Troibox - Intermodal containerized transportation of heavy crude oil

[White paper]

[Data file available at http://www.troibox.ca/NetbackCalculations.xlsx]

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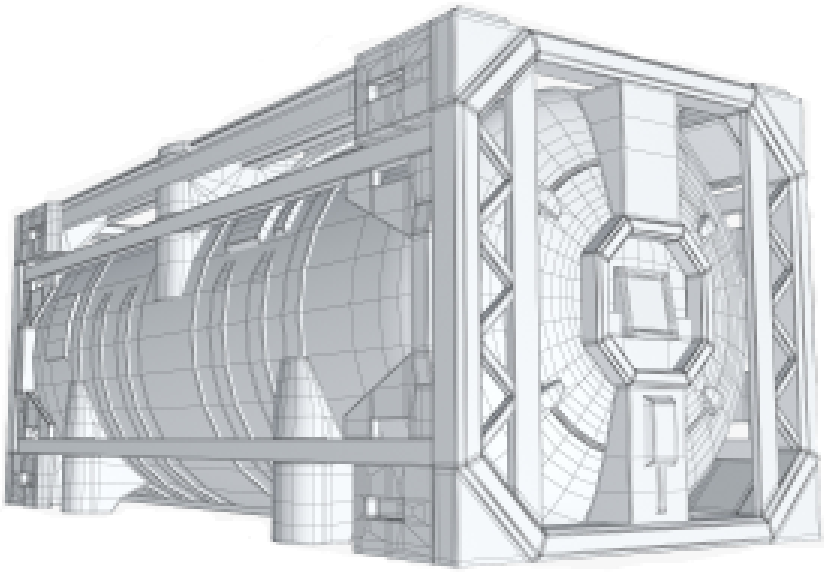

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Acronyms, abbreviations & notes

AB	Alberta
BC	British Columbia
bbl	Barrels
Bcf	Billion cubic feet
Sqft	Square feet
FID	Final investment decision
USGC	US Gulf Coast
HH	Henry Hub
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
m3	Cubic meters
mmbtu	Million British Thermal Units
mtpa	Million tonnes per annum
NGL	Natural gas liquids
US	United States
CBR	Crude by rail
DOT111	Old safety tank car standard
DOT117	New safety tank car standard
DWT	Deadweight tons, ship capacity
NIMBY	Not-In-My-Back-Yard

TroiBox	Dual purpose tank container for transport of crude oil and petroleum products
TroiPump	Containerized pumping mechanism suited for loading/unloading of TroiBox
TroiBoxLNG	Single purpose cryogenic tank container for transport of LNG
TroiBoxLPG	Single purpose pressurized tank container for transport of LPG
TroiShip	Roro category vessel suited for transport of TroiBox tank containers
TroiShipLNG	TroiShip suited for trasport of TroiBoxLNG and TroiBoxLPG tank containers

U.S. Patent Pending

All prices are in US dollars unless otherwise specified.

Summary

This technical paper offers a new logistic solution how to get heavy crude oil barrels from landlocked source areas to tidewaters. **It is a combination of trucking, rail and marine transport method with utilization of intermodal tank containers.** In order to be competitive with pipeline transport, the containerized transportation utilizes benefits of reduction of deadheading, integration with existing general cargo container flows and reduced infrastructure footprint.

Troibox can exist without any new facilities in the coastal areas. Everything important is done inland in the traditional oil and gas production areas. The system excels in heavy oil transport and even light oil transport where there are no pipelines at all. It cannot compete with pipelined light oil but it is orders of magnitude faster, linearly scalable and more economic than CBR. With some alterations the system can be tailored to LNG and LPG export.

Recent advances in composite materials manufacturing open many possibilities for how to improve existing transportation means. The effects are most visible in aeronautics and car manufacturing. The inland truck and rail transport is most sensitive to weight limitations and any reduction of cargo tare weight has a great impact on shippers profit. **The proposed tank container is built from composites, reducing its tare weight by more than 40%.** It works in tandem with containerized module pumps for loading and unloading, which is itself transportable by the same means as the tank container. **Minimal diluent use and heat preservation is the key to the transportation economics of bitumen and heavy oil.** Using 10% maximum dilution and 4 inch thick insulation it is possible to retain close to 40°C inner temperature after 8 days of transport. The composite tank is equipped with inner diaphragm which facilitates continuous unloading of viscous fluid. At the given temperature the fluid has composition of maple syrup, which is still possible to unload in a timely manner using the diaphragm push effect. If transported stacked, two in each car well, it is possible to transport 8% more barrels compared to DOT117 tank cars.

The diaphragm also divides the tank to compartments. It can allow loading of two liquids of different viscosity without contamination. This is the key aspect in reduction of deadheading. Such a system can bring crude oil to a refinery and distribute refined petroleum on the way back to the source.

Standard dimensions of the tank container allows merging with the current general cargo intermodal container flow, reducing the rail leg cost by one third, ultimately by half. Weight capacity of railway intermodal well cars is seldom fully utilized. In the North American continent most cargo weight flows from West to East, and there is a similar stream of empty cargo containers going from East to the West Coast returning back to Asia. The fastest and shortest

way to get cargo from China to Chicago is over a sea port in British Columbia and the route intersects crude oil production areas of Alberta and Saskatchewan. **By merging the crude oil weight into the empty stream and returning the empty containers with the full stream it is possible to spread out the required load capacity and achieve better resource utilization.**

The marine leg of the logistic system utilizes design of a RoRo ship. Versatility is an important factor here, since these ships can allow loading of any vehicle or containerized cargo using so-called cassette platforms. It isn't volumetrically as efficient as a tanker ship, but naturally, can transfer the same weight per DWT. In the combined ConRo version it is possible to house crude oil tank containers under deck and cargo containers above deck the same way as ACL Liners do. Each tank container slot has its dedicated pump mechanism which is itself modular in 8' sized containers connected to a permanent plumbing system in the ship walls. Its independent pumping action can achieve various pumping rates and controlled blending ratios.

The marine leg benefits from the same synergies as the Inland transport system. There are marine routes to countries which would greatly profit from integration of the traded product streams. For example South Korea is one of the biggest petroleum product exporters and is too much dependent on imports from the Middle East unstable regimes. The country also happens to be one of the largest exporters of electronics and cars. The integrated goods and products flow can greatly reduce or probably completely eliminate the crude oil front haul costs.

In comparison to pipelines, containerized crude oil delivery is possible in numerous small batches where one 40' tank container represents 300 barrels. **For a refinery, it can supply stabilized, chemically preprocessed feedstock, with clear origin description and predictable distillation essay.** Customized batches of exact 30°API crude oil can be mixed onboard the RoRo ship from tank containers carrying various grades of heavy and light oil. **Using controlled blending it is possible to "upgrade" less valued feedstock as bitumen is into midgrade crude oil.** None of a refinery has the same processing configuration and final product portfolio, there is always some variation which can be reflected in the feedstock tank container batch stream coming in from all kinds of different inland oil fields.

Unsurprisingly, the most profitable business case discussed in this technical paper is export of crude oil (or LNG) to Asia via the West Coast. The model assumes a blending ratio of 66:34 partially diluted bitumen vs Bakken light crude oil delivered containerized to Vancouver Delta port and shipped to Asia. Resulting Netback is almost $9 higher on average versus shipping WCS crude oil to Asia via the Transmountain Pipeline and tanker (Figure 1 - red bottom line).

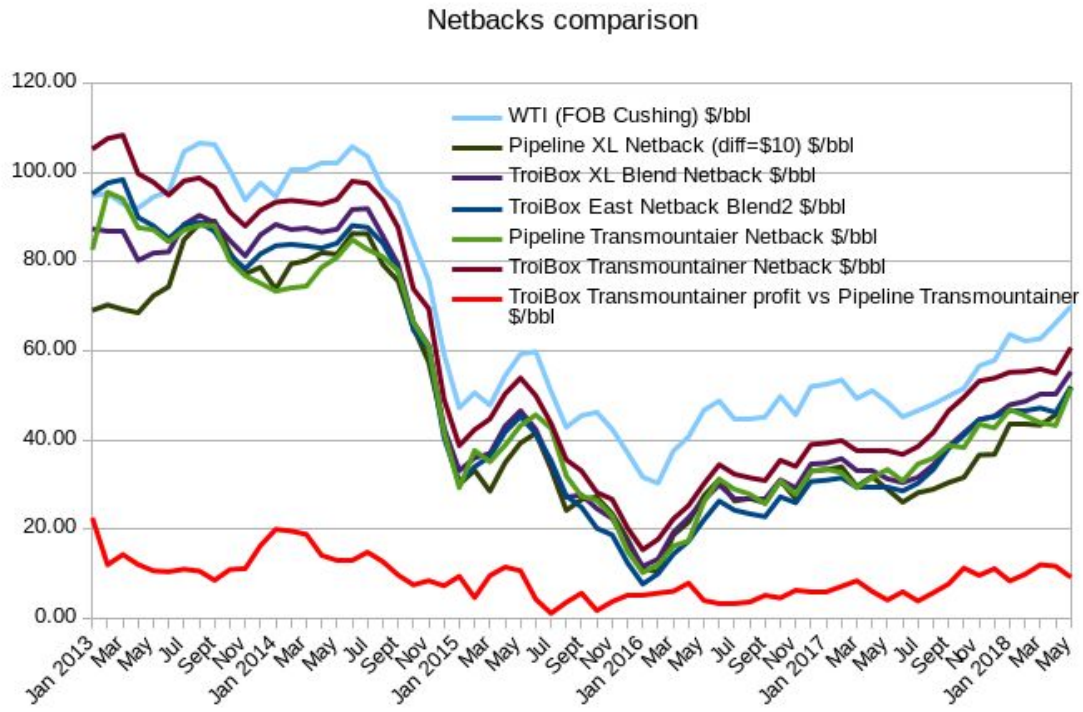

Figure 1 - Netbacks comparison

Comparison to WCS Hardisty spot price Netback is even more extreme (Figure 2).

