power requirements to pump crude oil from Fort McMurray to Kitimat along the Gateway China Pathway. It modeled 21 pump stations over 1008 miles of pipe ranging from 22 to 36 inches in diameter. Modeling indicates that the total kWh required for transporting crude oil from Fort McMurray to Kitimat 365 days a year, 24 hours a day, is 1.20 x 10^9 kWh. Calculation details are provided in Appendix A.

4.2.1.5 **Calculation 005, Pump Energy Requirements and Usage—St. James–Chicago Pathway**

Calculation 005 modeled the power requirements to pump crude oil from St. James, Louisiana, to Chicago along the St. James–Chicago Pathway. It modeled 24 pumps stations over 835 miles of pipe ranging from 26 to 40inches in diameter. Modeling indicates that the total kWh required for transporting crude oil from St. James to Chicago 365 days a year, 24 hours a day, is 3.89x10^9 kWh.

4.2.1.6 **Calculation 006, Pump Energy Requirements and Usage—Freeport Chicago Pathway**

Calculation 006 modeled the power requirements to pump crude oil from St. James to Chicago along the Freeport Chicago Pathway. It modeled 30 pump stations over 1,231 miles of pipe ranging from 22 to 30 inches in diameter. Modeling indicates that the total kWh required for transporting crude oil from St. James to Chicago 365 days a year, 24 hours a day, is 1.18 x 10^9 kWh.

4.2.2 GHG Emissions: Energy-Use Emission Factors

Calculating GHG emissions associated with pipeline energy use requires coupling modeled energy use with appropriate emission factors. In both the U.S. and Canada, GHG emission factors have been developed and are updated routinely for electricity production by region. For each region, total GHG emission estimates from power generation are coupled with total power production to yield an emission factor in mass of GHG emitted per gigawatt hour. For this analysis, emission factors for each province in Canada were obtained from Environment Canada, National Inventory Report, 1990-2006: Greenhouse Gas Sources and Sinks in Canada (May 2008), Annex 9: Electricity Intensity Tables[3]. Emission factors for major power-production regions in the U.S. were obtained from EPA's E-grid database (factors eGRID2007 Version 1.1 Subregion Location(Operator)-based File (Year 2005 Data) www.epa.gov/cleanenergy/energy-resources/egrid/index.html).

4.3 Tanker Transport: Methodology and Assumptions

Emissions from tanker transport were calculated by evaluating total fuel usage over the relevant trip distance and coupling fuel-usage estimates with fuel-specific GHG emission factors. Emissions were calculated on a per-barrel basis by dividing total-trip GHG emissions by the total quantity of crude transported per trip (in barrels). It is not uncommon for oil tankers to empty their crude at a destination port and make the return trip to the port of origin without cargo. Therefore, estimates of GHG emissions from tanker transport were completed for two possible scenarios: a one-way trip and a two-way, or "deadhead," trip.

4.3.1 Tanker Features and Transport Fuel Use

To calculate a fuel-use value for each potential tanker route under consideration, it was necessary to develop a "generic" tanker with a set of features including speed, capacity, and fuel efficiency that could be broadly applied across all relevant sea routes. A VLCC tanker (designed to carry up to 50,000 to 250,000 dead-weight tons of cargo) represents a reasonable potential vessel for transport of crude along the sea routes considered as part of this analysis. As noted above, shipping ports included in the analysis were chosen based on a general assessment of frequently used port locations capable of accommodating VLCCs.

Average VLCC characteristics were developed based on evaluation of three actual VLCC models that are currently part of a crude transportation fleet. These include the Patris (built in 2002), the BW Luck (built in 2003), and the Bunga Kasturi Enam (built in 2008). Based on specific fuel-

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[3] www.ec.gc.ca/pdb/ghg/inventory_report/2006_report/a9_eng.cfm

consumption estimates and speed estimates for each ship, average fuel usage (both laden and unladen) was calculated for use in the analysis. Appendix B provides detailed inputs and fuel usage calculations for the "average" tanker used in this analysis.

For each tanker transport route included in this analysis, the calculated "composite tanker" fuel usage rate (MMBtu/Nautical mile-barrel) was multiplied by total trip distance. Where deadhead trips were considered, unladen fuel-use rates were used for the return trip to the port of origin. An "average" VLCC tanker capacity of 2 million barrels was assumed, based on typical cargo-capacity volumes for VLCCs currently in service. All route distances were calculated using BP distance tables as indicated in Section 3.0.

Table 8 summarizes fuel-usage rates per barrel for each segment of tanker transport evaluated.

Table 8 Summary of Tanker Fuel Usage Estimates

Pathway	"Composite" tanker fuel-usage rate (MMBtu IFO 380/nautical mile—barrel)	Trip distance (nautical miles)	Fuel usage per barrel transported (MMBtu IFO 380/barrel)	Cargo transported per trip (barrels)
Basrah to Ningbo (laden)	5.33E-06	6,020	3.21E-02	2,000,000
Basrah to Ningbo (unladen)	4.59E-06	6,020	2.76E-02	2,000,000
Kitimat to Ningbo (laden)	5.33E-06	4,903	2.61E-02	2,000,000
Kitimat to Ningbo (unladen)	4.59E-06	4,903	2.25E-02	2,000,000
Basrah to Galveston (laden)	5.33E-06	13,102	6.98E-02	2,000,000
Basrah to Galveston (unladen)	4.59E-06	13,102	6.01E-02	2,000,000

4.3.2 GHG Emissions: Emission Factors for Tanker Transport

Calculating GHG emissions associated with tanker fuel use requires coupling modeled fuel usage with appropriate emission factors. Although the VLCC tankers considered in this evaluation commonly use intermediate fuel oil with a maximum viscosity of 380 centistokes (IFO-380), fuel-specific GHG emission factors were not available for IFO 380. Instead, fuel emission factors for residual fuel oil #5 and #6 were taken from The Climate Registry General Reporting Protocol v. 1.1 May 2008 (www.theclimateregistry.org/resources/protocols/general-reporting-protocol/).

5.0 Results

Transportation energy use and GHG-emission calculations were completed for the base case and crude shuffle case. GHG emissions were calculated on a per-barrel basis and a total basis to provide two metrics with which to evaluate crude-shuffle impacts. Detailed calculations are provided in Appendix B.

5.1 Transport Efficiency

As an intermediate step, before comparing the base case and crude shuffle directly, we assessed the efficiency of each of the modes of transportation evaluated. To this end, GHG emissions were calculated per barrel for each leg of transport for each case. Table 9 provides a comparison of GHG emissions per barrel transported for each pipeline pathway and for each tanker route (with and without a deadhead return trip).

Table 9 Transport Efficiency for Each Route Segment

Scenario	Mode of transport	Route	Metric tons CO2-e per barrel of crude transported	Distance transported	Metric tons CO2-e per barrel of crude transported/mile
Base Case	Pipeline	Edmonton to Chicago via Enbridge Pipeline	5.53E-03	1,637	3.38E-06
		Edmonton to Chicago via Express Chicago Pipeline	1.19E-02	2,078	5.72E-06
	Tanker	Basrah to Ningbo—One Way	2.55E-03	6,928	3.68E-07
		Basrah to Ningbo—Roundtrip/Deadhead	4.75E-03	6,928	6.86E-07
Crude Shuffle	Pipeline	Edmonton to Kitimat via TMPL China Pathway	3.09E-03	716	4.32E-06
		Edmonton to Kitimat via Gateway China Pathway	2.69E-03	739	3.64E-06
	Tanker	Kitimat to Ningbo—One Way	2.08E-03	5,673	3.66E-07
		Kitimat to Ningbo—Roundtrip/Deadhead	3.87E-03	5,673	6.82E-07
	Pipeline	Galveston to Chicago via St. James–Chicago Pathway	6.60E-03	835	7.90E-06
		Galveston to Chicago via Freeport–Chicago Pathway	6.74E-03	1,231	5.48E-06
	Tanker	Basrah to Galveston—One Way	5.55E-03	15,078	3.68E-07
		Basrah to Galveston—Roundtrip/Deadhead	1.03E-02	15,078	6.86E-07

5.2 Base Case and Crude Shuffle Comparison

5.2.1 Per-Barrel Basis

As noted in Section 3, calculating the impacts on a per-barrel basis requires identifying energy inputs for each segment of transport and linking this information with crude volume transported per unit of energy input. Pipeline energy use on a per-barrel basis was calculated by evaluating total energy use associated with known throughput rates for each segment of pipeline. Tanker energy use on a per-barrel basis was calculated by evaluating total energy use over a known trip distance for a given tanker capacity. Per-barrel energy use and GHG emissions for each case were calculated by summing across all transportation segments for that case. Table 10 provides a summary of GHG emissions per barrel for each scenario.

Table 10 Per-Barrel GHG Emissions

Scenario	Metric tons CO_2-e per barrel of crude transported (including tanker transport—one way)	Metric tons CO_2-e per barrel of crude transported (including tanker transport—roundtrip/deadhead)
BASE CASE (using Enbridge Pipeline option)	8.08E-03	1.03E-02
BASE CASE (using Express Pipeline option)	1.19E-02	1.19E-02
BASE CASE AVERAGE (average of potential pipeline routes)	9.98E-03	1.11E-02
CRUDE SHUFFLE (TMPL and St. James)	1.73E-02	2.39E-02
CRUDE SHUFFLE (TMPL and Freeport)	1.75E-02	2.40E-02
CRUDE SHUFFLE (Gateway and St. James)	1.69E-02	2.35E-02
CRUDE SHUFFLE (Gateway and Freeport)	1.71E-02	2.36E-02
CRUDE SHUFFLE AVERAGE (average of potential pipeline routes)	1.72E-02	2.38E-02

Table 10 shows per-barrel emissions with a separate row for each of the potential pipelines or combinations of pipelines that could be used to transport crude under each case. In addition, average emission intensity is shown for each scenario. Per-barrel emissions are shown in separate columns for one-way tanker transport and a round trip (deadhead).

5.2.2 Total GHG Emissions Basis

Evaluation of total GHG impacts involves linking per-barrel values with expected quantities of crude displaced under LCFS. As discussed in Section 3, total change in GHG emissions has been calculated for the displacement of all crude currently imported to the U.S. from Canada (2,436 thousand barrels per day) and all crude currently imported to the PADD II region of the U.S. from Canada (1,154 thousand barrels per day. Total crude transport volumes per day were obtained from U.S. Department of Energy data for 2008. The total volumes considered here cannot necessarily be accommodated by a single pipeline pathway (e.g., the Enbridge pipeline cannot accommodate all crude imported to the U.S. from Canada). A detailed market evaluation, beyond the scope of this study, would be required to pinpoint a likely combination of pipeline routes that may be used under the crude shuffle scenario, depending on total oil volume displaced. Therefore, a worst-case scenario has been assumed in the total GHG emissions calculations by adopting the GHG efficiency (metric tons CO_2-e per barrel) of the least efficient pipeline segment evaluated for all pipeline transport (See Table 10—Edmonton to Chicago via Enbridge Pathway).

Table 11 Total Transport GHG Emissions

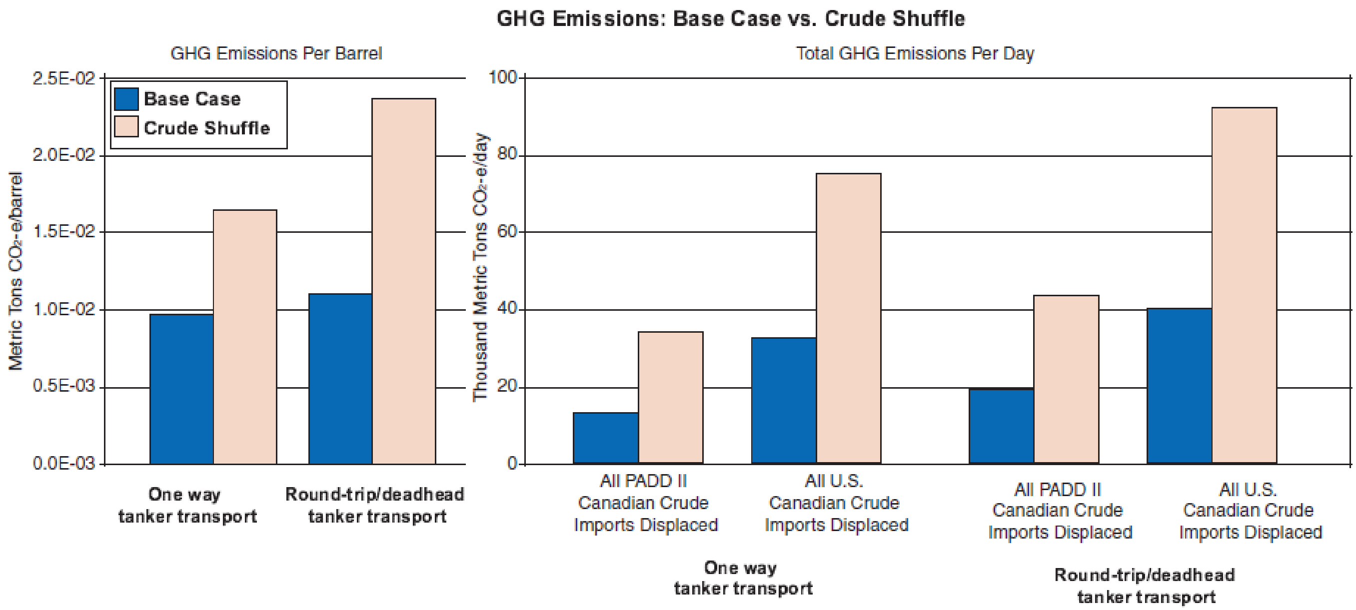
Scenario	Metric tons CO_2-e total per day (assumes tanker transport—one way)	Metric tons CO_2-e total per day (assumes tanker transport—roundtrip/ deadhead)
Base Case		
All Canadian Imports to U.S. displaced	35,160	40,519
All Canadian Imports to U.S. PADD II displaced	16,651	19,189
Crude Shuffle Case		
All Canadian Imports to U.S. displaced	76,478	92,507
All Canadian Imports to U.S. PADD II displaced	36,218	43,809

Table 11 shows total emissions per day with a separate row for each of the potential quantities of crude displaced. Total emissions are shown in separate columns for one-way tanker transport and for a round trip (deadhead).

6.0 Discussion and Conclusions

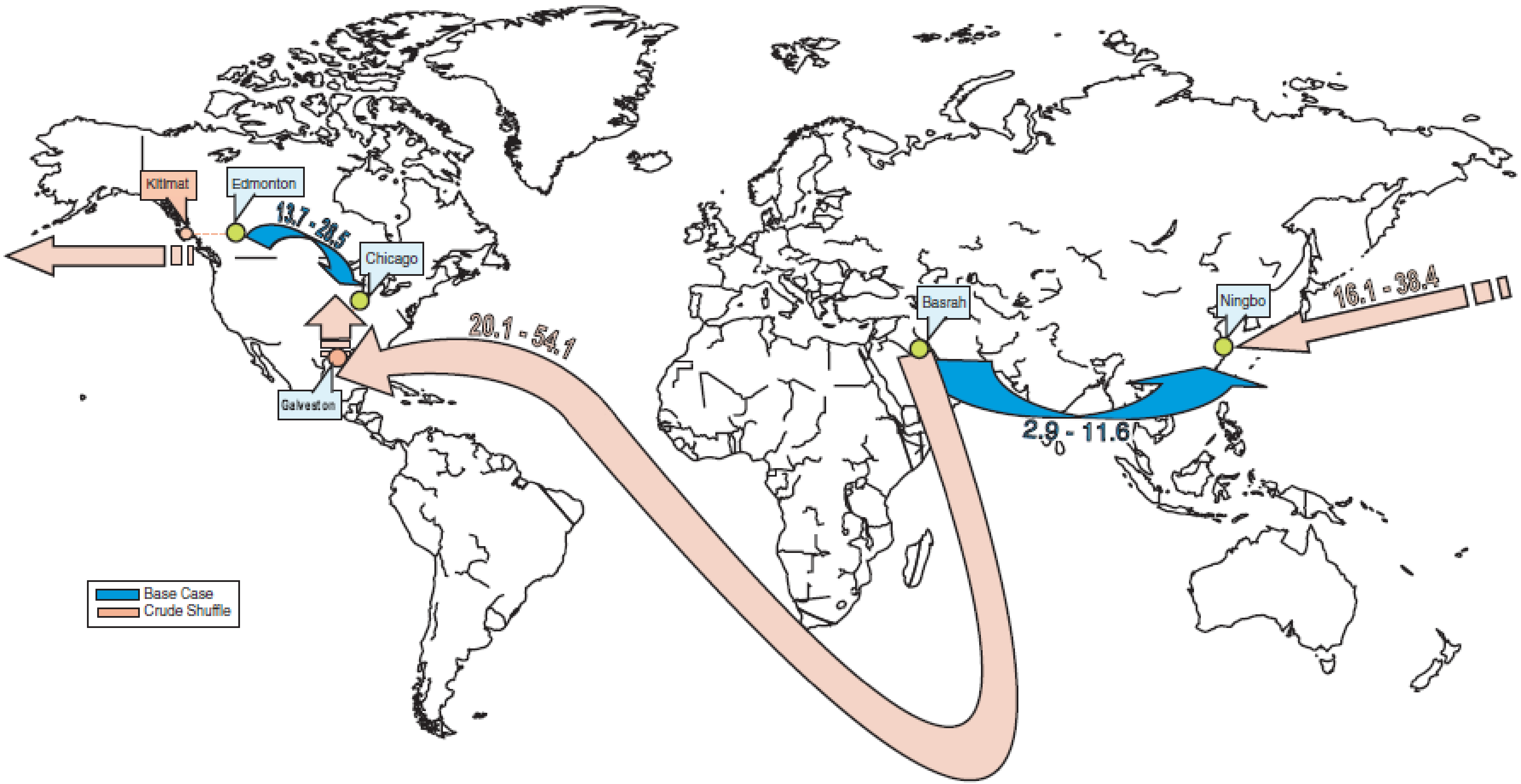
This analysis of the change in crude-transport-related emissions that will accompany implementation of an LCFS in the U.S. indicates that the net effect of the policy will be an increase in global GHG emissions. As shown in Figure 5, modeling results show a doubling of GHG emissions on both a per-barrel basis and on a total basis.

Figure 5 LCFS GHG Impacts: Base Case vs. Crude Shuffle



Implementation of an LCFS shifts crude import/export patterns in a manner that changes the mix of transport methods and requires that crude be transported over much greater distances. As indicated in Section 5.1, shifts in transportation mode might be expected to exert some influence over the GHG footprint associated with crude transport. In the case of the crude shuffle, however, the changes in the total distance traveled are significant in determining the magnitude of the change in GHG emissions. Under the base case, crude is transported approximately 8,500 to 9,000 miles from Edmonton to Chicago and from Basrah to Ningbo. Under the crude shuffle case, total transport distance nearly triples, with crude transported approximately 22,300 to 22,700 miles from Basrah to Chicago and from Edmonton to Ningbo. Resulting GHG emissions are approximately twice as high on a per-barrel basis and on a total basis (for any of the crude displacement scenarios considered). Figure 6 shows the range of total potential GHG emissions associated with transport for the base case and the crude shuffle case. The range of values presented represents the lower and upper bound of calculated GHG emissions, considering the possibility of tanker transport with and without a deadhead return trip, and considering a range of possible crude-displacement scenarios (all Canadian crude imports to U.S. displaced and all Canadian crude imports to U.S. PADD II displaced). Under all scenarios considered, the crude shuffle results in emissions that are approximately twice as great as the emissions associated with current base-case crude transport patterns.

Figure 6 Total Transport GHG Emissions (Thousand Metric Tons CO_2-e)



Note: range presented represents possibility of tanker transport with and without a deadhead return trip and considering a range of possible crude-displacement scenarios

6.1 Change in GHG Emissions: Per-Barrel Basis

Table 12 below highlights the change in GHG emissions per barrel associated with the crude shuffle (calculated using an average of modeled values for the various pipeline routes considered for each case). Implementation of an LCFS results in an increase in emissions on a per-barrel basis, but this increase is approximately twice as great if a deadhead return trip is considered for the tanker portion of the route.

Table 12 Change in Per-Barrel GHG Emissions

Scenario	Metric tons CO_2-e per barrel of crude transported (tanker transport—one way)	Metric tons CO_2-e per barrel of crude transported (tanker transport—roundtrip/deadhead)
Average of potential pipeline routes	7.21E-03	1.27E-02

6.2 Change in GHG Emissions: Total Basis

Table 13 below shows the total change in GHG emissions associated with the crude shuffle. While LCFS increases GHG emissions across all cases evaluated, the magnitude of the total increase in GHG emissions depends on the extent to which LCFS results in displacement of Canadian crude imports to the U.S. A nationwide LCFS that discouraged all Canadian imports to the U.S. could increase GHG by approximately 52,000 metric tons per day.

Table 13 Change in Total Transport GHG Emissions

Scenario	Metric tons CO_2-e total per day (including tanker transport—one way)	Metric tons CO_2-e total per day (including tanker transport—roundtrip/deadhead)
All Canadian imports to U.S. displaced	41,319	51,988
All Canadian imports to U.S. PADD II displaced	19,567	24,620

6.3 Conclusions

For the purpose of this study, it has been assumed that implementation of LCFS has the effect of making crude from certain sources with higher extraction-related carbon intensity unfavorable. While we have assumed LCFS in one region or in one country is not likely to change crude oil demand and consumption worldwide, the resulting change in preferences within the country or region where it is implemented is assumed to have a notable impact on import and export patterns. Under these assumptions, LCFS encourages transport from regions where fuel can be extracted with a low carbon footprint, resulting in inefficiencies as crude is transported over much longer distances to meet the shift in preferences. Because LCFS fails to influence worldwide demand, the only impact it has on total global GHG emissions is the increase associated with redistribution of crude imports and exports. The magnitude of this negative impact varies with the extent to which the LCFS results in displacement of crude from nearby sources and with the total increase in transport distance required to accommodate the fuel preferences created by the LCFS. For the scenarios evaluated as part of this analysis, the LCFS crude shuffle results in approximately a doubling of transport-related GHG emissions on a per-barrel and a total basis.

Appendix A

Pipeline Power Usage Modeling

BARR			Calc# 001 Date 6/15/2010	Sheet No. 1 of 7
Computed By: WJM	Checked By:SEM	Submitted By:	Project Name: Project Number:	
Date: 6/10/10	Date:6/15/10	Date:	Subject: Pump Energy Requirements and Usage – Enbridge Chicago Pathway	

1.0 Purpose:

Calculate the pumping energy required to transport crude oil from Fort McMurray to Chicago along the Enbridge Chicago Pathway.

2.0 Reference:

1. "Oil Sands Shuffle Work – Optimized Base Case" spreadsheet (Attached)
2. AFT Fathom 7.0 Output for each pipe routing (Attached)
3. Cameron Hydraulic Data, 18th Edition
4. Website, http://www.enbridge.com/ar2008/management-discussion-analysis/liquids-pipelines/enbridge-system-and-athabasca-system/
5. Website, http://www.enbridge.com/waupisoo/about-project/proposed-facilities.php
6. Website, http://www.enbridge.com/about/enbridgeCompanies/pdf/preliminary-information-package-enbridge_pipelines_inc.pdf
7. Website, http://www.allbusiness.com/construction/heavy-civil-construction-energy-utility-oil/12735957-1.html

8. Sulzer Pump estimated pump curves (Attached)

3.0 Assumptions:

1. Crude being transported has the characteristics of Western Canadian Select (WCS) as shown on the Enbridge 2009 Crude Characteristics table.
2. Crude is being transported at 10C and the temperature remains constant for the entire distance of transportation.
3. Piping to be steel with a wall thickness of 0.5inches
4. Piping lengths in Reference 1 and 2 include required fitting lengths.
5. Pumps are 70- 80% efficient
6. Pump motor is 95% efficient.
7. WCS viscosity is 350cST
8. Working pressure in pipeline is 800psig – 1200psig
9. Change is elevation from station to station is at a constant slope.

4.0 Conclusion:

The total kWh required to transport crude oil from Fort McMurray to Chicago 365 days a year, 24 hours a day is 2.25×10^9 kWh.

5.0 Calculation:

Fluid Characteristics: Crude Type = Western Canadian Select
Density = 927.1 kg/m^3
Viscosity = 350cST = 325.5cP
Flow Rate = See References 1 & 2
Specific Gravity = 0.927

Piping Characteristics: Pipe Type = Carbon Steel
Pipe Diameter = See References 1 & 2
Pipe Wall Thickness = 0.5inches (Assumption 3)
Absolute roughness = 0.00015feet

5.1 Calculate Piping Pressure Losses

AFT Fathom software was used to develop a piping model to calculate the piping pressure losses for the entire run of transport piping listed in References 1 and 2. The following components were entered into each model:

1. WCS density and viscosity
2. Piping diameters, absolute roughness, and lengths
3. Elevation differences between pipelines
4. Volumetric flow rates

The input and output for each transport piping arrangement is attached in Reference 2 of this calculation. Table 1 summarizes the results of the AFT modeling.

Table 1 - Athabasca & Enbridge Chicago Pathway

Crude Pathway	Total Length of Pipe (miles)	Total Pressure Loss in Piping (psid)	Head Loss (FT)
Enbridge Chicago Pathway	1,935	25,241	62,695

The results shown in Table 1 and Reference 2 were used to calculate the power required to transport the crude oil using the equation below.

$$\text{Hyd hp} = \frac{\text{lb of liquid per minute x H(in feet)}}{33{,}000} \qquad \text{(Reference 3)}$$

$$\text{Brake hp} = \frac{\text{Hyd hp}}{\text{Pump efficiency}} \qquad \text{(Reference 3)}$$

$$\text{KW input to motor} = \frac{\text{Brake hp x 0.7457}}{\text{motor efficiency}} \qquad \text{(Reference 3)}$$

$$\text{H (feet)} = \frac{\text{psi x 2.31}}{\text{Specific Gravity}} \qquad \text{(Reference 3)}$$

Table 2 below summarizes the results from the AFT modeling and the resulting pump input power required using the equations above. The pump efficiency is assumed to be 78% (Assumption 5) and the motor efficiency is assumed to be 95% (Assumption 6). The pump power calculated below is the power required to overcome the frictional pressure loss in the piping and does not account for additional pressure required for delivery of the crude oil.

Table 2 - Athabasca & Enbridge Chicago Pathway

Origin	Destination	Total Pressure Loss in Piping (psid)	Head Loss (ft)	Flow Rate (bbl/day)	Flow Rate (lb/min)	Pump Power Required (kw)
Ft. McMurray	Cheecham	1028	2,553	390000	88,043	6,856
Cheecham	Edmonton	3008	7,471	350000	79,013	18,003
Edomonton	Hardisty	2,490	6,185	880,000	198,662	37,469
Hardisty	Superior	7,669	19,049	450,000	101,588	59,013
Superior	Chicago	11,046	27,437	670,000	151,254	126,553
	Total	25,241	62,695			247,893

Table 3 summarizes the requirements for pumping power for several pump stations located along the Enbridge Chicago Pathway. Several pumping stations will be required to transport the crude from Edmonton to Chicago to reduce the operating pressure within the pipeline to meet code allowable working pressures. Table 2 shows the total pressure drop between each destination, since these pressure losses are higher than recommended operational pressures, intermediate pumping stations are suggested. Using Assumption 8 the total number of pumping stations and resulting power requirements can be calculated.

$$\# \text{ of Pump Stations} = \frac{\text{Total Pressure Loss}}{\text{Assumption 8 psig}} \text{ rounded up}$$

Edmonton to Hardisty = 2,490psi/850psi = 3 required pump stations

Three pumps having a total dynamic head of 850psi are required to pump 198,578lb/min of crude from Edmonton to Hardisty. Pumps were placed into the AFT model with a fixed pressure rise of 850psig. A pressure node was added for Edmonton to meet the requirements of the AFT modeling, this pressure is 850psi.

From Hardisty to Superior the AFT model was set up to closely model the pump locations of the Enbridge Alberta Clipper Pipeline pumping stations, see Reference 4. The locations and pump sizing is not exactly the same as the Enbridge pump stations; as the distances for each pump station were approximated using distances between the towns the pumps stations are located using an internet based map. Reference 4 indicates that nine pump stations exist between Hardisty and Gretna. Reference 5 indicates that there are four more pump stations from Gretna to and including

Superior. The AFT model was set up to show the pump stations in the towns indicated in the references with slight changes to total mileage between each town.

The same method described above for the pump locations from Edmonton to Hardisty was used between Superior and Chicago. Public documentation showing the location of existing pump stations along this line could not be found. Pumps were added at equal distance alone the entire line from Superior to Chicago. An adjustment in the pump stations total dynamic head were made to keep the operating pressure below or in the range of 800psig-1000psig.

Superior to Chicago = 11,407psi/800psi = 14 required pump stations

Thirteen pump stations were modeled at 800psi and one at 750psi.

The pump power was calculated using the equations above for each of the required pumps. The Sulzer pump online pump selection website was used to determine the approximate pump efficiency for each pump. Note that these are only approximate pump efficiencies but should be close to the final pump selection determined during detailed design. The pump curves are attached, see Reference 6. Several pumps may be required at each pump station depending on the flow requirements and head requirements; the total power at the pump station is shown as the Pump Power Required in Table 3 below.

Table 3 also shows the required kWh for the transport of the crude. The kWh required is calculated using the following equation.

Pump Power Required (kW) x running time(h) = kWh

Table 3 shows the kWh's required to operate the pumps 24 hours a day seven days a week for 365 days.

BARR	Calc# 001 Date 6/15/2010	Sheet No. 6 of 7

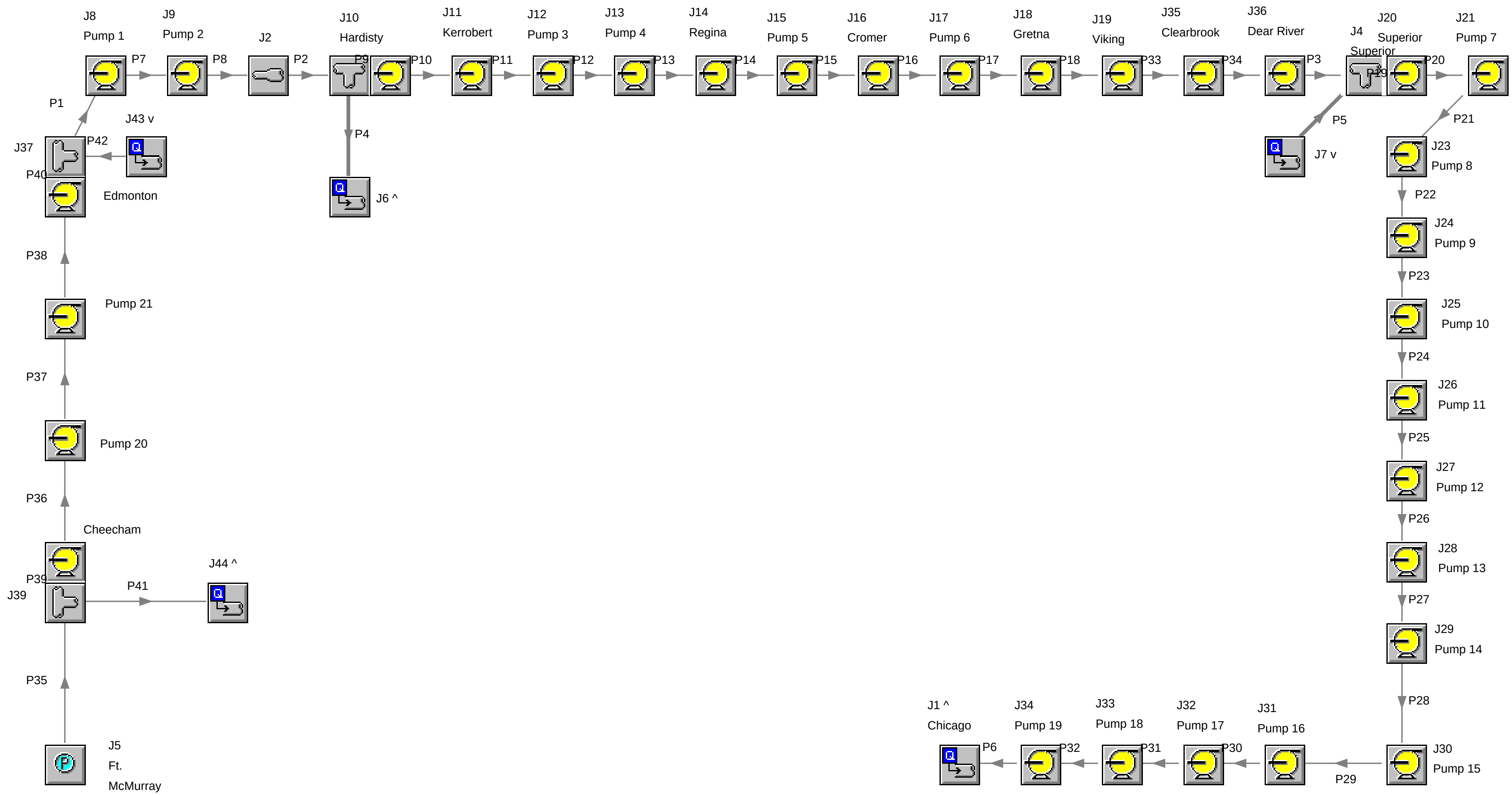
Computed By: WJM	Checked By:SEM	Submitted By:	Project Name:
			Project Number:
Date: 6/10/10	Date:6/15/10	Date:	Subject: Pump Energy Requirements and Usage – Enbridge Chicago Pathway

Table 3 -Athabasca & Enbridge Chicago Pathway

Station	Pump TDH	Flow Rate (bbl/day)	Flow Rate (lb/min)	Pump Power Required (kw)	kWh
Ft McMurray	2732	390000	88,043	7,335	6.4E+07
Cheecham	2484	350000	79,013	5,985	5.2E+07
Pump 20	2484	350000	79,013	5,985	5.2E+07
Pump 21	2484	350000	79,013	5,985	5.2E+07
Edomonton	2,111	880,000	198,662	12,789	1.1E+08
Pump 1	2,111	880,000	198,662	12,789	1.1E+08
Pump 2	2,111	880,000	198,662	12,789	1.1E+08
Hardisty	1,987	450,000	101,588	5,983	5.2E+07
Kerrobert	1,242	450,000	101,588	3,739	3.3E+07
Pump 3	1,118	450,000	101,588	3,366	2.9E+07
Pump 4	1,118	450,000	101,588	3,366	2.9E+07
Regina	1,490	450,000	101,588	4,486	3.9E+07
Pump 5	1,490	450,000	101,588	4,486	3.9E+07
Cromer	1,987	450,000	101,588	5,983	5.2E+07
Pump 6	1,739	450,000	101,588	5,236	4.6E+07
Gretna	1,863	450,000	101,588	5,609	4.9E+07
Viking	1,615	450,000	101,588	4,863	4.3E+07
Clearbrook	1,987	450,000	101,588	5,983	5.2E+07
Dear River	1,490	450,000	101,588	4,486	3.9E+07
Superior	1,863	670,000	151,254	9,132	8.0E+07
Pump 7	1,987	670,000	151,254	9,739	8.5E+07
Pump 8	1,987	670,000	151,254	9,739	8.5E+07
Pump 9	1,987	670,000	151,254	9,739	8.5E+07
Pump 10	1,987	670,000	151,254	9,739	8.5E+07
Pump 11	1,987	670,000	151,254	9,739	8.5E+07
Pump 12	1,863	670,000	151,254	9,132	8.0E+07
Pump 13	1,987	670,000	151,254	9,739	8.5E+07
Pump 14	1,987	670,000	151,254	9,739	8.5E+07
Pump 15	1,987	670,000	151,254	9,739	8.5E+07
Pump 16	1,987	670,000	151,254	9,739	8.5E+07
Pump 17	1,987	670,000	151,254	9,739	8.5E+07
Pump 18	1,987	670,000	151,254	9,739	8.5E+07
Pump 19	1,987	670,000	151,254	9,739	8.5E+07
Chicago					
			Total	256,380	2.25E+09

The required pump power in Table 3 is greater than the amount shown in Table 2 since there will be energy remaining in the pipeline when it is delivered to Chicago. The pressure in the AFT model is around 157psig into the Chicago station.

Athabasca and Enbridge Chicago Pathway



General

Title: AFT Fathom Model
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\Athabasca and Enbridge Chicago Pathway\Athabasca and Enbridge Chicago Pathway.fth
Scenario: Enbridge Chicago Pathway/Pump Case

Number Of Pipes= 42
Number Of Junctions= 43

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Pipe Input Table

Pipe	Name	Pipe Defined	Length	Length Units	Hydraulic Diameter	Hydraulic Diam. Units	Friction Data Set	Roughness	Roughness Units	Losses (K)
1	Pipe	Yes	28	miles	35	inches	Unspecified	0.00015	feet	0
2	Pipe	Yes	15	miles	47	inches	Unspecified	0.00015	feet	0
3	Pipe	Yes	77	miles	35	inches	Unspecified	0.00015	feet	0
4	Pipe	Yes	1	feet	100	inches	Unspecified	0.00015	feet	0
5	Pipe	Yes	1	feet	100	inches	Unspecified	0.0015	feet	0
6	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
7	Pipe	Yes	28	miles	35	inches	Unspecified	0.00015	feet	0
8	Pipe	Yes	29	miles	35	inches	Unspecified	0.00015	feet	0
9	Pipe	Yes	0.5	feet	35	inches	Unspecified	0.00015	feet	0
10	Pipe	Yes	115.6	miles	35	inches	Unspecified	0.00015	feet	0
11	Pipe	Yes	66.69999	miles	35	inches	Unspecified	0.00015	feet	0
12	Pipe	Yes	66.69999	miles	35	inches	Unspecified	0.00015	feet	0
13	Pipe	Yes	66.69999	miles	35	inches	Unspecified	0.00015	feet	0
14	Pipe	Yes	85	miles	35	inches	Unspecified	0.00015	feet	0
15	Pipe	Yes	85	miles	35	inches	Unspecified	0.00015	feet	0
16	Pipe	Yes	100	miles	35	inches	Unspecified	0.00015	feet	0
17	Pipe	Yes	100	miles	35	inches	Unspecified	0.00015	feet	0
18	Pipe	Yes	100	miles	35	inches	Unspecified	0.00015	feet	0
19	Pipe	Yes	0.5	feet	33	inches	Unspecified	0.00015	feet	0
20	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
21	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
22	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
23	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
24	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
25	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
26	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0

Pipe	Name	Pipe Defined	Length	Length Units	Hydraulic Diameter	Hydraulic Diam. Units	Friction Data Set	Roughness	Roughness Units	Losses (K)
27	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
28	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
29	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
30	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
31	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
32	Pipe	Yes	33.34999	miles	33	inches	Unspecified	0.00015	feet	0
33	Pipe	Yes	88	miles	35	inches	Unspecified	0.00015	feet	0
34	Pipe	Yes	120	miles	35	inches	Unspecified	0.00015	feet	0
35	Pipe	Yes	62	miles	29	inches	Unspecified	0.00015	feet	0
36	Pipe	Yes	78.6	miles	29	inches	Unspecified	0.00015	feet	0
37	Pipe	Yes	78.6	miles	29	inches	Unspecified	0.00015	feet	0
38	Pipe	Yes	78.6	miles	29	inches	Unspecified	0.00015	feet	0
39	Pipe	Yes	5	feet	29	inches	Unspecified	0.00015	feet	0
40	Pipe	Yes	5	feet	29	inches	Unspecified	0.00015	feet	0
41	Pipe	Yes	1	feet	29	inches	Unspecified	0.00015	feet	0
42	Pipe	Yes	1	feet	35	inches	Unspecified	0.00015	feet	0

Pipe	Junctions (Up,Down)	Geometry	Material	Special Condition
1	37, 8	Cylindrical Pipe	Unspecified	None
2	2, 3	Cylindrical Pipe	Unspecified	None
3	36, 4	Cylindrical Pipe	Unspecified	None
4	3, 6	Cylindrical Pipe	Unspecified	None
5	7, 4	Cylindrical Pipe	Unspecified	None
6	34, 1	Cylindrical Pipe	Unspecified	None
7	8, 9	Cylindrical Pipe	Unspecified	None
8	9, 2	Cylindrical Pipe	Unspecified	None
9	3, 10	Cylindrical Pipe	Unspecified	None
10	10, 11	Cylindrical Pipe	Unspecified	None
11	11, 12	Cylindrical Pipe	Unspecified	None
12	12, 13	Cylindrical Pipe	Unspecified	None
13	13, 14	Cylindrical Pipe	Unspecified	None
14	14, 15	Cylindrical Pipe	Unspecified	None
15	15, 16	Cylindrical Pipe	Unspecified	None
16	16, 17	Cylindrical Pipe	Unspecified	None
17	17, 18	Cylindrical Pipe	Unspecified	None
18	18, 19	Cylindrical Pipe	Unspecified	None
19	4, 20	Cylindrical Pipe	Unspecified	None
20	20, 21	Cylindrical Pipe	Unspecified	None
21	21, 23	Cylindrical Pipe	Unspecified	None
22	23, 24	Cylindrical Pipe	Unspecified	None
23	24, 25	Cylindrical Pipe	Unspecified	None
24	25, 26	Cylindrical Pipe	Unspecified	None
25	26, 27	Cylindrical Pipe	Unspecified	None
26	27, 28	Cylindrical Pipe	Unspecified	None
27	28, 29	Cylindrical Pipe	Unspecified	None
28	29, 30	Cylindrical Pipe	Unspecified	None
29	30, 31	Cylindrical Pipe	Unspecified	None
30	31, 32	Cylindrical Pipe	Unspecified	None
31	32, 33	Cylindrical Pipe	Unspecified	None
32	33, 34	Cylindrical Pipe	Unspecified	None
33	19, 35	Cylindrical Pipe	Unspecified	None
34	35, 36	Cylindrical Pipe	Unspecified	None
35	5, 39	Cylindrical Pipe	Unspecified	None

Pipe	Junctions (Up,Down)	Geometry	Material	Special Condition
36	38, 40	Cylindrical Pipe	Unspecified	None
37	40, 41	Cylindrical Pipe	Unspecified	None
38	41, 42	Cylindrical Pipe	Unspecified	None
39	39, 38	Cylindrical Pipe	Unspecified	None
40	42, 37	Cylindrical Pipe	Unspecified	None
41	39, 44	Cylindrical Pipe	Unspecified	None
42	43, 37	Cylindrical Pipe	Unspecified	None

Pipe Fittings & Losses

Area Change Table

Area Change	Name	Object Defined	Inlet Elevation	Elevation Units	Type	Geometry	Angle	Loss Factor
2	Area Change	Yes	2072	feet	Conical	Expansion	45.	0.1974294

Assigned Flow Table

Assigned Flow	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Type	Flow	Flow Units	Loss Factor
1	Chicago	Yes	579	feet	None	Outflow	670000	barrels/day	0
6	Assigned Flow	Yes	2051	feet	None	Outflow	430000	barrels/day	0
7	Assigned Flow	Yes	642	feet	None	Inflow	220000	barrels/day	0
43	Assigned Flow	Yes	2192	feet	None	Inflow	530000	barrels/day	0
44	Assigned Flow	Yes	1417	feet	None	Outflow	40000	barrels/day	0

Assigned Pressure Table

Assigned Pressure	Name	Object Defined	Inlet Elevation	Elevation Units	Initial Pressure	Initial Pressure Units	Pressure	Pressure Units
5	Ft. McMurray	Yes	1214	feet	1,100	psig	1100	psig

Assigned Pressure	Pressure Type	Balance Energy	Balance Concentration	(Pipe #1) K In, K Out
5	Stagnation	No	No	(P35) 0, 0

Pump Table

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
8	Pump 1	Yes	2163.8	feet	None	Fixed Pressure Rise	850	psid
9	Pump 2	Yes	2135.6	feet	None	Fixed Pressure Rise	850	psid
10	Hardisty	Yes	2051	feet	None	Fixed Pressure Rise	800	psid
11	Kerrobert	Yes	1910	feet	None	Fixed Pressure Rise	500	psid
12	Pump 3	Yes	1769	feet	None	Fixed Pressure Rise	450	psid
13	Pump 4	Yes	1628	feet	None	Fixed Pressure Rise	450	psid
14	Regina	Yes	1487	feet	None	Fixed Pressure Rise	600	psid
15	Pump 5	Yes	1346	feet	None	Fixed Pressure Rise	600	psid
16	Cromer	Yes	1205	feet	None	Fixed Pressure Rise	800	psid
17	Pump 6	Yes	1064	feet	None	Fixed Pressure Rise	700	psid
18	Gretna	Yes	923	feet	None	Fixed Pressure Rise	750	psid
19	Viking	Yes	780	feet	None	Fixed Pressure Rise	650	psid

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
20	Superior	Yes	642	feet	None	Fixed Pressure Rise	750	psid
21	Pump 7	Yes	637	feet	None	Fixed Pressure Rise	800	psid
23	Pump 8	Yes	632.12	feet	None	Fixed Pressure Rise	800	psid
24	Pump 9	Yes	627.18	feet	None	Fixed Pressure Rise	800	psid
25	Pump 10	Yes	622.24	feet	None	Fixed Pressure Rise	800	psid
26	Pump 11	Yes	617.3	feet	None	Fixed Pressure Rise	800	psid
27	Pump 12	Yes	612.36	feet	None	Fixed Pressure Rise	750	psid
28	Pump 13	Yes	607.42	feet	None	Fixed Pressure Rise	800	psid
29	Pump 14	Yes	602.48	feet	None	Fixed Pressure Rise	800	psid
30	Pump 15	Yes	597.54	feet	None	Fixed Pressure Rise	800	psid
31	Pump 16	Yes	592.6	feet	None	Fixed Pressure Rise	800	psid
32	Pump 17	Yes	587.66	feet	None	Fixed Pressure Rise	800	psid
33	Pump 18	Yes	582.77	feet	None	Fixed Pressure Rise	800	psid
34	Pump 19	Yes	579	feet	None	Fixed Pressure Rise	800	psid
35	Clearbrook	Yes	780	feet	None	Fixed Pressure Rise	800	psid
36	Dear River	Yes	780	feet	None	Fixed Pressure Rise	600	psid
38	Cheecham	Yes	1417	feet	None	Fixed Pressure Rise	1000	psid
40	Pump 20	Yes	1676	feet	None	Fixed Pressure Rise	1000	psid
41	Pump 21	Yes	1936	feet	None	Fixed Pressure Rise	1000	psid
42	Edmonton	Yes	2192	feet	None	Fixed Pressure Rise	800	psid

Pump	Current Configuration	Heat Added To Fluid	Heat Added Units
8	N/A	0	Percent
9	N/A	0	Percent
10	N/A	0	Percent
11	N/A	0	Percent
12	N/A	0	Percent
13	N/A	0	Percent
14	N/A	0	Percent
15	N/A	0	Percent
16	N/A	0	Percent
17	N/A	0	Percent
18	N/A	0	Percent
19	N/A	0	Percent
20	N/A	0	Percent
21	N/A	0	Percent
23	N/A	0	Percent
24	N/A	0	Percent
25	N/A	0	Percent
26	N/A	0	Percent
27	N/A	0	Percent
28	N/A	0	Percent
29	N/A	0	Percent
30	N/A	0	Percent
31	N/A	0	Percent
32	N/A	0	Percent
33	N/A	0	Percent
34	N/A	0	Percent
35	N/A	0	Percent
36	N/A	0	Percent
38	N/A	0	Percent
40	N/A	0	Percent
41	N/A	0	Percent

Pump	Current Configuration	Heat Added To Fluid	Heat Added Units
42	N/A	0	Percent

Tee or Wye Table

Tee or Wye	Name	Object Defined	Inlet Elevation	Elevation Units	Tee/Wye Type	Loss Type	Angle	Pipes A, B, C
3	Hardisty	Yes	2051	feet	Sharp Straight	Simple (no loss)	90	2, 4, 9
4	Superior	Yes	642	feet	Sharp Straight	Simple (no loss)	90	3, 5, 19
37	Tee or Wye	Yes	2192	feet	Sharp Straight	Simple (no loss)	90	1, 40, 42
39	Tee or Wye	Yes	1417	feet	Sharp Straight	Simple (no loss)	90	35, 39, 41

General

Title: AFT Fathom Model
Analysis run on: 6/10/2010 10:58:20 AM
Application version: AFT Fathom Version 7.0 (2009.11.02)
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\Athabasca and Enbridge Chicago Pathway\Athabasca and Enbridge Chicago Pathway.fth
Scenario: Enbridge Chicago Pathway/Pump Case
Output File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\Athabasca and Enbridge Chicago Pathway\Athabasca and Enbridge Chicago Pathway_1.out

Execution Time= 0.22 seconds
Total Number Of Head/Pressure Iterations= 0
Total Number Of Flow Iterations= 2
Total Number Of Temperature Iterations= 0
Number Of Pipes= 42
Number Of Junctions= 43
Matrix Method= Gaussian Elimination

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Total Inflow= 33,249 gal/min
Total Outflow= 33,249 gal/min
Maximum Static Pressure is 1,115 psia at Pipe 35 Inlet
Minimum Static Pressure is 53.11 psia at Pipe 34 Outlet

Fixed Energy Cost=0.076 U.S. Dollars per kW-hr

Total of All Model Costs = 0 U.S. Dollars

Pump Summary

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
8	Pump 1	25,666	3,310	850.0	2,115	100.0	N/A	12,724	N/A	N/A	201.1
9	Pump 2	25,666	3,310	850.0	2,115	100.0	N/A	12,724	N/A	N/A	344.8
10	Hardisty	13,125	1,692	800.0	1,990	100.0	N/A	6,124	N/A	N/A	206.8
11	Kerrobert	13,125	1,692	500.0	1,244	100.0	N/A	3,827	N/A	N/A	124.6
12	Pump 3	13,125	1,692	450.0	1,120	100.0	N/A	3,445	N/A	N/A	232.3
13	Pump 4	13,125	1,692	450.0	1,120	100.0	N/A	3,445	N/A	N/A	215.7
14	Regina	13,125	1,692	600.0	1,493	100.0	N/A	4,593	N/A	N/A	199.1
15	Pump 5	13,125	1,692	600.0	1,493	100.0	N/A	4,593	N/A	N/A	205.2
16	Cromer	13,125	1,692	800.0	1,990	100.0	N/A	6,124	N/A	N/A	211.3
17	Pump 6	13,125	1,692	700.0	1,742	100.0	N/A	5,358	N/A	N/A	427.8
18	Gretna	13,125	1,692	750.0	1,866	100.0	N/A	5,741	N/A	N/A	395.5

AFT Fathom Model

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
19	Viking	13,125	1,692	650.0	1,617	100.0	N/A	4,976	N/A	N/A	489.6
20	Superior	19,541	2,520	750.0	1,866	100.0	N/A	8,548	N/A	N/A	270.5
21	Pump 7	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	174.3
23	Pump 8	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	202.4
24	Pump 9	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	230.5
25	Pump 10	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	258.6
26	Pump 11	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	286.7
27	Pump 12	19,541	2,520	750.0	1,866	100.0	N/A	8,548	N/A	N/A	314.9
28	Pump 13	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	218.6
29	Pump 14	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	246.7
30	Pump 15	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	274.8
31	Pump 16	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	303.0
32	Pump 17	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	331.1
33	Pump 18	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	359.2
34	Pump 19	19,541	2,520	800.0	1,990	100.0	N/A	9,118	N/A	N/A	386.1
35	Clearbrook	13,125	1,692	800.0	1,990	100.0	N/A	6,124	N/A	N/A	421.7
36	Dear River	13,125	1,692	600.0	1,493	100.0	N/A	4,593	N/A	N/A	114.2
38	Cheecham	10,208	1,316	1,000.0	2,488	100.0	N/A	5,954	N/A	N/A	196.8
40	Pump 20	10,208	1,316	1,000.0	2,488	100.0	N/A	5,954	N/A	N/A	191.1
41	Pump 21	10,208	1,316	1,000.0	2,488	100.0	N/A	5,954	N/A	N/A	184.5
42	Edmonton	10,208	1,316	800.0	1,990	100.0	N/A	4,763	N/A	N/A	181.8

Jct	NPSHR (feet)
8	N/A
9	N/A
10	N/A
11	N/A
12	N/A
13	N/A
14	N/A
15	N/A
16	N/A
17	N/A
18	N/A
19	N/A
20	N/A
21	N/A
23	N/A
24	N/A
25	N/A
26	N/A
27	N/A
28	N/A
29	N/A
30	N/A
31	N/A
32	N/A
33	N/A
34	N/A
35	N/A
36	N/A

Jct	NPSHR (feet)
38	N/A
40	N/A
41	N/A
42	N/A

Cost Report

	Table Units: U.S. Dollars	Operation/ Energy	TOTAL
	TOTAL OF ALL MODEL COSTS		0
	Total of All Shown Costs	0	0

Pipe Output Table

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psig)	P Static Min (psig)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)	dP Gravity (psid)
1	Pipe	880,000	8.5588	865.25	73.00	2,192.0	2,163.8	7.922E+02	7.922E+02	-11.334
2	Pipe	880,000	4.7463	174.26	75.61	2,072.0	2,051.0	9.865E+01	9.865E+01	-8.440
3	Pipe	450,000	4.3766	638.41	101.25	780.0	642.0	5.372E+02	5.372E+02	-55.465
4	Pipe	430,000	0.5123	75.75	75.75	2,051.0	2,051.0	1.114E-05	1.114E-05	0.000
5	Pipe	220,000	0.2621	101.37	101.37	642.0	642.0	5.702E-06	5.702E-06	0.000
6	Pipe	670,000	7.3301	947.48	156.80	579.0	579.0	7.907E+02	7.907E+02	0.000
7	Pipe	880,000	8.5588	923.00	130.75	2,163.8	2,135.6	7.922E+02	7.922E+02	-11.334
8	Pipe	880,000	8.5588	980.75	174.03	2,135.6	2,072.0	8.067E+02	8.067E+02	-25.562
9	Pipe	450,000	4.3766	75.63	75.63	2,051.0	2,051.0	7.288E-04	7.288E-04	0.000
10	Pipe	450,000	4.3766	875.63	42.58	2,051.0	1,910.0	8.330E+02	8.330E+02	-56.671
11	Pipe	450,000	4.3766	542.58	85.89	1,910.0	1,769.0	4.567E+02	4.567E+02	-56.671
12	Pipe	450,000	4.3766	535.89	79.20	1,769.0	1,628.0	4.567E+02	4.567E+02	-56.671
13	Pipe	450,000	4.3766	529.20	72.51	1,628.0	1,487.0	4.567E+02	4.567E+02	-56.671
14	Pipe	450,000	4.3766	672.51	74.98	1,487.0	1,346.0	5.975E+02	5.975E+02	-56.671
15	Pipe	450,000	4.3766	674.98	77.44	1,346.0	1,205.0	5.975E+02	5.975E+02	-56.671
16	Pipe	450,000	4.3766	877.44	164.46	1,205.0	1,064.0	7.130E+02	7.130E+02	-56.671
17	Pipe	450,000	4.3766	864.46	151.48	1,064.0	923.0	7.130E+02	7.130E+02	-56.671
18	Pipe	450,000	4.3766	901.48	189.30	923.0	780.0	7.122E+02	7.122E+02	-57.475
19	Pipe	670,000	7.3301	101.03	101.03	642.0	642.0	2.245E-03	2.245E-03	0.000
20	Pipe	670,000	7.3301	851.03	62.36	642.0	637.0	7.887E+02	7.887E+02	-2.010
21	Pipe	670,000	7.3301	862.36	73.63	637.0	632.1	7.887E+02	7.887E+02	-1.961
22	Pipe	670,000	7.3301	873.63	84.94	632.1	627.2	7.887E+02	7.887E+02	-1.986
23	Pipe	670,000	7.3301	884.94	96.24	627.2	622.2	7.887E+02	7.887E+02	-1.986
24	Pipe	670,000	7.3301	896.24	107.54	622.2	617.3	7.887E+02	7.887E+02	-1.986
25	Pipe	670,000	7.3301	907.54	118.85	617.3	612.4	7.887E+02	7.887E+02	-1.986
26	Pipe	670,000	7.3301	868.85	80.15	612.4	607.4	7.887E+02	7.887E+02	-1.986
27	Pipe	670,000	7.3301	880.15	91.45	607.4	602.5	7.887E+02	7.887E+02	-1.986
28	Pipe	670,000	7.3301	891.45	102.76	602.5	597.5	7.887E+02	7.887E+02	-1.986
29	Pipe	670,000	7.3301	902.76	114.06	597.5	592.6	7.887E+02	7.887E+02	-1.986
30	Pipe	670,000	7.3301	914.06	125.36	592.6	587.7	7.887E+02	7.887E+02	-1.986
31	Pipe	670,000	7.3301	925.36	136.64	587.7	582.8	7.887E+02	7.887E+02	-1.965
32	Pipe	670,000	7.3301	936.64	147.48	582.8	579.0	7.892E+02	7.892E+02	-1.515
33	Pipe	450,000	4.3766	839.30	162.00	780.0	780.0	6.773E+02	6.773E+02	0.000
34	Pipe	450,000	4.3766	962.00	38.41	780.0	780.0	9.236E+02	9.236E+02	0.000
35	Pipe	390,000	5.5250	1,099.81	71.54	1,214.0	1,417.0	1.028E+03	1.028E+03	81.590

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psig)	P Static Min (psig)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)	dP Gravity (psid)
36	Pipe	350,000	4.9583	1,071.57	69.30	1,417.0	1,676.0	1.002E+03	1.002E+03	104.098
37	Pipe	350,000	4.9583	1,069.30	66.63	1,676.0	1,936.0	1.003E+03	1.003E+03	104.500
38	Pipe	350,000	4.9583	1,066.63	65.56	1,936.0	2,192.0	1.001E+03	1.001E+03	102.892
39	Pipe	350,000	4.9583	71.58	71.57	1,417.0	1,417.0	1.082E-02	1.082E-02	0.000
40	Pipe	350,000	4.9583	865.56	865.55	2,192.0	2,192.0	1.082E-02	1.082E-02	0.000
41	Pipe	40,000	0.5667	71.73	71.73	1,417.0	1,417.0	1.466E-04	1.466E-04	0.000
42	Pipe	530,000	5.1547	865.54	865.54	2,192.0	2,192.0	2.266E-03	2.266E-03	0.000

Pipe	dH (feet)	P Static In (psig)	P Static Out (psig)	P Stag. In (psig)	P Stag. Out (psig)
1	1.999E+03	865.25	73.00	865.71	73.46
2	2.664E+02	174.26	75.61	174.40	75.75
3	1.474E+03	638.41	101.25	638.53	101.37
4	2.773E-05	75.75	75.75	75.75	75.75
5	1.419E-05	101.37	101.37	101.37	101.37
6	1.967E+03	947.48	156.80	947.81	157.13
7	1.999E+03	923.00	130.75	923.46	131.21
8	2.071E+03	980.75	174.03	981.21	174.49
9	1.813E-03	75.63	75.63	75.75	75.75
10	2.214E+03	875.63	42.58	875.75	42.70
11	1.277E+03	542.58	85.89	542.70	86.01
12	1.277E+03	535.89	79.20	536.01	79.32
13	1.277E+03	529.20	72.51	529.32	72.63
14	1.628E+03	672.51	74.98	672.63	75.10
15	1.628E+03	674.98	77.44	675.10	77.56
16	1.915E+03	877.44	164.46	877.56	164.58
17	1.915E+03	864.46	151.48	864.58	151.60
18	1.915E+03	901.48	189.30	901.60	189.42
19	5.586E-03	101.03	101.03	101.37	101.36
20	1.967E+03	851.03	62.36	851.36	62.69
21	1.967E+03	862.36	73.63	862.69	73.97
22	1.967E+03	873.63	84.94	873.97	85.27
23	1.967E+03	884.94	96.24	885.27	96.58
24	1.967E+03	896.24	107.54	896.58	107.88
25	1.967E+03	907.54	118.85	907.88	119.18
26	1.967E+03	868.85	80.15	869.18	80.49
27	1.967E+03	880.15	91.45	880.49	91.79
28	1.967E+03	891.45	102.76	891.79	103.09
29	1.967E+03	902.76	114.06	903.09	114.39
30	1.967E+03	914.06	125.36	914.39	125.70
31	1.967E+03	925.36	136.64	925.70	136.98
32	1.967E+03	936.64	147.48	936.98	147.81
33	1.685E+03	839.30	162.00	839.42	162.12
34	2.298E+03	962.00	38.41	962.12	38.53
35	2.355E+03	1,099.81	71.54	1,100.00	71.73
36	2.235E+03	1,071.57	69.30	1,071.72	69.45
37	2.235E+03	1,069.30	66.63	1,069.45	66.78
38	2.235E+03	1,066.63	65.56	1,066.78	65.72
39	2.692E-02	71.58	71.57	71.73	71.72
40	2.692E-02	865.56	865.55	865.72	865.71
41	3.647E-04	71.73	71.73	71.73	71.73
42	5.639E-03	865.54	865.54	865.71	865.71

All Junction Table

Jct	Name	P Static In (psig)	P Static Out (psig)	P Stag. In (psig)	P Stag. Out (psig)	Vol. Flow Rate Thru Jct (barrels/day)	Mass Flow Rate Thru Jct (lbm/min)	Loss Factor (K)
1	Chicago	156.80	156.80	157.13	157.13	670,000	151,190	0.0000
2	Area Change	174.03	174.26	174.49	174.40	880,000	198,578	0.1974
3	Hardisty	75.69	75.69	75.75	75.75	N/A	N/A	0.0000
4	Superior	101.27	101.27	101.37	101.37	N/A	N/A	0.0000
5	Ft. McMurray	1,099.81	1,099.81	1,100.00	1,100.00	390,000	88,006	0.0000
6	Assigned Flow	75.75	75.75	75.75	75.75	430,000	97,032	0.0000
7	Assigned Flow	101.37	101.37	101.37	101.37	220,000	49,645	0.0000
8	Pump 1	73.00	923.00	73.46	923.46	880,000	198,578	0.0000
9	Pump 2	130.75	980.75	131.21	981.21	880,000	198,578	0.0000
10	Hardisty	75.63	875.63	75.75	875.75	450,000	101,546	0.0000
11	Kerrobert	42.58	542.58	42.70	542.70	450,000	101,546	0.0000
12	Pump 3	85.89	535.89	86.01	536.01	450,000	101,546	0.0000
13	Pump 4	79.20	529.20	79.32	529.32	450,000	101,546	0.0000
14	Regina	72.51	672.51	72.63	672.63	450,000	101,546	0.0000
15	Pump 5	74.98	674.98	75.10	675.10	450,000	101,546	0.0000
16	Cromer	77.44	877.44	77.56	877.56	450,000	101,546	0.0000
17	Pump 6	164.46	864.46	164.58	864.58	450,000	101,546	0.0000
18	Gretna	151.48	901.48	151.60	901.60	450,000	101,546	0.0000
19	Viking	189.30	839.30	189.42	839.42	450,000	101,546	0.0000
20	Superior	101.03	851.03	101.36	851.36	670,000	151,190	0.0000
21	Pump 7	62.36	862.36	62.69	862.69	670,000	151,190	0.0000
23	Pump 8	73.63	873.63	73.97	873.97	670,000	151,190	0.0000
24	Pump 9	84.94	884.94	85.27	885.27	670,000	151,190	0.0000
25	Pump 10	96.24	896.24	96.58	896.58	670,000	151,190	0.0000
26	Pump 11	107.54	907.54	107.88	907.88	670,000	151,190	0.0000
27	Pump 12	118.85	868.85	119.18	869.18	670,000	151,190	0.0000
28	Pump 13	80.15	880.15	80.49	880.49	670,000	151,190	0.0000
29	Pump 14	91.45	891.45	91.79	891.79	670,000	151,190	0.0000
30	Pump 15	102.76	902.76	103.09	903.09	670,000	151,190	0.0000
31	Pump 16	114.06	914.06	114.39	914.39	670,000	151,190	0.0000
32	Pump 17	125.36	925.36	125.70	925.70	670,000	151,190	0.0000
33	Pump 18	136.64	936.64	136.98	936.98	670,000	151,190	0.0000
34	Pump 19	147.48	947.48	147.81	947.81	670,000	151,190	0.0000
35	Clearbrook	162.00	962.00	162.12	962.12	450,000	101,546	0.0000
36	Dear River	38.41	638.41	38.53	638.53	450,000	101,546	0.0000
37	Tee or Wye	865.46	865.46	865.71	865.71	N/A	N/A	0.0000
38	Cheecham	71.57	1,071.57	71.72	1,071.72	350,000	78,980	0.0000
39	Tee or Wye	71.65	71.65	71.73	71.73	N/A	N/A	0.0000
40	Pump 20	69.30	1,069.30	69.45	1,069.45	350,000	78,980	0.0000
41	Pump 21	66.63	1,066.63	66.78	1,066.78	350,000	78,980	0.0000
42	Edmonton	65.56	865.56	65.72	865.72	350,000	78,980	0.0000
43	Assigned Flow	865.54	865.54	865.71	865.71	530,000	119,598	0.0000
44	Assigned Flow	71.73	71.73	71.73	71.73	40,000	9,026	0.0000

1.0 Purpose:

Calculate the pumping energy required to transport crude oil from Ft. McMurray to Edmonton and from Edmonton to Chicago along the Express Chicago Pathway.

2.0 Reference:

1. "Oil Sands Shuffle Work – Optimized Base Case" spreadsheet (Attached)
2. AFT Fathom 7.0 Output for each pipe routing (Attached)
3. Cameron Hydraulic Data, 18th Edition
4. Website, http://www.enbridge.com/ar2008/management-discussion-analysis/liquids-pipelines/enbridge-system-and-athabasca-system/
5. Website, http://www.enbridge.com/waupisoo/about-project/proposed-facilities.php
6. Website, http://www.kne.com/business/canada/Express_Platte.cfm
7. Website, http://www.bppipelines.com/asset_chicap.html
8. Sulzer Pump estimated pump curves (Attached)

3.0 Assumptions:

1. Crude being transported has the characteristics of Western Canadian Select (WCS) as shown on the Enbridge 2009 Crude Characteristics table.
2. Crude is being transported at 10C and the temperature remains constant for the entire distance of transportation.
3. Piping to be steel with a wall thickness of 0.5inches
4. Piping lengths in Reference 1 and 2 include required fitting lengths.
5. Pumps are 70-80% efficient, see attached pump curves
6. Pump motor is 95% efficient.
7. WCS viscosity is 350cST
8. Working pressure in pipeline is 800psig – 1100psig
9. Change is elevation from station to station is at a constant slope.

4.0 Conclusion:

The total kWh required to transport crude oil from Edmonton to Chicago 365 days a year, 24 hours a day is 2.20×10^9 kWh.

5.0 Calculation:

Fluid Characteristics: Crude Type = Western Canadian Select

Density = 927.1 kg/m^3

Viscosity = 350cST = 325.5cP
Flow Rate = See References 1 & 2
Specific Gravity = 0.927

Piping Characteristics: Pipe Type = Carbon Steel
Pipe Diameter = See References 1 & 2
Pipe Wall Thickness = 0.5inches (Assumption 3)
Absolute roughness = 0.00015feet

5.1 Calculate Piping Pressure Losses

AFT Fathom software was used to develop a piping model to calculate the piping pressure losses for the entire run of transport piping listed in References 1 and 2. The following components were entered into each model:

1. WCS density and viscosity
2. Piping diameters, absolute roughness, and lengths
3. Elevation differences between pipelines
4. Volumetric flow rates

The input and output for each transport piping arrangement is attached in Reference 2 of this calculation. Table 1 summarizes the results of the AFT modeling.

Table 1 - Athabasca & Express Chicago Pathway

Crude Pathway	Total Length of Pipe (miles)	Total Pressure Loss in Piping (psid)	Head Loss (FT)
Athabasca & Express Chicago Pathway	2,376	47,981	119,179

The results shown in Table 1 and Reference 2 were used to calculate the power required to transport the crude oil using the equation below.

$$\text{Hyd hp} = \frac{\text{lb of liquid per minute x H(in feet)}}{33{,}000}$$ (Reference 3)

$$\text{Brake hp} = \frac{\text{Hyd hp}}{\text{Pump efficiency}}$$ (Reference 3)

$$\text{KW input to motor} = \frac{\text{Brake hp x 0.7457}}{\text{motor efficiency}}$$ (Reference 3)

$$\text{H (feet)} = \frac{\text{psi x 2.31}}{\text{Specific Gravity}}$$ (Reference 3)

Table 2 below summarizes the results from the AFT modeling and the resulting pump input power required using the equations above. The pump efficiency is assumed to be 75% (Assumption 5) and the motor efficiency is assumed to be 95% (Assumption 6). The pump power calculated below is the power required to overcome the frictional pressure loss in the piping and does not account for additional pressure required for delivery of the crude oil.

Table 2 - Athabasca & Express Chicago Pathway

Origin	Destination	Total Pressure Loss in Piping (psid)	Head Loss (ft)	Flow Rate (bbl/day)	Flow Rate (lb/min)	Pump Power Required (kw)
Ft. McMurray	Cheecham	1028	2,553	390000	88,043	6,856
Cheecham	Edmonton	3008	7,471	350000	79,013	18,003
Edmonton	Hardisty	2,490	6,184	880,000	198,662	37,463
Hardisty	Casper	19,641	48,784	280,000	63,211	94,038
Casper	Wood River	14,164	35,182	164,000	37,023	39,722
Wood River	Patoka	1801	4,474	309,000	69,757	9,517
Patoka	Chicago	5849	14,528	360,000	81,271	36,007
	Total	47,981	119,178			241,605

Table 3 summarizes the requirements for pumping power for several pump stations located along the Express Chicago Pathway. Several pumping stations will be required to transport the crude from Edmonton to Chicago to reduce the operating pressure within the pipeline to meet code allowable working pressures. Table 2 shows the total pressure drop between each destination, since these pressure losses are higher than recommended operational pressures, intermediate pumping stations are suggested. Using Assumption 8 the total number of pumping stations and resulting power requirements can be calculated.

$$\text{\# of Pump Stations} = \frac{\text{Total Pressure Loss}}{\text{Assumption 8}} \text{ rounded up}$$

Edmonton to Hardisty = 2,490psi/850psi = 3 required pump stations

Three pumps having a total dynamic head of 850psi are required to pump 198,662lb/min of crude from Edmonton to Hardisty. Pumps were placed into the AFT model with a fixed pressure rise of 850psig. A pressure node was added for Edmonton to meet the requirements of the AFT modeling, this pressure is 850psi.

The same method described above for the pump locations from Edmonton to Hardisty was used for the remaining origin to destination pipelines. Public documentation showing the location of existing pump stations along this line could not be found. Pumps were added at equal distance alone the entire pipelines. An adjustment in the pump stations total dynamic head were made to keep the operating pressure below or in the range of 800psig-1100psig.

The pump power calculated using the equations above for each of the required pumps. The Sulzer pump online pump selction website was used to determine the approximate pump efficiency for each pump. Note that these are only approximate pump efficiencies but should be close to the final pump selection determined during detailed design. The pump curves are attached, see Reference 6. Several pumps may be required at each pump station depending on the flow requirements and head requirements, the total power at the pump station is shown as the Pump Power Required in Table 3 below.

Table 3 also shows the required kWh for the transport of the crude. The kWh required is calculated using the following equation.

Pump Power Required (kW) x running time(h) = kWh

Table 3 shows the kWh's required to operate the pumps 24 hours a day seven days a week for 365 days.