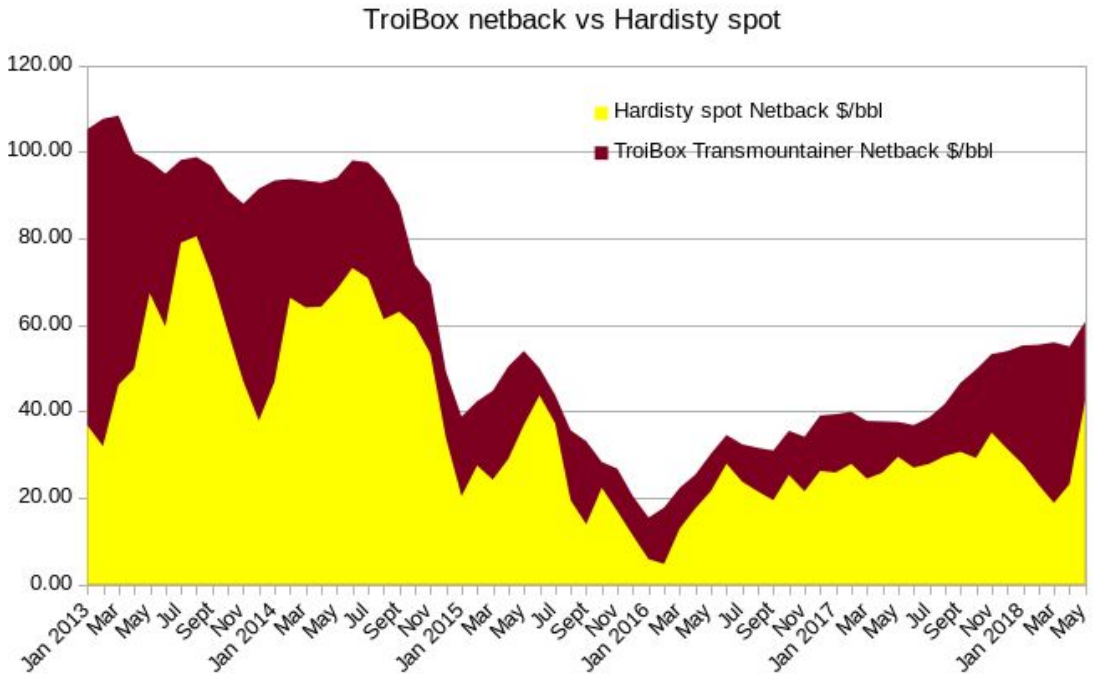

Figure 2 - Netback comparison TroiBox Transmountainer vs Hardisty spot

The dark red area represents potential profit for crude oil producers if they had invented containerized crude oil transport in January 2013. The business case is called TroiBox the Transmountainer and is discussed in detail further in the text. The two other cases, TroiBox XL and TroiBox East, are also more profitable on average than pipelines under some conditions. TroiBox XL achieved $4.44 better Netback compared to Pipeline XL and TroiBox East $2.81 versus Pipeline XL. In all cases the WTI/WCS differential number used in calculations was $10 as a better representation of normal situations.

Monetary profit isn’t the only point of view which favorizes this logistic system. There are also some political aspects making the solution attractive. Reducing Asian dependency on the Middle East crude oil imports is one of them.

Speed and flexibility pays a premium in today's economy and the presented logistic solution might be the key to the current complicated state of affairs in the Western Canadian oil patch.

Introduction

Western Canada has abundant reserves of extra heavy crude oil, located inland in provinces Alberta and Saskatchewan. Currently the biggest problem is to find out ways to get the barrels to the world energy market outside of the North American continent. Building new pipelines already became more political than technical and financial challenge. Current railway crude oil transportation model has its advantages, as speed, low diluent requirements and wider inland customer base. This is valid especially in case of transportation of extra heavy oil. But the system requires specialized infrastructure and equipment, which is expensive and inflexible.

The solution offered in this technical paper is a combination of intermodal road rail and marine transportation using specialized dual purpose tank containers. Its integrated system offers the possibility to achieve significant market share in crude oil, refined petroleum and general cargo transport markets combined. Therefore the chosen code name is TroiBox, a system integrating three markets together.

The primary goal of the integrated system is maximizing utilization of weight transportation capacity in both directions, from loading location to a customer and from the customer to the loading location wherever it is possible. As soon as there would be a greater volume of crude oil transferred, there would be a synergic effect on quality of service in the other two markets, distribution of fuels and general cargo, with better just in time delivery estimates, lower storage capacity requirements and faster transportation times. There is no shipping liner in the Pacific region which can offer daily service, normal schedule is one week. With sufficient export capacity the TroiBox can be the first one.

The system is set the way that the tank containers would supplement the current existing cargo containers traffic streams, which flow from west to east loaded, and from east to west usually empty. The tank containers loaded with oil would join the empty east to west stream and the empty ones would travel from seaport to production areas mixed with the full west to east stream. The marine part of the system benefits from the same synergies.

There are two factors affecting the price discount of Western Canadian crude oil. One is qualitative and second is geolocational. Since the majority of Western Canadian crude oil production is very heavy bituminous sour crude oil, it normally sells for lower price in comparison to lighter sweet grades of crude oil. A refinery must be specially equipped to process such a heavy feedstock. In order to overcome this natural disadvantage, there should be some other appealing factor for a customer. The magic word is customized blending and is discussed in detail in the Business cases section.

The first section of the technical paper describes details about the designed dual purpose tank container and pump, second section explains the connecting inland and marine transportation systems, third discusses economics of the solution in relation to existing and planned crude oil pipelines. Eventually there are sections discussing safety, environmental impact and challenges of the whole transport solution.

The TroiBox system

If there would be just two terms that would best describe the Troibox system, it would be modularity and mobility. Both components, the tank container (TroiBox) and the pump mechanism (TroiPump), are mobile and built in standard dimensions of a marine intermodal cargo container. This way they can move in tandem, although semi-permanent setup of TroiPumps allows for added benefits.

The tank container

The main idea behind the construction design of the tank container is elimination of fluid transfers and reduction of heat loss. The solution is completely independent of tank storage space on the way to a customer.

Once the tank container is loaded with crude oil, it goes all the way to the refinery where it unloads. Some degree of dilution is needed in case of heavier crude oil, together with the diaphragm push effect, in order to achieve continual discharge. The degree is dependent on seasonal weather variations and it is reasonable to believe that no more than 10% diluent admix would be required. The design of the tank container equipped with one diaphragm is in Figure 3.

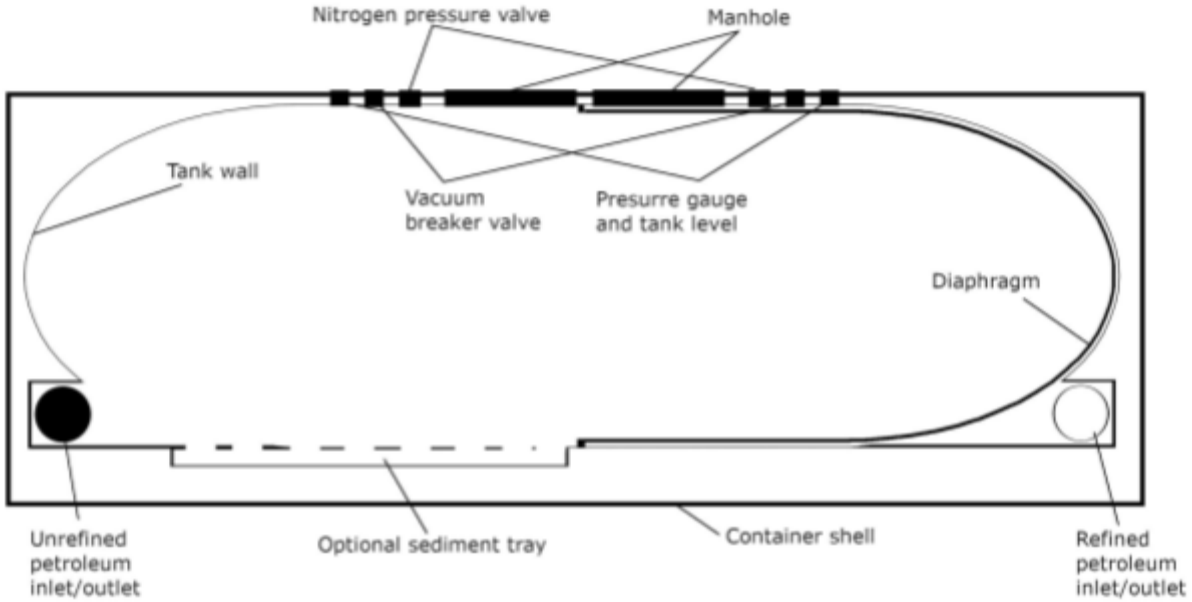

Figure 3 - TroiBox, The tank container

The inlet/outlet valves for unrefined and refined petroleum are separated and together with the diaphragm prevent contamination from a residual fluid in the opposite compartment. Two manholes allow tank side entry, and each side is also equipped with a vacuum breaker valve, pressure gauge and tank level. The tank is slightly pressurized using nitrogen gas from a generator present in TroiPump. The sediment tray allows gravitational separation and treatment of the loaded crude oil while it is transported. Excessive water, salt sediment and other possible impurities settle on the tray bottom, and get washed off every time the container arrives at a crude oil loading point.

The scheme in Figure 3 represents a 20 feet long tank container with designed capacity of 24 cubic meters (TEU). The 40 feet long version (FEU) has a designed capacity of 49.5 cubic meters and is equipped with two diaphragms dividing the tank on two side rooms and one middle room. The longer FEU version is the one called TroiBox further in the text, unless otherwise stated. The middle room of TroiBox would be better suited for refined petroleum, while the sides would form two separated compartments for crude oil. The capacity represents roughly 310 US barrels of 959 kg/m3 bitumen (49.5 x 6.29 =~ 310). Value of 300 bbl per TroiBox is used further in this text for simplification of calculations. These all exact values are given by road and rail transport restrictions, as is explained in section about Inland logistic system.