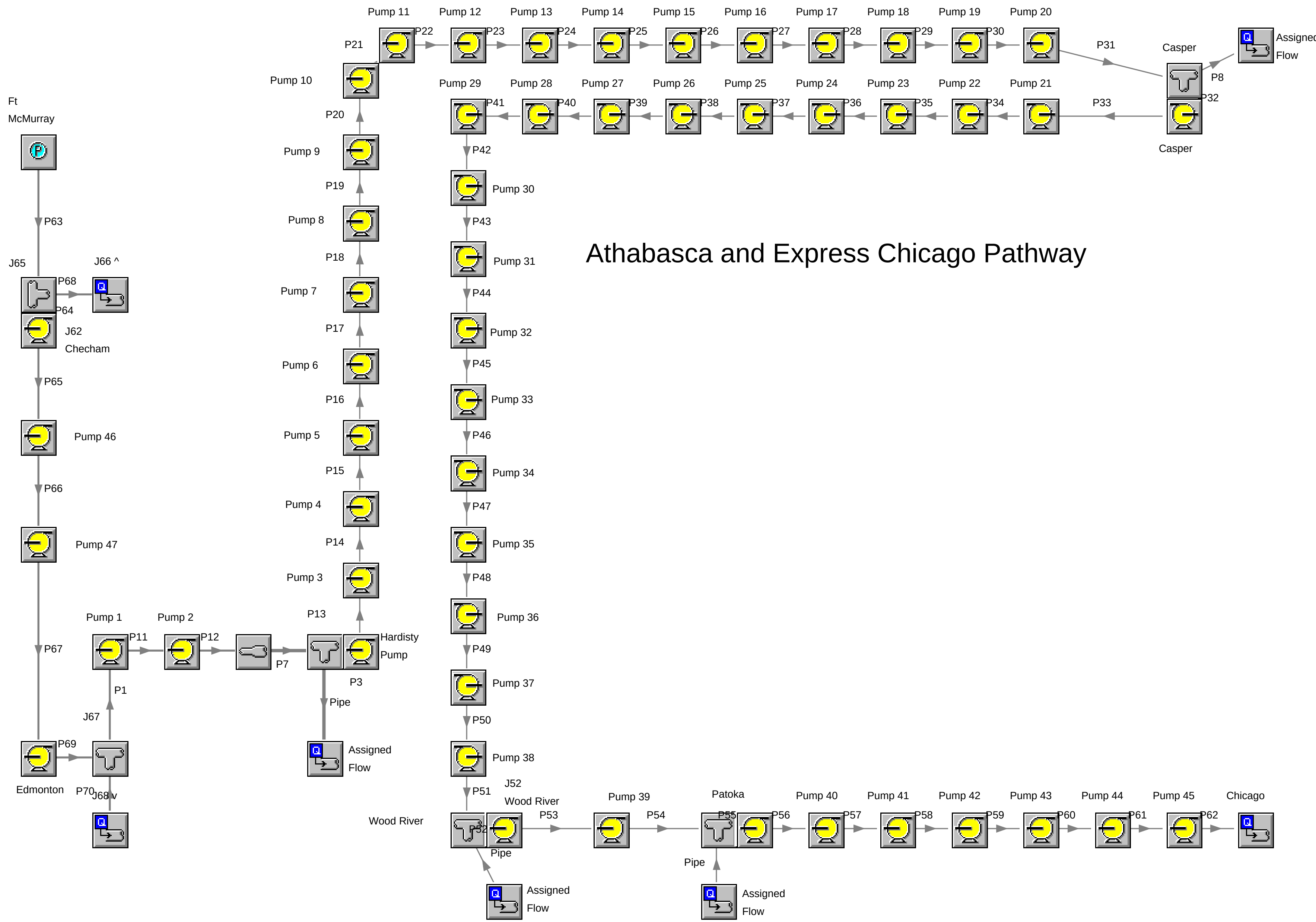
BARR			Calc# 002 Date 6/18/2010	Sheet No. 5 of 6
Computed By: WJM	Checked By: SEM	Submitted By:	Project Name:	
			Project Number:	
Date: 6/15/2010	Date:6/15/2010	Date:	Subject: Pump Energy Requirements and Usage –Express Chicago Pathway	

Table 3 -Athabasca & Express Chicago Pathway

Station	Pump TDH	Flow Rate (bbl/day)	Flow Rate (lb/min)	Pump Power Required (kw)	kWh
Ft McMurray	2732	390000	88,043	7,335	6.4E+07
Cheecham	2484	350000	79,013	5,985	5.2E+07
Pump 46	2484	350000	79,013	5,985	5.2E+07
Pump 47	2484	350000	79,013	5,985	5.2E+07
Edomonton	2,111	880,000	198,662	12,789	1.1E+08
Pump 1	2,111	880,000	198,662	12,789	1.1E+08
Pump 2	2,111	880,000	198,662	12,789	1.1E+08
Hardisty	2,568	280,000	63,211	5,176	4.5E+07
Pump 3	2,568	280,000	63,211	5,176	4.5E+07
Pump 4	2,568	280,000	63,211	5,176	4.5E+07
Pump 5	2,568	280,000	63,211	5,176	4.5E+07
Pump 6	2,568	280,000	63,211	5,176	4.5E+07
Pump 7	2,568	280,000	63,211	5,176	4.5E+07
Pump 8	2,568	280,000	63,211	5,176	4.5E+07
Pump 9	2,568	280,000	63,211	5,176	4.5E+07
Pump 10	2,568	280,000	63,211	5,176	4.5E+07
Pump 11	2,568	280,000	63,211	5,176	4.5E+07
Pump 12	2,568	280,000	63,211	5,176	4.5E+07
Pump 13	2,568	280,000	63,211	5,176	4.5E+07
Pump 14	2,568	280,000	63,211	5,176	4.5E+07
Pump 15	2,568	280,000	63,211	5,176	4.5E+07
Pump 16	2,568	280,000	63,211	5,176	4.5E+07
Pump 17	2,568	280,000	63,211	5,176	4.5E+07
Pump 18	2,568	280,000	63,211	5,176	4.5E+07
Pump 19	2,568	280,000	63,211	5,176	4.5E+07
Pump 20	2,568	280,000	63,211	5,176	4.5E+07
Casper	1,850	164,000	37,023	2,273	2.0E+07
Pump 21	1,850	164,000	37,023	2,273	2.0E+07
Pump 22	1,850	164,000	37,023	2,273	2.0E+07
Pump 23	1,850	164,000	37,023	2,273	2.0E+07
Pump 24	1,850	164,000	37,023	2,273	2.0E+07
Pump 25	1,850	164,000	37,023	2,273	2.0E+07
Pump 26	1,850	164,000	37,023	2,273	2.0E+07
Pump 27	1,850	164,000	37,023	2,273	2.0E+07
Pump 28	1,850	164,000	37,023	2,273	2.0E+07
Pump 29	1,850	164,000	37,023	2,273	2.0E+07
Pump 30	1,850	164,000	37,023	2,273	2.0E+07
Pump 31	1,850	164,000	37,023	2,273	2.0E+07
Pump 32	1,850	164,000	37,023	2,273	2.0E+07
Pump 33	1,850	164,000	37,023	2,273	2.0E+07
Pump 34	1,850	164,000	37,023	2,273	2.0E+07
Pump 35	1,850	164,000	37,023	2,273	2.0E+07
Pump 36	1,850	164,000	37,023	2,273	2.0E+07
Pump 37	1,850	164,000	37,023	2,273	2.0E+07
Pump 38	1,850	164,000	37,023	2,273	2.0E+07
Wood River	2,235	309,000	69,757	4,880	4.3E+07
Pump 39	2,235	309,000	69,757	4,880	4.3E+07
Patoka	2,111	360,000	81,271	5,232	4.6E+07
Pump 40	2,111	360,000	81,271	5,232	4.6E+07
Pump 41	2,111	360,000	81,271	5,232	4.6E+07
Pump 42	2,111	360,000	81,271	5,232	4.6E+07
Pump 43	2,111	360,000	81,271	5,232	4.6E+07
Pump 44	1,987	360,000	81,271	4,925	4.3E+07
Pump 45	1,987	360,000	81,271	4,925	4.3E+07
Chicago					
			Total	250,955	2.20E+09

The required pump power in Table 3 is greater than the amount shown in Table 2 since there will be energy remaining in the pipeline when it is delivered to Chicago. The pressure in the AFT model is around 96psig into the Chicago station.

Athabasca and Express Chicago Pathway



General

Title: AFT Fathom Model
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\Athabasca and Express Pathways\Athabasca and Express Chicago Pathway.fth
Scenario: Base Scenario/Pump Stations

Number Of Pipes= 67
Number Of Junctions= 68

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Pipe Input Table

Pipe	Name	Pipe Defined	Length	Length Units	Hydraulic Diameter	Hydraulic Diam. Units	Friction Data Set	Roughness	Roughness Units	Losses (K)
1	Pipe	Yes	28	miles	35	inches	Unspecified	0.00015	feet	0
2	Pipe	Yes	1	feet	47	inches	Unspecified	0.00015	feet	0
3	Express 24	Yes	0.5	feet	23	inches	Unspecified	0.00015	feet	0
7	Pipe	Yes	15	miles	47	inches	Unspecified	0.00015	feet	0
8	Pipe	Yes	1	feet	23	inches	Unspecified	0.00015	feet	0
9	Pipe	Yes	1	feet	19	inches	Unspecified	0.00015	feet	0
10	Pipe	Yes	1	feet	23	inches	Unspecified	0.00015	feet	0
11	Pipe	Yes	28	miles	35	inches	Unspecified	0.00015	feet	0
12	Pipe	Yes	29	miles	35	inches	Unspecified	0.00015	feet	0
13	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
14	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
15	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
16	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
17	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
18	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
19	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
20	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
21	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
22	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
23	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
24	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
25	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
26	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
27	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
28	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
29	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0

Pipe	Name	Pipe Defined	Length	Length Units	Hydraulic Diameter	Hydraulic Diam. Units	Friction Data Set	Roughness	Roughness Units	Losses (K)
30	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
31	Express 24	Yes	41.3	miles	23	inches	Unspecified	0.00015	feet	0
32	Pipe	Yes	0.5	feet	19	inches	Unspecified	0.00015	feet	0
33	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
34	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
35	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
36	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
37	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
38	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
39	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
40	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
41	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
42	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
43	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
44	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
45	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
46	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
47	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
48	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
49	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
50	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
51	Pipe	Yes	49	miles	19	inches	Unspecified	0.00015	feet	0
52	Pipe	Yes	0.5	feet	23	inches	Unspecified	0.00015	feet	0
53	Pipe	Yes	29	miles	23	inches	Unspecified	0.00015	feet	0
54	Pipe	Yes	29	miles	23	inches	Unspecified	0.00015	feet	0
55	Pipe	Yes	0.5	feet	25	inches	Unspecified	0.00015	feet	0
56	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
57	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
58	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
59	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
60	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
61	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
62	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
63	Pipe	Yes	62	miles	29	inches	Unspecified	0.00015	feet	0
64	Pipe	Yes	5	feet	29	inches	Unspecified	0.00015	feet	0
65	Pipe	Yes	78.6	miles	29	inches	Unspecified	0.00015	feet	0
66	Pipe	Yes	78.6	miles	29	inches	Unspecified	0.00015	feet	0
67	Pipe	Yes	78.6	miles	29	inches	Unspecified	0.00015	feet	0
68	Pipe	Yes	1	feet	29	inches	Unspecified	0.00015	feet	0
69	Pipe	Yes	5	feet	35	inches	Unspecified	0.00015	feet	0
70	Pipe	Yes	1	feet	35	inches	Unspecified	0.00015	feet	0

Pipe	Junctions (Up,Down)	Geometry	Material	Special Condition
1	67, 12	Cylindrical Pipe	Unspecified	None
2	2, 8	Cylindrical Pipe	Unspecified	None
3	2, 14	Cylindrical Pipe	Unspecified	None
7	7, 2	Cylindrical Pipe	Unspecified	None
8	3, 9	Cylindrical Pipe	Unspecified	None
9	10, 4	Cylindrical Pipe	Unspecified	None
10	11, 5	Cylindrical Pipe	Unspecified	None
11	12, 13	Cylindrical Pipe	Unspecified	None
12	13, 7	Cylindrical Pipe	Unspecified	None
13	14, 15	Cylindrical Pipe	Unspecified	None

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Pipe	Junctions (Up,Down)	Geometry	Material	Special Condition
14	15, 16	Cylindrical Pipe	Unspecified	None
15	16, 17	Cylindrical Pipe	Unspecified	None
16	17, 18	Cylindrical Pipe	Unspecified	None
17	18, 19	Cylindrical Pipe	Unspecified	None
18	19, 20	Cylindrical Pipe	Unspecified	None
19	20, 21	Cylindrical Pipe	Unspecified	None
20	21, 22	Cylindrical Pipe	Unspecified	None
21	22, 23	Cylindrical Pipe	Unspecified	None
22	23, 24	Cylindrical Pipe	Unspecified	None
23	24, 25	Cylindrical Pipe	Unspecified	None
24	25, 26	Cylindrical Pipe	Unspecified	None
25	26, 27	Cylindrical Pipe	Unspecified	None
26	27, 28	Cylindrical Pipe	Unspecified	None
27	28, 29	Cylindrical Pipe	Unspecified	None
28	29, 30	Cylindrical Pipe	Unspecified	None
29	30, 31	Cylindrical Pipe	Unspecified	None
30	31, 32	Cylindrical Pipe	Unspecified	None
31	32, 3	Cylindrical Pipe	Unspecified	None
32	3, 33	Cylindrical Pipe	Unspecified	None
33	33, 34	Cylindrical Pipe	Unspecified	None
34	34, 35	Cylindrical Pipe	Unspecified	None
35	35, 36	Cylindrical Pipe	Unspecified	None
36	36, 37	Cylindrical Pipe	Unspecified	None
37	37, 38	Cylindrical Pipe	Unspecified	None
38	38, 39	Cylindrical Pipe	Unspecified	None
39	39, 40	Cylindrical Pipe	Unspecified	None
40	40, 41	Cylindrical Pipe	Unspecified	None
41	41, 42	Cylindrical Pipe	Unspecified	None
42	42, 43	Cylindrical Pipe	Unspecified	None
43	43, 44	Cylindrical Pipe	Unspecified	None
44	44, 45	Cylindrical Pipe	Unspecified	None
45	45, 46	Cylindrical Pipe	Unspecified	None
46	46, 47	Cylindrical Pipe	Unspecified	None
47	47, 48	Cylindrical Pipe	Unspecified	None
48	48, 49	Cylindrical Pipe	Unspecified	None
49	49, 50	Cylindrical Pipe	Unspecified	None
50	50, 51	Cylindrical Pipe	Unspecified	None
51	51, 4	Cylindrical Pipe	Unspecified	None
52	4, 52	Cylindrical Pipe	Unspecified	None
53	52, 53	Cylindrical Pipe	Unspecified	None
54	53, 5	Cylindrical Pipe	Unspecified	None
55	5, 54	Cylindrical Pipe	Unspecified	None
56	54, 55	Cylindrical Pipe	Unspecified	None
57	55, 56	Cylindrical Pipe	Unspecified	None
58	56, 57	Cylindrical Pipe	Unspecified	None
59	57, 58	Cylindrical Pipe	Unspecified	None
60	58, 59	Cylindrical Pipe	Unspecified	None
61	59, 60	Cylindrical Pipe	Unspecified	None
62	60, 1	Cylindrical Pipe	Unspecified	None
63	6, 65	Cylindrical Pipe	Unspecified	None
64	65, 62	Cylindrical Pipe	Unspecified	None
65	62, 63	Cylindrical Pipe	Unspecified	None
66	63, 64	Cylindrical Pipe	Unspecified	None
67	64, 61	Cylindrical Pipe	Unspecified	None

Pipe	Junctions (Up,Down)	Geometry	Material	Special Condition
68	65, 66	Cylindrical Pipe	Unspecified	None
69	61, 67	Cylindrical Pipe	Unspecified	None
70	68, 67	Cylindrical Pipe	Unspecified	None

Pipe Fittings & Losses

Area Change Table

Area Change	Object Defined	Inlet Elevation	Elevation Units	Type	Geometry	Angle	Loss Factor
7	Yes	2072	feet	Conical	Expansion	45.	0.1974294

Assigned Flow Table

Assigned Flow	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Type	Flow	Flow Units	Loss Factor
1	Chicago	Yes	579	feet	None	Outflow	360000	barrels/day	0
8	Assigned Flow	Yes	2051	feet	None	Outflow	600000	barrels/day	0
9	Assigned Flow	Yes	5123	feet	None	Outflow	116000	barrels/day	0
10	Assigned Flow	Yes	430	feet	None	Inflow	145000	barrels/day	0
11	Assigned Flow	Yes	505	feet	None	Inflow	51000	barrels/day	0
66	Assigned Flow	Yes	1417	feet	None	Outflow	40000	barrels/day	0
68	Assigned Flow	Yes	2192	feet	None	Inflow	530000	barrels/day	0

Assigned Pressure Table

Assigned Pressure	Name	Object Defined	Inlet Elevation	Elevation Units	Initial Pressure	Initial Pressure Units	Pressure	Pressure Units
6	Ft McMurray	Yes	1214	feet	1,100	psig	1100	psig

Assigned Pressure	Pressure Type	Balance Energy	Balance Concentration	(Pipe #1) K In, K Out
6	Stagnation	No	No	(P63) 0, 0

Pump Table

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
12	Pump 1	Yes	2163.8	feet	None	Fixed Pressure Rise	850	psid
13	Pump 2	Yes	2135.6	feet	None	Fixed Pressure Rise	850	psid
14	Hardisty Pump	Yes	2051	feet	None	Fixed Pressure Rise	1035	psid
15	Pump 3	Yes	2212	feet	None	Fixed Pressure Rise	1034	psid
16	Pump 4	Yes	2373	feet	None	Fixed Pressure Rise	1034	psid
17	Pump 5	Yes	2534	feet	None	Fixed Pressure Rise	1034	psid
18	Pump 6	Yes	2695	feet	None	Fixed Pressure Rise	1034	psid
19	Pump 7	Yes	2856	feet	None	Fixed Pressure Rise	1034	psid
20	Pump 8	Yes	3017	feet	None	Fixed Pressure Rise	1034	psid
21	Pump 9	Yes	3178	feet	None	Fixed Pressure Rise	1034	psid
22	Pump 10	Yes	3339	feet	None	Fixed Pressure Rise	1034	psid
23	Pump 11	Yes	3500	feet	None	Fixed Pressure Rise	1034	psid
24	Pump 12	Yes	3661	feet	None	Fixed Pressure Rise	1034	psid
25	Pump 13	Yes	3822	feet	None	Fixed Pressure Rise	1034	psid

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
26	Pump 14	Yes	3983	feet	None	Fixed Pressure Rise	1034	psid
27	Pump 15	Yes	4144	feet	None	Fixed Pressure Rise	1034	psid
28	Pump 16	Yes	4305	feet	None	Fixed Pressure Rise	1034	psid
29	Pump 17	Yes	4466	feet	None	Fixed Pressure Rise	1034	psid
30	Pump 18	Yes	4627	feet	None	Fixed Pressure Rise	1034	psid
31	Pump 19	Yes	4788	feet	None	Fixed Pressure Rise	1034	psid
32	Pump 20	Yes	4949	feet	None	Fixed Pressure Rise	1034	psid
33	Casper	Yes	5123	feet	None	Fixed Pressure Rise	745	psid
34	Pump 21	Yes	4876	feet	None	Fixed Pressure Rise	745	psid
35	Pump 22	Yes	4629	feet	None	Fixed Pressure Rise	745	psid
36	Pump 23	Yes	4382	feet	None	Fixed Pressure Rise	745	psid
37	Pump 24	Yes	4135	feet	None	Fixed Pressure Rise	745	psid
38	Pump 25	Yes	3888	feet	None	Fixed Pressure Rise	745	psid
39	Pump 26	Yes	3641	feet	None	Fixed Pressure Rise	745	psid
40	Pump 27	Yes	3394	feet	None	Fixed Pressure Rise	745	psid
41	Pump 28	Yes	3147	feet	None	Fixed Pressure Rise	745	psid
42	Pump 29	Yes	2900	feet	None	Fixed Pressure Rise	745	psid
43	Pump 30	Yes	2653	feet	None	Fixed Pressure Rise	745	psid
44	Pump 31	Yes	2406	feet	None	Fixed Pressure Rise	745	psid
45	Pump 32	Yes	2159	feet	None	Fixed Pressure Rise	745	psid
46	Pump 33	Yes	1912	feet	None	Fixed Pressure Rise	745	psid
47	Pump 34	Yes	1665	feet	None	Fixed Pressure Rise	745	psid
48	Pump 35	Yes	1418	feet	None	Fixed Pressure Rise	745	psid
49	Pump 36	Yes	1171	feet	None	Fixed Pressure Rise	745	psid
50	Pump 37	Yes	924	feet	None	Fixed Pressure Rise	745	psid
51	Pump 38	Yes	677	feet	None	Fixed Pressure Rise	745	psid
52	Wood River	Yes	430	feet	None	Fixed Pressure Rise	900	psid
53	Pump 39	Yes	467.5	feet	None	Fixed Pressure Rise	900	psid
54	Pump	Yes	505	feet	None	Fixed Pressure Rise	850	psid
55	Pump 40	Yes	515.58	feet	None	Fixed Pressure Rise	850	psid
56	Pump 41	Yes	526.15	feet	None	Fixed Pressure Rise	850	psid
57	Pump 42	Yes	536.72	feet	None	Fixed Pressure Rise	850	psid
58	Pump 43	Yes	547.29	feet	None	Fixed Pressure Rise	850	psid
59	Pump 44	Yes	557.86	feet	None	Fixed Pressure Rise	800	psid
60	Pump 45	Yes	568.43	feet	None	Fixed Pressure Rise	800	psid
61	Edmonton	Yes	2192	feet	None	Fixed Pressure Rise	800	psid
62	Checham	Yes	1417	feet	None	Fixed Pressure Rise	1000	psid
63	Pump 46	Yes	1676	feet	None	Fixed Pressure Rise	1000	psid
64	Pump 47	Yes	1936	feet	None	Fixed Pressure Rise	1000	psid

Pump	Current Configuration	Heat Added To Fluid	Heat Added Units
12	N/A	0	Percent
13	N/A	0	Percent
14	N/A	0	Percent
15	N/A	0	Percent
16	N/A	0	Percent
17	N/A	0	Percent
18	N/A	0	Percent
19	N/A	0	Percent
20	N/A	0	Percent
21	N/A	0	Percent
22	N/A	0	Percent
23	N/A	0	Percent

Pump	Current Configuration	Heat Added To Fluid	Heat Added Units
24	N/A	0	Percent
25	N/A	0	Percent
26	N/A	0	Percent
27	N/A	0	Percent
28	N/A	0	Percent
29	N/A	0	Percent
30	N/A	0	Percent
31	N/A	0	Percent
32	N/A	0	Percent
33	N/A	0	Percent
34	N/A	0	Percent
35	N/A	0	Percent
36	N/A	0	Percent
37	N/A	0	Percent
38	N/A	0	Percent
39	N/A	0	Percent
40	N/A	0	Percent
41	N/A	0	Percent
42	N/A	0	Percent
43	N/A	0	Percent
44	N/A	0	Percent
45	N/A	0	Percent
46	N/A	0	Percent
47	N/A	0	Percent
48	N/A	0	Percent
49	N/A	0	Percent
50	N/A	0	Percent
51	N/A	0	Percent
52	N/A	0	Percent
53	N/A	0	Percent
54	N/A	0	Percent
55	N/A	0	Percent
56	N/A	0	Percent
57	N/A	0	Percent
58	N/A	0	Percent
59	N/A	0	Percent
60	N/A	0	Percent
61	N/A	0	Percent
62	N/A	0	Percent
63	N/A	0	Percent
64	N/A	0	Percent

Tee or Wye Table

Tee or Wye	Name	Object Defined	Inlet Elevation	Elevation Units	Tee/Wye Type	Loss Type	Angle	Pipes A, B, C
2	Hardisty	Yes	2051	feet	Sharp Straight	Simple (no loss)	90	7, 2, 3
3	Casper	Yes	5123	feet	Sharp Straight	Simple (no loss)	90	31, 8, 32
4	Wood River	Yes	430	feet	Sharp Straight	Simple (no loss)	90	51, 52, 9
5	Patoka	Yes	505	feet	Sharp Straight	Simple (no loss)	90	54, 10, 55
65	Tee or Wye	Yes	1417	feet	Sharp Straight	Simple (no loss)	90	63, 64, 68
67	Tee or Wye	Yes	2192	feet	Sharp Straight	Simple (no loss)	90	69, 1, 70

General

Title: AFT Fathom Model
Analysis run on: 6/10/2010 10:25:15 AM
Application version: AFT Fathom Version 7.0 (2009.11.02)
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\Athabasca and Express Pathways\Athabasca and Express Chicago Pathway.fth
Scenario: Base Scenario/Pump Stations
Output File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\Athabasca and Express Pathways\Athabasca and Express Chicago Pathway_2.out

Execution Time= 0.33 seconds
Total Number Of Head/Pressure Iterations= 0
Total Number Of Flow Iterations= 2
Total Number Of Temperature Iterations= 0
Number Of Pipes= 67
Number Of Junctions= 68
Matrix Method= Gaussian Elimination

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Total Inflow= 32,549 gal/min
Total Outflow= 32,549 gal/min
Maximum Static Pressure is 1,142 psia at Pipe 31 Inlet
Minimum Static Pressure is 80.26 psia at Pipe 67 Outlet

Pump Summary

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
12	Pump 1	25,666	3,309.6	850.0	2,115	100.0	N/A	12,724	N/A	N/A	201.1
13	Pump 2	25,666	3,309.6	850.0	2,115	100.0	N/A	12,724	N/A	N/A	344.8
14	Hardisty Pump	8,166	1,053.1	1,035.0	2,575	100.0	N/A	4,930	N/A	N/A	206.8
15	Pump 3	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	211.6
16	Pump 4	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	214.0
17	Pump 5	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	216.3
18	Pump 6	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	218.6
19	Pump 7	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	220.9
20	Pump 8	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	223.3
21	Pump 9	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	225.6
22	Pump 10	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	227.9
23	Pump 11	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	230.2
24	Pump 12	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	232.6
25	Pump 13	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	234.9
26	Pump 14	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	237.2

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
27	Pump 15	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	239.5
28	Pump 16	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	241.9
29	Pump 17	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	244.2
30	Pump 18	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	246.5
31	Pump 19	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	248.8
32	Pump 20	8,166	1,053.1	1,034.0	2,573	100.0	N/A	4,925	N/A	N/A	251.2
33	Casper	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	240.5
34	Pump 21	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	241.5
35	Pump 22	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	242.6
36	Pump 23	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	243.6
37	Pump 24	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	244.6
38	Pump 25	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	245.7
39	Pump 26	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	246.7
40	Pump 27	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	247.8
41	Pump 28	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	248.8
42	Pump 29	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	249.8
43	Pump 30	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	250.9
44	Pump 31	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	251.9
45	Pump 32	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	252.9
46	Pump 33	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	254.0
47	Pump 34	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	255.0
48	Pump 35	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	256.1
49	Pump 36	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	257.1
50	Pump 37	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	258.1
51	Pump 38	4,783	616.8	745.0	1,854	100.0	N/A	2,078	N/A	N/A	259.2
52	Wood River	9,012	1,162.1	900.0	2,239	100.0	N/A	4,731	N/A	N/A	260.2
53	Pump 39	9,012	1,162.1	900.0	2,239	100.0	N/A	4,731	N/A	N/A	258.8
54	Pump	10,500	1,353.9	850.0	2,115	100.0	N/A	5,205	N/A	N/A	257.4
55	Pump 40	10,500	1,353.9	850.0	2,115	100.0	N/A	5,205	N/A	N/A	293.3
56	Pump 41	10,500	1,353.9	850.0	2,115	100.0	N/A	5,205	N/A	N/A	329.1
57	Pump 42	10,500	1,353.9	850.0	2,115	100.0	N/A	5,205	N/A	N/A	365.0
58	Pump 43	10,500	1,353.9	850.0	2,115	100.0	N/A	5,205	N/A	N/A	400.9
59	Pump 44	10,500	1,353.9	800.0	1,990	100.0	N/A	4,899	N/A	N/A	436.7
60	Pump 45	10,500	1,353.9	800.0	1,990	100.0	N/A	4,899	N/A	N/A	348.2
61	Edmonton	10,208	1,316.3	800.0	1,990	100.0	N/A	4,763	N/A	N/A	181.8
62	Checham	10,208	1,316.3	1,000.0	2,488	100.0	N/A	5,954	N/A	N/A	196.8
63	Pump 46	10,208	1,316.3	1,000.0	2,488	100.0	N/A	5,954	N/A	N/A	191.1
64	Pump 47	10,208	1,316.3	1,000.0	2,488	100.0	N/A	5,954	N/A	N/A	184.5

Jct	NPSHR (feet)
12	N/A
13	N/A
14	N/A
15	N/A
16	N/A
17	N/A
18	N/A
19	N/A
20	N/A
21	N/A
22	N/A

Jct	NPSHR (feet)
23	N/A
24	N/A
25	N/A
26	N/A
27	N/A
28	N/A
29	N/A
30	N/A
31	N/A
32	N/A
33	N/A
34	N/A
35	N/A
36	N/A
37	N/A
38	N/A
39	N/A
40	N/A
41	N/A
42	N/A
43	N/A
44	N/A
45	N/A
46	N/A
47	N/A
48	N/A
49	N/A
50	N/A
51	N/A
52	N/A
53	N/A
54	N/A
55	N/A
56	N/A
57	N/A
58	N/A
59	N/A
60	N/A
61	N/A
62	N/A
63	N/A
64	N/A

Pipe Output Table

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psig)	P Static Min (psig)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)
1	Pipe	880,000	8.5588	865.26	73.01	2,192.0	2,163.8	792.2496338	792.2496338
2	Pipe	600,000	3.2361	75.69	75.69	2,051.0	2,051.0	0.0005905	0.0005905
3	Express 24	280,000	6.3062	75.51	75.51	2,051.0	2,051.0	0.0022203	0.0022203
7	Pipe	880,000	4.7463	174.26	75.62	2,072.0	2,051.0	98.6460495	98.6460495
8	Pipe	116,000	2.6126	89.24	89.24	5,123.0	5,123.0	0.0010744	0.0010744

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psig)	P Static Min (psig)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)
9	Pipe	145,000	4.7855	97.08	97.08	430.0	430.0	0.0028838	0.0028838
10	Pipe	51,000	1.1486	96.09	96.09	505.0	505.0	0.0004724	0.0004724
11	Pipe	880,000	8.5588	923.01	130.76	2,163.8	2,135.6	792.2496338	792.2496338
12	Pipe	880,000	8.5588	980.76	174.04	2,135.6	2,072.0	806.7208862	806.7208862
13	Express 24	280,000	6.3062	1,110.51	77.44	2,051.0	2,212.0	1,033.0656738	1,033.0656738
14	Express 24	280,000	6.3062	1,111.44	78.38	2,212.0	2,373.0	1,033.0656738	1,033.0656738
15	Express 24	280,000	6.3062	1,112.38	79.31	2,373.0	2,534.0	1,033.0656738	1,033.0656738
16	Express 24	280,000	6.3062	1,113.31	80.24	2,534.0	2,695.0	1,033.0656738	1,033.0656738
17	Express 24	280,000	6.3062	1,114.24	81.18	2,695.0	2,856.0	1,033.0656738	1,033.0656738
18	Express 24	280,000	6.3062	1,115.18	82.11	2,856.0	3,017.0	1,033.0656738	1,033.0656738
19	Express 24	280,000	6.3062	1,116.11	83.05	3,017.0	3,178.0	1,033.0656738	1,033.0656738
20	Express 24	280,000	6.3062	1,117.05	83.98	3,178.0	3,339.0	1,033.0656738	1,033.0656738
21	Express 24	280,000	6.3062	1,117.98	84.92	3,339.0	3,500.0	1,033.0656738	1,033.0656738
22	Express 24	280,000	6.3062	1,118.92	85.85	3,500.0	3,661.0	1,033.0656738	1,033.0656738
23	Express 24	280,000	6.3062	1,119.85	86.78	3,661.0	3,822.0	1,033.0656738	1,033.0656738
24	Express 24	280,000	6.3062	1,120.78	87.72	3,822.0	3,983.0	1,033.0656738	1,033.0656738
25	Express 24	280,000	6.3062	1,121.72	88.65	3,983.0	4,144.0	1,033.0656738	1,033.0656738
26	Express 24	280,000	6.3062	1,122.65	89.59	4,144.0	4,305.0	1,033.0656738	1,033.0656738
27	Express 24	280,000	6.3062	1,123.59	90.52	4,305.0	4,466.0	1,033.0656738	1,033.0656738
28	Express 24	280,000	6.3062	1,124.52	91.46	4,466.0	4,627.0	1,033.0656738	1,033.0656738
29	Express 24	280,000	6.3062	1,125.46	92.39	4,627.0	4,788.0	1,033.0656738	1,033.0656738
30	Express 24	280,000	6.3062	1,126.39	93.33	4,788.0	4,949.0	1,033.0656738	1,033.0656738
31	Express 24	280,000	6.3062	1,127.33	89.03	4,949.0	5,123.0	1,038.2906494	1,038.2906494
32	Pipe	164,000	5.4125	89.10	89.10	5,123.0	5,123.0	0.0016308	0.0016308
33	Pipe	164,000	5.4125	834.10	89.52	5,123.0	4,876.0	744.5822144	744.5822144
34	Pipe	164,000	5.4125	834.52	89.93	4,876.0	4,629.0	744.5822144	744.5822144
35	Pipe	164,000	5.4125	834.93	90.35	4,629.0	4,382.0	744.5822144	744.5822144
36	Pipe	164,000	5.4125	835.35	90.77	4,382.0	4,135.0	744.5822144	744.5822144
37	Pipe	164,000	5.4125	835.77	91.19	4,135.0	3,888.0	744.5822144	744.5822144
38	Pipe	164,000	5.4125	836.19	91.61	3,888.0	3,641.0	744.5822144	744.5822144
39	Pipe	164,000	5.4125	836.61	92.02	3,641.0	3,394.0	744.5822144	744.5822144
40	Pipe	164,000	5.4125	837.02	92.44	3,394.0	3,147.0	744.5822144	744.5822144
41	Pipe	164,000	5.4125	837.44	92.86	3,147.0	2,900.0	744.5822144	744.5822144
42	Pipe	164,000	5.4125	837.86	93.28	2,900.0	2,653.0	744.5822144	744.5822144
43	Pipe	164,000	5.4125	838.28	93.69	2,653.0	2,406.0	744.5822144	744.5822144
44	Pipe	164,000	5.4125	838.69	94.11	2,406.0	2,159.0	744.5822144	744.5822144
45	Pipe	164,000	5.4125	839.11	94.53	2,159.0	1,912.0	744.5822144	744.5822144
46	Pipe	164,000	5.4125	839.53	94.95	1,912.0	1,665.0	744.5822144	744.5822144
47	Pipe	164,000	5.4125	839.95	95.36	1,665.0	1,418.0	744.5822144	744.5822144
48	Pipe	164,000	5.4125	840.36	95.78	1,418.0	1,171.0	744.5822144	744.5822144
49	Pipe	164,000	5.4125	840.78	96.20	1,171.0	924.0	744.5822144	744.5822144
50	Pipe	164,000	5.4125	841.20	96.62	924.0	677.0	744.5822144	744.5822144
51	Pipe	164,000	5.4125	841.62	97.04	677.0	430.0	744.5822144	744.5822144
52	Pipe	309,000	6.9593	96.92	96.91	430.0	430.0	0.0028915	0.0028915
53	Pipe	309,000	6.9593	996.91	96.35	430.0	467.5	900.5610962	900.5610962
54	Pipe	309,000	6.9593	996.35	95.79	467.5	505.0	900.5610962	900.5610962
55	Pipe	360,000	6.8626	95.80	95.80	505.0	505.0	0.0027147	0.0027147
56	Pipe	360,000	6.8626	945.80	110.21	505.0	515.6	835.5904541	835.5904541
57	Pipe	360,000	6.8626	960.21	124.62	515.6	526.2	835.5864258	835.5864258
58	Pipe	360,000	6.8626	974.62	139.03	526.2	536.7	835.5863647	835.5863647
59	Pipe	360,000	6.8626	989.03	153.45	536.7	547.3	835.5864258	835.5864258
60	Pipe	360,000	6.8626	1,003.45	167.86	547.3	557.9	835.5864258	835.5864258
61	Pipe	360,000	6.8626	967.86	132.27	557.9	568.4	835.5864258	835.5864258

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psig)	P Static Min (psig)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)
62	Pipe	360,000	6.8626	932.27	96.69	568.4	579.0	835.5864258	835.5864258
63	Pipe	390,000	5.5250	1,099.81	71.54	1,214.0	1,417.0	1,028.2658691	1,028.2658691
64	Pipe	350,000	4.9583	71.58	71.57	1,417.0	1,417.0	0.0108211	0.0108211
65	Pipe	350,000	4.9583	1,071.57	69.30	1,417.0	1,676.0	1,002.2698975	1,002.2698975
66	Pipe	350,000	4.9583	1,069.30	66.63	1,676.0	1,936.0	1,002.6718140	1,002.6718140
67	Pipe	350,000	4.9583	1,066.63	65.56	1,936.0	2,192.0	1,001.0641479	1,001.0641479
68	Pipe	40,000	0.5667	71.73	71.73	1,417.0	1,417.0	0.0001466	0.0001466
69	Pipe	350,000	3.4041	865.64	865.64	2,192.0	2,192.0	0.0037400	0.0037400
70	Pipe	530,000	5.1547	865.55	865.55	2,192.0	2,192.0	0.0022664	0.0022664

Pipe	dP Gravity (psid)	dH (feet)	P Static In (psig)	P Static Out (psig)	P Stag. In (psig)	P Stag. Out (psig)
1	-11.334	1,999.3460867	865.26	73.01	865.71	73.46
2	0.000	0.0014691	75.69	75.69	75.76	75.76
3	0.000	0.0055243	75.51	75.51	75.76	75.75
7	-8.440	266.4349882	174.26	75.62	174.40	75.76
8	0.000	0.0026731	89.24	89.24	89.28	89.28
9	0.000	0.0071750	97.08	97.08	97.22	97.22
10	0.000	0.0011752	96.09	96.09	96.09	96.09
11	-11.334	1,999.3460867	923.01	130.76	923.46	131.21
12	-25.562	2,070.7512499	980.76	174.04	981.21	174.49
13	64.710	2,409.3050944	1,110.51	77.44	1,110.75	77.69
14	64.710	2,409.3050944	1,111.44	78.38	1,111.69	78.62
15	64.710	2,409.3050944	1,112.38	79.31	1,112.62	79.56
16	64.710	2,409.3050944	1,113.31	80.24	1,113.56	80.49
17	64.710	2,409.3050944	1,114.24	81.18	1,114.49	81.43
18	64.710	2,409.3050944	1,115.18	82.11	1,115.43	82.36
19	64.710	2,409.3050944	1,116.11	83.05	1,116.36	83.30
20	64.710	2,409.3050944	1,117.05	83.98	1,117.30	84.23
21	64.710	2,409.3050944	1,117.98	84.92	1,118.23	85.16
22	64.710	2,409.3050944	1,118.92	85.85	1,119.16	86.10
23	64.710	2,409.3050944	1,119.85	86.78	1,120.10	87.03
24	64.710	2,409.3050944	1,120.78	87.72	1,121.03	87.97
25	64.710	2,409.3050944	1,121.72	88.65	1,121.97	88.90
26	64.710	2,409.3050944	1,122.65	89.59	1,122.90	89.84
27	64.710	2,409.3050944	1,123.59	90.52	1,123.84	90.77
28	64.710	2,409.3050944	1,124.52	91.46	1,124.77	91.70
29	64.710	2,409.3050944	1,125.46	92.39	1,125.71	92.64
30	64.710	2,409.3050944	1,126.39	93.33	1,126.64	93.57
31	69.935	2,409.3050944	1,127.33	89.03	1,127.57	89.28
32	0.000	0.0040576	89.10	89.10	89.28	89.28
33	-99.275	2,099.5478745	834.10	89.52	834.28	89.70
34	-99.275	2,099.5478745	834.52	89.93	834.70	90.12
35	-99.275	2,099.5478745	834.93	90.35	835.12	90.53
36	-99.275	2,099.5478745	835.35	90.77	835.53	90.95
37	-99.275	2,099.5478745	835.77	91.19	835.95	91.37
38	-99.275	2,099.5478745	836.19	91.61	836.37	91.79
39	-99.275	2,099.5478745	836.61	92.02	836.79	92.21
40	-99.275	2,099.5478745	837.02	92.44	837.21	92.62
41	-99.275	2,099.5478745	837.44	92.86	837.62	93.04
42	-99.275	2,099.5478745	837.86	93.28	838.04	93.46
43	-99.275	2,099.5478745	838.28	93.69	838.46	93.88

Pipe	dP Gravity (psid)	dH (feet)	P Static In (psig)	P Static Out (psig)	P Stag. In (psig)	P Stag. Out (psig)
44	-99.275	2,099.5478745	838.69	94.11	838.88	94.29
45	-99.275	2,099.5478745	839.11	94.53	839.29	94.71
46	-99.275	2,099.5478745	839.53	94.95	839.71	95.13
47	-99.275	2,099.5478745	839.95	95.36	840.13	95.55
48	-99.275	2,099.5478745	840.36	95.78	840.55	95.97
49	-99.275	2,099.5478745	840.78	96.20	840.97	96.38
50	-99.275	2,099.5478745	841.20	96.62	841.38	96.80
51	-99.275	2,099.5478745	841.62	97.04	841.80	97.22
52	0.000	0.0071941	96.92	96.91	97.22	97.22
53	15.072	2,203.1289519	996.91	96.35	997.22	96.66
54	15.072	2,203.1289519	996.35	95.79	996.66	96.09
55	0.000	0.0067542	95.80	95.80	96.09	96.09
56	4.252	2,068.3995815	945.80	110.21	946.09	110.50
57	4.248	2,068.3995815	960.21	124.62	960.50	124.91
58	4.248	2,068.3995815	974.62	139.03	974.91	139.33
59	4.248	2,068.3995815	989.03	153.45	989.33	153.74
60	4.248	2,068.3995815	1,003.45	167.86	1,003.74	168.16
61	4.248	2,068.3995815	967.86	132.27	968.16	132.57
62	4.248	2,068.3995815	932.27	96.69	932.57	96.98
63	81.590	2,355.3632636	1,099.81	71.54	1,100.00	71.73
64	0.000	0.0269234	71.58	71.57	71.73	71.72
65	104.098	2,234.6842236	1,071.57	69.30	1,071.72	69.45
66	104.500	2,234.6842236	1,069.30	66.63	1,069.45	66.78
67	102.892	2,234.6842236	1,066.63	65.56	1,066.78	65.72
68	0.000	0.0003647	71.73	71.73	71.73	71.73
69	0.000	0.0093053	865.64	865.64	865.72	865.71
70	0.000	0.0056390	865.55	865.55	865.72	865.71

All Junction Table

Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (barrels/day)	Mass Flow Rate Thru Jct (lbm/min)	Loss Factor (K)
1	Chicago	111.38	111.38	111.68	111.68	360,000	81,236	0.0000
2	Hardisty	90.31	90.31	90.45	90.45	N/A	N/A	0.0000
3	Casper	103.84	103.84	103.98	103.98	N/A	N/A	0.0000
4	Wood River	111.71	111.71	111.91	111.91	N/A	N/A	0.0000
5	Patoka	110.63	110.63	110.79	110.79	N/A	N/A	0.0000
6	Ft McMurray	1,114.51	1,114.51	1,114.70	1,114.70	390,000	88,006	0.0000
7		188.73	188.96	189.19	189.10	880,000	198,578	0.1974
8	Assigned Flow	90.39	90.39	90.45	90.45	600,000	135,394	0.0000
9	Assigned Flow	103.94	103.94	103.98	103.98	116,000	26,176	0.0000
10	Assigned Flow	111.77	111.77	111.92	111.92	145,000	32,720	0.0000
11	Assigned Flow	110.78	110.78	110.79	110.79	51,000	11,509	0.0000
12	Pump 1	87.70	937.70	88.16	938.16	880,000	198,578	0.0000
13	Pump 2	145.45	995.45	145.91	995.91	880,000	198,578	0.0000
14	Hardisty Pump	90.20	1,125.20	90.45	1,125.45	280,000	63,184	0.0000
15	Pump 3	92.14	1,126.14	92.39	1,126.39	280,000	63,184	0.0000
16	Pump 4	93.07	1,127.07	93.32	1,127.32	280,000	63,184	0.0000
17	Pump 5	94.01	1,128.01	94.25	1,128.25	280,000	63,184	0.0000
18	Pump 6	94.94	1,128.94	95.19	1,129.19	280,000	63,184	0.0000
19	Pump 7	95.87	1,129.87	96.12	1,130.12	280,000	63,184	0.0000

AFT Fathom Model

Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (barrels/day)	Mass Flow Rate Thru Jct (lbm/min)	Loss Factor (K)
20	Pump 8	96.81	1,130.81	97.06	1,131.06	280,000	63,184	0.0000
21	Pump 9	97.74	1,131.74	97.99	1,131.99	280,000	63,184	0.0000
22	Pump 10	98.68	1,132.68	98.93	1,132.93	280,000	63,184	0.0000
23	Pump 11	99.61	1,133.61	99.86	1,133.86	280,000	63,184	0.0000
24	Pump 12	100.55	1,134.55	100.79	1,134.79	280,000	63,184	0.0000
25	Pump 13	101.48	1,135.48	101.73	1,135.73	280,000	63,184	0.0000
26	Pump 14	102.42	1,136.42	102.66	1,136.66	280,000	63,184	0.0000
27	Pump 15	103.35	1,137.35	103.60	1,137.60	280,000	63,184	0.0000
28	Pump 16	104.28	1,138.28	104.53	1,138.53	280,000	63,184	0.0000
29	Pump 17	105.22	1,139.22	105.47	1,139.47	280,000	63,184	0.0000
30	Pump 18	106.15	1,140.15	106.40	1,140.40	280,000	63,184	0.0000
31	Pump 19	107.09	1,141.09	107.34	1,141.34	280,000	63,184	0.0000
32	Pump 20	108.02	1,142.02	108.27	1,142.27	280,000	63,184	0.0000
33	Casper	103.79	848.79	103.98	848.98	164,000	37,008	0.0000
34	Pump 21	104.21	849.21	104.40	849.40	164,000	37,008	0.0000
35	Pump 22	104.63	849.63	104.81	849.81	164,000	37,008	0.0000
36	Pump 23	105.05	850.05	105.23	850.23	164,000	37,008	0.0000
37	Pump 24	105.47	850.47	105.65	850.65	164,000	37,008	0.0000
38	Pump 25	105.88	850.88	106.07	851.07	164,000	37,008	0.0000
39	Pump 26	106.30	851.30	106.48	851.48	164,000	37,008	0.0000
40	Pump 27	106.72	851.72	106.90	851.90	164,000	37,008	0.0000
41	Pump 28	107.14	852.14	107.32	852.32	164,000	37,008	0.0000
42	Pump 29	107.55	852.55	107.74	852.74	164,000	37,008	0.0000
43	Pump 30	107.97	852.97	108.16	853.16	164,000	37,008	0.0000
44	Pump 31	108.39	853.39	108.57	853.57	164,000	37,008	0.0000
45	Pump 32	108.81	853.81	108.99	853.99	164,000	37,008	0.0000
46	Pump 33	109.23	854.23	109.41	854.41	164,000	37,008	0.0000
47	Pump 34	109.64	854.64	109.83	854.83	164,000	37,008	0.0000
48	Pump 35	110.06	855.06	110.24	855.24	164,000	37,008	0.0000
49	Pump 36	110.48	855.48	110.66	855.66	164,000	37,008	0.0000
50	Pump 37	110.90	855.90	111.08	856.08	164,000	37,008	0.0000
51	Pump 38	111.31	856.31	111.50	856.50	164,000	37,008	0.0000
52	Wood River	111.61	1,011.61	111.91	1,011.91	309,000	69,728	0.0000
53	Pump 39	111.05	1,011.05	111.35	1,011.35	309,000	69,728	0.0000
54	Pump	110.49	960.49	110.79	960.79	360,000	81,236	0.0000
55	Pump 40	124.90	974.90	125.20	975.20	360,000	81,236	0.0000
56	Pump 41	139.32	989.32	139.61	989.61	360,000	81,236	0.0000
57	Pump 42	153.73	1,003.73	154.02	1,004.02	360,000	81,236	0.0000
58	Pump 43	168.14	1,018.14	168.44	1,018.44	360,000	81,236	0.0000
59	Pump 44	182.56	982.56	182.85	982.85	360,000	81,236	0.0000
60	Pump 45	146.97	946.97	147.26	947.26	360,000	81,236	0.0000
61	Edmonton	80.26	880.34	80.41	880.41	350,000	78,980	0.0000
62	Checham	86.27	1,086.27	86.42	1,086.42	350,000	78,980	0.0000
63	Pump 46	84.00	1,084.00	84.15	1,084.15	350,000	78,980	0.0000
64	Pump 47	81.32	1,081.32	81.48	1,081.48	350,000	78,980	0.0000
65	Tee or Wye	86.35	86.35	86.43	86.43	N/A	N/A	0.0000
66	Assigned Flow	86.43	86.43	86.43	86.43	40,000	9,026	0.0000
67	Tee or Wye	880.21	880.21	880.41	880.41	N/A	N/A	0.0000
68	Assigned Flow	880.25	880.25	880.41	880.41	530,000	119,598	0.0000

BARR			Calc# 003 Date 4/15/2010	Sheet No. 1 of 6
Computed By: WJM	Checked By: SEM	Submitted By:	Project Name: Project Number:	
Date: 6/07/2010	Date:6/15/2010	Date:	Subject: Pump Energy Requirements and Usage – TMPL China Pathway	

1.0 Purpose:

Calculate the pumping energy required to transport crude oil from Ft. McMurray to Vancouver along the AOSPL and TMPL China Pathway.

2.0 Reference:

1. "Oil Sands Shuffle Work – Crude Shuffle Case" spreadsheet (Attached)
2. AFT Fathom 7.0 Output for each pipe routing (Attached)
3. Cameron Hydraulic Data, 18th Edition
4. Kinder Morgan TMPL map (Attached)
5. Website,http://www.kindermorgan.com/business/canada/data/2/rec_docs/KMinCanada_web.pdf
6. Website, http://phx.corporate-ir.net/phoenix.zhtml?c=63581&p=irol-pipelines
7. Sulzer Pump estimated pump curves (Attached)
8. Website, http://phx.corporate-ir.net/phoenix.zhtml?c=63581&p=irol-pipelines

3.0 Assumptions:

1. Crude being transported has the characteristics of Western Canadian Select (WCS) as shown on the Enbridge 2009 Crude Characteristics table.
2. Crude is being transported at 10C and the temperature remains constant for the entire distance of transportation.
3. Piping to be steel with a wall thickness of 0.5inches
4. Piping lengths in Reference 1 and 2 include required fitting lengths.
5. Pump is 74% efficient, see Sulzer pump curve
6. Pump motor is 95% efficient
7. WCS viscosity is 350cST
8. Working pressure in pipeline is maximum 1200psig
9. Change is elevation from station to station is at a constant slope.

4.0 Conclusion:

The total kWh required to transport crude oil from Edmonton to Vancouver 365 days a year, 24 hours a day is 9.45x 10^8 kWh.

5.0 Calculation:

Fluid Characteristics: Crude Type = Western Canadian Select

Density = 927.1 kg/m^3

Viscosity = 350cST = 325.5cP

Flow Rate = See References 1 & 2
Specific Gravity = 0.927

Piping Characteristics: Pipe Type = Carbon Steel
Pipe Diameter = See References 1 & 2
Pipe Wall Thickness = 0.5inches (Assumption 3)
Absolute roughness = 0.00015feet

5.1 Calculate Piping Pressure Losses

AFT Fathom software was used to develop a piping model to calculate the piping pressure losses for the entire run of transport piping listed in References 1 and 2. The following components were entered into each model:

1. WCS density and viscosity
2. Piping diameters, absolute roughness, and lengths
3. Elevation differences between pipelines
4. Volumetric flow rates

The input and output for each transport piping arrangement is attached in Reference 2 of this calculation. Table 1 summarizes the results of the AFT modeling.

Table 1 - TMPL China Pathway			
Crude Pathway	**Total Length of Pipe (miles)**	**Total Pressure Loss in Piping (psid)**	**Head Loss (FT)**
AOSPL andTMPL China Pathway	986	19,274	47,874

The results shown in Table 1 and Reference 2 were used to calculate the power required to transport the crude oil using the equation below.

$$\text{Hyd hp} = \frac{\text{lb of liquid per minute x H(in feet)}}{33{,}000} \qquad \text{(Reference 3)}$$

$$\text{Brake hp} = \frac{\text{Hyd hp}}{\text{Pump efficiency}} \qquad \text{(Reference 3)}$$

$$\text{KW input to motor} = \frac{\text{Brake hp} \times 0.7457}{\text{motor efficiency}} \qquad \text{(Reference 3)}$$

$$H\ (\text{feet}) = \frac{\text{psi} \times 2.31}{\text{Specific Gravity}} \qquad \text{(Reference 3)}$$

Table 2 below summarizes the results from the AFT modeling and the resulting pump input power required using the equations above. The pump efficiency is assumed to be 80% (Assumption 5) and the motor efficiency is assumed to be 95% (Assumption 6). The pump power calculated below is the power required to overcome the frictional pressure loss in the piping and does not account for additional pressure required for delivery of the crude oil.

Table 2 - TMPL China Pathway

Origin	Destination	Total Pressure Loss in Piping (psid)	Head Loss (ft)	Flow Rate (bbl/day)	Flow Rate (lb/min)	Pump Power Required (kw)
Ft. McMurray	Edmonton	6,404	15,907	275,000	62,082	29,362
Edmonton	Vancouver	12,870	31,967	260,000	58,696	55,789
	Total	19,274	47,874		62,082	85,151

Table 3 summarizes the requirements for pumping power for several pump stations located along the TMPL China Pathway. Several pumping stations will be required to transport the crude from Edmonton to Vancouver to reduce the operating pressure within the pipeline to meet code allowable working pressures. Table 2 shows the total pressure drop between each destination, since these pressure losses are higher than recommended operational pressures, intermediate pumping stations are suggested.

From Edmonton to Vancouver the AFT model was set up to closely model the pump locations of the TMPL pumping stations, see Reference 4. The locations and pump sizing is not exactly the same as the Kinder Morgan pump stations; as the distances for each pump station were approximated using distances between the towns the pumps stations are located using an internet based map. Reference 5 indicates that 24 pump stations exist between Edmonton and Vancouver. The AFT model was set up to show the pump stations in the towns indicated in the references with slight changes to total mileage between each town. Elevations for each pump station were entered based on the town the pump stations are located in. Some elevations were estimated for small towns which the information could not readily be located.

Table 3 also shows the required kWh for the transport of the crude. The kWh required is calculated using the following equation.

Pump Power Required (kW) x running time(h) = kWh

Table 3 shows the kWh's required to operate the pumps 24 hours a day seven days a week for 365 days.

BARR			Calc# 003 Date 4/15/2010	Sheet No. 5 of 6
Computed By: WJM	Checked By: SEM	Submitted By:	Project Name: Project Number:	
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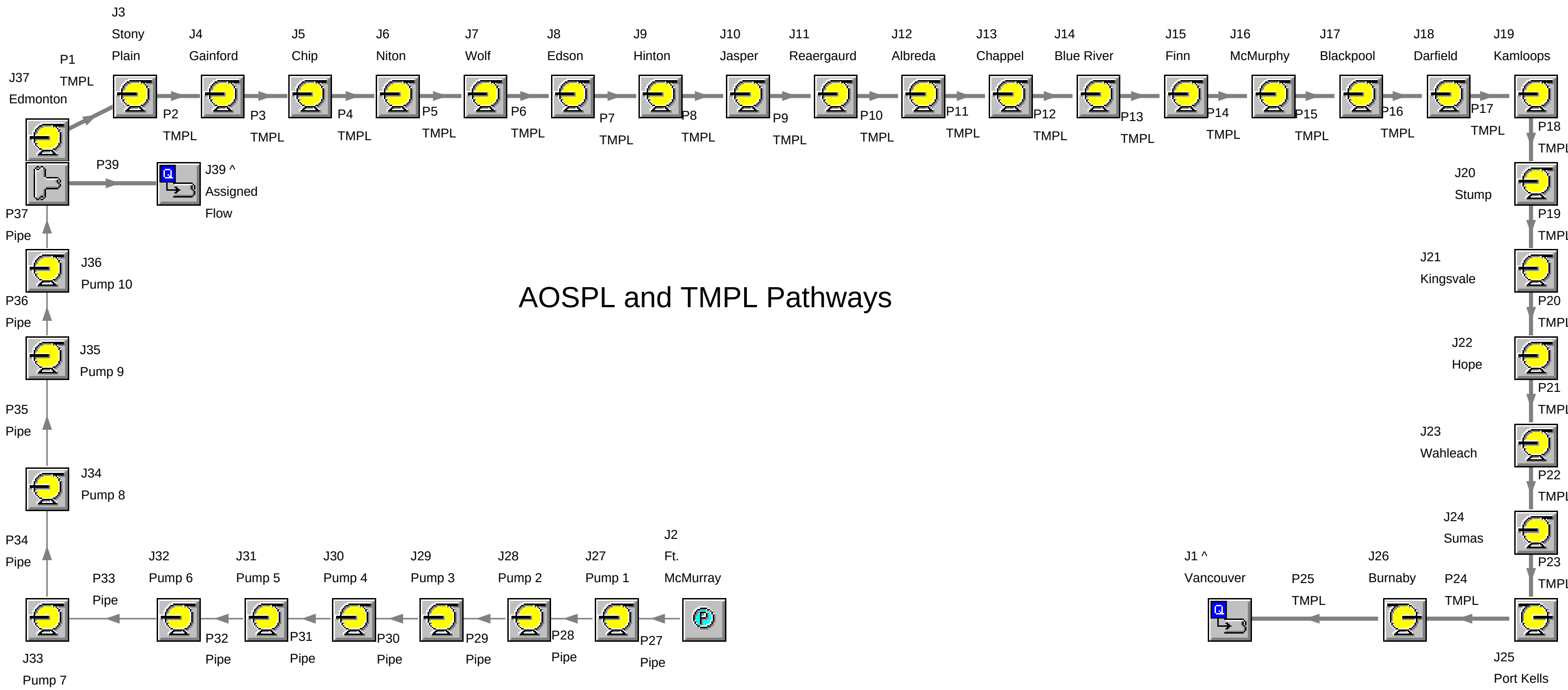
Table 3 -TMPL China Pathway

Station	Pump TDH	Flow Rate (bbl/day)	Flow Rate (lb/min)	Pump Power Required (kw)	kWh
Ft. Mc Murray	2608	275,000	62,082	5,135	4.5E+07
Pump 1	2360	275,000	62,082	4,904	4.3E+07
Pump 2	2360	275,000	62,082	4,904	4.3E+07
Pump 3	2360	275,000	62,082	4,904	4.3E+07
Pump 4	2360	275,000	62,082	4,904	4.3E+07
Pump 5	2360	275,000	62,082	4,904	4.3E+07
Pump 6	2360	275,000	62,082	4,904	4.3E+07
Pump 7	2360	275,000	62,082	4,904	4.3E+07
Pump 8	2360	275,000	62,082	4,904	4.3E+07
Pump 9	2360	275,000	62,082	4,904	4.3E+07
Pump 10	2360	275,000	62,082	4,904	4.3E+07
Edomonton	1,490	260,000	58,696	2,928	2.6E+07
Stony Plain	1,863	260,000	58,696	3,661	3.2E+07
Gainford	1,118	260,000	58,696	2,197	1.9E+07
Chip	745	260,000	58,696	1,464	1.3E+07
Niton	497	260,000	58,696	977	8.6E+06
Wolf	1,118	260,000	58,696	2,197	1.9E+07
Edson	2,732	260,000	58,696	5,368	4.7E+07
Hinton	2,484	260,000	58,696	4,881	4.3E+07
Jasper	2,235	260,000	58,696	4,392	3.8E+07
Rearguard	1,242	260,000	58,696	2,440	2.1E+07
Albreda	1,366	260,000	58,696	2,684	2.4E+07
Chappel	497	260,000	58,696	977	8.6E+06
Blue River	497	260,000	58,696	977	8.6E+06
Finn	994	260,000	58,696	1,953	1.7E+07
McMurphy	745	260,000	58,696	1,464	1.3E+07
Blackpool	1,366	260,000	58,696	2,684	2.4E+07
Darfield	1,863	260,000	58,696	3,661	3.2E+07
Kamloops	1,490	260,000	58,696	2,928	2.6E+07
Stump	1,490	260,000	58,696	2,928	2.6E+07
Kingsvale	1,615	260,000	58,696	3,173	2.8E+07
Hope	1,242	260,000	58,696	2,440	2.1E+07
Wahleach	621	260,000	58,696	1,220	1.1E+07
Sumas	994	260,000	58,696	1,953	1.7E+07
Port Kells	994	260,000	58,696	1,953	1.7E+07
Burnaby	869	260,000	58,696	1,708	1.5E+07
Vancouver					
			Total	117,383	1.03E+09

The required pump power in Table 3 is greater than the amount shown in Table 2 since there will be energy remaining in the pipeline when it is delivered to Vancouver. The pressure in the AFT model is around 108psig into the Vancouver station.

AOSPL and TMPL Pathways



General

Title: AFT Fathom Model
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\AOSPL and TMPL Pathway\AOSPL to TMPL China Pathway.fth
Scenario: Base Scenario/Pump Case

Number Of Pipes= 38
Number Of Junctions= 39

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Pipe Input Table

Pipe	Name	Pipe Defined	Length	Length Units	Hydraulic Diameter	Hydraulic Diam. Units	Friction Data Set	Roughness	Roughness Units	Losses (K)
1	TMPL	Yes	26	miles	23	inches	Unspecified	0.00015	feet	0
2	TMPL	Yes	37	miles	23	inches	Unspecified	0.00015	feet	0
3	TMPL	Yes	20	miles	23	inches	Unspecified	0.00015	feet	0
4	TMPL	Yes	10	miles	23	inches	Unspecified	0.00015	feet	0
5	TMPL	Yes	10	miles	23	inches	Unspecified	0.00015	feet	0
6	TMPL	Yes	20	miles	23	inches	Unspecified	0.00015	feet	0
7	TMPL	Yes	50	miles	23	inches	Unspecified	0.00015	feet	0
8	TMPL	Yes	49	miles	23	inches	Unspecified	0.00015	feet	0
9	TMPL	Yes	44	miles	23	inches	Unspecified	0.00015	feet	0
10	TMPL	Yes	25	miles	23	inches	Unspecified	0.00015	feet	0
11	TMPL	Yes	30	miles	23	inches	Unspecified	0.00015	feet	0
12	TMPL	Yes	25	miles	23	inches	Unspecified	0.00015	feet	0
13	TMPL	Yes	20	miles	23	inches	Unspecified	0.00015	feet	0
14	TMPL	Yes	25	miles	23	inches	Unspecified	0.00015	feet	0
15	TMPL	Yes	30	miles	23	inches	Unspecified	0.00015	feet	0
16	TMPL	Yes	25	miles	23	inches	Unspecified	0.00015	feet	0
17	TMPL	Yes	50	miles	23	inches	Unspecified	0.00015	feet	0
18	TMPL	Yes	40	miles	23	inches	Unspecified	0.00015	feet	0
19	TMPL	Yes	40	miles	23	inches	Unspecified	0.00015	feet	0
20	TMPL	Yes	40	miles	23	inches	Unspecified	0.00015	feet	0
21	TMPL	Yes	20	miles	23	inches	Unspecified	0.00015	feet	0
22	TMPL	Yes	20	miles	23	inches	Unspecified	0.00015	feet	0
23	TMPL	Yes	20	miles	23	inches	Unspecified	0.00015	feet	0
24	TMPL	Yes	20	miles	23	inches	Unspecified	0.00015	feet	0
25	TMPL	Yes	20	miles	23	inches	Unspecified	0.00015	feet	0
27	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0

AFT Fathom Model

Pipe	Name	Pipe Defined	Length	Length Units	Hydraulic Diameter	Hydraulic Diam. Units	Friction Data Set	Roughness	Roughness Units	Losses (K)
28	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
29	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
30	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
31	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
32	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
33	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
34	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
35	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
36	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
37	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
38	Pipe	Yes	1	feet	23	inches	Unspecified	0.00015	feet	0
39	Pipe	Yes	1	feet	23	inches	Unspecified	0.00015	inches	0

Pipe	Junctions (Up,Down)	Geometry	Material	Special Condition
1	37, 3	Cylindrical Pipe	Unspecified	None
2	3, 4	Cylindrical Pipe	Unspecified	None
3	4, 5	Cylindrical Pipe	Unspecified	None
4	5, 6	Cylindrical Pipe	Unspecified	None
5	6, 7	Cylindrical Pipe	Unspecified	None
6	7, 8	Cylindrical Pipe	Unspecified	None
7	8, 9	Cylindrical Pipe	Unspecified	None
8	9, 10	Cylindrical Pipe	Unspecified	None
9	10, 11	Cylindrical Pipe	Unspecified	None
10	11, 12	Cylindrical Pipe	Unspecified	None
11	12, 13	Cylindrical Pipe	Unspecified	None
12	13, 14	Cylindrical Pipe	Unspecified	None
13	14, 15	Cylindrical Pipe	Unspecified	None
14	15, 16	Cylindrical Pipe	Unspecified	None
15	16, 17	Cylindrical Pipe	Unspecified	None
16	17, 18	Cylindrical Pipe	Unspecified	None
17	18, 19	Cylindrical Pipe	Unspecified	None
18	19, 20	Cylindrical Pipe	Unspecified	None
19	20, 21	Cylindrical Pipe	Unspecified	None
20	21, 22	Cylindrical Pipe	Unspecified	None
21	22, 23	Cylindrical Pipe	Unspecified	None
22	23, 24	Cylindrical Pipe	Unspecified	None
23	24, 25	Cylindrical Pipe	Unspecified	None
24	25, 26	Cylindrical Pipe	Unspecified	None
25	26, 1	Cylindrical Pipe	Unspecified	None
27	2, 27	Cylindrical Pipe	Unspecified	None
28	27, 28	Cylindrical Pipe	Unspecified	None
29	28, 29	Cylindrical Pipe	Unspecified	None
30	29, 30	Cylindrical Pipe	Unspecified	None
31	30, 31	Cylindrical Pipe	Unspecified	None
32	31, 32	Cylindrical Pipe	Unspecified	None
33	32, 33	Cylindrical Pipe	Unspecified	None
34	33, 34	Cylindrical Pipe	Unspecified	None
35	34, 35	Cylindrical Pipe	Unspecified	None
36	35, 36	Cylindrical Pipe	Unspecified	None
37	36, 38	Cylindrical Pipe	Unspecified	None
38	38, 37	Cylindrical Pipe	Unspecified	None
39	38, 39	Cylindrical Pipe	Unspecified	None

Pipe Fittings & Losses

Assigned Flow Table

Assigned Flow	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Type	Flow	Flow Units	Loss Factor
1	Vancouver	Yes	7	feet	None	Outflow	260000	barrels/day	0
39	Assigned Flow	Yes	2192	feet	None	Outflow	15000	barrels/day	0

Assigned Pressure Table

Assigned Pressure	Name	Object Defined	Inlet Elevation	Elevation Units	Initial Pressure	Initial Pressure Units	Pressure	Pressure Units
2	Ft. McMurray	Yes	1214	feet	1,050	psig	1050	psig

Assigned Pressure	Pressure Type	Balance Energy	Balance Concentration	(Pipe #1) K In, K Out
2	Stagnation	No	No	(P27) 0, 0

Pump Table

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
3	Stony Plain	Yes	2313	feet	None	Fixed Pressure Rise	750	psid
4	Gainford	Yes	2428	feet	None	Fixed Pressure Rise	450	psid
5	Chip	Yes	2598	feet	None	Fixed Pressure Rise	300	psid
6	Niton	Yes	2900	feet	None	Fixed Pressure Rise	200	psid
7	Wolf	Yes	2950	feet	None	Fixed Pressure Rise	450	psid
8	Edson	Yes	3035	feet	None	Fixed Pressure Rise	1100	psid
9	Hinton	Yes	3291	feet	None	Fixed Pressure Rise	1000	psid
10	Jasper	Yes	3484	feet	None	Fixed Pressure Rise	900	psid
11	Reaergaurd	Yes	3730	feet	None	Fixed Pressure Rise	500	psid
12	Albreda	Yes	3710	feet	None	Fixed Pressure Rise	550	psid
13	Chappel	Yes	3700	feet	None	Fixed Pressure Rise	200	psid
14	Blue River	Yes	2234	feet	None	Fixed Pressure Rise	200	psid
15	Finn	Yes	2100	feet	None	Fixed Pressure Rise	400	psid
16	McMurphy	Yes	2000	feet	None	Fixed Pressure Rise	300	psid
17	Blackpool	Yes	1300	feet	None	Fixed Pressure Rise	550	psid
18	Darfield	Yes	1200	feet	None	Fixed Pressure Rise	750	psid
19	Kamloops	Yes	1132	feet	None	Fixed Pressure Rise	600	psid
20	Stump	Yes	800	feet	None	Fixed Pressure Rise	600	psid
21	Kingsvale	Yes	500	feet	None	Fixed Pressure Rise	650	psid
22	Hope	Yes	135	feet	None	Fixed Pressure Rise	500	psid
23	Wahleach	Yes	80	feet	None	Fixed Pressure Rise	250	psid
24	Sumas	Yes	50	feet	None	Fixed Pressure Rise	400	psid
25	Port Kells	Yes	30	feet	None	Fixed Pressure Rise	400	psid
26	Burnaby	Yes	7	feet	None	Fixed Pressure Rise	350	psid
27	Pump 1	Yes	1303	feet	None	Fixed Pressure Rise	950	psid
28	Pump 2	Yes	1392	feet	None	Fixed Pressure Rise	950	psid
29	Pump 3	Yes	1481	feet	None	Fixed Pressure Rise	950	psid
30	Pump 4	Yes	1570	feet	None	Fixed Pressure Rise	950	psid
31	Pump 5	Yes	1659	feet	None	Fixed Pressure Rise	950	psid
32	Pump 6	Yes	1748	feet	None	Fixed Pressure Rise	950	psid
33	Pump 7	Yes	1837	feet	None	Fixed Pressure Rise	950	psid
34	Pump 8	Yes	1926	feet	None	Fixed Pressure Rise	950	psid

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
35	Pump 9	Yes	2015	feet	None	Fixed Pressure Rise	950	psid
36	Pump 10	Yes	2104	feet	None	Fixed Pressure Rise	950	psid
37	Edmonton	Yes	2192	feet	None	Fixed Pressure Rise	600	psid

Pump	Current Configuration	Heat Added To Fluid	Heat Added Units
3	N/A	0	Percent
4	N/A	0	Percent
5	N/A	0	Percent
6	N/A	0	Percent
7	N/A	0	Percent
8	N/A	0	Percent
9	N/A	0	Percent
10	N/A	0	Percent
11	N/A	0	Percent
12	N/A	0	Percent
13	N/A	0	Percent
14	N/A	0	Percent
15	N/A	0	Percent
16	N/A	0	Percent
17	N/A	0	Percent
18	N/A	0	Percent
19	N/A	0	Percent
20	N/A	0	Percent
21	N/A	0	Percent
22	N/A	0	Percent
23	N/A	0	Percent
24	N/A	0	Percent
25	N/A	0	Percent
26	N/A	0	Percent
27	N/A	0	Percent
28	N/A	0	Percent
29	N/A	0	Percent
30	N/A	0	Percent
31	N/A	0	Percent
32	N/A	0	Percent
33	N/A	0	Percent
34	N/A	0	Percent
35	N/A	0	Percent
36	N/A	0	Percent
37	N/A	0	Percent