For bulk transport carriers it is critical to achieve as little tare weight as possible. Therefore the TroiBox inner tank is made of composite material[1]. This way it can achieve weight reduction by 40% compared to traditional materials like stainless steel and attains better thermal protection properties[2]. There are also antistatic versions for volatile products with flash point below 60°C[3].

In order to facilitate a seamless unloading process, the fluid inside the tank must retain as much heat as possible. Primary design of TroiBox doesn't count with heating elements inside of the tank, although the option exists and may be used in some special cases. This way it allows the manufacturing and delivery process to stay as simple as possible. Thermal loss formula (Figure 4) estimates the final cargo temperature at the arrival point.

[1] "Tankwell present composite tank containers in Amsterdam | Bulk ...." 27 Oct. 2017, https://bulk-distributor.com/2017/10/tankwell-present-composite-tank-containers-in-amsterdam/. Accessed 21 Aug. 2018.
[2] "weight savings and increased payload with composite tank ... - Aliancys." https://aliancys.com/en/cases/weight-savings-and-increased-payload-with-composite-tank-containers/. Accessed 21 Aug. 2018.
[3] "December 2017: Tankwell introduces anti-static tank container ...." https://tankwell.nl/news/4182/december-2017-tankwell-introduces-anti-static-tank-container. Accessed 21 Aug. 2018.

$$Q = \frac{(k)(A)(\Delta T)(1.1)}{L} \text{ Heat Loss, BTU/hr}$$

Figure 4 - thermal loss formula (source: https://www.process-heating.com)[4]

L is the insulation thickness in inches,
k is thermal conductivity, (BTU)(in)/(ft2)(deg F)(hr)
A is the surface area of object, sqft
ΔT is the temperature difference (T1 -T2), deg F

(k) value for polyurethane spray foam is 0.16, L insulation thickness 4 inches (same as DOT117 tank car[5]), A surface area in ft^2 of 40ft container is 4(sides) x 40(length) x 8(width) + 2(small sides) x 8(height) x 8(depth) = 1280 + 128 = 1408 ft^2, adding 10% for radiant and convection heat losses. This is simplification since the real surface area of a barrel is less than a cuboid.

Temperature difference varies with route. Since summertime is not a concern, the winter time January average temperatures at various points along the route are used. These values are further adjusted lower for the windchill effect of 60 mph wind (travel speed of a train). Table 1 presents heat loss values and cargo temperature at the various points on the route.

City	Avg Jan deg F	Windchill deg F	Transit time (hrs)	Heat loss BTU/hrs	Cargo temp deg F	Cargo temp deg C
Fort McMurray	-10	-48	48	557676	129	54
Edmonton	3	-29	24	234752	125	51
Winnipeg	0	-33	24	234392	120	49
Chicago	21	-3	48	364986	113	45
Memphis	32	13	24	148288	110	43
New Orleans	46	33	24	113920	108	42

Table 1 - Cargo heat loss calculation

The calculations and base values are further defined in the Appendix I.

Route from Fort McMurray to Luisiana (8 days) is used as a representative example. The cargo temperature is 60°C (140 F) at the start of the journey and 42°C at the end. This temperature

[4] "Calculating Heat Loss | 2016-12-01 | Process Heating." 1 Dec. 2016, https://www.process-heating.com/articles/87988-calculating-heat-loss. Accessed 21 Aug. 2018.
[5] "4 Insulation & Jacket - UTLX : Build a Tank Car." https://www.utlx.com/build-a-tank-car/4-jacket.html. Accessed 11 Sep. 2018.

implies viscosity of 2000 cP for 995 kg/m3 density bitumen diluted with 4.7% vol of toluene[6]. Such viscosity is similar to maple syrup[7].

The pump

The loading and unloading pump mechanism is designed similarly to a containerized mobile pump[8] or a packaged fire pump station[9] (Figure 5). It is equipped with a number of loading docks which can serve multiple TroiBoxes simultaneously. Each dock is equipped with a set of electric pumps governed by a central computer according to levels and pressures present inside the TroiBox inner tank compartments. This allows parallel loading and unloading or pressurizing of a given compartment using nitrogen gas generated by an integrated nitrogen generator.

Installation of a TroiPump is fairly simple, just connecting the appropriate riser using insulated fluid transfer hose and setting up power connection. Versions with diesel generators would also be available. All loaded or unloaded fluids are checked for temperature and API gravity. Blending with various solvents and other chemicals is done in-fly at the moment when the liquid passes the pump. Anywhere along the flowline is an opportunity to check for other fluid properties, like viscosity, impurities presence, sulphur volume, TAN, water, asphaltenes etc. All data describing every loaded batch and its related TroiBox is stored in an information system which tracks all TroiBoxes along the way to their customer. It is able to alter the route or even final customer anywhere and anytime on the way. Same way as TroiPump loads fluid, it can also unload fluid while performing the same properties check. This can be useful if there is some degree of gravity separation or chemical changes expected. The mechanism can inject a required amount of additive chemicals according to this sensor data.

[6] "Expanded Fluid Viscosity Model in VMGSim - Virtual Materials Group." https://virtualmaterials.com/sept2014-expanded-fluid-viscosity. Accessed 11 Sep. 2018.
[7] "Adhesive Viscosity Information and Comparison Chart – Hotmelt.com." https://www.hotmelt.com/blogs/blog/adhesive-viscosity-information-and-comparison-chart. Accessed 11 Sep. 2018.
[8] "Mobile pumping station powered by diesel Technojet MH | Technosub ...." 13 Feb. 2015, https://www.technosub.net/en/achievements/mobile_pumping_station_diesel_technojet/2015/02/13. Accessed 12 Sep. 2018.
[9] "Packaged Pump Houses | Holzhauer Pumpen." https://www.holzhauer-pumpen.de/en/packaged-pump-houses/. Accessed 12 Sep. 2018.

Figure 5 - TroiPump suggested design. (Source: www.holzhauer-pumpen.de[10], Wikipedia[11])

The TroiPump system is customizable according to various performance options and also according to designed fluid properties. Loading and unloading rate is variable, but approximately 150 m^3/hour is expected. There is also a smaller sized marine version discussed further in the text.

Inland logistic system

Since the Western Canadian crude oil resources are landlocked, their production must be moved via land transportation methods, optionally followed by marine transport. This is also valid for some of the new shale oil plays in the US. TroiBox inland logistic chain includes road trucking and railway transport. If a loading point facility has access to a railway sidetrack, the trucking leg can be skipped.

Trucking

Trucking is the shortest and most expensive per mile leg. But it is also the most versatile and allows for centralized placement of intermodal rail-to-road transshipment yards. The limit of maximum cargo container weight is set by standard road truck GVW capacity. Fully loaded TroiBox weighs 50 tonnes and is designed for Canadian roads with a GVW limit of 63.5 tonnes. [12] US interstate highways allow maximum GVW 80 000 lbs without permit[13], which is too low for

[10] "Packaged Pump Houses | Holzhauer Pumpen." https://www.holzhauer-pumpen.de/en/packaged-pump-houses/. Accessed 12 Sep. 2018.
[11] "File:Truck trailer loading dock - Flickr - Joost J. Bakker IJmuiden.jpg ...." 2 Feb. 2018, https://commons.wikimedia.org/wiki/File:Truck_trailer_loading_dock_-_Flickr_-_Joost_J._Bakker_IJmuiden.jpg. Accessed 12 Sep. 2018.
[12] "Government of Alberta Ministry of Transportation: Regulation Summary." http://www.transportation.alberta.ca/4777.htm. Accessed 20 Aug. 2018.
[13] "Commercial Vehicle Size and Weight Program - Freight Professional ...." 20 Jun. 2018, https://ops.fhwa.dot.gov/freight/sw/overview/index.htm. Accessed 20 Aug. 2018.

a regular 40’ TroiBox. Some states have higher GVW limits, for example in North Dakota it is 105000 lbs GVW. Anything overweight is subject to a special permitting process. TroiBox could legally access US roads only partially loaded or in a smaller 20’ long TEU version.

Similar to the cargo container delivery process, TroiBox is collected in an intermodal yard by a truck equipped with a chassis trailer and is driven to a crude oil loading point. It could be located in a field battery or any other produced emulsion treatment facility. TroiPump fills up the inner tank to a desired level while thinning the crude at predetermined ratio and adding treatment chemicals. Since every TroiBox is loaded once and emptied at the end of the journey at a refinery, the transport time is utilized for further treatment of the loaded crude oil. After TroiBox finishes the loading process, it is trucked back to the intermodal rail yard and transferred onto a train using a crane or a reach stacker.

Although certainly possible, a pure inland only TroiBox logistic chain would require installation of unloading pump equipment in every cooperating refinery. Average 100 000 bbl/day supply would require managing daily flow of 330 truck loads, generating significant heavy traffic in a local area. TroiBox implicitly assumes marine delivery to a refinery. Using a delivery ship (TroiShip) it is possible to supply a number of customer points with large transporting capacity. This is the most economic logistic configuration and is further discussed in the following paragraphs.

Rail

The rail leg is the second most costly part of the TroiBox supply chain per tavelled mile. However, in absolute terms it is the most expensive one. 5% extra tare weight makes a big difference in a thin margin business as crude oil rail transportation is. From the outside point of view TroiBox is just a container with the same dimensions as other intermodal cargo containers. This allows merging with existing intermodal infrastructure and cargo flow streams.

From an infrastructure point of view, the system would require two or three big container yards, preferably located in Fort McMurray, near Edmonton and centrally in conventional oil producing areas. There would be smaller yards for loading of manifest trains in suitable local railway yards or old grain elevator side tracks. The point of choosing the right location is to shorten last mile trucking as much as possible. As there is no need for fluid transfer operation, the time needed for loading a train is radically reduced. One of the main advantages of containerized transloading is that the technology and infrastructure is already existing and proven.

Weight advantage

As reaction to public outrage regarding unfortunate accidents related to crude oil transport, the US and Canadian authorities agreed on a new standard, DOT117, for railway cars involved in transportation of crude oil and refined petroleum. The new standard means thicker tank walls and thus more tare weight. A new tank car built after 2015 weights approximately 85500 lbs[14]. In case of coiled and insulated tank cars, the tare weight is approximately 94200 lbs[15]. The oldest DOT111 models were already phased out, and the updated CPC1232 models are scheduled to be phased out by May 2025 latest.

Maximum weight per a railway car in North America is 286 000 lbs. In case of DOT117 insulated and coiled tank car the maximum cargo weight is 191 800 lbs. 191 800 / 2.2 = 87 180 kg, which can be used for loading of 90 m3 of 959 kg/m3 bitumen. Realistically there is room for about 571 barrels (90/0.159).

There are three possible container transport car options available, multi unit well cars or single unit cars, stacked or flat.

Multi unit well cars

Flow of the weight of goods in North America is very unevenly distributed. There is the heavy stream, from the West Coast to the North East of the US and eastern parts of Canada. These destinations are the most populated parts of the continent. And there is the return stream of empty containers flowing the opposite way. Prairie provinces happen to be on this route and streams of TroiBoxes can benefit from the bidirectional uneven traffic by adding its weight to the light westward stream and joining the full eastward stream when empty.

[14] "North American Car Fleet: Trends - The North East Association of Rail ...." https://www.nears.org/2015%20updates/FALL/Presentation%20Page/15_NEARS_Pickel.pdf. Accessed 19 Aug. 2018.
[15] "28.4K Tank - Crude Oil & General Purpose | Greenbrier." https://www.gbrx.com/manufacturing/north-america-rail/tank-cars/284k-tank-crude-oil-general-purpose/. Accessed 19 Aug. 2018.

Standard multiwell container flat cars have capacity of about 60 tonnes per well, not enough for double stacking of TroiBoxes. But they are widely available and can be used to maximize utilization of car weight capacity as a way to share costs with standard cargo container traffic.

Example of a three well intermodal car is in Figure 6, as the most used and representative of all well cars in North America.

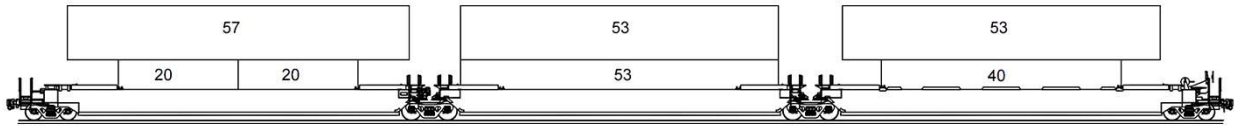

Figure 6 - Three unit articulated double-stack well car[16]

Containerized transport is priced per container, which means it is priced per volume. In average, trains achieve about 60% of the car weight capacity utilization rate.[17]

Tare weight of an articulated three-unit flat car is 125000 lbs, approximately 41 600 lbs (19 tonnes) per a well.[18] Assuming fixed cost per car well is divided between two containers, and counting in approximate weight 4000kg for the composite TroiBox. TroiBox has a capacity of 310 barrels in case of 959 kg/m3 bitumen load.

For every railway is by far the biggest limiting factor the number and availability of locomotives. For better understanding of the container merging concept, there is an example.

Example 1 - Fully loaded train going from Vancouver to Edmonton and back empty.

4 locomotives and 200 well cars carrying 400 containers

[16] "Maxi-Stack® IV Car | Greenbrier." https://www.gbrx.com/manufacturing/north-america-rail/double-stack-cars/maxi-stack-iv-car/. Accessed 20 Aug. 2018.
[17] "North American Car Fleet: Trends - The North East Association of Rail ...." https://www.nears.org/2015%20updates/FALL/Presentation%20Page/15_NEARS_Pickel.pdf. Accessed 20 Aug. 2018.
[18] "Maxi-Stack® IV Car | Greenbrier." https://www.gbrx.com/manufacturing/north-america-rail/double-stack-cars/maxi-stack-iv-car/. Accessed 20 Aug. 2018.

maximum weight of the transport: 29 tonnes per container and average well car tare weight 19 tonnes makes 77 tonnes per car, 15400 tonnes per train, 3850 tonnes per locomotive.

When the same train returns to Vancouver with empty containers, the transported weight per a car is 27 tonnes (container average tare is 4t). Each locomotive transports just 1350 tonnes. The train deadweight tonnage on the way back is 10000 tonnes.

Example 2 - Fully loaded train going from Vancouver to Edmonton and back loaded with Troiboxes.

4 locomotives and 200 well cars carrying 400 containers + **1 extra locomotive** and 115 well cars carrying 230 Troiboxes

Weight of the transport Vancouver -> Edmonton, 15400 tonnes + 115 x (19 + 8(2 empty Troiboxes, 4000kg tare weight)) = 18505 tonnes, 3701 tonnes per locomotive

Weight of the transport Edmonton -> Vancouver, 15400 - 10000 + 115 x (19 + 100(2 full Troiboxes, 50 tonnes each) = 19085 tonnes, 3817 tonnes per locomotive

As you can see, by increasing the locomotive power by 25% it's possible to evenly balance transported weight in both directions. According to some estimates standard CBR is charged $8/bbl in this direction. **Translating the cost structure directly, Troibox system can transport 62000 bbl per train for $2 each. Transmountain currently charges $2.1 per bbl of extra heavy oil for transfer between Edmonton and Westridge terminals.** If accounting for diluent penalty, Troibox would be approximately 25-30% more economic than pipeline.

To assure a safe transport, railways always try to put as much weight on a train as possible to avoid crosswind related accidents and derailing.[19]

Single unit cars

There will be parts of a TroiBox route which will not benefit from the cargo merging concept, like Edmonton to Fort McMurray track, for the reason that there is minimal cargo container traffic. But it would be possible to equip this route with heavy duty single well flat cars capable of carrying up to 100 tonnes double stacked. (Figure 7)

[19] "Transportation Safety Board of Canada - Railway Investigation Report ...." 4 Sep. 2013, http://www.bst-tsb.gc.ca/eng/rapports-reports/rail/2012/R12W0165/R12W0165.asp. Accessed 20 Aug. 2018.

Figure 7 - Heavy duty double stack well and single stack flat car[20]

The cars have tare weight 60 000 lbs and can carry 225 400 lbs of cargo weight[21]. Counting in 8 tonnes (17600 lbs) tare weight of two TroiBoxes, the total transport capacity is 620 barrels per car.

Single stacking unit flat cars have the same tare weight[22] as well cars so the calculations would be the same. They can carry two 40’ containers and their length is 90’ on average. Train composed of single stack flat cars would be 50% longer than a double stacked train since well cars have length of 62' on average.

Troibox's ability to carry almost 50 extra barrels compared to standard DOT117 tank cars represent 8.6% higher efficiency.

Economics

The North American tank car fleet is currently undergoing forced transformation thanks to the phase out schedule for old DOT111 tank cars. Price of a new DOT117 car is well over CAD 200 000[23]. In contrast to the expected TroiBox manufacturing price of approximately CAD 25 000 and wide availability of multimodal well cars, it is a better solution even from an initial capital cost view.

Time is money. The largest tank car loading stations have capacity to load or unload one train a day and cost hundreds of millions to build. Double stacked intermodal trains of 250 cars can be

[20] "National Steel Car Limited: 83-Foot 7-Inch Container Flat Car." https://www.progressiverailroading.com/railproducts/product.aspx?id=5025. Accessed 21 Aug. 2018.
[21] "48-Foot Heavy Duty Well Car - Progressive Railroading." https://www.progressiverailroading.com/railproducts/product.aspx?id=129. Accessed 21 Aug. 2018.
[22] "Heavy Duty Flatcar | Greenbrier." https://www.gbrx.com/manufacturing/north-america-rail/flatcars/heavy-duty-flatcar/. Accessed 21 Aug. 2018.
[23] "Technology - Altex Energy." 11 Apr. 2018, https://altex-energy.com/wp-content/uploads/2018/04/Hydro-Transport-2018-Technological-Breakthroughs.pdf. Accessed 21 Aug. 2018.

unloaded and loaded within 4 hours using 10 reach stackers. Intermodal container train is statistically more than twice as fast as a bulk freight train[24].

From a business risk control view, any investment into intermodal transport is also investment into general cargo transportation infrastructure. If hard times hit, and there is limited demand for crude oil transport, all the equipment has a secondary use. Standard CBR equipment cannot match this versatility and sits idle when not in demand[25].

Marine logistic system

In order to explain the marine transportation concept of the TroiBox idea, it is necessary to understand a Ro-Ro (roll on roll off) ship design (Figure 8). The design allows motorized cargo to enter and leave the ship under deck area on their own. Roro ships also can carry standard cargo containers on top of the deck. TroiBox Ro-Ro ship (TroiShip) utilizes similar design.

Figure 8 - Ro-Ro ship

The main idea behind the TroiShip design is maximization of berth time savings using specially designed container cassettes. Underdeck space, which is normally occupied by various vehicles, is dedicated solely for storing TroiBoxes. In 14000 TEU (1 TEU = 10 DWT) equivalent TroiShip, the cargo load is divided as is in standard container ship, where is roughly 45% cargo

[24] "Canadian National - CN Rail." 30 Apr. 2010, https://www.cn.ca/-/media/Files/Customer-Centre/Customer-Centre-Documents/CN-Submission-RSR-30apr10-en.pdf?la=en&hash=385E57815F6F5B1B9F47D90500182470C7CC039C. Accessed 21 Aug. 2018.
[25] "Global Partners cuts workers, scraps crude at rail terminal | Reuters." 28 Jan. 2016, https://www.reuters.com/article/us-globalpartners-layoffs-idUSKCN0V633R. Accessed 21 Aug. 2018.

volume underdeck[26]. Calculating 45% from 14000 TEU assigns approximately 6300 TEU to the underdeck area. A loaded TroiBox weighs 50 tonnes, and has a volume of two TEU. Theoretically it would be possible to squeeze 3150 TroiBoxes under the deck, but that would exceed total ship DWT capacity. The available room setup (service space) also requires room for installation of pumps and plumbing for loading/unloading mechanism. If the service space would be ⅓ of the total available space it would allow loading of about 2050 TroiBoxes. Then the loaded ship weight would be 2050 x 50 = 102500 DWT in underdeck space. It would be still possible to load another 37500 DWT above deck. Calculating 37500 / (14000-6300) = 4.5 tonne per TEU above deck. Average gross weight per loaded TEU is statistically about 14.2 tons[27]. If the TroiShip should leave full, most of the cargo containers above deck would have to be empty. And that would perfectly fit into the containerized cargo stream to and from North America, since containers come in full and more than half leave empty[28]. It is another business opportunity because shipping lines container repositioning represent extra cost. To move empty container costs almost the same as full[29].