Tee or Wye Table

Tee or Wye	Name	Object Defined	Inlet Elevation	Elevation Units	Tee/Wye Type	Loss Type	Angle	Pipes A, B, C
38	Tee or Wye	Yes	2192	feet	Sharp Straight	Simple (no loss)	90	37, 38, 39

General

Title: AFT Fathom Model
Analysis run on: 6/7/2010 11:42:08 AM
Application version: AFT Fathom Version 7.0 (2009.11.02)
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\AOSPL and TMPL Pathway\AOSPL to TMPL China Pathway.fth
Scenario: Base Scenario/Pump Case
Output File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\AOSPL and TMPL Pathway\AOSPL to TMPL China Pathway_2.out

Execution Time= 0.25 seconds
Total Number Of Head/Pressure Iterations= 0
Total Number Of Flow Iterations= 2
Total Number Of Temperature Iterations= 0
Number Of Pipes= 38
Number Of Junctions= 39
Matrix Method= Gaussian Elimination

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Total Inflow= 8,021 gal/min
Total Outflow= 8,021 gal/min
Maximum Static Pressure is 1,221 psia at Pipe 7 Inlet
Minimum Static Pressure is 69.38 psia at Pipe 19 Outlet

Pump Summary

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
3	Stony Plain	7,583	977.8	750.0	1,866.0	100.0	N/A	3,317.1	N/A	N/A	302.2
4	Gainford	7,583	977.8	450.0	1,119.6	100.0	N/A	1,990.3	N/A	N/A	281.1
5	Chip	7,583	977.8	300.0	746.4	100.0	N/A	1,326.8	N/A	N/A	272.8
6	Niton	7,583	977.8	200.0	497.6	100.0	N/A	884.6	N/A	N/A	238.2
7	Wolf	7,583	977.8	450.0	1,119.6	100.0	N/A	1,990.3	N/A	N/A	206.9
8	Edson	7,583	977.8	1,100.0	2,736.8	100.0	N/A	4,865.1	N/A	N/A	283.6
9	Hinton	7,583	977.8	1,000.0	2,488.0	100.0	N/A	4,422.8	N/A	N/A	369.6
10	Jasper	7,583	977.8	900.0	2,239.2	100.0	N/A	3,980.5	N/A	N/A	317.7
11	Reaergaurd	7,583	977.8	500.0	1,244.0	100.0	N/A	2,211.4	N/A	N/A	203.5
12	Albreda	7,583	977.8	550.0	1,368.4	100.0	N/A	2,432.5	N/A	N/A	270.1
13	Chappel	7,583	977.8	200.0	497.6	100.0	N/A	884.6	N/A	N/A	211.6
14	Blue River	7,583	977.8	200.0	497.6	100.0	N/A	884.6	N/A	N/A	977.8
15	Finn	7,583	977.8	400.0	995.2	100.0	N/A	1,769.1	N/A	N/A	651.5
16	McMurphy	7,583	977.8	300.0	746.4	100.0	N/A	1,326.8	N/A	N/A	549.3
17	Blackpool	7,583	977.8	550.0	1,368.4	100.0	N/A	2,432.5	N/A	N/A	558.8

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
18	Darfield	7,583	977.8	750.0	1,866.0	100.0	N/A	3,317.1	N/A	N/A	829.8
19	Kamloops	7,583	977.8	600.0	1,492.8	100.0	N/A	2,653.7	N/A	N/A	369.0
20	Stump	7,583	977.8	600.0	1,492.8	100.0	N/A	2,653.7	N/A	N/A	278.0
21	Kingsvale	7,583	977.8	650.0	1,617.2	100.0	N/A	2,874.8	N/A	N/A	154.9
22	Hope	7,583	977.8	500.0	1,244.0	100.0	N/A	2,211.4	N/A	N/A	221.3
23	Wahleach	7,583	977.8	250.0	622.0	100.0	N/A	1,105.7	N/A	N/A	562.4
24	Sumas	7,583	977.8	400.0	995.2	100.0	N/A	1,769.1	N/A	N/A	256.4
25	Port Kells	7,583	977.8	400.0	995.2	100.0	N/A	1,769.1	N/A	N/A	313.7
26	Burnaby	7,583	977.8	350.0	870.8	100.0	N/A	1,548.0	N/A	N/A	374.0
27	Pump 1	8,021	1,034.3	950.0	2,363.6	100.0	N/A	4,444.0	N/A	N/A	258.7
28	Pump 2	8,021	1,034.3	950.0	2,363.6	100.0	N/A	4,444.0	N/A	N/A	250.3
29	Pump 3	8,021	1,034.3	950.0	2,363.6	100.0	N/A	4,444.0	N/A	N/A	241.9
30	Pump 4	8,021	1,034.3	950.0	2,363.6	100.0	N/A	4,444.0	N/A	N/A	233.5
31	Pump 5	8,021	1,034.3	950.0	2,363.6	100.0	N/A	4,444.0	N/A	N/A	225.1
32	Pump 6	8,021	1,034.3	950.0	2,363.6	100.0	N/A	4,444.0	N/A	N/A	216.7
33	Pump 7	8,021	1,034.3	950.0	2,363.6	100.0	N/A	4,444.0	N/A	N/A	208.3
34	Pump 8	8,021	1,034.3	950.0	2,363.6	100.0	N/A	4,444.0	N/A	N/A	199.9
35	Pump 9	8,021	1,034.3	950.0	2,363.6	100.0	N/A	4,444.0	N/A	N/A	191.5
36	Pump 10	8,021	1,034.3	950.0	2,363.6	100.0	N/A	4,444.0	N/A	N/A	183.1
37	Edmonton	7,583	977.8	600.0	1,492.8	100.0	N/A	2,653.7	N/A	N/A	175.7

Jct	NPSHR (feet)
3	N/A
4	N/A
5	N/A
6	N/A
7	N/A
8	N/A
9	N/A
10	N/A
11	N/A
12	N/A
13	N/A
14	N/A
15	N/A
16	N/A
17	N/A
18	N/A
19	N/A
20	N/A
21	N/A
22	N/A
23	N/A
24	N/A
25	N/A
26	N/A
27	N/A
28	N/A
29	N/A
30	N/A
31	N/A

Jct	NPSHR (feet)
32	N/A
33	N/A
34	N/A
35	N/A
36	N/A
37	N/A

Pipe Output Table

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psia)	P Static Min (psia)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)	dP Gravity (psid)
1	TMPL	260,000	5.8557	677.74	128.59	2,192.000	2,313.000	549.1517334	549.1517334	48.633
2	TMPL	260,000	5.8557	878.59	120.09	2,313.000	2,428.000	758.4981689	758.4981689	46.221
3	TMPL	260,000	5.8557	570.09	116.75	2,428.000	2,598.000	453.3415527	453.3415527	68.327
4	TMPL	260,000	5.8557	416.75	102.86	2,598.000	2,900.000	313.8881531	313.8881531	121.381
5	TMPL	260,000	5.8557	302.86	90.26	2,900.000	2,950.000	212.6034546	212.6034546	20.096
6	TMPL	260,000	5.8557	540.26	121.08	2,950.000	3,035.000	419.1780701	419.1780701	34.163
7	TMPL	260,000	5.8557	1,221.08	155.65	3,035.000	3,291.000	1,065.4288330	1,065.4288330	102.892
8	TMPL	260,000	5.8557	1,155.65	134.79	3,291.000	3,484.000	1,020.8569946	1,020.8569946	77.571
9	TMPL	260,000	5.8557	1,034.79	88.89	3,484.000	3,730.000	945.9052734	945.9052734	98.873
10	TMPL	260,000	5.8557	588.89	115.66	3,730.000	3,710.000	473.2297974	473.2297974	-8.038
11	TMPL	260,000	5.8557	665.66	92.16	3,710.000	3,700.000	573.5026855	573.5026855	-4.019
12	TMPL	260,000	5.8557	400.11	292.16	3,700.000	2,234.000	-107.9514160	-107.9514160	-589.220
13	TMPL	260,000	5.8557	600.11	268.95	2,234.000	2,100.000	331.1568604	331.1568604	-53.858
14	TMPL	260,000	5.8557	668.95	227.88	2,100.000	2,000.000	441.0759277	441.0759277	-40.192
15	TMPL	260,000	5.8557	527.88	231.70	2,000.000	1,300.000	296.1755676	296.1755676	-281.346
16	TMPL	260,000	5.8557	781.70	340.62	1,300.000	1,200.000	441.0759277	441.0759277	-40.192
17	TMPL	260,000	5.8557	1,090.62	155.42	1,200.000	1,132.000	935.2056885	935.2056885	-27.331
18	TMPL	260,000	5.8557	755.42	118.83	1,132.000	800.000	636.5906372	636.5906372	-133.439
19	TMPL	260,000	5.8557	718.83	69.38	800.000	500.000	649.4521484	649.4521484	-120.577
20	TMPL	260,000	5.8557	719.38	96.05	500.000	135.000	623.3271484	623.3271484	-146.702
21	TMPL	260,000	5.8557	596.05	233.14	135.000	80.000	362.9088135	362.9088135	-22.106
22	TMPL	260,000	5.8557	483.14	110.18	80.000	50.000	372.9568787	372.9568787	-12.058
23	TMPL	260,000	5.8557	510.18	133.21	50.000	30.000	376.9761353	376.9761353	-8.038
24	TMPL	260,000	5.8557	533.21	157.44	30.000	7.000	375.7703552	375.7703552	-9.244
25	TMPL	260,000	5.8557	507.44	122.42	7.000	7.000	385.0146179	385.0146179	0.000
27	Pipe	275,000	7.4295	1,064.35	110.97	1,214.000	1,303.000	953.3762207	953.3762207	35.771
28	Pipe	275,000	7.4295	1,060.97	107.60	1,303.000	1,392.000	953.3762207	953.3762207	35.771
29	Pipe	275,000	7.4295	1,057.60	104.22	1,392.000	1,481.000	953.3762207	953.3762207	35.771
30	Pipe	275,000	7.4295	1,054.22	100.85	1,481.000	1,570.000	953.3762207	953.3762207	35.771
31	Pipe	275,000	7.4295	1,050.85	97.47	1,570.000	1,659.000	953.3762207	953.3762207	35.771
32	Pipe	275,000	7.4295	1,047.47	94.09	1,659.000	1,748.000	953.3762207	953.3762207	35.771
33	Pipe	275,000	7.4295	1,044.09	90.72	1,748.000	1,837.000	953.3762207	953.3762207	35.771
34	Pipe	275,000	7.4295	1,040.72	87.34	1,837.000	1,926.000	953.3762207	953.3762207	35.771
35	Pipe	275,000	7.4295	1,037.34	83.97	1,926.000	2,015.000	953.3762207	953.3762207	35.771
36	Pipe	275,000	7.4295	1,033.97	80.59	2,015.000	2,104.000	953.3762207	953.3762207	35.771
37	Pipe	275,000	7.4295	1,030.59	77.61	2,104.000	2,192.000	952.9743042	952.9743042	35.369
38	Pipe	260,000	5.8557	77.75	77.74	2,192.000	2,192.000	0.0036460	0.0036460	0.000
39	Pipe	15,000	0.3378	77.96	77.96	2,192.000	2,192.000	0.0001389	0.0001389	0.000

Pipe	dH (feet)	P Static In (psig)	P Static Out (psig)	P Stag. In (psig)	P Stag. Out (psig)
1	1,245.3095623	663.05	113.89	663.26	114.11
2	1,772.1712126	863.89	105.40	864.11	105.61
3	957.9303975	555.40	102.05	555.61	102.27
4	478.9651988	402.05	88.17	402.27	88.38
5	478.9651988	288.17	75.56	288.38	75.78
6	957.9303975	525.56	106.38	525.78	106.60
7	2,394.8260697	1,206.38	140.96	1,206.60	141.17
8	2,346.9295423	1,140.96	120.10	1,141.17	120.31
9	2,107.4469049	1,020.10	74.19	1,020.31	74.41
10	1,197.4130349	574.19	100.96	574.41	101.18
11	1,436.8956722	650.96	77.46	651.18	77.68
12	1,197.4130349	277.46	385.41	277.68	385.63
13	957.9303975	585.41	254.26	585.63	254.47
14	1,197.4130349	654.26	213.18	654.47	213.39
15	1,436.8956722	513.18	217.00	513.39	217.22
16	1,197.4130349	767.00	325.93	767.22	326.14
17	2,394.8260697	1,075.93	140.72	1,076.14	140.94
18	1,915.8607950	740.72	104.13	740.94	104.35
19	1,915.8607950	704.13	54.68	704.35	54.89
20	1,915.8607950	704.68	81.35	704.89	81.57
21	957.9303975	581.35	218.44	581.57	218.66
22	957.9303975	468.44	95.49	468.66	95.70
23	957.9303975	495.49	118.51	495.70	118.72
24	957.9303975	518.51	142.74	518.72	142.95
25	957.9304734	492.74	107.73	492.95	107.94
27	2,283.0349575	1,049.66	96.28	1,050.00	96.62
28	2,283.0349575	1,046.28	92.90	1,046.62	93.25
29	2,283.0349575	1,042.90	89.53	1,043.25	89.87
30	2,283.0349575	1,039.53	86.15	1,039.87	86.50
31	2,283.0349575	1,036.15	82.77	1,036.50	83.12
32	2,283.0349575	1,032.77	79.40	1,033.12	79.74
33	2,283.0349575	1,029.40	76.02	1,029.74	76.37
34	2,283.0349575	1,026.02	72.65	1,026.37	72.99
35	2,283.0349575	1,022.65	69.27	1,022.99	69.61
36	2,283.0349575	1,019.27	65.89	1,019.61	66.24
37	2,283.0349575	1,015.89	62.92	1,016.24	63.26
38	0.0090713	63.05	63.05	63.26	63.26
39	0.0003457	63.26	63.26	63.26	63.26

All Junction Table

Jct	Name	P Static In (psia)	P Static Out (psig)	P Stag. In (psig)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (barrels/day)	Mass Flow Rate Thru Jct (lbm/min)	Loss Factor (K)
1	Vancouver	122.42	107.73	107.94	122.64	260,000	58,671	0
2	Ft. McMurray	1,064.35	1,049.66	1,050.00	1,064.70	275,000	62,056	0
3	Stony Plain	128.59	863.89	114.11	878.80	260,000	58,671	0
4	Gainford	120.09	555.40	105.61	570.31	260,000	58,671	0
5	Chip	116.75	402.05	102.27	416.96	260,000	58,671	0
6	Niton	102.86	288.17	88.38	303.08	260,000	58,671	0
7	Wolf	90.26	525.56	75.78	540.47	260,000	58,671	0
8	Edson	121.08	1,206.38	106.60	1,221.29	260,000	58,671	0

Jct	Name	P Static In (psia)	P Static Out (psig)	P Stag. In (psig)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (barrels/day)	Mass Flow Rate Thru Jct (lbm/min)	Loss Factor (K)
9	Hinton	155.65	1,140.96	141.17	1,155.87	260,000	58,671	0
10	Jasper	134.79	1,020.10	120.31	1,035.01	260,000	58,671	0
11	Reaergaurd	88.89	574.19	74.41	589.10	260,000	58,671	0
12	Albreda	115.66	650.96	101.18	665.87	260,000	58,671	0
13	Chappel	92.16	277.46	77.68	292.37	260,000	58,671	0
14	Blue River	400.11	585.41	385.63	600.32	260,000	58,671	0
15	Finn	268.95	654.26	254.47	669.17	260,000	58,671	0
16	McMurphy	227.88	513.18	213.39	528.09	260,000	58,671	0
17	Blackpool	231.70	767.00	217.22	781.91	260,000	58,671	0
18	Darfield	340.62	1,075.93	326.14	1,090.84	260,000	58,671	0
19	Kamloops	155.42	740.72	140.94	755.63	260,000	58,671	0
20	Stump	118.83	704.13	104.35	719.04	260,000	58,671	0
21	Kingsvale	69.38	704.68	54.89	719.59	260,000	58,671	0
22	Hope	96.05	581.35	81.57	596.26	260,000	58,671	0
23	Wahleach	233.14	468.44	218.66	483.35	260,000	58,671	0
24	Sumas	110.18	495.49	95.70	510.40	260,000	58,671	0
25	Port Kells	133.21	518.51	118.72	533.42	260,000	58,671	0
26	Burnaby	157.44	492.74	142.95	507.65	260,000	58,671	0
27	Pump 1	110.97	1,046.28	96.62	1,061.32	275,000	62,056	0
28	Pump 2	107.60	1,042.90	93.25	1,057.94	275,000	62,056	0
29	Pump 3	104.22	1,039.53	89.87	1,054.57	275,000	62,056	0
30	Pump 4	100.85	1,036.15	86.50	1,051.19	275,000	62,056	0
31	Pump 5	97.47	1,032.77	83.12	1,047.81	275,000	62,056	0
32	Pump 6	94.09	1,029.40	79.74	1,044.44	275,000	62,056	0
33	Pump 7	90.72	1,026.02	76.37	1,041.06	275,000	62,056	0
34	Pump 8	87.34	1,022.65	72.99	1,037.69	275,000	62,056	0
35	Pump 9	83.97	1,019.27	69.61	1,034.31	275,000	62,056	0
36	Pump 10	80.59	1,015.89	66.24	1,030.93	275,000	62,056	0
37	Edmonton	77.74	663.05	63.26	677.96	260,000	58,671	0
38	Tee or Wye	77.83	63.13	63.26	77.96	N/A	N/A	0
39	Assigned Flow	77.96	63.26	63.26	77.96	15,000	3,385	0

BARR			Calc# 008 Date 4/15/2010	Sheet No. 1 of 5
Computed By: WJM	Checked By: SEM	Submitted By:	Project Name:	
			Project Number:	
Date: 6/07/2010	Date: 6/15/10	Date:	Subject: Pump Energy Requirements and Usage –Gateway China Pathway	

1.0 Purpose:

Calculate the pumping energy required to transport crude oil from Ft. McMurray to Kitimat along the AOSPL and Gateway China Pathways.

2.0 Reference:

1. "Oil Sands Shuffle Work – Crude Shuffle Case" spreadsheet (Attached)
2. AFT Fathom 7.0 Output for each pipe routing (Attached)
3. Cameron Hydraulic Data, 18th Edition
   Website, http://phx.corporate-ir.net/phoenix.zhtml?c=63581&p=irol-pipelines
4. Website, http://www.northerngateway.ca/project-info/northern-gateway-at-a-glance
5. Sulzer Pump estimated pump curves (Attached)
6. Website, http://phx.corporate-ir.net/phoenix.zhtml?c=63581&p=irol-pipelines

3.0 Assumptions:

1. Crude being transported has the characteristics of Western Canadian Select (WCS) as shown on the Enbridge 2009 Crude Characteristics table.
2. Crude is being transported at 10C and the temperature remains constant for the entire distance of transportation.
3. Piping to be steel with a wall thickness of 0.5inches
4. Piping lengths in Reference 1 and 2 include required fitting lengths.
5. Pump is 74% efficient, see Sulzer pump curve
6. Pump motor is 95% efficient
7. WCS viscosity is 350cST
8. Working pressure in pipeline is maximum 1200psig
9. Change is elevation from station to station is at a constant slope.

4.0 Conclusion:

The total kWh required to transport crude oil from Edmonton to Vancouver 365 days a year, 24 hours a day is 1.20 x 10^9 kWh.

5.0 Calculation:

Fluid Characteristics: Crude Type = Western Canadian Select

Density = 927.1 kg/m^3

Viscosity = 350cST = 325.5cP

Flow Rate = See References 1 & 2
Specific Gravity = 0.927

Piping Characteristics: Pipe Type = Carbon Steel
Pipe Diameter = See References 1 & 2
Pipe Wall Thickness = 0.5inches (Assumption 3)
Absolute roughness = 0.00015feet

5.1 Calculate Piping Pressure Losses

AFT Fathom software was used to develop a piping model to calculate the piping pressure losses for the entire run of transport piping listed in References 1 and 2. The following components were entered into each model:

1. WCS density and viscosity
2. Piping diameters, absolute roughness, and lengths
3. Elevation differences between pipelines
4. Volumetric flow rates

The input and output for each transport piping arrangement is attached in Reference 2 of this calculation. Table 1 summarizes the results of the AFT modeling.

Table 1 - AOSPL and Gateway China Pathway			
Crude Pathway	**Total Length of Pipe (miles)**	**Total Pressure Loss in Piping (psid)**	**Head Loss (FT)**
AOSPL and Gateway China Pathway	1,008	14,186	35,236

The results shown in Table 1 and Reference 2 were used to calculate the power required to transport the crude oil using the equation below.

$$\text{Hyd hp} = \frac{\text{lb of liquid per minute x H(in feet)}}{33{,}000} \qquad \text{(Reference 3)}$$

Brake hp = ____Hyd hp____ (Reference 3)

Pump efficiency

$$\text{KW input to motor} = \frac{\text{Brake hp x } 0.7457}{\text{motor efficiency}}$$ (Reference 3)

$$\text{H (feet)} = \frac{\text{psi x } 2.31}{\text{Specific Gravity}}$$ (Reference 3)

Table 2 below summarizes the results from the AFT modeling and the resulting pump input power required using the equations above. The pump efficiency is assumed to be 75% (Assumption 5) and the motor efficiency is assumed to be 95% (Assumption 6). The pump power calculated below is the power required to overcome the frictional pressure loss in the piping and does not account for additional pressure required for delivery of the crude oil.

Table 2 - AOSPL and Gateway China Pathway

Origin	Destination	Total Pressure Loss in Piping (psid)	Head Loss (ft)	Flow Rate (bbl/day)	Flow Rate (lb/min)	Pump Power Required (kw)
Ft McMurray	Bruderheim	6,404	15,907	275000	62,082	33,059
Bruderheim	Kitimat	7,782	19,329	525,000	118,520	76,693
	Total	14,186	35,236			109,752

Table 3 summarizes the requirements for pumping power for several pump stations located along the Gateway China Pathway. Several pumping stations will be required to transport the crude from Bruderheim to Kitimat to reduce the operating pressure within the pipeline to meet code allowable working pressures. Table 2 shows the total pressure drop between each destination, since these pressure losses are higher than recommended operational pressures, intermediate pumping stations are suggested.

From Bruderheim to Kitimat the AFT model was set up to closely model the pump locations of the Gateway Pipeline pumping stations see Reference 4. The locations and pump sizing is not exactly the same as the Gateway pump stations; as the distances for each pump station were approximated using distances between the towns the pumps stations are located using an internet based map. Reference 5 indicates that 10 pump stations exist between Bruderheim and Kitimat. The AFT model was set up to show the pump stations in the towns indicated in the references with slight changes to total mileage between each town. Elevations for each pump station were entered based on the town the pump stations are located in. Some elevations were estimated for small towns which the information could not readily be located.

Table 3 also shows the required kWh for the transport of the crude. The kWh required is calculated using the following equation.

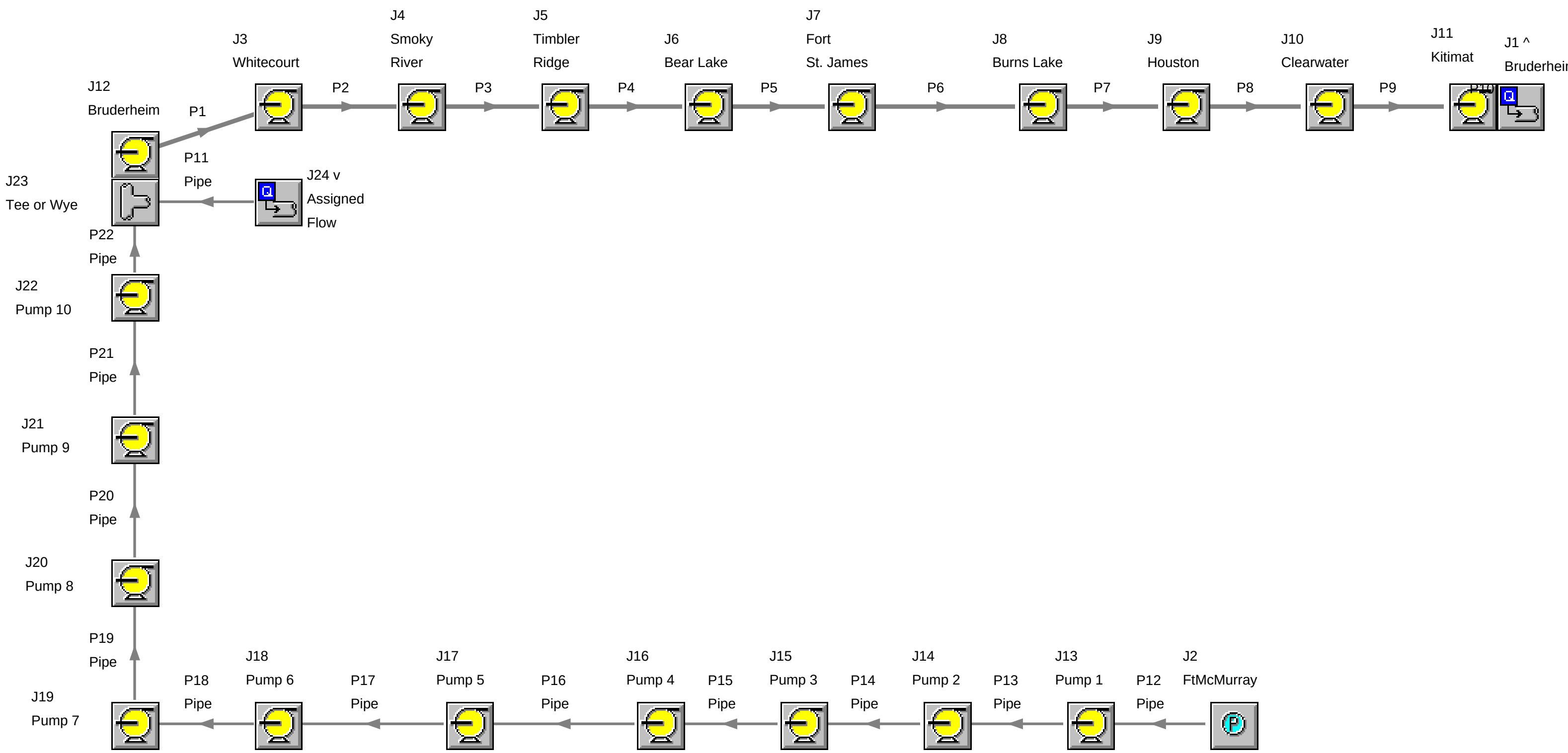
Pump Power Required (kW) x running time(h) = kWh

Table 3 shows the kWh's required to operate the pumps 24 hours a day seven days a week for 365 days.

Table 3 - AOSPL and Gateway China Pathway					
Station	**Pump Head (ft)**	**Flow Rate (bbl/day)**	**Flow Rate (lb/min)**	**Pump Power Required (kw)**	**kWh**
Ft. Mc Murray	2608	275,000	62,082	5,135	4.5E+07
Pump 1	2360	275,000	62,082	4,904	4.3E+07
Pump 2	2360	275,000	62,082	4,904	4.3E+07
Pump 3	2360	275,000	62,082	4,904	4.3E+07
Pump 4	2360	275,000	62,082	4,904	4.3E+07
Pump 5	2360	275,000	62,082	4,904	4.3E+07
Pump 6	2360	275,000	62,082	4,904	4.3E+07
Pump 7	2360	275,000	62,082	4,904	4.3E+07
Pump 8	2360	275,000	62,082	4,904	4.3E+07
Pump 9	2360	275,000	62,082	4,904	4.3E+07
Pump 10	2360	275,000	62,082	4,904	4.3E+07
Bruderheim	2,981	525,000	118,520	12,150	1.1E+08
Whitecourt	2,732	525,000	118,520	11,138	9.8E+07
Smokey River	2,856	525,000	118,520	11,644	1.0E+08
Timbler Ridge	2,111	525,000	118,520	8,525	7.5E+07
Bear Lake	2,111	525,000	118,520	8,525	7.5E+07
Fort St. James	2,608	525,000	118,520	10,631	9.3E+07
Burns Lake	1,987	525,000	118,520	8,023	7.0E+07
Houston	2,360	525,000	118,520	9,619	8.4E+07
Clearwater	373	525,000	118,520	1,408	1.2E+07
Kitimat	373	525,000	118,520	1,408	1.2E+07
			Total	137,249	1.20E+09

The required pump power in Table 3 is greater than the amount shown in Table 2 since there will be energy remaining in the pipeline when it is delivered to Kitimat. The pump station in Kitimat will require sufficient head to pump crude to the vessels, the pump currently is sized at 150psig or 373ft of head.

AOSPL and Gateway China Pathway



General

Title: AFT Fathom Model
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\AOSPL and Gateway Pathway\Gateway China Pathway.fth
Scenario: Base Scenario/Pump Case

Number Of Pipes= 23
Number Of Junctions= 24

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Pipe Input Table

Pipe	Name	Pipe Defined	Length	Length Units	Hydraulic Diameter	Hydraulic Diam. Units	Friction Data Set	Roughness	Roughness Units	Losses (K)
1	Gateway	Yes	90	miles	35	inches	Unspecified	0.00015	feet	0
2	Gateway	Yes	90	miles	35	inches	Unspecified	0.00015	feet	0
3	Gateway	Yes	90	miles	35	inches	Unspecified	0.00015	feet	0
4	Gateway	Yes	80	miles	35	inches	Unspecified	0.00015	feet	0
5	Gateway	Yes	80	miles	35	inches	Unspecified	0.00015	feet	0
6	Gateway	Yes	88.27	miles	35	inches	Unspecified	0.00015	feet	0
7	Gateway	Yes	80	miles	35	inches	Unspecified	0.00015	feet	0
8	Gateway	Yes	80	miles	35	inches	Unspecified	0.00015	feet	0
9	Gateway	Yes	60	miles	35	inches	Unspecified	0.00015	feet	0
10	Gateway	Yes	250	feet	35	inches	Unspecified	0.00015	feet	0
11	Pipe	Yes	1	feet	21	inches	Unspecified	0.00015	feet	0
12	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
13	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
14	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
15	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
16	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
17	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
18	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
19	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
20	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
21	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
22	Pipe	Yes	24.5	miles	21	inches	Unspecified	0.00015	feet	0
23	Pipe	Yes	1	feet	21	inches	Unspecified	0.00015	feet	0

Pipe	Junctions (Up,Down)	Geometry	Material	Special Condition
1	12, 3	Cylindrical Pipe	Unspecified	None
2	3, 4	Cylindrical Pipe	Unspecified	None
3	4, 5	Cylindrical Pipe	Unspecified	None
4	5, 6	Cylindrical Pipe	Unspecified	None
5	6, 7	Cylindrical Pipe	Unspecified	None
6	7, 8	Cylindrical Pipe	Unspecified	None
7	8, 9	Cylindrical Pipe	Unspecified	None
8	9, 10	Cylindrical Pipe	Unspecified	None
9	10, 11	Cylindrical Pipe	Unspecified	None
10	11, 1	Cylindrical Pipe	Unspecified	None
11	24, 23	Cylindrical Pipe	Unspecified	None
12	2, 13	Cylindrical Pipe	Unspecified	None
13	13, 14	Cylindrical Pipe	Unspecified	None
14	14, 15	Cylindrical Pipe	Unspecified	None
15	15, 16	Cylindrical Pipe	Unspecified	None
16	16, 17	Cylindrical Pipe	Unspecified	None
17	17, 18	Cylindrical Pipe	Unspecified	None
18	18, 19	Cylindrical Pipe	Unspecified	None
19	19, 20	Cylindrical Pipe	Unspecified	None
20	20, 21	Cylindrical Pipe	Unspecified	None
21	21, 22	Cylindrical Pipe	Unspecified	None
22	22, 23	Cylindrical Pipe	Unspecified	None
23	23, 12	Cylindrical Pipe	Unspecified	None

Pipe Fittings & Losses

Assigned Flow Table

Assigned Flow	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Type	Flow	Flow Units	Loss Factor
1	Bruderheim	Yes	131	feet	None	Outflow	525000	barrels/day	0
24	Assigned Flow	Yes	2067	feet	None	Inflow	250000	barrels/day	0

Assigned Pressure Table

Assigned Pressure	Name	Object Defined	Inlet Elevation	Elevation Units	Initial Pressure	Initial Pressure Units	Pressure	Pressure Units
2	FtMcMurray	Yes	1214	feet	1,050	psig	1050	psig

Assigned Pressure	Pressure Type	Balance Energy	Balance Concentration	(Pipe #1) K In, K Out
2	Stagnation	No	No	(P12) 0, 0

Pump Table

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
3	Whitecourt	Yes	2297	feet	None	Fixed Pressure Rise	1100	psid
4	Smoky River	Yes	2400	feet	None	Fixed Pressure Rise	1150	psid
5	Timbler Ridge	Yes	2723	feet	None	Fixed Pressure Rise	850	psid
6	Bear Lake	Yes	2500	feet	None	Fixed Pressure Rise	850	psid
7	Fort St. James	Yes	2297	feet	None	Fixed Pressure Rise	1050	psid

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
8	Burns Lake	Yes	2362	feet	None	Fixed Pressure Rise	800	psid
9	Houston	Yes	2001	feet	None	Fixed Pressure Rise	950	psid
10	Clearwater	Yes	2000	feet	None	Fixed Pressure Rise	150	psid
11	Kitimat	Yes	131	feet	None	Fixed Pressure Rise	150	psid
12	Bruderheim	Yes	2067	feet	None	Fixed Pressure Rise	1200	psid
13	Pump 1	Yes	1303	feet	None	Fixed Pressure Rise	950	psid
14	Pump 2	Yes	1392	feet	None	Fixed Pressure Rise	950	psid
15	Pump 3	Yes	1481	feet	None	Fixed Pressure Rise	950	psid
16	Pump 4	Yes	1570	feet	None	Fixed Pressure Rise	950	psid
17	Pump 5	Yes	1659	feet	None	Fixed Pressure Rise	950	psid
18	Pump 6	Yes	1748	feet	None	Fixed Pressure Rise	950	psid
19	Pump 7	Yes	1837	feet	None	Fixed Pressure Rise	950	psid
20	Pump 8	Yes	1926	feet	None	Fixed Pressure Rise	950	psid
21	Pump 9	Yes	2015	feet	None	Fixed Pressure Rise	950	psid
22	Pump 10	Yes	2104	feet	None	Fixed Pressure Rise	950	psid

Pump	Current Configuration	Heat Added To Fluid	Heat Added Units
3	N/A	0	Percent
4	N/A	0	Percent
5	N/A	0	Percent
6	N/A	0	Percent
7	N/A	0	Percent
8	N/A	0	Percent
9	N/A	0	Percent
10	N/A	0	Percent
11	N/A	0	Percent
12	N/A	0	Percent
13	N/A	0	Percent
14	N/A	0	Percent
15	N/A	0	Percent
16	N/A	0	Percent
17	N/A	0	Percent
18	N/A	0	Percent
19	N/A	0	Percent
20	N/A	0	Percent
21	N/A	0	Percent
22	N/A	0	Percent

Tee or Wye Table

Tee or Wye	Name	Object Defined	Inlet Elevation	Elevation Units	Tee/Wye Type	Loss Type	Angle	Pipes A, B, C
23	Tee or Wye	Yes	2067	feet	Sharp Straight	Simple (no loss)	90	11, 22, 23

General

Title: AFT Fathom Model
Analysis run on: 6/7/2010 1:42:26 PM
Application version: AFT Fathom Version 7.0 (2009.11.02)
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\AOSPL and Gateway Pathway\Gateway China Pathway.fth
Scenario: Base Scenario/Pump Case
Output File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\AOSPL and Gateway Pathway\Gateway China Pathway_2.out

Execution Time= 0.19 seconds
Total Number Of Head/Pressure Iterations= 0
Total Number Of Flow Iterations= 2
Total Number Of Temperature Iterations= 0
Number Of Pipes= 23
Number Of Junctions= 24
Matrix Method= Gaussian Elimination

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Total Inflow= 15,312 gal/min
Total Outflow= 15,312 gal/min
Maximum Static Pressure is 1,345 psia at Pipe 3 Inlet
Minimum Static Pressure is 80.59 psia at Pipe 21 Outlet