Another problem in cargo container transport is berth availability. The true ship arrival time seldom matches the expected arrival time. This can be, in some cases, solved by installation of ondeck container/cargo crane[30].

The biggest container ships today have capacity over 20 000 TEU. In order to load and unload such a large amount of containers they dwell at ports for days. Many spend more days moored than on the open sea, during the productive life. Average West Coast berth productivity, measured as number of crane moves per hour, is around 80[31]. Some Asian terminals double this number. If a berth crane can move TroiBox's 50 tonnes as fast as a standard container, it would translate to a loading rate of 24000 bbl/hour. LOOP tanker load/unload platform in USGC can ultimately move 100 000 bbl/hour[32]. A container terminal can also achieve such an imaginary flow rate by multiplying the number of employed berths, but at the additional expense of 4 times as much working equipment, manpower and vessels. The current standard terminal

[26] "“ON DECK STOWAGE OF CONTAINERS” - AIMU Papers Available ...." https://www.aimuedu.org/aimupapers/OnDeck.pdf. Accessed 18 Aug. 2018.
[27] "Filling Ultra-Large Container Ships - The Maritime Executive." 16 Mar. 2015, https://www.maritime-executive.com/article/filling-ultra-large-container-ships. Accessed 18 Aug. 2018.
[28] "The Repositioning of Empty Containers - Hanseatic Chartering." 12 Feb. 2016, http://hanseatic-chartering.com/the-repositioning-of-empty-containers/. Accessed 18 Aug. 2018.
[29] "The Repositioning of Empty Containers | The Geography of Transport ...." https://transportgeography.org/?page_id=9481. Accessed 18 Aug. 2018.
[30] "Hydraulic material handlers | Mantsinen Group Ltd Oy." http://www.mantsinen.com/en/products/material-handlers/. Accessed 30 Aug. 2018.
[31] "Asian, Mideast ports maintain port productivity lead - JOC.com." 9 Jun. 2015, https://www.joc.com/port-news/port-productivity/asian-mideast-ports-maintain-port-productivity-lead_20150609.html. Accessed 19 Aug. 2018.
[32] "The VLCC Race: US midstream companies plan to export more oil faster." 23 Jul. 2018, http://blogs.platts.com/2018/07/23/vlcc-midstream-us-crude-oil-export/. Accessed 19 Aug. 2018.

set up has its limits at about 165 moves/hour under some conditions[33]. Twice as fast performance would be needed to compete with existing and planned VLCC loading terminals.

How to achieve such productivity? First, it is necessary to understand how shipping lines work. In any transocean trade a ship should visit as many ports as possible, in order to utilize maximum of its capacity. A shipping liner schedules trips on a route anywhere between 5-10 days apart and seldom gets a ship completely loaded and unloaded at a single port. The port rotation is essential to profitability and every shipping line utilizes different schemes according to demand prediction. For TroiShip, cargo container transport is secondary business after crude oil delivery. It can focus on some routes and ports, as close to planned crude oil transfer points. And since it shares costs with potential refined petroleum distribution backhaul, it can also reflex some elasticity in pricing. But the major point is that TroiShip gets always completely unloaded and loaded at a domestic crude oil point of export. This fact gives some advantage in the domestic port configuration. TroiShip design calculates with altered loading/unloading scheme since above and under deck areas are permanently divided. It allows loading cargo containers into permanent hold structures - cell guides, the same as ACL liners offer[34]. To service the underdeck area is more challenging since it is technically confined space, accessible either by back or side doors. One of possible solutions is to divide the space into separate levels, connected internally using hydraulically liftable ramps. Every level is divided into tight lined slots for double stacked TroiBox cassettes. Each slot has a connection to a dedicated pump mechanism built in the TroiShip walls. These small TroiPumps have a fraction of power and speed compared to their inland counterparts, but since they unload many TroiBoxes at once the total flow rate is many times multiplied. TroiBoxes would be moved from and into the slots using translifters, just like cargo containers in a classic RoRo ship (Figure 9). NT Liftec has solution for up to 200 tonnes[35]. Such cassettes can carry 4 TroiBoxes at once. With the right workflow management and with the right number of berth cranes this solution can provide flow performance comparable to LOOP platform.

[33] "Time to get real on container terminal berth productivity? | Neil Davidson." 28 Sep. 2017, https://www.linkedin.com/pulse/time-get-real-container-terminal-berth-productivity-neil-davidson. Accessed 19 Aug. 2018.
[34] "Atlantic Container Line." http://www.aclcargo.com/pdfs/acl_roro_2013.pdf. Accessed 19 Aug. 2018.
[35] "Applications - NT Liftec."https://www.ntliftec.com/cassette-systems/. Accessed 19 Aug. 2018.

Figure 9 - NT Liftec cassettes[36]

2050 TroiBoxes in the underdeck area represent capacity of well over 600 000 barrels in neopanamax ship class (140 000 DWT). A TroiShip can leave the port terminal fully loaded within one day. A valid argument is that standard neopanamax class tankers can carry almost double the capacity in barrels. But they are dependent on a specific loading location. TroiShip can load its crude oil cargo from any port equipped with appropriately sized berths with railway access. There is also a problem of accessibility to most sea shore harbors and transfer stations. Draft limit at Burrard inlet in Vancouver doesn't allow tanker ships to pass through with more than 550 000 barrels[37].

Marine transportation generally is the most economical form of transport. Almost every refinery has marine access to its tank farm. TroiShip utilizes this access not just for unloading ordered crude oil slate, but also for loading refined petroleum into the same TroiBoxes. Each TroiBox slot within the TroiShip is equipped with two independent electric pumps, governing loading or unloading each side of the tank separately.

Every single TroiBox represents 300 barrels of ingredients in the final batch. Every ingredient can have different properties and using controlled discharge from each TroiBox, it is possible to simulate in-fly blend preparation while unloading. This feature would have enormous influence on feedstock scheduling formulation in today's refinery processes and represents one of the major added values of the TroiBox system. Finding an optimal solution for a dynamic process of many unpredictable variables is a mathematically unresolveable task. Some refinery scheduling models use mixed integer linear programming generating 21504 variables for a problem with pipeline receiving three parcels of oil, six charging tanks, one distillation unit and three types of crude oil[38]. (Figure 10)

[36] "Applications - NT Liftec."https://www.ntliftec.com/applications/. Accessed 19 Aug. 2018.
[37] "Canada oil sands Asia export dream faces port bottleneck | Reuters." 20 Nov. 2016, https://www.reuters.com/article/us-canada-ports-crude-analysis/canada-oil-sands-asia-export-dream-faces-port-bottleneck-idUSKBN13G016. Accessed 19 Aug. 2018.
[38] "Short-term Scheduling for Refinery Process - Semantic Scholar." https://pdfs.semanticscholar.org/7a59/7e6ca2376d4c9bf27396787638dcef60c71b.pdf. Accessed 19 Aug. 2018.

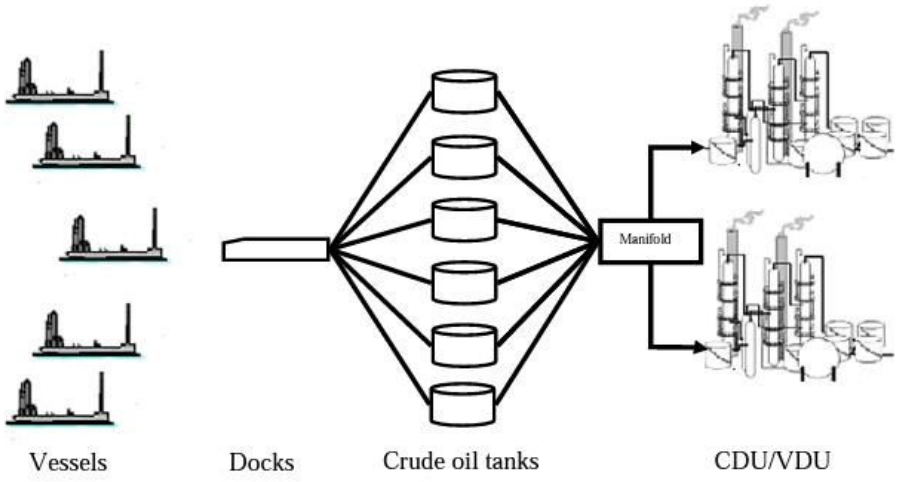

Figure 10 - Refinery crude slate blending problem.[39]

Just-In-Time delivery method is widely used in discrete manufacturing systems, and scheduling for refinery processes is perfect fit for the same approach. Up to now all short term refinery planning models deliver so called push schedule[40], often resulting in extra products that must later find its customer. In today's world of tight refinery margins is a way more useful pull system, when a refinery reacts on actual market opportunities, and supply just demanded production in order to minimize inventory cost. TroiBox logistics allows use of a pull system together with integrated Just-In-Time delivery of the feedstock and also optional distribution of refined products. Simply said, using TroiBox a refiner has the option to select exact crude slate and get it blended a la carte with minimal operational and storage requirements.