Pump Summary

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
3	Whitecourt	15,312	1,974	1,100.0	2,736.8	100.0	N/A	9,824	N/A	N/A	444.7
4	Smoky River	15,312	1,974	1,150.0	2,861.2	100.0	N/A	10,270	N/A	N/A	467.0
5	Timbler Ridge	15,312	1,974	850.0	2,114.8	100.0	N/A	7,591	N/A	N/A	393.6
6	Bear Lake	15,312	1,974	850.0	2,114.8	100.0	N/A	7,591	N/A	N/A	410.0
7	Fort St. James	15,312	1,974	1,050.0	2,612.4	100.0	N/A	9,377	N/A	N/A	406.4
8	Burns Lake	15,312	1,974	800.0	1,990.4	100.0	N/A	7,144	N/A	N/A	392.4
9	Houston	15,312	1,974	950.0	2,363.6	100.0	N/A	8,484	N/A	N/A	422.4
10	Clearwater	15,312	1,974	150.0	373.2	100.0	N/A	1,340	N/A	N/A	465.6
11	Kitimat	15,312	1,974	150.0	373.2	100.0	N/A	1,340	N/A	N/A	966.8
12	Bruderheim	15,312	1,974	1,200.0	2,985.6	100.0	N/A	10,717	N/A	N/A	300.7
13	Pump 1	8,021	1,034	950.0	2,363.6	100.0	N/A	4,444	N/A	N/A	258.7
14	Pump 2	8,021	1,034	950.0	2,363.6	100.0	N/A	4,444	N/A	N/A	250.3
15	Pump 3	8,021	1,034	950.0	2,363.6	100.0	N/A	4,444	N/A	N/A	241.9
16	Pump 4	8,021	1,034	950.0	2,363.6	100.0	N/A	4,444	N/A	N/A	233.5
17	Pump 5	8,021	1,034	950.0	2,363.6	100.0	N/A	4,444	N/A	N/A	225.1

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
18	Pump 6	8,021	1,034	950.0	2,363.6	100.0	N/A	4,444	N/A	N/A	216.7
19	Pump 7	8,021	1,034	950.0	2,363.6	100.0	N/A	4,444	N/A	N/A	208.3
20	Pump 8	8,021	1,034	950.0	2,363.6	100.0	N/A	4,444	N/A	N/A	199.9
21	Pump 9	8,021	1,034	950.0	2,363.6	100.0	N/A	4,444	N/A	N/A	191.5
22	Pump 10	8,021	1,034	950.0	2,363.6	100.0	N/A	4,444	N/A	N/A	183.1

Jct	NPSHR (feet)
3	N/A
4	N/A
5	N/A
6	N/A
7	N/A
8	N/A
9	N/A
10	N/A
11	N/A
12	N/A
13	N/A
14	N/A
15	N/A
16	N/A
17	N/A
18	N/A
19	N/A
20	N/A
21	N/A
22	N/A

Pipe Output Table

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psia)	P Static Min (psia)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)	dP Gravity (psid)
1	Gateway	525,000	5.106	1,328.0	185.90	2,067.0	2,297.0	1,142.108643	1,142.108643	92.4424
2	Gateway	525,000	5.106	1,285.9	194.84	2,297.0	2,400.0	1,091.064331	1,091.064331	41.3981
3	Gateway	525,000	5.106	1,344.8	165.35	2,400.0	2,723.0	1,179.487549	1,179.487549	129.8212
4	Gateway	525,000	5.106	1,015.4	171.94	2,723.0	2,500.0	843.407776	843.407776	-89.6289
5	Gateway	525,000	5.106	1,021.9	170.50	2,500.0	2,297.0	851.446228	851.446228	-81.5904
6	Gateway	525,000	5.106	1,220.5	164.88	2,297.0	2,362.0	1,055.614258	1,055.614258	26.1250
7	Gateway	525,000	5.106	964.9	176.94	2,362.0	2,001.0	787.942383	787.942383	-145.0943
8	Gateway	525,000	5.106	1,126.9	194.31	2,001.0	2,000.0	932.634766	932.634766	-0.4019
9	Gateway	525,000	5.106	395.7	344.31	2,000.0	131.0	-51.417236	-51.417236	-751.1948
10	Gateway	525,000	5.106	545.7	545.17	131.0	131.0	0.552231	0.552231	0.0000
11	Pipe	250,000	6.754	127.9	127.92	2,067.0	2,067.0	0.005497	0.005497	0.0000
12	Pipe	275,000	7.429	1,064.4	110.98	1,214.0	1,303.0	953.376160	953.376160	35.7712
13	Pipe	275,000	7.429	1,061.0	107.60	1,303.0	1,392.0	953.376160	953.376160	35.7712
14	Pipe	275,000	7.429	1,057.6	104.22	1,392.0	1,481.0	953.376160	953.376160	35.7712
15	Pipe	275,000	7.429	1,054.2	100.85	1,481.0	1,570.0	953.376160	953.376160	35.7712
16	Pipe	275,000	7.429	1,050.8	97.47	1,570.0	1,659.0	953.376160	953.376160	35.7712
17	Pipe	275,000	7.429	1,047.5	94.09	1,659.0	1,748.0	953.376160	953.376160	35.7712
18	Pipe	275,000	7.429	1,044.1	90.72	1,748.0	1,837.0	953.376160	953.376160	35.7712

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psia)	P Static Min (psia)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)	dP Gravity (psid)
19	Pipe	275,000	7.429	1,040.7	87.34	1,837.0	1,926.0	953.376160	953.376160	35.7712
20	Pipe	275,000	7.429	1,037.3	83.97	1,926.0	2,015.0	953.376160	953.376160	35.7712
21	Pipe	275,000	7.429	1,034.0	80.59	2,015.0	2,104.0	953.376160	953.376160	35.7712
22	Pipe	275,000	7.429	1,030.6	127.86	2,104.0	2,067.0	902.733826	902.733826	-14.8712
23	Pipe	525,000	14.184	126.9	126.92	2,067.0	2,067.0	0.024949	0.024949	0.0000

Pipe	dH (feet)	P Static In (psig)	P Static Out (psia)	P Stag. In (psig)	P Stag. Out (psig)
1	2,611.60811	1,313.3	185.90	1,313.5	171.37
2	2,611.60811	1,271.2	194.84	1,271.4	180.31
3	2,611.60811	1,330.1	165.35	1,330.3	150.82
4	2,321.42944	1,000.7	171.94	1,000.8	157.41
5	2,321.42944	1,007.2	170.50	1,007.4	155.97
6	2,561.40699	1,205.8	164.88	1,206.0	150.35
7	2,321.42944	950.2	176.94	950.4	162.41
8	2,321.42944	1,112.2	194.31	1,112.4	179.77
9	1,741.07212	329.6	395.72	329.8	381.19
10	1.37397	531.0	545.17	531.2	530.64
11	0.01368	113.2	127.92	113.5	113.50
12	2,283.03481	1,049.7	110.98	1,050.0	96.62
13	2,283.03481	1,046.3	107.60	1,046.6	93.25
14	2,283.03481	1,042.9	104.22	1,043.2	89.87
15	2,283.03481	1,039.5	100.85	1,039.9	86.50
16	2,283.03481	1,036.2	97.47	1,036.5	83.12
17	2,283.03481	1,032.8	94.09	1,033.1	79.74
18	2,283.03481	1,029.4	90.72	1,029.7	76.37
19	2,283.03481	1,026.0	87.34	1,026.4	72.99
20	2,283.03481	1,022.6	83.97	1,023.0	69.61
21	2,283.03481	1,019.3	80.59	1,019.6	66.24
22	2,283.03481	1,015.9	127.86	1,016.2	113.50
23	0.06207	112.2	126.92	113.5	113.48

All Junction Table

Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (barrels/day)	Mass Flow Rate Thru Jct (lbm/min)	Loss Factor (K)
1	Bruderheim	545.17	545.2	545.33	545.3	525,000	118,470	0
2	FtMcMurray	1,064.35	1,064.4	1,064.70	1,064.7	275,000	62,056	0
3	Whitecourt	185.90	1,285.9	186.07	1,286.1	525,000	118,470	0
4	Smoky River	194.84	1,344.8	195.00	1,345.0	525,000	118,470	0
5	Timbler Ridge	165.35	1,015.4	165.52	1,015.5	525,000	118,470	0
6	Bear Lake	171.94	1,021.9	172.11	1,022.1	525,000	118,470	0
7	Fort St. James	170.50	1,220.5	170.66	1,220.7	525,000	118,470	0
8	Burns Lake	164.88	964.9	165.05	965.0	525,000	118,470	0
9	Houston	176.94	1,126.9	177.10	1,127.1	525,000	118,470	0
10	Clearwater	194.31	344.3	194.47	344.5	525,000	118,470	0
11	Kitimat	395.72	545.7	395.89	545.9	525,000	118,470	0
12	Bruderheim	126.92	1,328.0	128.18	1,328.2	525,000	118,470	0
13	Pump 1	110.98	1,061.0	111.32	1,061.3	275,000	62,056	0
14	Pump 2	107.60	1,057.6	107.94	1,057.9	275,000	62,056	0
15	Pump 3	104.22	1,054.2	104.57	1,054.6	275,000	62,056	0

AFT Fathom Model

Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (barrels/day)	Mass Flow Rate Thru Jct (lbm/min)	Loss Factor (K)
16	Pump 4	100.85	1,050.8	101.19	1,051.2	275,000	62,056	0
17	Pump 5	97.47	1,047.5	97.82	1,047.8	275,000	62,056	0
18	Pump 6	94.09	1,044.1	94.44	1,044.4	275,000	62,056	0
19	Pump 7	90.72	1,040.7	91.06	1,041.1	275,000	62,056	0
20	Pump 8	87.34	1,037.3	87.69	1,037.7	275,000	62,056	0
21	Pump 9	83.97	1,034.0	84.31	1,034.3	275,000	62,056	0
22	Pump 10	80.59	1,030.6	80.93	1,030.9	275,000	62,056	0
23	Tee or Wye	127.64	127.6	128.20	128.2	N/A	N/A	0
24	Assigned Flow	127.92	127.9	128.21	128.2	250,000	56,414	0

BARR			Calc# 005 Date 4/16/2010	Sheet No. 1 of 5
Computed By: WJM	Checked By: SEM	Submitted By:	Project Name: Project Number:	
Date:	Date: 6/15/2010	Date:	Subject: Pump Energy Requirements and Usage – St. James Chicago Pathway	

1.0 Purpose:

Calculate the pumping energy required to transport crude oil from St. James, LA to Chicago, IL along the St. James Chicago Pathway.

2.0 Reference:

1. "Oil Sands Shuffle Work – Crude Shuffle Case" spreadsheet (Attached)
2. AFT Fathom 7.0 Output for each pipe routing (Attached)
3. Cameron Hydraulic Data, 18th Edition
4. Website, http://www.bppipelines.com/asset_capline.html
5. Website, http://www.bppipelines.com/asset_chicap.html
6. Sulzer Pump estimated pump curves (Attached)
7. Capline System Schematic Map (Attached)

3.0 Assumptions:

1. Crude being transported has the characteristics of Western Canadian Select (WCS) as shown on the Enbridge 2009 Crude Characteristics table.
2. Crude is being transported at 10C and the temperature remains constant for the entire distance of transportation.
3. Piping to be steel with a wall thickness of 0.5inches
4. Piping lengths in Reference 1 and 2 include required fitting lengths.
5. Pumps are 70-80% efficient, see attached pump curves
6. Pump motor is 95% efficient.
7. WCS viscosity is 350cST
8. Working pressure in pipeline is 1000psig – 1500psig
9. Change is elevation from station to station is at a constant slope.

4.0 Conclusion:

The total kWh required to transport crude oil from St. James to Chicago 365 days a year, 24 hours a day is 3.89×10^9 kWh.

5.0 Calculation:

Fluid Characteristics: Crude Type = Western Canadian Select
Density = 927.1 kg/m^3
Viscosity = 350cST = 325.5cP
Flow Rate = See References 1 & 2
Specific Gravity = 0.927

Piping Characteristics: Pipe Type = Carbon Steel
Pipe Diameter = See References 1 & 2
Pipe Wall Thickness = 0.5inches (Assumption 3)
Absolute roughness = 0.00015feet

5.1 Calculate Piping Pressure Losses

AFT Fathom software was used to develop a piping model to calculate the piping pressure losses for the entire run of transport piping listed in References 1 and 2. The following components were entered into each model:

1. WCS density and viscosity
2. Piping diameters, absolute roughness, and lengths
3. Elevation differences between pipelines
4. Volumetric flow rates

The input and output for each transport piping arrangement is attached in Reference 2 of this calculation. Table 1 summarizes the results of the AFT modeling.

Table 1 - St James Chicago Pathway

Crude Pathway	Total Length of Pipe (miles)	Total Pressure Loss in Piping (psid)	Head Loss (FT)
St James Chicago Pathway	835	24,170	60,035

The results shown in Table 1 and Reference 2 were used to calculate the power required to transport the crude oil using the equation below.

$$\text{Hyd hp} = \frac{\text{lb of liquid per minute} \times \text{H(in feet)}}{33{,}000} \qquad \text{(Reference 3)}$$

$$\text{Brake hp} = \frac{\text{Hyd hp}}{\text{Pump efficiency}} \qquad \text{(Reference 3)}$$

$$\text{KW input to motor} = \frac{\text{Brake hp} \times 0.7457}{\text{motor efficiency}} \qquad \text{(Reference 3)}$$

$$\text{H (feet)} = \frac{\text{psi} \times 2.31}{\text{Specific Gravity}} \qquad \text{(Reference 3)}$$

Table 2 below summarizes the results from the AFT modeling and the resulting pump input power required using the equations above. The pump efficiency is assumed to be 75% (Assumption 5) and the motor efficiency is assumed to be 95% (Assumption 6). The pump power calculated below is the power required to overcome the frictional pressure loss in the piping and does not account for additional pressure required for delivery of the crude oil.

Table 2 - St. James Chicago Pathway

Origin	Destination	Total Pressure Loss in Piping (psid)	Head Loss (ft)	Flow Rate (bbl/day)	Flow Rate (lb/min)	Pump Power Required (kw)
St. James	Patoka	18,546	46,066	1,200,000	270,903	395,783
Patoka	Chicago	5,624	13,969	360,000	81,271	36,006
	Total	24,170	60,035			431,789

Table 3 summarizes the requirements for pumping power for several pump stations located along the St. James Chicago Pathway. Several pumping stations will be required to transport the crude from St. James to Chicago to reduce the operating pressure within the pipeline to meet code allowable working pressures. Table 2 shows the total pressure drop between each destination, since these pressure losses are higher than recommended operational pressures, intermediate pumping stations are suggested.

Using Reference 7 the pump stations from St. James to Patoka were inserted at each city location shown. The distances between each city were estimated using an online map website. Elevations were estimated for each city using information from a map website. The pump pressure were calculated an adjusted to meet the pumping head requirements between each pump station. Pump input pressure is and estimate and may change during a detail design.

Using Assumption 8 the total number of pumping stations and resulting power requirements were calculated from Patoka to Chicago.

$$\# \text{ of Pump Stations} = \frac{\text{Total Pressure Loss}}{\text{Assumption 8}} \text{ rounded up}$$

Patoka to Chicago = 5,225psi/850psi = 7 required pump stations

Seven pumps having a total dynamic head of 850psi are required to pump 81,271lb/min of crude from Patoka to Chicago. Pumps were placed into the AFT model with a fixed pressure rise of 850psig. The AFT uses five pumps at 850psig and two pumps at 800psig to meet the pumping requirements due to changes in elevation from Patoka to Chicago.

The pump power calculated using the equations above for each of the required pumps. The Sulzer pump online pump selection website was used to determine the approximate pump efficiency for each pump. Note that these are only approximate pump efficiencies but should be close to the final pump selection determined during detailed design. The pump curves are attached, see Reference 6. Several pumps may be required at each pump station depending on the flow requirements and head requirements; the total power at the pump station is shown as the Pump Power Required in Table 3 below.

Table 3 also shows the required kWh for the transport of the crude. The kWh required is calculated using the following equation.

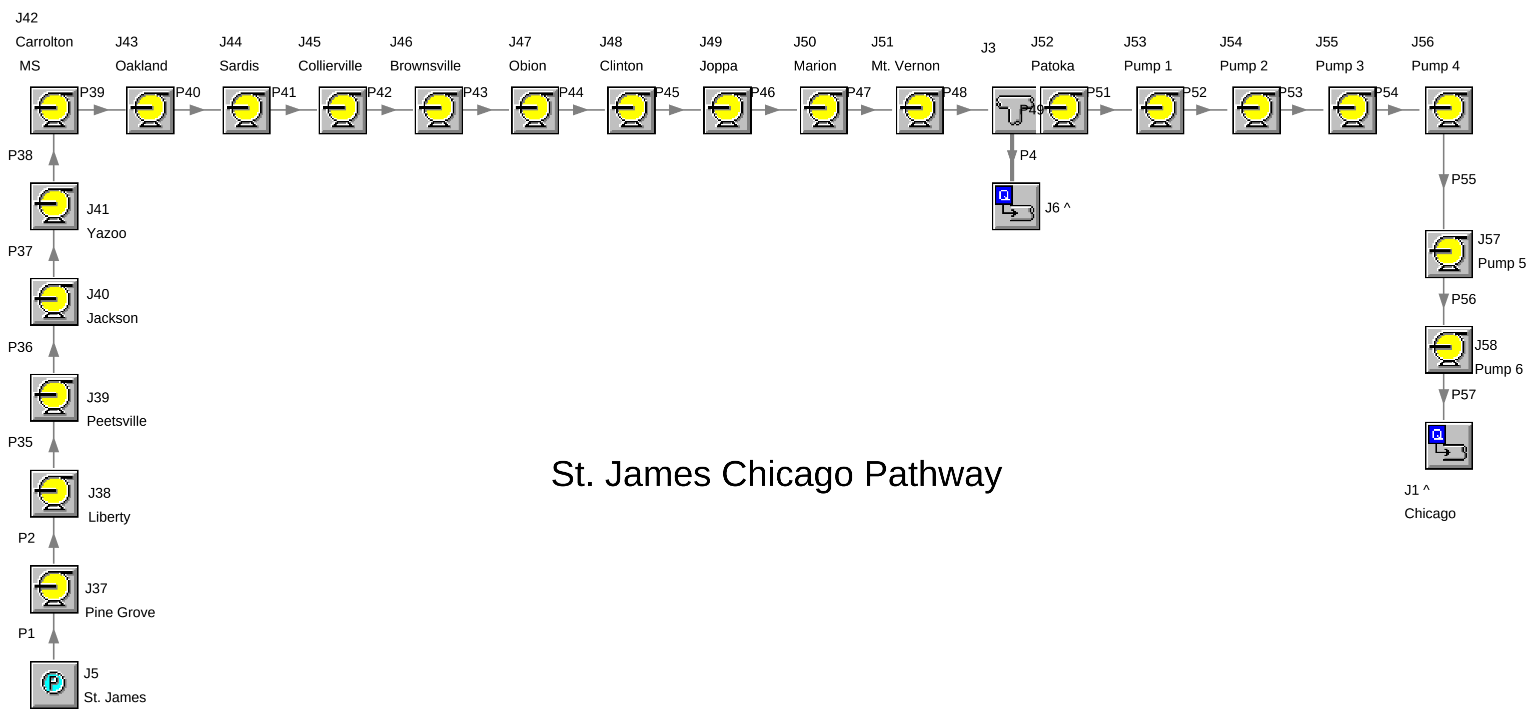
Pump Power Required (kW) x running time(h) = kWh

Table 3 shows the kWh's required to operate the pumps 24 hours a day seven days a week for 365 days.

The required pump power in Table 3 is greater than the amount shown in Table 2 since there will be energy remaining in the pipeline when it is delivered to Chicago. The pressure in the AFT model is around 88.5psig into the Chicago station.

Table 3 -St. James Chicago Pathway

Station	Pump TDH	Flow Rate (bbl/day)	Flow Rate (lb/min)	Pump Power Required (kw)	kWh
St. James	3,850	1,200,000	270,903	33,657	2.9E+08
Pine Grove	2,981	1,200,000	270,903	26,057	2.3E+08
Liberty	2,919	1,200,000	270,903	25,514	2.2E+08
Peetsville	3,105	1,200,000	270,903	27,143	2.4E+08
Jackson	2,919	1,200,000	270,903	25,514	2.2E+08
Yazoo	2,919	1,200,000	270,903	25,514	2.2E+08
Carrolton	2,919	1,200,000	270,903	25,514	2.2E+08
Oakland	2,235	1,200,000	270,903	19,543	1.7E+08
Sardis	2,856	1,200,000	270,903	24,971	2.2E+08
Collerville	3,105	1,200,000	270,903	27,143	2.4E+08
Brownsville	3,540	1,200,000	270,903	30,943	2.7E+08
Obion	2,919	1,200,000	270,903	25,514	2.2E+08
Clinton	2,235	1,200,000	270,903	19,543	1.7E+08
Joppa	2,981	1,200,000	270,903	26,057	2.3E+08
Marion	2,360	1,200,000	270,903	20,628	1.8E+08
Mt. Vernon	2,856	1,200,000	270,903	24,971	2.2E+08
Patoka	2,111	360,000	81,271	5,233	4.6E+07
Pump 1	2,111	360,000	81,271	5,233	4.6E+07
Pump 2	2,111	360,000	81,271	5,233	4.6E+07
Pump 3	2,111	360,000	81,271	5,233	4.6E+07
Pump 4	2,111	360,000	81,271	5,233	4.6E+07
Pump 5	1,987	360,000	81,271	4,925	4.3E+07
Pump 6	1,987	360,000	81,271	4,925	4.3E+07
Chicago					
			Total	444,238	3.89E+09


J42
Carrolton
MS
J43
Oakland
J44
Sardis
J45
Collierville
J46
Brownsville
J47
Obion
J48
Clinton
J49
Joppa
J50
Marion
J51
Mt. Vernon
J3
J52
Patoka
J53
Pump 1
J54
Pump 2
J55
Pump 3
J56
Pump 4
P39
P40
P41
P42
P43
P44
P45
P46
P47
P48
P49
P51
P52
P53
P54
P38
P4
J6 ^
P55
J41
Yazoo
P37
J57
Pump 5
J40
Jackson
P56
P36
J58
Pump 6
P57
J39
Peetsville
P35
St. James Chicago Pathway
J1 ^
Chicago
J38
Liberty
P2
J37
Pine Grove
P1
J5
St. James

General

Title: AFT Fathom Model
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\St. James Chicago Pathway\St. James Chicago Pathway v0.1.fth
Scenario: St. James Chicago Pathway

Number Of Pipes= 25
Number Of Junctions= 26

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Pipe Input Table

Pipe	Name	Pipe Defined	Length	Length Units	Hydraulic Diameter	Hydraulic Diam. Units	Friction Data Set	Roughness	Roughness Units	Losses (K)
1	Pipe	Yes	50	miles	39	inches	Unspecified	0.00015	feet	0
2	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
4	Pipe	Yes	1	feet	39	inches	Unspecified	0.00015	feet	0
35	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
36	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
37	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
38	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
39	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
40	Pipe	Yes	30	miles	39	inches	Unspecified	0.00015	feet	0
41	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
42	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
43	Pipe	Yes	50	miles	39	inches	Unspecified	0.00015	feet	0
44	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
45	Pipe	Yes	30	miles	39	inches	Unspecified	0.00015	feet	0
46	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
47	Pipe	Yes	32	miles	39	inches	Unspecified	0.00015	feet	0
48	Pipe	Yes	40	miles	39	inches	Unspecified	0.00015	feet	0
49	Pipe	Yes	1	feet	39.5	inches	Unspecified	0.00015	feet	0
51	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
52	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
53	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
54	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
55	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
56	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
57	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0

Pipe	Junctions (Up,Down)	Geometry	Material	Special Condition
1	5, 37	Cylindrical Pipe	Unspecified	None
2	37, 38	Cylindrical Pipe	Unspecified	None
4	3, 6	Cylindrical Pipe	Unspecified	None
35	38, 39	Cylindrical Pipe	Unspecified	None
36	39, 40	Cylindrical Pipe	Unspecified	None
37	40, 41	Cylindrical Pipe	Unspecified	None
38	41, 42	Cylindrical Pipe	Unspecified	None
39	42, 43	Cylindrical Pipe	Unspecified	None
40	43, 44	Cylindrical Pipe	Unspecified	None
41	44, 45	Cylindrical Pipe	Unspecified	None
42	45, 46	Cylindrical Pipe	Unspecified	None
43	46, 47	Cylindrical Pipe	Unspecified	None
44	47, 48	Cylindrical Pipe	Unspecified	None
45	48, 49	Cylindrical Pipe	Unspecified	None
46	49, 50	Cylindrical Pipe	Unspecified	None
47	50, 51	Cylindrical Pipe	Unspecified	None
48	51, 3	Cylindrical Pipe	Unspecified	None
49	3, 52	Cylindrical Pipe	Unspecified	None
51	52, 53	Cylindrical Pipe	Unspecified	None
52	53, 54	Cylindrical Pipe	Unspecified	None
53	54, 55	Cylindrical Pipe	Unspecified	None
54	55, 56	Cylindrical Pipe	Unspecified	None
55	56, 57	Cylindrical Pipe	Unspecified	None
56	57, 58	Cylindrical Pipe	Unspecified	None
57	58, 1	Cylindrical Pipe	Unspecified	None

Pipe Fittings & Losses

Assigned Flow Table

Assigned Flow	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Type	Flow	Flow Units	Loss Factor
1	Chicago	Yes	579	feet	None	Outflow	360000	barrels/day	0
6	Assigned Flow	Yes	505	feet	None	Outflow	840000	barrels/day	0

Assigned Pressure Table

Assigned Pressure	Name	Object Defined	Inlet Elevation	Elevation Units	Initial Pressure	Initial Pressure Units	Pressure	Pressure Units
5	St. James	Yes	20	feet	1,550	psig	1550	psig

Assigned Pressure	Pressure Type	Balance Energy	Balance Concentration	(Pipe #1) K In, K Out
5	Static	No	No	(P1) 0, 0

Pump Table

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
37	Pine Grove	Yes	37	feet	None	Fixed Pressure Rise	1200	psid
38	Liberty	Yes	70	feet	None	Fixed Pressure Rise	1175	psid
39	Peetsville	Yes	150	feet	None	Fixed Pressure Rise	1250	psid

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
40	Jackson	Yes	341	feet	None	Fixed Pressure Rise	1175	psid
41	Yazoo	Yes	350	feet	None	Fixed Pressure Rise	1175	psid
42	Carrolton MS	Yes	360	feet	None	Fixed Pressure Rise	1175	psid
43	Oakland	Yes	370	feet	None	Fixed Pressure Rise	900	psid
44	Sardis	Yes	350	feet	None	Fixed Pressure Rise	1150	psid
45	Collierville	Yes	320	feet	None	Fixed Pressure Rise	1250	psid
46	Brownsville	Yes	300	feet	None	Fixed Pressure Rise	1425	psid
47	Obion	Yes	384	feet	None	Fixed Pressure Rise	1175	psid
48	Clinton	Yes	384	feet	None	Fixed Pressure Rise	900	psid
49	Joppa	Yes	384	feet	None	Fixed Pressure Rise	1200	psid
50	Marion	Yes	469	feet	None	Fixed Pressure Rise	950	psid
51	Mt. Vernon	Yes	479	feet	None	Fixed Pressure Rise	1150	psid
52	Patoka	Yes	505	feet	None	Fixed Pressure Rise	850	psid
53	Pump 1	Yes	515.58	feet	None	Fixed Pressure Rise	850	psid
54	Pump 2	Yes	526.15	feet	None	Fixed Pressure Rise	850	psid
55	Pump 3	Yes	536.72	feet	None	Fixed Pressure Rise	850	psid
56	Pump 4	Yes	547.29	feet	None	Fixed Pressure Rise	850	psid
57	Pump 5	Yes	557.86	feet	None	Fixed Pressure Rise	800	psid
58	Pump 6	Yes	568.43	feet	None	Fixed Pressure Rise	800	psid

Pump	Current Configuration	Heat Added To Fluid	Heat Added Units
37	N/A	0	Percent
38	N/A	0	Percent
39	N/A	0	Percent
40	N/A	0	Percent
41	N/A	0	Percent
42	N/A	0	Percent
43	N/A	0	Percent
44	N/A	0	Percent
45	N/A	0	Percent
46	N/A	0	Percent
47	N/A	0	Percent
48	N/A	0	Percent
49	N/A	0	Percent
50	N/A	0	Percent
51	N/A	0	Percent
52	N/A	0	Percent
53	N/A	0	Percent
54	N/A	0	Percent
55	N/A	0	Percent
56	N/A	0	Percent
57	N/A	0	Percent
58	N/A	0	Percent

Tee or Wye Table

Tee or Wye	Name	Object Defined	Inlet Elevation	Elevation Units	Tee/Wye Type	Loss Type	Angle	Pipes A, B, C
3	Patoka	Yes	505	feet	Sharp Straight	Simple (no loss)	90	48, 4, 49

General

Title: AFT Fathom Model
Analysis run on: 5/20/2010 4:03:01 PM
Application version: AFT Fathom Version 7.0 (2009.11.02)
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\St. James Chicago Pathway\St. James Chicago Pathway v0.1.fth
Scenario: St. James Chicago Pathway
Output File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\St. James Chicago Pathway\St. James Chicago Pathway v0.1_1.out

Execution Time= 0.22 seconds
Total Number Of Head/Pressure Iterations= 0
Total Number Of Flow Iterations= 2
Total Number Of Temperature Iterations= 0
Number Of Pipes= 25
Number Of Junctions= 26
Matrix Method= Gaussian Elimination

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Total Inflow= 34,999 gal/min
Total Outflow= 34,999 gal/min
Maximum Static Pressure is 1,570 psia at Pipe 43 Inlet
Minimum Static Pressure is 44.19 psia at Pipe 48 Outlet

Fixed Energy Cost=0.076 U.S. Dollars per kW-hr

Total of All Model Costs = 0 U.S. Dollars

Pump Summary

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
37	Pine Grove	34,999	4,513	1,200.0	2,986	100.0	N/A	24,495	N/A	N/A	202.78
38	Liberty	34,999	4,513	1,175.0	2,923	100.0	N/A	23,985	N/A	N/A	230.32
39	Peetsville	34,999	4,513	1,250.0	3,110	100.0	N/A	25,516	N/A	N/A	148.65
40	Jackson	34,999	4,513	1,175.0	2,923	100.0	N/A	23,985	N/A	N/A	142.59
41	Yazoo	34,999	4,513	1,175.0	2,923	100.0	N/A	23,985	N/A	N/A	131.93
42	Carrolton MS	34,999	4,513	1,175.0	2,923	100.0	N/A	23,985	N/A	N/A	120.26
43	Oakland	34,999	4,513	900.0	2,239	100.0	N/A	18,372	N/A	N/A	108.60
44	Sardis	34,999	4,513	1,150.0	2,861	100.0	N/A	23,475	N/A	N/A	174.00
45	Collierville	34,999	4,513	1,250.0	3,110	100.0	N/A	25,516	N/A	N/A	140.13
46	Brownsville	34,999	4,513	1,425.0	3,545	100.0	N/A	29,088	N/A	N/A	345.07
47	Obion	34,999	4,513	1,175.0	2,923	100.0	N/A	23,985	N/A	N/A	150.13

AFT Fathom Model

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
48	Clinton	34,999	4,513	900.0	2,239	100.0	N/A	18,372	N/A	N/A	148.47
49	Joppa	34,999	4,513	1,200.0	2,986	100.0	N/A	24,495	N/A	N/A	193.87
50	Marion	34,999	4,513	950.0	2,364	100.0	N/A	19,392	N/A	N/A	169.41
51	Mt. Vernon	34,999	4,513	1,150.0	2,861	100.0	N/A	23,475	N/A	N/A	182.95
52	Patoka	10,500	1,354	850.0	2,115	100.0	N/A	5,205	N/A	N/A	93.09
53	Pump 1	10,500	1,354	850.0	2,115	100.0	N/A	5,205	N/A	N/A	128.94
54	Pump 2	10,500	1,354	850.0	2,115	100.0	N/A	5,205	N/A	N/A	164.80
55	Pump 3	10,500	1,354	850.0	2,115	100.0	N/A	5,205	N/A	N/A	200.66
56	Pump 4	10,500	1,354	850.0	2,115	100.0	N/A	5,205	N/A	N/A	236.52
57	Pump 5	10,500	1,354	800.0	1,990	100.0	N/A	4,899	N/A	N/A	272.38
58	Pump 6	10,500	1,354	800.0	1,990	100.0	N/A	4,899	N/A	N/A	183.84

Jct	NPSHR (feet)
37	N/A
38	N/A
39	N/A
40	N/A
41	N/A
42	N/A
43	N/A
44	N/A
45	N/A
46	N/A
47	N/A
48	N/A
49	N/A
50	N/A
51	N/A
52	N/A
53	N/A
54	N/A
55	N/A
56	N/A
57	N/A
58	N/A

Cost Report

	Table Units: U.S. Dollars	Operation/ Energy	TOTAL
	TOTAL OF ALL MODEL COSTS		0
	Total of All Shown Costs	0	0

Pipe Output Table

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psia)	P Static Min (psia)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)	dP Gravity (psid)
1	Pipe	1,200,000	9.400	1,564.70	88.28	20.00	37.00	1,476.4194336	1,476.4194336	6.833
2	Pipe	1,200,000	9.400	1,288.28	99.34	37.00	70.00	1,188.9328613	1,188.9328613	13.263
4	Pipe	840,000	6.580	44.47	44.47	505.00	505.00	0.0030099	0.0030099	0.000

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psia)	P Static Min (psia)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)	dP Gravity (psid)
35	Pipe	1,200,000	9.400	1,274.34	66.52	70.00	150.00	1,207.8232422	1,207.8232422	32.154
36	Pipe	1,200,000	9.400	1,316.52	64.08	150.00	341.00	1,252.4367676	1,252.4367676	76.767
37	Pipe	1,200,000	9.400	1,239.08	59.80	341.00	350.00	1,179.2867432	1,179.2867432	3.617
38	Pipe	1,200,000	9.400	1,234.80	55.11	350.00	360.00	1,179.6887207	1,179.6887207	4.019
39	Pipe	1,200,000	9.400	1,230.11	50.42	360.00	370.00	1,179.6887207	1,179.6887207	4.019
40	Pipe	1,200,000	9.400	950.42	76.71	370.00	350.00	873.7136230	873.7136230	-8.038
41	Pipe	1,200,000	9.400	1,226.71	63.09	350.00	320.00	1,163.6116943	1,163.6116943	-12.058
42	Pipe	1,200,000	9.400	1,313.09	145.46	320.00	300.00	1,167.6309814	1,167.6309814	-8.038
43	Pipe	1,200,000	9.400	1,570.46	67.12	300.00	384.00	1,503.3483887	1,503.3483887	33.762
44	Pipe	1,200,000	9.400	1,242.12	66.45	384.00	384.00	1,175.6694336	1,175.6694336	0.000
45	Pipe	1,200,000	9.400	966.45	84.69	384.00	384.00	881.7520752	881.7520752	0.000
46	Pipe	1,200,000	9.400	1,284.69	74.86	384.00	469.00	1,209.8328857	1,209.8328857	34.163
47	Pipe	1,200,000	9.400	1,024.86	80.31	469.00	479.00	944.5547485	944.5547485	4.019
48	Pipe	1,200,000	9.400	1,230.31	44.19	479.00	505.00	1,186.1193848	1,186.1193848	10.450
49	Pipe	360,000	2.749	44.69	44.69	505.00	505.00	0.0004087	0.0004087	0.000
51	Pipe	360,000	6.863	894.44	58.85	505.00	515.58	835.5904541	835.5904541	4.252
52	Pipe	360,000	6.863	908.85	73.27	515.58	526.15	835.5864258	835.5864258	4.248
53	Pipe	360,000	6.863	923.27	87.68	526.15	536.72	835.5863647	835.5863647	4.248
54	Pipe	360,000	6.863	937.68	102.09	536.72	547.29	835.5864258	835.5864258	4.248
55	Pipe	360,000	6.863	952.09	116.51	547.29	557.86	835.5864258	835.5864258	4.248
56	Pipe	360,000	6.863	916.51	80.92	557.86	568.43	835.5864258	835.5864258	4.248
57	Pipe	360,000	6.863	880.92	45.34	568.43	579.00	835.5864258	835.5864258	4.248

Pipe	dH (feet)	P Static In (psig)	P Static Out (psig)	P Stag. In (psig)	P Stag. Out (psig)
1	3,656.385773	1,550.00	73.58	1,550.55	74.13
2	2,925.108619	1,273.58	84.65	1,274.13	85.20
4	0.007489	29.77	29.77	30.04	30.04
35	2,925.108619	1,259.65	51.82	1,260.20	52.38
36	2,925.108619	1,301.82	49.39	1,302.38	49.94
37	2,925.108619	1,224.39	45.10	1,224.94	45.65
38	2,925.108619	1,220.10	40.41	1,220.65	40.96
39	2,925.108619	1,215.41	35.72	1,215.96	36.28
40	2,193.831464	935.72	62.01	936.28	62.56
41	2,925.108619	1,212.01	48.40	1,212.56	48.95
42	2,925.108619	1,298.40	130.77	1,298.95	131.32
43	3,656.385773	1,555.77	52.42	1,556.32	52.97
44	2,925.108619	1,227.42	51.75	1,227.97	52.30
45	2,193.831464	951.75	70.00	952.30	70.55
46	2,925.108619	1,270.00	60.16	1,270.55	60.72
47	2,340.086834	1,010.16	65.61	1,010.72	66.16
48	2,925.108619	1,215.61	29.49	1,216.16	30.04
49	0.001017	30.00	29.99	30.04	30.04
51	2,068.399581	879.75	44.16	880.04	44.45
52	2,068.399581	894.16	58.57	894.45	58.87
53	2,068.399581	908.57	72.98	908.87	73.28
54	2,068.399581	922.98	87.40	923.28	87.69
55	2,068.399581	937.40	101.81	937.69	102.11
56	2,068.399581	901.81	66.23	902.11	66.52
57	2,068.399581	866.23	30.64	866.52	30.93

All Junction Table

AFT Fathom Model

Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (barrels/day)	Mass Flow Rate Thru Jct (lbm/min)	Loss Factor (K)
1	Chicago	45.34	45.34	45.63	45.63	360,000	81,236	0
3	Patoka	44.50	44.50	44.74	44.74	N/A	N/A	0
5	St. James	1,564.70	1,564.70	1,565.25	1,565.25	1,200,000	270,788	0
6	Assigned Flow	44.47	44.47	44.74	44.74	840,000	189,552	0
37	Pine Grove	88.28	1,288.28	88.83	1,288.83	1,200,000	270,788	0
38	Liberty	99.34	1,274.34	99.90	1,274.90	1,200,000	270,788	0
39	Peetsville	66.52	1,316.52	67.07	1,317.07	1,200,000	270,788	0
40	Jackson	64.08	1,239.08	64.64	1,239.64	1,200,000	270,788	0
41	Yazoo	59.80	1,234.80	60.35	1,235.35	1,200,000	270,788	0
42	Carrolton MS	55.11	1,230.11	55.66	1,230.66	1,200,000	270,788	0
43	Oakland	50.42	950.42	50.97	950.97	1,200,000	270,788	0
44	Sardis	76.71	1,226.71	77.26	1,227.26	1,200,000	270,788	0
45	Collierville	63.09	1,313.09	63.65	1,313.65	1,200,000	270,788	0
46	Brownsville	145.46	1,570.46	146.02	1,571.02	1,200,000	270,788	0
47	Obion	67.12	1,242.12	67.67	1,242.67	1,200,000	270,788	0
48	Clinton	66.45	966.45	67.00	967.00	1,200,000	270,788	0
49	Joppa	84.69	1,284.69	85.25	1,285.25	1,200,000	270,788	0
50	Marion	74.86	1,024.86	75.41	1,025.41	1,200,000	270,788	0
51	Mt. Vernon	80.31	1,230.31	80.86	1,230.86	1,200,000	270,788	0
52	Patoka	44.69	894.44	44.74	894.74	360,000	81,236	0
53	Pump 1	58.85	908.85	59.15	909.15	360,000	81,236	0
54	Pump 2	73.27	923.27	73.56	923.56	360,000	81,236	0
55	Pump 3	87.68	937.68	87.97	937.97	360,000	81,236	0
56	Pump 4	102.09	952.09	102.39	952.39	360,000	81,236	0
57	Pump 5	116.51	916.51	116.80	916.80	360,000	81,236	0
58	Pump 6	80.92	880.92	81.22	881.22	360,000	81,236	0

BARR			Calc# 002 Date 4/19/2010	Sheet No. 1 of 5
Computed By: WJM	Checked By: SEM	Submitted By:	Project Name:	
			Project Number:	
Date:	Date: 6/16/2010	Date:	Subject: Pump Energy Requirements and Usage – Freeport Chicago Pathway	

1.0 Purpose:

Calculate the pumping energy required to transport crude oil from Freeport, TX to Chicago, IL along the Freeport Chicago Pathway.