Chemical stability of containerized batches is critical for quality control[41]. There are two chemical injection points, at the TroiBox primary loading spot, done by TroiPump, and during the berth blending/unloading operation on the board of TroiShip. This allows for separated treatment during transport and stabilization of crude oil blend during preparation.

Abundant sources of heavy oil in Canada, together with tight oil drilling frenzy in the US create new business opportunities for transfer terminal operators. It is possible to imitate some higher

[39] "Scheduling of Loading and Unloading of Crude oil in a Refinery." http://www.mie.uth.gr/ekp_yliko/SchedulingofCrudeOilSaharidisVersion_1.pdf. Accessed 19 Aug. 2018.
[40] "Short-term Scheduling for Refinery Process - Semantic Scholar." https://pdfs.semanticscholar.org/7a59/7e6ca2376d4c9bf27396787638dcef60c71b.pdf. Accessed 19 Aug. 2018.
[41] "processing shale feedstocks - DigitalRefining." 12 Jun. 2015, http://www.digitalrefining.com/data/digital_magazines/file/385073581.pdf. Accessed 16 Sep. 2018.

crude oil streams as Alaskan ANS or Arab Heavy using blend of bitumen and a shale crude oil[42]. The blending operation itself represents risk since incompatibility of crudes can lead to asphaltene precipitation. Asphaltenes are broadly present in heavy oil and bitumen. The kinetics of this effect hasn't been getting much attention, but can be critical in solving the mystery of refinery equipment fouling. Despite popular belief, the precipitation onset isn't a real set point but an always ongoing process[43]. TroiBoxes in TroiShip allow separate treatment of blend components and delay the blending operation as much as possible to slow down this process. The less contact a crude oil batch gets with incompatible matter the better. The concept can imitate exactly the blend a refinery is set up for[44].

TroiBox allows for simultaneous loading of various fuels, such as gasoline, diesel, kerosene or chemicals and solvents, while the crude oil blend is being unloaded. The job of fuel distribution is normally done by specialized barges, which, same way as crude oil tankers, deliver their cargo and return back loaded with ballast water. The world commodity transport system terribly wastes resources since at any given time, around 45% of dry-bulk ships are cruising the seas carrying no cargo at all[45]. These ships burn fuel and spend fixed and variable capital just to haul seawater in ballast tanks all around the globe. It is the natural outcome of specialized ship design. It is unrealistic to expect an iron ore carrier to distribute finished steel products on its way back from Asia to South America. But there are different situations in case of liquids. If the crude oil route matches the refined products delivery route, there is a clear business case for a dual purpose vessel. Clean tanker rates are usually double of dirty rates[46] and the ease and time savings of simultaneous unloading of crude oil and loading of refined products is another added benefit of TroiShip design. The product blend, gasoline or fuel oil, can be achieved the same way as the desired crude slate. First South Korean refinery on the way supplies FCC low octane gasoline, second reformate and a third, Japanese refinery, alkylate products, thus, again, benefiting from possible arbitrages. (And somewhere on the way, TroiShip can stop at a terminal and load 1000 cargo containers loaded with Asian made cars.) Petroleum products can be kept separated in the TroiBoxes until blended while unloaded either at a coastal fuel terminal or inland railway terminal. It is effectively avoiding cost of treatment of transmix barrels and

[42] "Port%of%Beaumont%Terminal% Crude%Blending%Issues% - LBCG." https://www.lbcg.com/media/downloads/events/447/mark-viator-jefferson-energy-companies.7827.pdf. Accessed 19 Aug. 2018.
[43] "ii UNDERSTANDING THE KINETICS OF ASPHALTENE ... - Deep Blue." https://deepblue.lib.umich.edu/bitstream/handle/2027.42/84624/tabish_1.pdf?sequence=1. Accessed 19 Aug. 2018.
[44] "UPDATE 1-Sinopec says some refineries would be hit by a halt in Iran ...." 27 Aug. 2018, https://af.reuters.com/article/africaTech/idAFL3N1VI30K. Accessed 30 Aug. 2018.
[45] "Global trade in commodities is so imbalanced that 45% of ships travel ...." 30 Nov. 2017, https://qz.com/1031020/heres-a-sign-of-our-massive-global-trade-imbalance-right-now-45-of-ships-are-traveling-without-cargo/. Accessed 14 Sep. 2018.
[46] "Low tanker rates are enabling more long-distance crude oil and ... - EIA." 27 Oct. 2016, https://www.eia.gov/todayinenergy/detail.php?id=28532. Accessed 19 Aug. 2018.

downgrading of product as it is in case of pipeline transportation[47]. This feature would solve, at least partially, the product blending logistic problem for refiners.

TroiShip business scheme also hedges from rising charter rates. Petroleum tanker market currently suffers from overcapacity, depressing the cost of crude oil transport. Charges can easily double or triple once the market scraps old ships[48]. This normally happens when the world economy is in conjuncture and there is strong demand for transport. At that moment container transport rates also rise. Flexibility is a bonus which pays a premium in today's economy and the multi usability of TroiShip is a perfect tool for arbitration especially in east Asia global transportation and refining hubs.

Business cases

Just as pipelines are built to the most profitable markets, the same way TroiBox logistic solution aims to reach the tidewaters. Since it is designed the same way as standard intermodal containers, it has unique versatility incomparable to any other means of transport. Next paragraphs describe three possible routes for TroiBoxes and their comparison with the currently proposed pipeline solutions together with calculation of expected netbacks. There is also a business case for LNG and LPG logistics.

TroiBox XL

The refinery cluster located on the USGC represents the biggest and most technically advanced refining capacity in the world. It is a natural target for any heavy oil barrel in North America.

The cost model of possible viable routes assumes some constant values and expected netback formulas. It compares pipeline, rail and TroiBox transportation costs. The formula for pipeline netback uses the WCS Hardisty benchmark as the sales point, actual cost of transport to the Hardisty tank farm and diluent penalty. It assumes standard 30:70 diluent to bitumen blending ratio.

A - price of WCS[49]
B - transport to Hardisty (pipeline and other related costs as tankage etc.) - assumed $3[50]

[47] "Transmix Downgrade - HubSpot." http://cdn2.hubspot.net/hubfs/210162/Transmix_App_Note.pdf. Accessed 12 Sep. 2018.
[48] "Is the VLCC market bottoming out? | Crucial Perspective." https://crucialperspective.com/vlcc-market-bottoming-out/. Accessed 19 Aug. 2018.
[49] "Baytex Energy Corp. - Benchmark Heavy Oil Prices." http://www.baytexenergy.com/operations/marketing/benchmark-heavy-oil-prices.cfm. Accessed 20 Aug. 2018.
[50] "Understanding Bitumen Pricing | GLJ Petroleum Consultants." 18 May. 2016, https://www.gljpc.com/blog/understanding-bitumen-pricing. Accessed 20 Aug. 2018.

C - cost of diluent (Edmonton hub)[51]
D - cost of diluent logistic - assumed $1.5 (pipeline toll + other handing)[52]

Pipeline netback formula = (A - B - (C+D)x0.3)/0.7 (normalization to one barrel of bitumen)

Formula for CBR is a little different from pipeline, since it integrates local heavy oil benchmark price (Mexican Maya) at USGC. It uses RailBit 20:80 diluent to bitumen blend ratio.

A2 - landed cost of Maya crude oil at USGC[53]
B2 - cost of transport plus loading and unloading fee - assumed $18 (unit train tariff Fort McMurray to USGC 2500 miles $15 + 2x$1.50)
D - cost of diluent transport, assumed $5.5 trucking from Edmonton[54]

// Rail tariff breakdown //
Generic tariff, cents per ton mile (Rail Trends 2017 p. 23)[55] - 4.59 cents C$ = 3.58 cents US$ (exchange rate 0.78)
Cost per bbl = [130 tonnes (max weight of a railway car) x 2500 (distance in miles) x 0.0358 (generic tariff)] / 571 = $20 (DOT117 insulated and coiled tank car can carry maximum 571 bbl of 959 kg/m3 bitumen, it weights 94200 lbs empty[56] (286000 lbs - 94200 lbs)/2.2 (lbs to kg) /959 /0.159(m3 to bbl)))
Unit train cost per bbl = cost per bbl x 0.75 = 20 x 0.75 = $15 (25% discount)[57]

CBR netback formula = (A2 - B2 - (C+D2)x0.2)/0.8 (normalization to one barrel of bitumen)

In case of TroiBox, 10% dilution is sufficient for transportation since the TroiBoxes have superior insulation. TroiBox has also a weight advantage. DOT117 crude oil tank car coiled and insulated

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[51] "Historical Data." 14 May. 2018, https://www.capp.ca/~/media/capp/customer-portal/documents/86750.pdf?la=en&modified=20180514154720. Accessed 20 Aug. 2018.
[52] "Understanding Bitumen Pricing | GLJ Petroleum Consultants." 18 May. 2016, https://www.gljpc.com/blog/understanding-bitumen-pricing. Accessed 20 Aug. 2018.
[53] "US Landed Costs of Mexican Mayan Crude Oil (Dollars per Barrel) - EIA." https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=IMX2810008&f=M. Accessed 20 Aug. 2018.
[54] "Understanding Bitumen Pricing | GLJ Petroleum Consultants." 18 May. 2016, https://www.gljpc.com/blog/understanding-bitumen-pricing. Accessed 20 Aug. 2018.
[55] "Rail Trends 2017 - Railway Association of Canada." https://www.railcan.ca/wp-content/uploads/2018/01/Rail_Trends_2017.pdf. Accessed 20 Aug. 2018.
[56] "28.4K Tank - Crude Oil & General Purpose | Greenbrier." https://www.gbrx.com/manufacturing/north-america-rail/tank-cars/284k-tank-crude-oil-general-purpose/. Accessed 20 Aug. 2018.
[57] "Economics of Rail versus Pipeline – Welcome to Altex Energy." https://altex-energy.com/economics-of-rail-versus-pipeline/. Accessed 20 Aug. 2018.

weighs 94200 lbs. Heavy duty single well double stack flat car weighs 60000 lbs[58], and together with tare weight of two TroiBoxes (4 tonnes each, 17600 lbs in total), it weighs 77600 lbs. There is 16600 lbs tare weight advantage representing additional capacity for 50 bbls. These barrels make up for 8.76% higher efficiency. (50/571 = 0.0876) Cost of diluent transport is assumed the same as pipelines. TroiBox is designed for utilization of backhaul and the lower costs represent ease of implementation.

TroiBox netback formula = ((A2 - B2 - (C - D)x0.1)/0.9)*1.0876 (8.76% higher efficiency than CBR)

Substituting all formula variables with monthly values of crude oil and diluent prices from Jan 2013 to May 2018 gives the following chart (Figure 11).

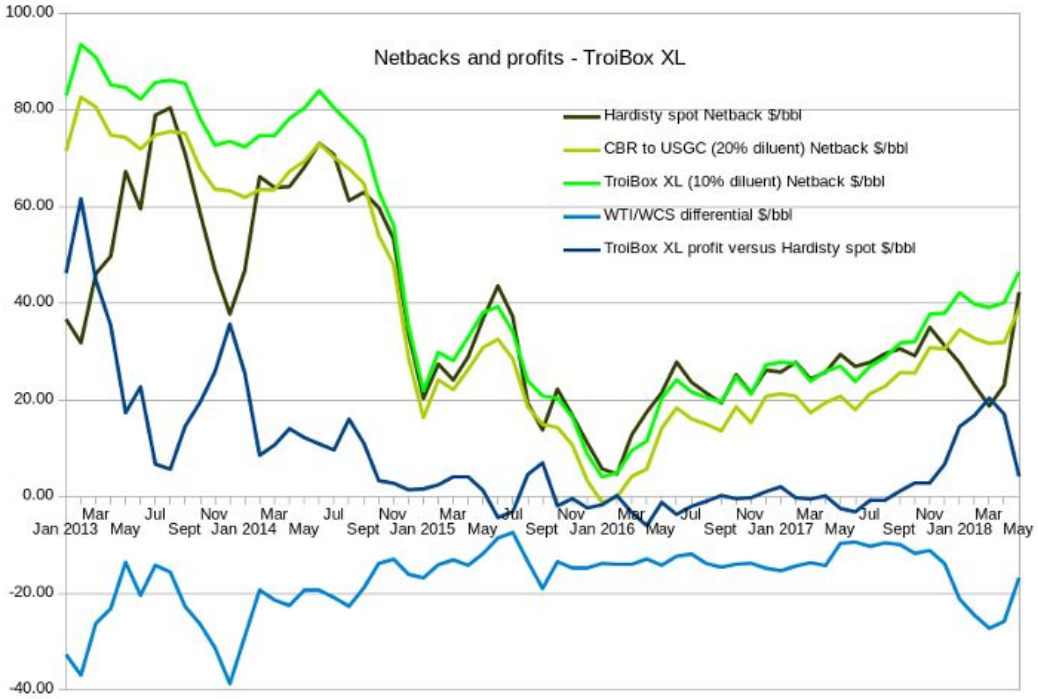


Figure 11 - TroiBox XL netbacks and profit

The dark blue line represents overall profitability of TroiBox versus pipeline. There is an inverse relation with the light blue line, which is the price differential between WTI and WCS. This differential has values anywhere between -40 and -6 with an approximate median of $12-$13. Assuming a value of $10 as “natural”, ($5 pipeline tariff Hardisty to Cushing + $5 light/heavy crude differential - April 2017 to Sep 2017 on the chart) would render TroiBox uncompetitive

[58] "48-Foot Heavy Duty Well Car - Progressive Railroading." https://www.progressiverailroading.com/railproducts/product.aspx?id=129. Accessed 20 Aug. 2018.

with pipelines on this route. This pipeline route with the natural differential is called Pipeline XL further in the text.

What to do? Well, the answer is to offer some additional value. And that would be blending. A crude oil stream consisting of 34% light oil and 66% bitumen has similar refining yield as Arab Heavy crude[59]. There is about $2 differential between Light and Heavy Arabian oil and the average landed costs for Arabian Light in April were $67.56[60]. Average April Louisiana Sweet Crude price was $64.53[61]. TroiShip can stop by St. James (FOB port for Louisiana Sweet) and load 34% of TroiBoxes with the light crude, while on the way to a customer in the Mississippi delta. Estimated netback is calculated in Table 2 using average data for April 2018.

April 2018	$ per bbl
WTI (FOB Cushing)	66.25
Arab Heavy - landed cost in US	65.51
C5+ (FOB Edmonton)	69.48
WTI/WCS differential	10.00
Louisiana Sweet (FOB St. James)	64.53
Pipeline XL netback (WTI - 3 - WTI/WCS differential - (C5+ + 1.5)x0.3) / 0.7	45.65
Blend netback - profit per bbl versus pipeline	
Bitumen (((Arab Heavy - CBR tariff - (C5+ + 1.5)*0.1) / 0.9)*1.086) - Pipeline Netback	3.11
Louisiana Sweet (Arab Heavy - Louisiana Sweet)	0.98
Avg. profit per bbl - bitumen (weight 66%), Louisiana (weight 34%)	**2.39**
TroiBox XL Netback (Pipeline Netback + Avg. profit per bbl)	***48.04***

Table 2 - TroiBox XL sample calculation

TroiBox solution would generate $2.39 higher netback in comparison to pipeline in April 2018. There are other two factors which can improve TroiBox efficiency. One is backhaul opportunity and second is “sponsored” CBR tariff as discussed in the chapter about Inland Logistic.

[59] "US Crude Oil Export Ban Repeal Creates New Outlets for Canadian ...." 3 Feb. 2016, https://www.linkedin.com/pulse/us-crude-oil-export-ban-repeal-creates-new-outlets-canadian-collins. Accessed 16 Sep. 2018.
[60] "Landed Costs of Imported Crude for Selected Crude Streams - EIA." https://www.eia.gov/dnav/pet/pet_pri_land2_k_m.htm. Accessed 16 Sep. 2018.
[61] "Light Louisiana Sweet First Purchase Price (Dollars per Barrel) - EIA." https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=F003075773&f=M. Accessed 16 Sep. 2018.

There is almost 3.15 million barrels of refined petroleum transported daily from PADD 3 to PADD 1 and 2[62]. These barrels flow through Explorer and Plantation/Colonial products pipelines. Pipeline operators charge $2.50 per each barrel arriving in Chicago[63]. TroiBoxes are designed for loading and transport of refined petroleum products which can be delivered on the backheading route from USGC. There is also a stream of containers full of farm production leaving daily the Chicago area and destined for Asia via Canadian West Coast ports. Versatility and modularity of TroiBoxes can benefit from all these factors. The CBR tariff in previous calculations is set at $15 per bbl per unit train. Counting in the potential cost reduction factors, it is reasonable to guess the savings would represent approximately $3 dollars per bbl. That would depress CBR tariff to $12 per bbl per unit train. The resulting profitability using historic crude oil prices is presented in Figure 12.

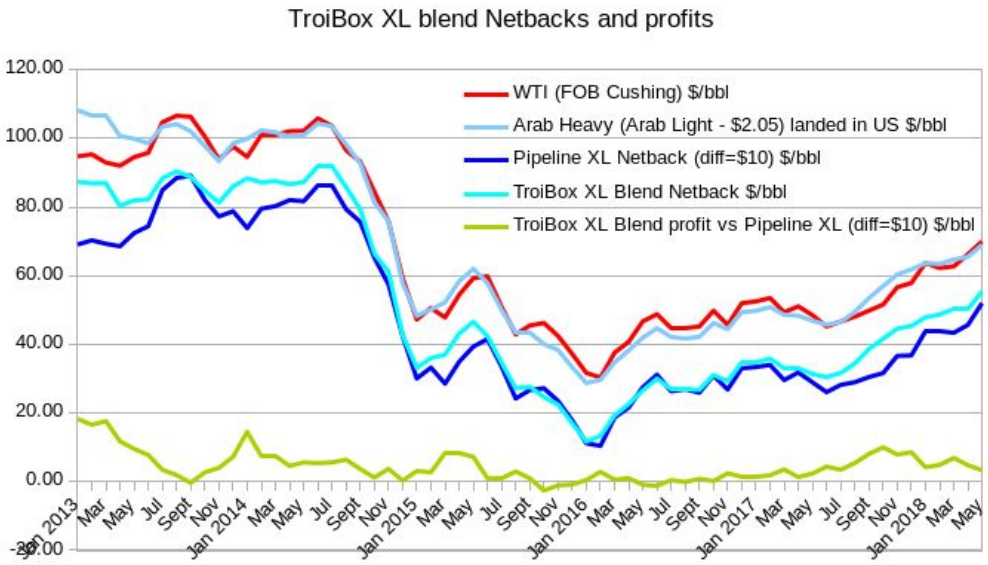


Figure 12 - TroiBoxXL blend Netbacks and profit

Arab Heavy crude price closely follows WTI. Dark blue line is pipeline netback as it would be when pipeline export capacity is sufficient. It assumes a fixed natural $10 differential between WCS and WTI. Light green line represents profitability of blended crude oil delivery versus pipeline, with constant $10 WTI/WCS differential, CBR tariff $12 per bbl and assumed $2.05 differential between Arab Light and Arab Heavy crudes. The line is 90% of the time above $0 with an average value of $4.44 per bbl for Jan 2013 - Apr 2018 period.

[62] "PADD regions enable regional analysis of petroleum product ... - EIA." 7 Feb. 2012, https://www.eia.gov/todayinenergy/detail.php?id=4890. Accessed 16 Sep. 2018.
[63] "EXPLORER PIPELINE COMPANY." http://www.explorerpipeline.com/Media/tariffs/Tariff-FERCNo-100-69-0.pdf. Accessed 16 Sep. 2018.