2.0 Reference:

1. "Oil Sands Shuffle Work – Crude Shuffle Case" spreadsheet (Attached)
2. AFT Fathom 7.0 Output for each pipe routing (Attached)
3. Cameron Hydraulic Data, 18th Edition
4. Website,http://www.teppco.com/operations/onshoreCrudeOilPipelinesServices.htm
5. Website,http://www.enbridgeus.com/Main.aspx?id=2374&tmi=138&tmt=4
6. Website, http://www.bppipelines.com/asset_chicap.html
7. Sulzer Pump estimated pump curves (Attached)

3.0 Assumptions:

1. Crude being transported has the characteristics of Western Canadian Select (WCS) as shown on the Enbridge 2009 Crude Characteristics table.
2. Crude is being transported at 10C and the temperature remains constant for the entire distance of transportation.
3. Piping to be steel with a wall thickness of 0.5inches
4. Piping lengths in Reference 1 and 2 include required fitting lengths.
5. Pumps are 70-80% efficient, see attached pump curves
6. Pump motor is 95% efficient.
7. WCS viscosity is 350cST
8. Working pressure in pipeline is 800psig – 1100psig
9. Change is elevation from station to station is at a constant slope.

4.0 Conclusion:

The total kWh required to transport crude oil from Edmonton to Chicago 365 days a year, 24 hours a day is 1.18×10^9 kWh.

5.0 Calculation:

Fluid Characteristics: Crude Type = Western Canadian Select
Density = 927.1 kg/m^3
Viscosity = 350cST = 325.5cP
Flow Rate = See References 1 & 2

Specific Gravity = 0.927

Piping Characteristics: Pipe Type = Carbon Steel
Pipe Diameter = See References 1 & 2
Pipe Wall Thickness = 0.5inches (Assumption 3)
Absolute roughness = 0.00015feet

5.1 Calculate Piping Pressure Losses

AFT Fathom software was used to develop a piping model to calculate the piping pressure losses for the entire run of transport piping listed in References 1 and 2. The following components were entered into each model:

1. WCS density and viscosity
2. Piping diameters, absolute roughness, and lengths
3. Elevation differences between pipelines
4. Volumetric flow rates

The input and output for each transport piping arrangement is attached in Reference 2 of this calculation. Table 1 summarizes the results of the AFT modeling.

Table 1 - Freeport Chicago Pathway

Crude Pathway	Total Length of Pipe (miles)	Total Pressure Loss in Piping (psid)	Head Loss (FT)
Freeport Chicago Pathway	1,231	25,209	62,616

The results shown in Table 1 and Reference 2 were used to calculate the power required to transport the crude oil using the equation below.

$$\text{Hyd hp} = \frac{\text{lb of liquid per minute x H(in feet)}}{33{,}000} \qquad \text{(Reference 3)}$$

$$\text{Brake hp} = \frac{\text{Hyd hp}}{\text{Pump efficiency}} \qquad \text{(Reference 3)}$$

$$\text{KW input to motor} = \frac{\text{Brake hp x 0.7457}}{\text{motor efficiency}}$$ (Reference 3)

$$\text{H (feet)} = \frac{\text{psi x 2.31}}{\text{Specific Gravity}}$$ (Reference 3)

Table 2 below summarizes the results from the AFT modeling and the resulting pump input power required using the equations above. The pump efficiency is assumed to be 76% (Assumption 5) and the motor efficiency is assumed to be 95% (Assumption 6). The pump power calculated below is the power required to overcome the frictional pressure loss in the piping and does not account for additional pressure required for delivery of the crude oil.

Table 2 - Freeport Chicago Pathway

Origin	Destination	Total Pressure Loss in Piping (psid)	Head Loss (ft)	Flow Rate (bbl/day)	Flow Rate (lb/min)	Pump Power Required (kw)
Freeport	Cushing	6,438	15,991	350,000	79,013	39,545
Cushing	Wood River	11,121	27,623	239,000	53,955	46,646
Wood River	Patoka	1,801	4,473	309,000	69,757	9,767
Patoka	Chicago	5,849	14,528	360,000	81,271	36,954
	Total	25,209	62,616			132,912

Table 3 summarizes the requirements for pumping power for several pump stations located along the Freeport Chicago Pathway. Several pumping stations will be required to transport the crude from Freeport to Chicago to reduce the operating pressure within the pipeline to meet code allowable working pressures. Table 2 shows the total pressure drop between each destination, since these pressure losses are higher than recommended operational pressures, intermediate pumping stations are suggested. Using Assumption 8 the total number of pumping stations and resulting power requirements can be calculated.

$$\text{\# of Pump Stations} = \frac{\text{Total Pressure Loss}}{\text{Assumption 8}} \text{ rounded up}$$

Freeport to Cushing = 6,432psi/850psi = 8 required pump stations

The AFT model was set up with a 900psi pump in Freeport and seven 800psi pumps between Freeport and Cushing. A pressure node was added for Freeport to meet the requirements of the AFT modeling, this pressure is 900psi. The pumps were input at equal distances from each other along the entire distance from Freeport to Cushing, a map showing the exact pump stations along the Seaway pipeline could not be found.

The same method described above for the pump locations from Freeport to Cushing was used for the remaining origin to destination pipelines. Public documentation showing the location of existing pump stations along this line could not be found. Pumps were added at equal distance alone the entire pipelines. An adjustment in the pump stations total dynamic head were made to keep the operating pressure below or in the range of 800psig-1100psig.

The pump power calculated using the equations above for each of the required pumps. The Sulzer pump online pump selection website was used to determine the approximate pump efficiency for each pump. Note that these are only approximate pump efficiencies but should be close to the final pump selection determined during detailed design. The pump curves are attached, see Reference 7. Several pumps may be required at each pump station depending on the flow requirements and head requirements; the total power at the pump station is shown as the Pump Power Required in Table 3 below.

Table 3 also shows the required kWh for the transport of the crude. The kWh required is calculated using the following equation.

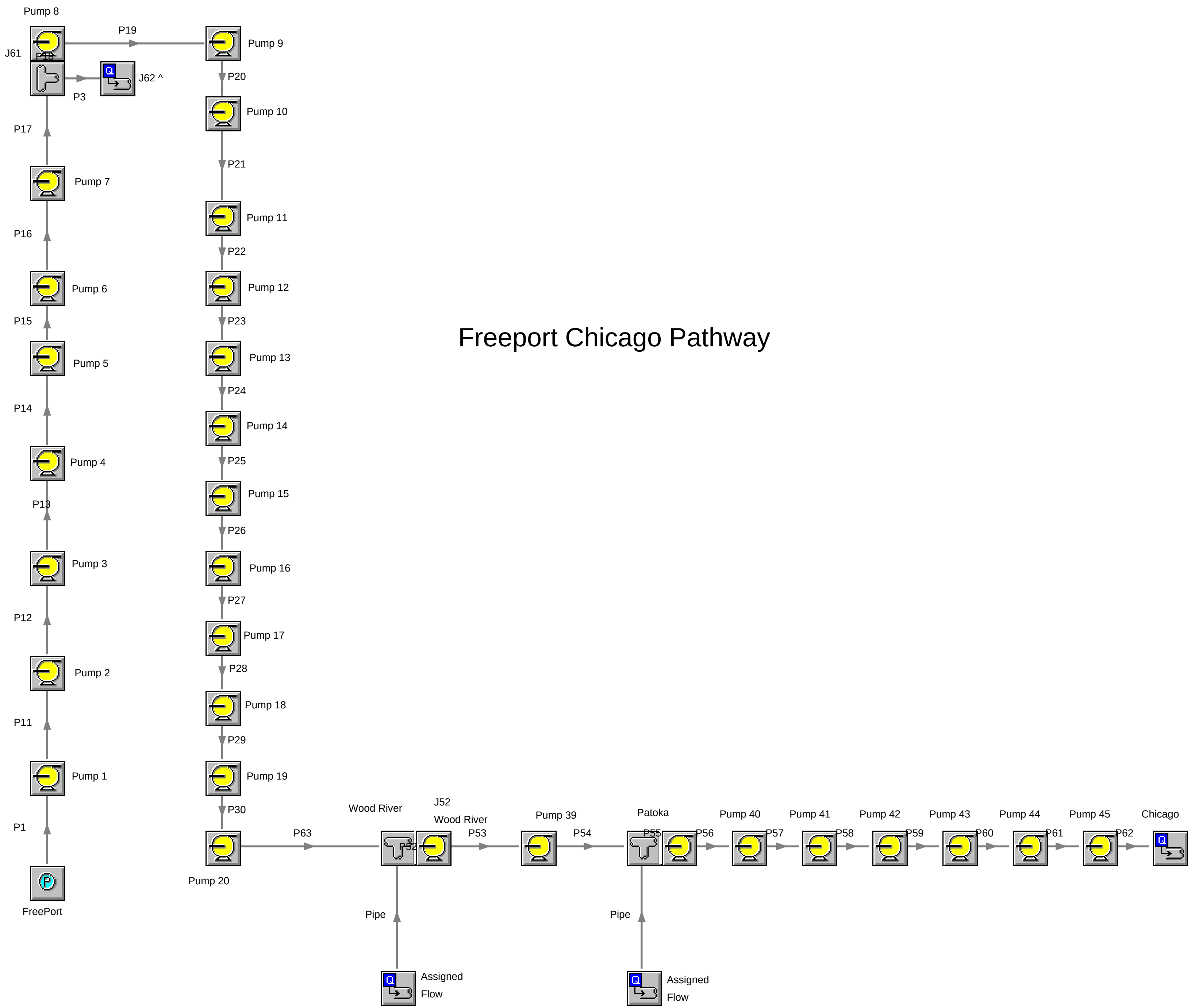
Pump Power Required (kW) x running time(h) = kWh

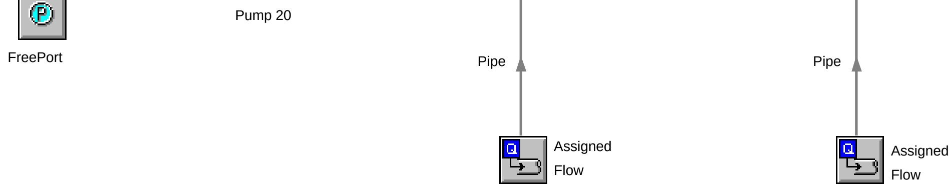
Table 3 shows the kWh's required to operate the pumps 24 hours a day seven days a week for 365 days.

Table 3 - Freeport Chicago Pathway					
Station	**Pump TDH**	**Flow Rate (bbl/day)**	**Flow Rate (lb/min)**	**Pump Power Required (kw)**	**kWh**
Freeport	2,235	350,000	79,013	5,462	4.8E+07
Pump 1	1,987	350,000	79,013	4,855	4.3E+07
Pump 2	1,987	350,000	79,013	4,855	4.3E+07
Pump 3	1,987	350,000	79,013	4,855	4.3E+07
Pump 4	1,987	350,000	79,013	4,855	4.3E+07
Pump 5	1,987	350,000	79,013	4,855	4.3E+07
Pump 6	1,987	350,000	79,013	4,855	4.3E+07
Pump 7	1,987	350,000	79,013	4,855	4.3E+07
Cushing	2,111	239,000	53,955	3,763	3.3E+07
Pump 9	2,111	239,000	53,955	3,763	3.3E+07
Pump 10	2,111	239,000	53,955	3,763	3.3E+07
Pump 11	2,111	239,000	53,955	3,763	3.3E+07
Pump 12	2,111	239,000	53,955	3,763	3.3E+07
Pump 13	2,173	239,000	53,955	3,874	3.4E+07
Pump 14	2,173	239,000	53,955	3,874	3.4E+07
Pump 15	2,111	239,000	53,955	3,763	3.3E+07
Pump 16	2,111	239,000	53,955	3,763	3.3E+07
Pump 17	2,111	239,000	53,955	3,763	3.3E+07
Pump 18	2,173	239,000	53,955	3,874	3.4E+07
Pump 19	2,173	239,000	53,955	3,874	3.4E+07
Pump 20	2,111	239,000	53,955	3,763	3.3E+07
Wood River	1,987	309,000	69,757	4,282	3.8E+07
Pump 39	2,235	309,000	69,757	4,817	4.2E+07
Patoka	2,111	360,000	81,271	5,301	4.6E+07
Pump 40	2,111	360,000	81,271	5,301	4.6E+07
Pump 41	2,111	360,000	81,271	5,301	4.6E+07
Pump 42	2,111	360,000	81,271	5,301	4.6E+07
Pump 43	2,111	360,000	81,271	5,301	4.6E+07
Pump 44	1,987	360,000	81,271	4,989	4.4E+07
Pump 45	1,987	360,000	81,271	4,989	4.4E+07
Chicago	62,594				
			Total	134,394	1.18E+09

The required pump power in Table 3 is greater than the amount shown in Table 2 since there will be energy remaining in the pipeline when it is delivered to Chicago. The pressure in the AFT model is around 100psi into the Chicago station.

Freeport Chicago Pathway




Pump 20
FreePort
Pipe
Pipe
Assigned
Flow
Assigned
Flow

General

Title: AFT Fathom Model
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\Freeport Chicago Pathway\Freeport Chicago Pathway v0.1.fth
Scenario: Base Scenario/Pump Stations

Number Of Pipes= 36
Number Of Junctions= 37

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Pipe Input Table

Pipe	Name	Pipe Defined	Length	Length Units	Hydraulic Diameter	Hydraulic Diam. Units	Friction Data Set	Roughness	Roughness Units	Losses (K)
1	Pipe	Yes	66.25	miles	29	inches	Unspecified	0.00015	feet	0
3	Ozark	Yes	0.5	feet	21	inches	Unspecified	0.00015	feet	0
9	Pipe	Yes	1	feet	19	inches	Unspecified	0.00015	feet	0
10	Pipe	Yes	1	feet	23	inches	Unspecified	0.00015	feet	0
11	Pipe	Yes	66.25	miles	29	inches	Unspecified	0.00015	feet	0
12	Pipe	Yes	66.25	miles	29	inches	Unspecified	0.00015	feet	0
13	Pipe	Yes	66.25	miles	29	inches	Unspecified	0.00015	feet	0
14	Pipe	Yes	66.25	miles	29	inches	Unspecified	0.00015	feet	0
15	Pipe	Yes	66.25	miles	29	inches	Unspecified	0.00015	feet	0
16	Pipe	Yes	66.25	miles	29	inches	Unspecified	0.00015	feet	0
17	Pipe	Yes	66.25	miles	29	inches	Unspecified	0.00015	feet	0
18	Express 24	Yes	10	feet	21	inches	Unspecified	0.00015	feet	0
19	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
20	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
21	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
22	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
23	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
24	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
25	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
26	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
27	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
28	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
29	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
30	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0
52	Pipe	Yes	0.5	feet	23	inches	Unspecified	0.00015	feet	0
53	Pipe	Yes	29	miles	23	inches	Unspecified	0.00015	feet	0

Pipe	Name	Pipe Defined	Length	Length Units	Hydraulic Diameter	Hydraulic Diam. Units	Friction Data Set	Roughness	Roughness Units	Losses (K)
54	Pipe	Yes	29	miles	23	inches	Unspecified	0.00015	feet	0
55	Pipe	Yes	0.5	feet	25	inches	Unspecified	0.00015	feet	0
56	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
57	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
58	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
59	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
60	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
61	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
62	Pipe	Yes	29	miles	25	inches	Unspecified	0.00015	feet	0
63	Pipe	Yes	33.84999	miles	21	inches	Unspecified	0.00015	feet	0

Pipe	Junctions (Up,Down)	Geometry	Material	Special Condition
1	6, 12	Cylindrical Pipe	Unspecified	None
3	61, 62	Cylindrical Pipe	Unspecified	None
9	10, 4	Cylindrical Pipe	Unspecified	None
10	11, 5	Cylindrical Pipe	Unspecified	None
11	12, 13	Cylindrical Pipe	Unspecified	None
12	13, 15	Cylindrical Pipe	Unspecified	None
13	15, 16	Cylindrical Pipe	Unspecified	None
14	16, 17	Cylindrical Pipe	Unspecified	None
15	17, 18	Cylindrical Pipe	Unspecified	None
16	18, 19	Cylindrical Pipe	Unspecified	None
17	19, 61	Cylindrical Pipe	Unspecified	None
18	61, 20	Cylindrical Pipe	Unspecified	None
19	20, 21	Cylindrical Pipe	Unspecified	None
20	21, 22	Cylindrical Pipe	Unspecified	None
21	22, 23	Cylindrical Pipe	Unspecified	None
22	23, 24	Cylindrical Pipe	Unspecified	None
23	24, 25	Cylindrical Pipe	Unspecified	None
24	25, 26	Cylindrical Pipe	Unspecified	None
25	26, 27	Cylindrical Pipe	Unspecified	None
26	27, 28	Cylindrical Pipe	Unspecified	None
27	28, 29	Cylindrical Pipe	Unspecified	None
28	29, 30	Cylindrical Pipe	Unspecified	None
29	30, 31	Cylindrical Pipe	Unspecified	None
30	31, 32	Cylindrical Pipe	Unspecified	None
52	4, 52	Cylindrical Pipe	Unspecified	None
53	52, 53	Cylindrical Pipe	Unspecified	None
54	53, 5	Cylindrical Pipe	Unspecified	None
55	5, 54	Cylindrical Pipe	Unspecified	None
56	54, 55	Cylindrical Pipe	Unspecified	None
57	55, 56	Cylindrical Pipe	Unspecified	None
58	56, 57	Cylindrical Pipe	Unspecified	None
59	57, 58	Cylindrical Pipe	Unspecified	None
60	58, 59	Cylindrical Pipe	Unspecified	None
61	59, 60	Cylindrical Pipe	Unspecified	None
62	60, 1	Cylindrical Pipe	Unspecified	None
63	32, 4	Cylindrical Pipe	Unspecified	None

Pipe Fittings & Losses

Assigned Flow Table

Assigned Flow	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Type	Flow	Flow Units	Loss Factor
1	Chicago	Yes	579	feet	None	Outflow	360000	barrels/day	0
10	Assigned Flow	Yes	430	feet	None	Inflow	70000	barrels/day	0
11	Assigned Flow	Yes	505	feet	None	Inflow	51000	barrels/day	0
62	Assigned Flow	Yes	950	feet	None	Outflow	111000	barrels/day	0

Assigned Pressure Table

Assigned Pressure	Name	Object Defined	Inlet Elevation	Elevation Units	Initial Pressure	Initial Pressure Units	Pressure	Pressure Units
6	FreePort	Yes	0	feet	900.0	psig	900	psig

Assigned Pressure	Pressure Type	Balance Energy	Balance Concentration	(Pipe #1) K In, K Out
6	Stagnation	No	No	(P1) 0, 0

Pump Table

Pump	Name	Object Defined	Inlet Elevation	Elevation Units	Special Condition	Pump Type	Design Flow Rate	Design Flow Rate Units
12	Pump 1	Yes	118.75	feet	None	Fixed Pressure Rise	800	psid
13	Pump 2	Yes	237.5	feet	None	Fixed Pressure Rise	800	psid
15	Pump 3	Yes	356.25	feet	None	Fixed Pressure Rise	800	psid
16	Pump 4	Yes	475	feet	None	Fixed Pressure Rise	800	psid
17	Pump 5	Yes	593.25	feet	None	Fixed Pressure Rise	800	psid
18	Pump 6	Yes	711.5	feet	None	Fixed Pressure Rise	800	psid
19	Pump 7	Yes	829.75	feet	None	Fixed Pressure Rise	800	psid
20	Cushing	Yes	950	feet	None	Fixed Pressure Rise	850	psid
21	Pump 9	Yes	910	feet	None	Fixed Pressure Rise	850	psid
22	Pump 10	Yes	870	feet	None	Fixed Pressure Rise	850	psid
23	Pump 11	Yes	830	feet	None	Fixed Pressure Rise	850	psid
24	Pump 12	Yes	790	feet	None	Fixed Pressure Rise	850	psid
25	Pump 13	Yes	750	feet	None	Fixed Pressure Rise	875	psid
26	Pump 14	Yes	710	feet	None	Fixed Pressure Rise	875	psid
27	Pump 15	Yes	710	feet	None	Fixed Pressure Rise	850	psid
28	Pump 16	Yes	670	feet	None	Fixed Pressure Rise	850	psid
29	Pump 17	Yes	630	feet	None	Fixed Pressure Rise	850	psid
30	Pump 18	Yes	590	feet	None	Fixed Pressure Rise	875	psid
31	Pump 19	Yes	550	feet	None	Fixed Pressure Rise	875	psid
32	Pump 20	Yes	475	feet	None	Fixed Pressure Rise	850	psid
52	Wood River	Yes	430	feet	None	Fixed Pressure Rise	900	psid
53	Pump 39	Yes	467.5	feet	None	Fixed Pressure Rise	900	psid
54	Patoka	Yes	505	feet	None	Fixed Pressure Rise	850	psid
55	Pump 40	Yes	515.58	feet	None	Fixed Pressure Rise	850	psid
56	Pump 41	Yes	526.15	feet	None	Fixed Pressure Rise	850	psid
57	Pump 42	Yes	536.72	feet	None	Fixed Pressure Rise	850	psid
58	Pump 43	Yes	547.29	feet	None	Fixed Pressure Rise	850	psid
59	Pump 44	Yes	557.86	feet	None	Fixed Pressure Rise	800	psid
60	Pump 45	Yes	568.43	feet	None	Fixed Pressure Rise	800	psid

Pump	Current Configuration	Heat Added To Fluid	Heat Added Units
12	N/A	0	Percent
13	N/A	0	Percent
15	N/A	0	Percent
16	N/A	0	Percent
17	N/A	0	Percent
18	N/A	0	Percent
19	N/A	0	Percent
20	N/A	0	Percent
21	N/A	0	Percent
22	N/A	0	Percent
23	N/A	0	Percent
24	N/A	0	Percent
25	N/A	0	Percent
26	N/A	0	Percent
27	N/A	0	Percent
28	N/A	0	Percent
29	N/A	0	Percent
30	N/A	0	Percent
31	N/A	0	Percent
32	N/A	0	Percent
52	N/A	0	Percent
53	N/A	0	Percent
54	N/A	0	Percent
55	N/A	0	Percent
56	N/A	0	Percent
57	N/A	0	Percent
58	N/A	0	Percent
59	N/A	0	Percent
60	N/A	0	Percent

Tee or Wye Table

Tee or Wye	Name	Object Defined	Inlet Elevation	Elevation Units	Tee/Wye Type	Loss Type	Angle	Pipes A, B, C
4	Wood River	Yes	430	feet	Sharp Straight	Simple (no loss)	90	63, 52, 9
5	Patoka	Yes	505	feet	Sharp Straight	Simple (no loss)	90	54, 10, 55
61	Tee or Wye	Yes	950	feet	Sharp Straight	Simple (no loss)	90	17, 3, 18

General

Title: AFT Fathom Model
Analysis run on: 5/20/2010 2:38:57 PM
Application version: AFT Fathom Version 7.0 (2009.11.02)
Input File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\Freeport Chicago Pathway\Freeport Chicago Pathway v0.1.fth
Scenario: Base Scenario/Pump Stations
Output File: P:\Mpls\23 MN\19\23191059 Crude Shuffle GHG Impacts Analyses\WorkFiles\Pipeline Analysis\Freeport Chicago Pathway\Freeport Chicago Pathway v0.1_2.out

Execution Time= 0.25 seconds
Total Number Of Head/Pressure Iterations= 0
Total Number Of Flow Iterations= 2
Total Number Of Temperature Iterations= 0
Number Of Pipes= 36
Number Of Junctions= 37
Matrix Method= Gaussian Elimination

Pressure/Head Tolerance= 0.0001 relative change
Flow Rate Tolerance= 0.0001 relative change
Temperature Tolerance= 0.0001 relative change
Flow Relaxation= (Automatic)
Pressure Relaxation= (Automatic)

Constant Fluid Property Model
Fluid Database: Unspecified
Fluid= WCS
Density= 927.1 kg/m3
Viscosity= 325.5 centipoise
Vapor Pressure= 50.5 kPa
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Total Inflow= 13,737 gal/min
Total Outflow= 13,737 gal/min
Maximum Static Pressure is 1,010 psia at Pipe 60 Inlet
Minimum Static Pressure is 48.20 psia at Pipe 23 Outlet

Pump Summary

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
12	Pump 1	10,208	1,316.3	800.0	1,990	100.0	N/A	4,763	N/A	N/A	255.3
13	Pump 2	10,208	1,316.3	800.0	1,990	100.0	N/A	4,763	N/A	N/A	243.4
15	Pump 3	10,208	1,316.3	800.0	1,990	100.0	N/A	4,763	N/A	N/A	231.5
16	Pump 4	10,208	1,316.3	800.0	1,990	100.0	N/A	4,763	N/A	N/A	219.6
17	Pump 5	10,208	1,316.3	800.0	1,990	100.0	N/A	4,763	N/A	N/A	208.2
18	Pump 6	10,208	1,316.3	800.0	1,990	100.0	N/A	4,763	N/A	N/A	196.9
19	Pump 7	10,208	1,316.3	800.0	1,990	100.0	N/A	4,763	N/A	N/A	185.5
20	Cushing	6,971	898.9	850.0	2,115	100.0	N/A	3,456	N/A	N/A	172.0
21	Pump 9	6,971	898.9	850.0	2,115	100.0	N/A	3,456	N/A	N/A	158.0
22	Pump 10	6,971	898.9	850.0	2,115	100.0	N/A	3,456	N/A	N/A	144.1
23	Pump 11	6,971	898.9	850.0	2,115	100.0	N/A	3,456	N/A	N/A	130.2
24	Pump 12	6,971	898.9	850.0	2,115	100.0	N/A	3,456	N/A	N/A	116.3
25	Pump 13	6,971	898.9	875.0	2,177	100.0	N/A	3,557	N/A	N/A	102.4
26	Pump 14	6,971	898.9	875.0	2,177	100.0	N/A	3,557	N/A	N/A	150.6
27	Pump 15	6,971	898.9	850.0	2,115	100.0	N/A	3,456	N/A	N/A	158.9

Jct	Name	Vol. Flow (gal/min)	Mass Flow (lbm/sec)	dP (psid)	dH (feet)	Overall Efficiency (Percent)	Speed (Percent)	Overall Power (hp)	BEP (gal/min)	% of BEP (Percent)	NPSHA (feet)
28	Pump 16	6,971	898.9	850.0	2,115	100.0	N/A	3,456	N/A	N/A	145.0
29	Pump 17	6,971	898.9	850.0	2,115	100.0	N/A	3,456	N/A	N/A	131.1
30	Pump 18	6,971	898.9	875.0	2,177	100.0	N/A	3,557	N/A	N/A	117.1
31	Pump 19	6,971	898.9	875.0	2,177	100.0	N/A	3,557	N/A	N/A	165.4
32	Pump 20	6,971	898.9	850.0	2,115	100.0	N/A	3,456	N/A	N/A	248.7
52	Wood River	9,012	1,162.1	900.0	2,239	100.0	N/A	4,731	N/A	N/A	239.8
53	Pump 39	9,012	1,162.1	900.0	2,239	100.0	N/A	4,731	N/A	N/A	238.4
54	Patoka	10,500	1,353.9	850.0	2,115	100.0	N/A	5,205	N/A	N/A	237.0
55	Pump 40	10,500	1,353.9	850.0	2,115	100.0	N/A	5,205	N/A	N/A	272.8
56	Pump 41	10,500	1,353.9	850.0	2,115	100.0	N/A	5,205	N/A	N/A	308.7
57	Pump 42	10,500	1,353.9	850.0	2,115	100.0	N/A	5,205	N/A	N/A	344.6
58	Pump 43	10,500	1,353.9	850.0	2,115	100.0	N/A	5,205	N/A	N/A	380.4
59	Pump 44	10,500	1,353.9	800.0	1,990	100.0	N/A	4,899	N/A	N/A	416.3
60	Pump 45	10,500	1,353.9	800.0	1,990	100.0	N/A	4,899	N/A	N/A	327.7

Jct	NPSHR (feet)
12	N/A
13	N/A
15	N/A
16	N/A
17	N/A
18	N/A
19	N/A
20	N/A
21	N/A
22	N/A
23	N/A
24	N/A
25	N/A
26	N/A
27	N/A
28	N/A
29	N/A
30	N/A
31	N/A
32	N/A
52	N/A
53	N/A
54	N/A
55	N/A
56	N/A
57	N/A
58	N/A
59	N/A
60	N/A

Pipe Output Table

AFT Fathom Model

Pipe	Name	Vol. Flow Rate (barrels/day)	Velocity (feet/sec)	P Static Max (psig)	P Static Min (psig)	Elevation Inlet (feet)	Elevation Outlet (feet)	dP Stag. Total (psid)	dP Static Total (psid)	dP Gravity (psid)
1	Pipe	350,000	4.958	899.85	95.07	0.0	118.8	804.7754517	804.7754517	47.728
3	Ozark	111,000	2.999	61.74	61.74	950.0	950.0	0.0007396	0.0007396	0.000
9	Pipe	70,000	2.310	88.97	88.97	430.0	430.0	0.0013922	0.0013922	0.000
10	Pipe	51,000	1.149	87.87	87.87	505.0	505.0	0.0004724	0.0004724	0.000
11	Pipe	350,000	4.958	895.07	90.30	118.8	237.5	804.7754517	804.7754517	47.728
12	Pipe	350,000	4.958	890.30	85.52	237.5	356.3	804.7754517	804.7754517	47.728
13	Pipe	350,000	4.958	885.52	80.74	356.3	475.0	804.7754517	804.7754517	47.728
14	Pipe	350,000	4.958	880.74	76.17	475.0	593.3	804.5744629	804.5744629	47.527
15	Pipe	350,000	4.958	876.17	71.60	593.3	711.5	804.5744629	804.5744629	47.527
16	Pipe	350,000	4.958	871.60	67.02	711.5	829.8	804.5744629	804.5744629	47.527
17	Pipe	350,000	4.958	867.02	61.64	829.8	950.0	805.3783569	805.3783569	48.331
18	Express 24	239,000	6.457	61.54	61.49	950.0	950.0	0.0487709	0.0487709	0.000
19	Pipe	239,000	6.457	911.49	55.89	950.0	910.0	855.5957031	855.5957031	-16.077
20	Pipe	239,000	6.457	905.89	50.30	910.0	870.0	855.5957031	855.5957031	-16.077
21	Pipe	239,000	6.457	900.30	44.70	870.0	830.0	855.5957031	855.5957031	-16.077
22	Pipe	239,000	6.457	894.70	39.10	830.0	790.0	855.5957031	855.5957031	-16.077
23	Pipe	239,000	6.457	889.10	33.51	790.0	750.0	855.5957031	855.5957031	-16.077
24	Pipe	239,000	6.457	908.51	52.91	750.0	710.0	855.5957031	855.5957031	-16.077
25	Pipe	239,000	6.457	927.91	56.24	710.0	710.0	871.6726685	871.6726685	0.000
26	Pipe	239,000	6.457	906.24	50.64	710.0	670.0	855.5957031	855.5957031	-16.077
27	Pipe	239,000	6.457	900.64	45.05	670.0	630.0	855.5957031	855.5957031	-16.077
28	Pipe	239,000	6.457	895.05	39.45	630.0	590.0	855.5957031	855.5957031	-16.077
29	Pipe	239,000	6.457	914.45	58.86	590.0	550.0	855.5957031	855.5957031	-16.077
30	Pipe	239,000	6.457	933.86	92.33	550.0	475.0	841.5284424	841.5284424	-30.144
52	Pipe	309,000	6.959	88.70	88.70	430.0	430.0	0.0028915	0.0028915	0.000
53	Pipe	309,000	6.959	988.70	88.14	430.0	467.5	900.5610962	900.5610962	15.072
54	Pipe	309,000	6.959	988.14	87.58	467.5	505.0	900.5610962	900.5610962	15.072
55	Pipe	360,000	6.863	87.58	87.58	505.0	505.0	0.0027147	0.0027147	0.000
56	Pipe	360,000	6.863	937.58	101.99	505.0	515.6	835.5904541	835.5904541	4.252
57	Pipe	360,000	6.863	951.99	116.40	515.6	526.2	835.5864258	835.5864258	4.248
58	Pipe	360,000	6.863	966.40	130.82	526.2	536.7	835.5863647	835.5863647	4.248
59	Pipe	360,000	6.863	980.82	145.23	536.7	547.3	835.5864258	835.5864258	4.248
60	Pipe	360,000	6.863	995.23	159.65	547.3	557.9	835.5864258	835.5864258	4.248
61	Pipe	360,000	6.863	959.65	124.06	557.9	568.4	835.5864258	835.5864258	4.248
62	Pipe	360,000	6.863	924.06	88.47	568.4	579.0	835.5864258	835.5864258	4.248
63	Pipe	239,000	6.457	942.33	88.74	475.0	430.0	853.5861206	853.5861206	-18.087

Pipe	dH (feet)	P Static In (psig)	P Static Out (psig)	P Stag. In (psig)	P Stag. Out (psig)
1	1,883.560813	899.85	95.07	900.00	95.22
3	0.001840	61.74	61.74	61.80	61.80
9	0.003464	88.97	88.97	89.00	89.00
10	0.001175	87.87	87.87	87.88	87.88
11	1,883.560813	895.07	90.30	895.22	90.45
12	1,883.560813	890.30	85.52	890.45	85.67
13	1,883.560813	885.52	80.74	885.67	80.90
14	1,883.560813	880.74	76.17	880.90	76.32
15	1,883.560813	876.17	71.60	876.32	71.75
16	1,883.560813	871.60	67.02	871.75	67.17
17	1,883.560813	867.02	61.64	867.17	61.80
18	0.121344	61.54	61.49	61.80	61.75
19	2,168.753531	911.49	55.89	911.75	56.15

Pipe	dH (feet)	P Static In (psig)	P Static Out (psig)	P Stag. In (psig)	P Stag. Out (psig)
20	2,168.753531	905.89	50.30	906.15	50.56
21	2,168.753531	900.30	44.70	900.56	44.96
22	2,168.753531	894.70	39.10	894.96	39.36
23	2,168.753531	889.10	33.51	889.36	33.77
24	2,168.753531	908.51	52.91	908.77	53.17
25	2,168.753531	927.91	56.24	928.17	56.50
26	2,168.753531	906.24	50.64	906.50	50.90
27	2,168.753531	900.64	45.05	900.90	45.31
28	2,168.753531	895.05	39.45	895.31	39.71
29	2,168.753531	914.45	58.86	914.71	59.12
30	2,168.753531	933.86	92.33	934.12	92.59
52	0.007194	88.70	88.70	89.00	89.00
53	2,203.128952	988.70	88.14	989.00	88.44
54	2,203.128952	988.14	87.58	988.44	87.88
55	0.006754	87.58	87.58	87.88	87.88
56	2,068.399581	937.58	101.99	937.88	102.28
57	2,068.399581	951.99	116.40	952.28	116.70
58	2,068.399581	966.40	130.82	966.70	131.11
59	2,068.399581	980.82	145.23	981.11	145.53
60	2,068.399581	995.23	159.65	995.53	159.94
61	2,068.399581	959.65	124.06	959.94	124.35
62	2,068.399581	924.06	88.47	924.35	88.77
63	2,168.753531	942.33	88.74	942.59	89.00

<u>All Junction Table</u>

Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (barrels/day)	Mass Flow Rate Thru Jct (lbm/min)	Loss Factor (K)
1	Chicago	103.17	103.17	103.46	103.46	360,000	81,236	0
4	Wood River	103.53	103.53	103.70	103.70	N/A	N/A	0
5	Patoka	102.42	102.42	102.57	102.57	N/A	N/A	0
6	FreePort	914.54	914.54	914.70	914.70	350,000	78,980	0
10	Assigned Flow	103.67	103.67	103.70	103.70	70,000	15,796	0
11	Assigned Flow	102.57	102.57	102.57	102.57	51,000	11,509	0
12	Pump 1	109.77	909.77	109.92	909.92	350,000	78,980	0
13	Pump 2	104.99	904.99	105.15	905.15	350,000	78,980	0
15	Pump 3	100.22	900.22	100.37	900.37	350,000	78,980	0
16	Pump 4	95.44	895.44	95.59	895.59	350,000	78,980	0
17	Pump 5	90.87	890.87	91.02	891.02	350,000	78,980	0
18	Pump 6	86.29	886.29	86.45	886.45	350,000	78,980	0
19	Pump 7	81.72	881.72	81.87	881.87	350,000	78,980	0
20	Cushing	76.18	926.18	76.44	926.44	239,000	53,932	0
21	Pump 9	70.59	920.59	70.85	920.85	239,000	53,932	0
22	Pump 10	64.99	914.99	65.25	915.25	239,000	53,932	0
23	Pump 11	59.40	909.40	59.66	909.66	239,000	53,932	0
24	Pump 12	53.80	903.80	54.06	904.06	239,000	53,932	0
25	Pump 13	48.20	923.20	48.46	923.46	239,000	53,932	0
26	Pump 14	67.61	942.61	67.87	942.87	239,000	53,932	0
27	Pump 15	70.94	920.94	71.20	921.20	239,000	53,932	0
28	Pump 16	65.34	915.34	65.60	915.60	239,000	53,932	0
29	Pump 17	59.74	909.74	60.00	910.01	239,000	53,932	0

AFT Fathom Model

Jct	Name	P Static In (psia)	P Static Out (psia)	P Stag. In (psia)	P Stag. Out (psia)	Vol. Flow Rate Thru Jct (barrels/day)	Mass Flow Rate Thru Jct (lbm/min)	Loss Factor (K)
30	Pump 18	54.15	929.15	54.41	929.41	239,000	53,932	0
31	Pump 19	73.55	948.55	73.81	948.81	239,000	53,932	0
32	Pump 20	107.02	957.02	107.29	957.29	239,000	53,932	0
52	Wood River	103.39	1,003.39	103.70	1,003.70	309,000	69,728	0
53	Pump 39	102.83	1,002.83	103.14	1,003.14	309,000	69,728	0
54	Patoka	102.28	952.28	102.57	952.57	360,000	81,236	0
55	Pump 40	116.69	966.69	116.98	966.98	360,000	81,236	0
56	Pump 41	131.10	981.10	131.39	981.39	360,000	81,236	0
57	Pump 42	145.51	995.51	145.81	995.81	360,000	81,236	0
58	Pump 43	159.93	1,009.93	160.22	1,010.22	360,000	81,236	0
59	Pump 44	174.34	974.34	174.64	974.64	360,000	81,236	0
60	Pump 45	138.75	938.75	139.05	939.05	360,000	81,236	0
61	Tee or Wye	76.35	76.35	76.49	76.49	N/A	N/A	0
62	Assigned Flow	76.44	76.44	76.49	76.49	111,000	25,048	0

Appendix B

GHG Emission Calculations

Low Carbon Fuel Standard "Crude Shuffle" Greenhouse Gas Impacts Analysis
Prepared for
Crude Shuffle Report
May 2010

Base Case (No LCFS)

	Metric Tons CO_2-e per barrel of crude transported	
	Tanker Transport - One Way	Tanker Transport - Roundtrip/Deadhead
Crude Transport from Canada to U.S.		
Pipeline		
Edmonton to Chicago via Enbridge Pipeline		5.53E-03
Edmonton to Chicago via Express Chicago Pipeline		1.19E-02
Tanker	One Way	Roundtrip - Deadhead
None	0	0
Total (using Enbridge Pipeline option)	5.53E-03	5.53E-03
Total (using Express Pipeline option)	1.19E-02	1.19E-02

Crude Transport from Middle East to China		
Pipeline		
None		
Tanker	One Way	Roundtrip - Deadhead
Basrah to Ningbo	2.55E-03	4.75E-03
Total	2.55E-03	4.75E-03

BASE CASE TOTAL TRANSPORT GHG EMISSIONS (using Enbridge Pipeline option)	8.08E-03	1.03E-02
BASE CASE TOTAL TRANSPORT GHG EMISSIONS (using Express Pipeline option)	1.19E-02	1.19E-02
BASE CASE AVERAGE TRANSPORT GHG EMISSIONS (Average of Potential Pipeline Routes)	9.98E-03	1.11E-02

Crude Shuffle (LCFS)

	CO_2-e per barrel of crude transported	
Crude Transport from Canada to China		
Pipeline		
Edmonton to Kitimat via TMPL China Pathway		3.09E-03
Edmonton to Kitimat via Gateway China Pathway		2.69E-03
Tanker	One Way	Roundtrip - Deadhead
Kitimat to Ningbo	2.08E-03	3.87E-03
Total (using TMPL pipeline option)	5.17E-03	6.96E-03
Total (using Gateway pipeline option)	4.77E-03	6.56E-03

Crude Transport from Middle East to U.S.		
Pipeline		
Galveston to Chicago via St. James Chicago Pathway		6.60E-03
Galveston to Chicago via Freeport Chicago Pathway		6.74E-03
Tanker	One Way	Roundtrip - Deadhead
Basrah to Galveston	5.55E-03	1.03E-02
Total (using St. James pipeline option)	1.21E-02	1.69E-02
Total (using Freeport pipeline option)	1.23E-02	1.71E-02

CRUDE SHUFFLE TOTAL TRANSPORT GHG EMISSIONS (TMPL and St. James)	1.73E-02	2.39E-02
CRUDE SHUFFLE TOTAL TRANSPORT GHG EMISSIONS (TMPL and Freeport)	1.75E-02	2.40E-02
CRUDE SHUFFLE TOTAL TRANSPORT GHG EMISSIONS (Gateway and St. James)	1.69E-02	2.35E-02
CRUDE SHUFFLE TOTAL TRANSPORT GHG EMISSIONS (Gateway and Freeport)	1.71E-02	2.36E-02
CRUDE SHUFFLE AVERAGE TRANPORT GHG EMISSIONS (Average of Potential Pipeline Routes)	1.72E-02	2.38E-02

Appendix B:
Greehouse Gas Impact Calculations
Summary Total

Low Carbon Fuel Standard "Crude Shuffle" Greenhouse Gas Impacts Analysis
Prepared for
Crude Shuffle Report
May 2010

Total Displaced Crude - All Canadian Imports to U.S. (thousand Barrels Per day)	2,436
Total Displaced Crude - All Canadian Imports to U.S. PADD II (thousand Barrels Per day)	1,154

Base Case (No LCFS)

	Metric Tons CO_2-e per barrel of crude transported		Total GHG Emissions Metric Tons CO_2-e per day			
	Tanker Transport - One Way	Tanker Transport - Roundtrip/Deadhead	**All Canadian Imports to U.S. Displaced**	**All Canadian Imports to U.S. PADD II Displaced**	**All Canadian Imports to U.S. Displaced**	**All Canadian Imports to U.S. PADD II Displaced**
			Assuming Tanker Transport - One Way		**Assuming Tanker Transport - Roundtrip/Deadhead**	
Crude Transport from Canada to U.S.						
Pipeline						
Pipeline Any Route		1.19E-02	28,944	13,707	28,944	13,707
Tanker	One Way	Roundtrip - Deadhead				
None	0	0	0	0	0	0
Total	1.19E-02	1.19E-02	28,944	13,707	28,944	13,707
Crude Transport from Middle East to China						
Pipeline						
None			0	0	0	0
Tanker	One Way	Roundtrip - Deadhead				
Basrah to Ningbo	2.55E-03	4.75E-03	6,216	2,944	11,575	5,482
Total	2.55E-03	4.75E-03	6,216	2,944	11,575	5,482
BASE CASE TOTAL TRANSPORT GHG EMISSIONS	1.44E-02	1.66E-02	35,160	16,651	40,519	19,189

Crude Shuffle (LCFS)

	Metric Tons CO_2-e per barrel of crude transported		Total GHG Emissions Metric Tons CO_2-e per day			
	Tanker Transport - One Way	Tanker Transport - Roundtrip/Deadhead	**All Canadian Imports to U.S. Displaced**	**All Canadian Imports to U.S. PADD II Displaced**	**All Canadian Imports to U.S. Displaced**	**All Canadian Imports to U.S. PADD II Displaced**
			Assuming Tanker Transport - One Way		**Assuming Tanker Transport - Roundtrip/Deadhead**	
Crude Transport from Canada to China						
Pipeline						
Pipeline Any Route		1.19E-02	28,944	13,707	28,944	13,707
Tanker	One Way	Roundtrip - Deadhead				
Kitimat to Ningbo	2.08E-03	3.87E-03	5,062	2,397	9,427	4,464
Total	1.40E-02	1.58E-02	34,006	16,105	38,371	18,172
Crude Transport from Middle East to U.S.						
Pipeline						
Pipeline Any Route		1.19E-02	28,944	13,707	28,944	13,707
Tanker	One Way	Roundtrip - Deadhead				
Basrah to Galveston	5.55E-03	1.03E-02	13,528	6,407	25,192	11,930
Total	1.74E-02	2.22E-02	42,472	20,114	54,136	25,637
CRUDE SHUFFLE TOTAL TRANSPORT GHG	3.14E-02	3.80E-02	76,478	36,218	92,507	43,809

Appendix B:
Greehouse Gas Impact Calculations
Transport Efficiency by Mode

Low Carbon Fuel Standard "Crude Shuffle" Greenhouse Gas Impacts Analysis
Prepared for
Crude Shuffle Report
May 2010

Base Case (No LCFS)

	Metric Tons CO_2-e per barrel of crude transported		Miles Transported	Total Metric Tons CO_2-e/mile	
Crude Transport from Canada to U.S.					
Pipeline					
Edmonton to Chicago via Enbridge Pipeline		5.53E-03	1637		3.38E-06
Edmonton to Chicago via Express Chicago Pipeline		1.19E-02	2078		5.72E-06
Tanker	One Way	Roundtrip - Deadhead		One Way	Roundtrip - Deadhead
None	0	0	0	0	0
Total (using Enbridge Pipeline option)	5.53E-03	5.53E-03		3.38E-06	3.38E-06
Total (using Express Pipeline option)	1.19E-02	1.19E-02		5.72E-06	5.72E-06

Crude Transport from Middle East to China					
Pipeline					
None					
Tanker	One Way	Roundtrip - Deadhead		One Way	Roundtrip - Deadhead
Basrah to Ningbo	2.55E-03	4.75E-03	6,928	3.68E-07	6.86E-07
Total (average)	2.55E-03	4.75E-03		3.68E-07	6.86E-07

BASE CASE TOTAL TRANSPORT GHG EMISSIONS (using Enbridge Pipeline option)	8.08E-03	1.03E-02		3.75E-06	4.06E-06
BASE CASE TOTAL TRANSPORT GHG EMISSIONS (using Express Pipeline option)	1.19E-02	1.19E-02		5.72E-06	5.72E-06

Crude Shuffle (LCFS)

	CO_2-e per barrel of crude transported		Miles Transported	Total Metric Tons CO_2-e/mile	
Crude Transport from Canada to China					
Pipeline					
Edmonton to Kitimat via TMPL China Pathway		3.09E-03	716		4.32E-06
Edmonton to Kitimat via Gateway China Pathway		2.69E-03	739		3.64E-06
Tanker	One Way	Roundtrip - Deadhead		One Way	Roundtrip - Deadhead
Kitimat to Ningbo	2.08E-03	3.87E-03	5,673	3.66E-07	6.82E-07
Total (using TMPL pipeline option)	5.17E-03	6.96E-03		4.68E-06	5.00E-06
Total (using Gateway pipeline option)	4.77E-03	6.96E-03		4.00E-06	8.63E-06

Crude Transport from Middle East to U.S.					
Pipeline					
Galveston to Chicago via St. James Chicago Pathway		6.60E-03	835		7.90E-06
Galveston to Chicago via Freeport Chicago Pathway		6.74E-03	1231		5.48E-06
Tanker	One Way	Roundtrip - Deadhead		One Way	Roundtrip - Deadhead
Basrah to Galveston	5.55E-03	1.03E-02	15,078	3.68E-07	6.86E-07
Total (using St. James pipeline option)	1.21E-02	1.69E-02		8.27E-06	8.59E-06
Total (using Freeport pipeline option)	1.23E-02	1.71E-02		5.84E-06	6.16E-06

CRUDE SHUFFLE TOTAL TRANSPORT GHG EMISSIONS (TMPL and St. James)	1.73E-02	2.39E-02		1.29E-05	1.36E-05
CRUDE SHUFFLE TOTAL TRANSPORT GHG EMISSIONS (TMPL and Freeport)	1.75E-02	2.40E-02		1.05E-05	1.12E-05
CRUDE SHUFFLE TOTAL TRANSPORT GHG EMISSIONS (Gateway and St. James)	1.69E-02	2.39E-02		1.23E-05	1.72E-05
CRUDE SHUFFLE TOTAL TRANSPORT GHG EMISSIONS (Gateway and Freeport)	1.71E-02	2.40E-02		9.85E-06	1.48E-05

GHG Emissions Optimized Base Case

Optimized Base Case

Crude Transport from Canada to U.S.

Pipeline GHG Emissions

Emission Unit Description	Pollutant	Pollutant Type: CO_2	Pollutant Type: CH_4	Pollutant Type: N_2O	Energy Usage Rate	Energy Usage Rate Units	Emission Factor number	Emission Factor Units	Emission Factor Source	Estimated Actual Emissions (m.t./barrel)	Global Warming Potential (GWP)	Estimated Actual Emissions (m.t. CO_2-e /Barrel)
Edmonton to Chicago via Enbridge Pipeline												
All pump stations within Alberta	CO2-e	x	x	x	4.17E-03	MWh/Barrel	930	lb CO_2-e/MWh	[1]	1.76E-03	N/A	1.76E-03
All pump stations within MRO Region	CO_2	x			4.53E-03	MWh/Barrel	1,824	lb CO_2/MWh	[2]	3.75E-03	1	3.75E-03
All pump stations within MRO Region	CH_4		x		4.53E-03	MWh/Barrel	28	lb CH_4/GWh	[2]	5.75E-08	21	1.21E-06
All pump stations within MRO Region	N_2O			x	4.53E-03	MWh/Barrel	31	lb N_2O/GWh	[2]	6.30E-08	310	1.95E-05
Edmonton to Chicago via Express Chicago Pipeline												
All pump stations within Alberta	CO2-e	x	x	x	9.48E-03	MWh/Barrel	930	lb CO_2-e/MWh	[1]	4.00E-03	N/A	4.00E-03
All pump stations within MRO Region	CO_2	x			9.48E-03	MWh/Barrel	1,824	lb CO_2/MWh	[2]	7.84E-03	1	7.84E-03
All pump stations within MRO Region	CH_4		x		9.48E-03	MWh/Barrel	28	lb CH_4/GWh	[2]	1.20E-07	21	2.52E-06
All pump stations within MRO Region	N_2O			x	9.48E-03	MWh/Barrel	31	lb N_2O/GWh	[2]	1.32E-07	310	4.09E-05

[1] Environment Canada, National Inventory Report, 1990-2006: Greenhouse Gas Sources and Sinks in Canada (May 2008), Annex 9: Electricity Intensity Tables (http://www.ec.gc.ca/pdb/ghg/inventory_report/2006_report/a9_eng.cfm)
[2] eGRID2007 Version 1.1 Year 2005 GHG Annual Output Emission Rates (http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html)

Tanker GHG Emissions

NONE

Appendix B:
Greehouse Gas Impact Calculations
GHG - OP Base Case

Low Carbon Fuel Standard "Crude Shuffle" Greenhouse Gas Impacts Analysis
Prepared for
Crude Shuffle Report
May 2010

GHG Emissions Optimized Base Case

Crude Transport from Middle East to China

Pipeline GHG Emissions
NONE

Tanker GHG Emissions

Emission Unit Description	Pollutant	Pollutant Type: CO2	Pollutant Type: CH4	Pollutant Type: N2O	Fuel Usage Rate	Fuel Usage Rate Units	Note	Distance	Distance Units	Note	Total Cargo Transported (per trip)	Total Cargo Transported Units	Note	Emission Factor Number	Emission Factor Units	Emission Factor Source	Estimated Actual Emissions (m.t./barrel)	Global Warming Potential (GWP)	Estimated Actual Emissions (m.t. CO_2-e /Barrel)
Basrah to Ningbo, Laden																			
"Average VLCC Tanker	CO_2	x			5.33E-06	MMBtu IFO 380/nautical mile- barrel	[1]	6,020	nautical miles	[2]	2,000,000	barrels	[3]	2.15E+01	kg C/MMBt	[4]	2.53E-03	1	2.53E-03
"Average VLCC Tanker	CH_4		x		5.33E-06	MMBtu IFO 380/nautical mile- barrel	[1]	6,020	nautical miles	[2]	2,000,000	barrels	[3]	8.60E-01	g CH_4/gallo	[5]	1.84E-07	21	3.87E-06
"Average VLCC Tanker	N_2O			x	5.33E-06	MMBtu IFO 380/nautical mile- barrel	[1]	6,020	nautical miles	[2]	2,000,000	barrels	[3]	3.00E-01	g N_2O/gallo	[5]	6.43E-08	310	1.99E-05
Basrah to Ningbo, Without Cargo																			
"Average VLCC Tanker	CO_2	x			4.59E-06	MMBtu IFO 380/nautical mile- barrel	[1]	6,020	nautical miles	[2]	N/A	barrels	[3]	2.15E+01	kg C/MMBt	[4]	2.18E-03	1	2.18E-03
"Average VLCC Tanker	CH_4		x		4.59E-06	MMBtu IFO 380/nautical mile- barrel	[1]	6,020	nautical miles	[2]	N/A	barrels	[3]	8.60E-01	g CH_4/gallo	[5]	1.59E-07	21	3.34E-06
"Average VLCC Tanker	N_2O			x	4.59E-06	MMBtu IFO 380/nautical mile- barrel	[1]	6,020	nautical miles	[2]	N/A	barrels	[3]	3.00E-01	g N_2O/gallo	[5]	5.55E-08	310	1.72E-05

[1] Fuel use for "Composite" tanker based on information available for three VLCC tankers in use with crude transport (see calcs in "average" tanker tab) which are powered via combustion of IFO 380. The ports identified in this analysis are all capable of accommodating VLCC tankers.
[2] Port to Port distances derived from BP distance tables
[3] Assume Cargo Capacity of 2,000,000 Barrels - per Currie Evans (typical VLCC capacity)
[4] Carbon content of 21.49 kg C/MMBtu (Residual Fuel Oil #5, 6 The Climate Registry General Reporting Protocol v. 1.1 May 2008 Table 13.1)
[5] Emission factors from The Climate Registry General Reporting Protocol v. 1.1 May 2008 Table 13.6 Ships and Boats, residual fuel oil. Assume a heat content of 6.287 MMBtu/barrel (Residual Fuel Oil #5, 6 The Climate Registry General Reporting Protocol v. 1.1 May 2008 Table 13.1))

GHG Emissions Crude Shuffle Case

Crude Shuffle Case

Crude Transport from Canada to China

Pipeline GHG Emissions

Pipeline Pump Station	Pollutant	Pollutant Type: CO_2	CH_4	N_2O	Energy Usage Rate	Energy Usage Rate Units	Emission Factor number	Emission Factor Units	Emission Factor Source	Estimated Actual Emissions (m.t./barrel)	Global Warming Potential (GWP)	Estimated Actual Emissions (m.t. CO_2-e/Barrel)
Edmonton to Kitimat via TMPL China Pathway												
All pump stations within Alberta	CO2-e	x	x	x	7.32E-03	MWh/Barrel	930	lb/MWh	[1]	3.09E-03	N/A	3.09E-03
All pump stations within British Columbia	CO2-e	x	x	x	2.48E-04	MWh/Barrel	20	lb/MWh	[1]	2.25E-06	N/A	2.25E-06
Edmonton to Kitimat via Gateway China Pathway												
All pump stations within Alberta	CO2-e	x	x	x	6.33E-03	MWh/Barrel	930	lb/MWh	[1]	2.67E-03	N/A	2.67E-03
All pump stations within British Columbia	CO2-e	x	x	x	2.20E-03	MWh/Barrel	20	lb/MWh	[1]	2.00E-05	N/A	2.00E-05

[1] Environment Canada, National Inventory Report, 1990-2006: Greenhouse Gas Sources and Sinks in Canada (May 2008), Annex 9: Electricity Intensity Tables (http://www.ec.gc.ca/pdb/ghg/inventory_report/2006_report/a9_eng.cfm)

Tanker GHG Emissions

Emission Unit Description	Pollutant	Pollutant Type: CO_2	CH_4	N_2O	Fuel Usage Rate	Fuel Usage Rate Units	Note	Distance	Distance Units	Note	Total Cargo Transported (per trip)	Total Cargo Transported Units	Note	Emission Factor Number	Emission Factor Units	Emission Factor Source	Estimated Actual Emissions (m.t./barrel)	Global Warming Potential (GWP)	Estimated Actual Emissions (m.t. CO_2-e /Barrel)
Kitimat to Ningbo, Laden																			
"Average VLCC Tanker	CO_2	x			5.33E-06	MMBtu IFO 380/nautical mile- barrel	[1]	4,903	nautical miles	[2]	2,000,000	barrels	[3]	2.15E+01	kg C/MMBt	[4]	2.06E-03	1	2.06E-03
"Average VLCC Tanker	CH_4		x		5.33E-06	MMBtu IFO 380/nautical mile- barrel	[1]	4,903	nautical miles	[2]	2,000,000	barrels	[3]	8.60E-01	g CH_4/gallo	[5]	1.50E-07	21	3.15E-06
"Average VLCC Tanker	N_2O			x	5.33E-06	MMBtu IFO 380/nautical mile- barrel	[1]	4,903	nautical miles	[2]	2,000,000	barrels	[3]	3.00E-01	g N_2O/gallo	[5]	5.24E-08	310	1.62E-05
Kitimat to Ningbo, Without Cargo																			
"Average VLCC Tanker	CO_2	x			4.59E-06	MMBtu IFO 380/nautical mile- barrel	[1]	4,903	nautical miles	[2]	N/A	barrels	[3]	2.15E+01	kg C/MMBt	[4]	1.78E-03	1	1.78E-03
"Average VLCC Tanker	CH_4		x		4.59E-06	MMBtu IFO 380/nautical mile- barrel	[1]	4,903	nautical miles	[2]	N/A	barrels	[3]	8.60E-01	g CH_4/gallo	[5]	1.29E-07	21	2.72E-06
"Average VLCC Tanker	N_2O			x	4.59E-06	MMBtu IFO 380/nautical mile- barrel	[1]	4,903	nautical miles	[2]	N/A	barrels	[3]	3.00E-01	g N_2O/gallo	[5]	4.52E-08	310	1.40E-05

[1] Fuel use for "Composite" tanker based on information available for three VLCC tankers in use with crude transport (see calcs in "average" tanker tab) which are powered via combustion of IFO 380. The ports identified in this analysis are all capable of accommodating VLCC tankers.
[2] Port to Port distances derived from BP distance tables
[3] Assume Cargo Capacity of 2,000,000 Barrels - per Currie Evans (typical VLCC capacity)
[4] Carbon content of 21.49 kg C/MMBtu (Residual Fuel Oil #5, 6 The Climate Registry General Reporting Protocol v. 1.1 May 2008 Table 13.1)
[5] Emission factors from The Climate Registry General Reporting Protocol v. 1.1 May 2008 Table 13.6 Ships and Boats, residual fuel oil. Assume a heat content of 6.287 MMBtu/barrel (Residual Fuel Oil #5, 6 The Climate Registry General Reporting Protocol v. 1.1 May 2008 Table 13.1))

Appendix B:
Greehouse Gas Impact Calculations
GHG - Shuffle Case

Low Carbon Fuel Standard "Crude Shuffle" Greenhouse Gas Impacts Analysis
Prepared for
Crude Shuffle Report
May 2010

Crude Transport from Middle East to U.S.

Pipeline GHG Emissions

Pipeline Pump Station	Pollutant	Pollutant Type CO_2	CH_4	N_2O	Energy Usage Rate	Energy Usage Rate Units	Emission Factor number	Emission Factor Units	Emission Factor Source	Estimated Actual Emissions (m.t./barrel)	Global Warming Potential (GWP)	Estimated Actual Emissions (m.t. CO_2-e /Barrel)
Galveston to Chicago via St. James Chicago Pathway												
All pump stations within SERC Region	CO_2	x			1.06E-02	MWh/Barrel	1,369	lb CO_2/MWh	[1]	6.56E-03	1	6.56E-03
	CH_4		x		1.06E-02	MWh/Barrel	23.32	lb CH_4/GWh	[1]	1.12E-07	21	2.35E-06
	N_2O			x	1.06E-02	MWh/Barrel	22.54	lb N_2O/GWh	[1]	1.08E-07	310	3.35E-05
Galveston to Chicago via Freeport Chicago Pathway												
All pump stations within SERC Region	CO_2	x			1.08E-02	MWh/Barrel	1,369	lb CO_2/MWh	[1]	6.70E-03	1	6.70E-03
	CH_4		x		1.08E-02	MWh/Barrel	23.32	lb CH_4/GWh	[1]	1.14E-07	21	2.40E-06
	N_2O			x	1.08E-02	MWh/Barrel	22.54	lb N_2O/GWh	[1]	1.10E-07	310	3.42E-05

[1] eGRID2007 Version 1.1 Year 2005 GHG Annual Output Emission Rates (http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html)

Tanker GHG Emissions

Emission Unit Description	Pollutant	Pollutant Type CO_2	CH_4	N_2O	Fuel Usage Rate	Fuel Usage Rate Units	Note	Distance	Distance Units	Note	Total Cargo Transported (per trip)	Total Cargo Transported Units	Note	Emission Factor Number	Emission Factor Units	Emission Factor Source	Estimated Actual Emissions (m.t./barrel)	Global Warming Potential (GWP)	Estimated Actual Emissions (m.t. CO_2-e /Barrel)
Basrah to Galveston, TX, Laden																			
"Average VLCC Tanker	CO_2	x			5.33E-06	MMBtu IFO 380/nautical mile- barrel	[1]	13,102	nautical miles	[2]	2,000,000	barrels	[3]	2.15E+01	kg C/MMBt	[4]	5.50E-03	1	5.50E-03
"Average VLCC Tanker	CH_4		x		5.33E-06	MMBtu IFO 380/nautical mile- barrel	[1]	13,102	nautical miles	[2]	2,000,000	barrels	[3]	8.60E-01	g CH_4/gallo	[5]	4.01E-07	21	8.43E-06
"Average VLCC Tanker	N_2O			x	5.33E-06	MMBtu IFO 380/nautical mile- barrel	[1]	13,102	nautical miles	[2]	2,000,000	barrels	[3]	3.00E-01	g N_2O/gallo	[5]	1.40E-07	310	4.34E-05
Basrah to Galveston, TX, Without Cargo																			
"Average VLCC Tanker	CO_2	x			4.59E-06	MMBtu IFO 380/nautical mile- barrel	[1]	13,102	nautical miles	[2]	N/A	barrels	[3]	2.15E+01	kg C/MMBt	[4]	4.74E-03	1	4.74E-03
"Average VLCC Tanker	CH_4		x		4.59E-06	MMBtu IFO 380/nautical mile- barrel	[1]	13,102	nautical miles	[2]	N/A	barrels	[3]	8.60E-01	g CH_4/gallo	[5]	3.46E-07	21	7.27E-06
"Average VLCC Tanker	N_2O			x	4.59E-06	MMBtu IFO 380/nautical mile- barrel	[1]	13,102	nautical miles	[2]	N/A	barrels	[3]	3.00E-01	g N_2O/gallo	[5]	1.21E-07	310	3.74E-05

[1] Fuel use for "Composite" tanker based on information available for three VLCC tankers in use with crude transport (see calcs in "average" tanker tab) which are powered via combustion of IFO 380. The ports identified in this analysis are all capable of accommodating VLCC tankers.
[2] Port to Port distances derived from BP distance tables
[3] Assume Cargo Capacity of 2,000,000 Barrels - per Currie Evans (typical VLCC capacity)
[4] Carbon content of 21.49 kg C/MMBtu (Residual Fuel Oil #5, 6 The Climate Registry General Reporting Protocol v. 1.1 May 2008 Table 13.1)
[5] Emission factors from The Climate Registry General Reporting Protocol v. 1.1 May 2008 Table 13.6 Ships and Boats, residual fuel oil. Assume a heat content of 6.287 MMBtu/barrel (Residual Fuel Oil #5, 6 The Climate Registry General Reporting Protocol v. 1.1 May 2008 Table 13.1))

Appendix B: **Low Carbon Fuel Standard "Crude Shuffle" Greenhouse Gas Impacts Analysis**

Greehouse Gas
Impact Calculations
"Average" tanker calcs

Prepared for
Crude Shuffle Report
May 2010

Average Crude Tanker Based on 3 VLCC models in crude fleet

Sample VLCC 1:				**Patris (Built in 2000)**
Speed (laden)		15		knots
		360		nautical miles per day
Fuel Consumption (laden)	95-98			MT IFO 380/day
Speed (w/o cargo)		15.5		knots
		372		nautical miles per day
Fuel Consumption (w/o cargo)	85-88			MT IFO 380/day
Cubic capacity (total)		330573		cubic meters
Slop tank capacity		10067		cubic meters
Fuel usage rate (laden)		1.32E-07	1.35E-07	metric tons IFO 380/nautical mile-barrel
Fuel usage rate (w/o cargo)		1.14E-07	1.17E-07	metric tons IFO 380/nautical mile-barrel

Sample VLCC 2:			**BW Luck (Built in 2003)**
Speed (laden)	15		knots
	360		nautical miles per day
Fuel Consumption (laden)	95		MT IFO 380/day
Speed (w/o cargo)	15.5		knots
	372		nautical miles per day
Fuel Consumption (w/o cargo)	81		MT IFO 380/day
Cubic capacity (total)	337418		cubic meters
Slop tank capacity	7627.6		cubic meters
Fuel usage rate (laden)		1.32E-07	metric tons IFO 380/nautical mile-barrel
Fuel usage rate (w/o cargo)		1.09E-07	metric tons IFO 380/nautical mile-barrel

Sample VLCC 3:			**Bunga Kasturi Enam (2008)**
Speed (laden)	15		knots
	360		nautical miles per day
Fuel Consumption (laden)	92.5		MT IFO 380/day
Speed (w/o cargo)	15.5		knots
	372		nautical miles per day
Fuel Consumption (w/o cargo)	85		MT IFO 380/day
Cubic capacity (total)	299319		cubic meters
Slop tank capacity	8706		cubic meters
Fuel usage rate (laden)		1.29E-07	metric tons IFO 380/nautical mile-barrel
Fuel usage rate (w/o cargo)		1.14E-07	metric tons IFO 380/nautical mile-barrel

	Average/Composite Tanker		
Fuel usage rate (laden)	5.329E-06		MMBtu IFO 380/nautical mile-barrel
Fuel usage rate (w/o cargo)	4.594E-06		MMBtu IFO 380/nautical mile-barrel
Assumed Transport Capacity	2000000		Typical VLCC transport capacity