TroiBox East

In a world of $10 WTI/WCS differential, crude oil producers would have no incentive to ship Canadian bitumen eastward. To send heavy oil via pipeline to Montreal cost about the same as sending the same barrels to Cushing. The marine transport is what adds too high costs to a barrel. But a marine tanker is no match for TroiShip. Sure, it can carry more barrels, but it is a single purpose vessel. It delivers cargo and then hauls back sea water in ballast tanks. TroiShip can transport cargo containers on front and backhaul, and utilize empty TroiBoxes for transport of refined petroleum on the way back. The logistic system would cover the costs related to fronthaul of crude oil. There is also potential for premium fast service routes between Europe and Asia. Standard container ships travel the route about 30 days. Shortcut via Canada would cut the transport time by 10 days (4 days from Antwerp to Halifax, 7 days across Canada[64] and 8 days across pacific at 27 knots[65]). Maersk once planed design of container ships able to speed up to 30 knots, but the plans were cancelled after the industry went through change due to rising fuel prices[66].

China runs subsidized train routes to Europe called the New Silk Road. Trains run single stacked, usually carrying 80-90 containers, arriving in Europe in approximately 15 days. Shippers of time sensitive goods are willing to pay 2-3 times more in comparison to marine tariff ($1900 per FEU), after counting in China government subsidy (Table 3).

Table 3

[64] "CN Transit Calculator." https://ecprod.cn.ca/velocity/TransitCalculator/english/wtc_WTCQuery. Accessed 20 Aug. 2018.
[65] "Sea Distances." https://sea-distances.org/. Accessed 20 Aug. 2018.
[66] "World's fastest container ships mothballed | Financial Times." 22 Feb. 2010, https://www.ft.com/content/65e522dc-1fce-11df-8deb-00144feab49a. Accessed 20 Aug. 2018.

The railway connection offers a vital (and expensive) option for China to diversify trade routes. Containers avoid marine traffic choking and dangerous points like the Strait of Malacca and Bab el-Mandeb near Somalia. These places would be also avoided if containers travel on TroiShips cruising atlantic and pacific ocean.

There is a pipeline and two TroiBox options compared to the TroiBox East business case. The pipeline assumes WCS export via Enbridge line 9 to Montreal and tanker to Europe. April WCS landed cost in Europe was $60 (Average price for Maya $58.50 in April plus $1.5 tanker rate), $7 tariff for pipeline Hardisty to Montreal, $1.5 tanker rate and standard diluent penalty. First TroiBox option ships containers with bitumen and bakken light crude to Montreal port by rail and sent via TroiShip to Europe. Second option is similar, but utilizes pipeline and loads light Bakken crude from Enbridge terminal in Montreal.

Sample calculation with April 2018 data is in the Table 4.

April 2018	$ per bbl
Maya - landed cost in EU	60.08
Arab Heavy - landed cost in EU	65.21
C5+ (FOB Edmonton)	69.48
Bakken Light (FOB Williston)	55.25
Pipeline netback (Maya - 3(cost to Hardisty) -7 (pipeline tariff) -1.5 (Montreal to Europe) - (C5+ + 1.5)x0.3) / 0.7	38.98
Blend - profit per bbl versus pipeline	
Bitumen in blend ((((Arab Heavy - 18(CBR tariff) - (C5+ + 1.5)*0.1) / 0.9)*1.086) - Pipeline Netback)	9.42
Bakken Light Sweet in blend (((Arab Heavy - 18(CBR tariff))*1.086 - Bakken Light)	-3.98
Pipelined Bakken Light Sweet in blend (Arab Heavy - 7 (pipeline tariff) - Bakken Light)	2.96
OPT 1 Blend - Avg. profit per bbl - bitumen (weight 66%), Bakken Light (weight 34%)	**4.87**
OPT 2 Blend - Avg. profit per bbl - bitumen (weight 66%), Pipeline Bakken Light (weight 34%)	**7.22**
TroiBox East - OPT 1 Netback (Pipeline Netback + Avg. profit per bbl in blend)	***43.85***
TroiBox East - OPT 2 Netback (Pipeline Netback + Avg. profit per bbl in blend)	***46.20***

Table 4 - TroiBox East Netback sample calculations

Pipeline netback in this business case is quite lower than in the first case of pipeline to the USGC. For this reason both blend options are compared to Pipeline XL netback in Figure 13. First blend option is more or less similar to Pipeline XL and the second option is profitable, making on average $2.81 per bbl from January 2013 to May 2018. Calculations also confirm that without backhaul opportunity, TroiBox is uneconomical in transporting light oil in comparison to pipelines. Figure 13 shows Pipeline XL and both TroiBox East blend options netback curves.

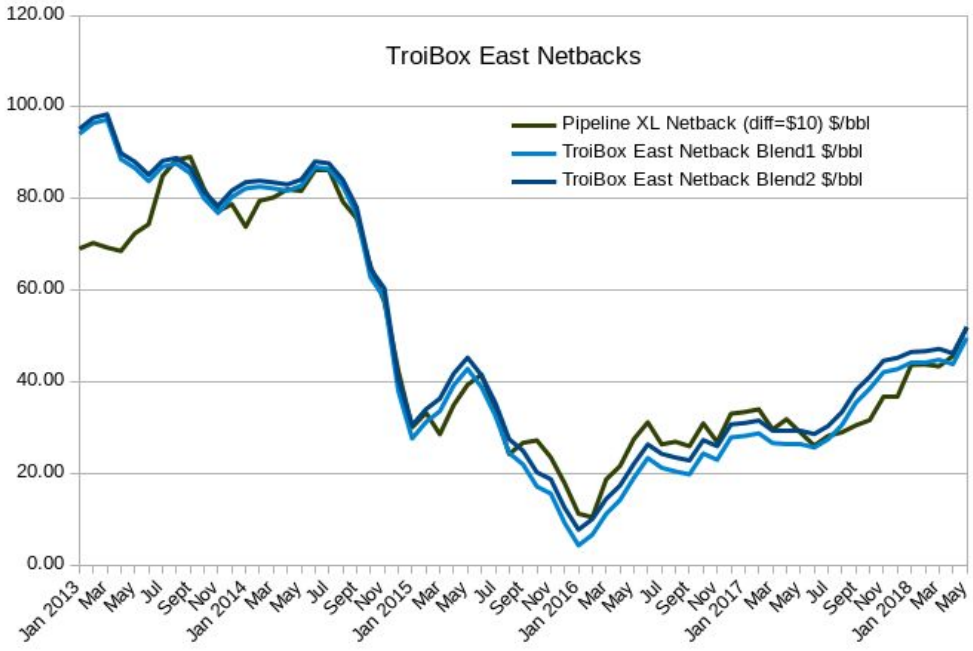


Figure 13 - TroiBox East Netbacks

Since the marine transportation costs are not included in the TroiBox East business case (they are deemed covered by TroiShip business scheme), it is all dependent on a negotiated railway tariff. Projects on Eastern Coast[67] plan to benefit from current resizing of container transportation fleet, and thus help to lower costs by supplying more business for Canadian Railways. In general, this business case makes sense just in case there isn't enough southward takeaway capacity.

TroiBox the Transmountainer

Canadian Western Coast represents the closest and potentially most profitable route to Asia for North American crude oil. But, due to prevailing NIMBY politics, it is also the most challenging to access.

In this business case, we assume the Transmountain Pipeline Expansion has already been built. The sea terminal would allow WCS crude to be sold in Asia for Maya plus $1.5 (transportation) pricing. Mexican PEMEX equalizes prices for different customers, sponsoring transportation costs. TroiBox would supply blends similar to Arab Heavy to the same Asian market. It would utilize existing intermodal infrastructure, for example Delta port in Vancouver. The blend consists of 10% thinned bitumen and Bakken light sweet crude oil in ratio 66:34. CBR

[67] "Port of Sydney deal could bring massive container ships to Cape Breton." 12 Dec. 2016, https://www.cbc.ca/news/canada/nova-scotia/ports-america-novaporte-sydney-harbour-investment-partners-1.3893551. Accessed 16 Sep. 2018.

tariff is estimated $10 including loading and unloading for both rail delivery routes[68], one from Fort McMurray and second from Williston basin in North Dakota, both ending in Vancouver Delta port. Asian landed cost of Arab Heavy is assumed similar to the landed cost in the US.

Calculations with April 2018 data are in the Table 5.

April 2018	$ per bbl
Maya - landed cost in Asia	60.08
Arab Heavy - landed cost in Asia	65.51
C5+ (FOB Edmonton)	69.48
Bakken Light (FOB Williston)	55.25
Pipeline Transmountainer (Maya - 3(cost to Hardisty) -4 (pipeline tariff) -1.5 (Vancouver to Asia) - (C5+ + 1.5)x0.3) / 0.7	43.27
Blend - profit per bbl versus pipeline	
Bitumen in blend ((((Arab Heavy - 10(CBR tariff) - (C5+ + 1.5)*0.1) / 0.9)*1.086) - Pipeline Netback)	15.15
Bakken Light Sweet in blend (((Arab Heavy - 10(CBR tariff))*1.086 - Bakken Light)	5.03
Avg. profit per bbl - bitumen (weight 66%), Bakken Light (weight 34%)	**11.71**
TroiBox Transmountainer Netback (Pipeline Netback + Avg. profit per bbl in blend)	***54.98***

Table 5 - TroiBox Transmountainer netback calculation sample

Same as in the case of TroiBox East, there would also be possible to load the light oil from the Transmountainer pipeline terminal in Vancouver. Depending on the spot pricing it would be possible to decide if to complete blend using US or Canadian light oil. If a refinery would wish, it would be even possible to load admixture of Alaskan North Slope oil from Valdez terminal on the way to Asia.

This business case has the highest netback profit vs pipeline, in average $8.94 for data from January 2013 to May 2018.

The final comparison of netbacks using historical crude oil prices is in Figure 14.

[68] "DAPL Completion Good for Bakken Netbacks - BTU Analytics." 25 Apr. 2017, https://btuanalytics.com/dapl-completion-good-bakken-netbacks/. Accessed 16 Sep. 2018.

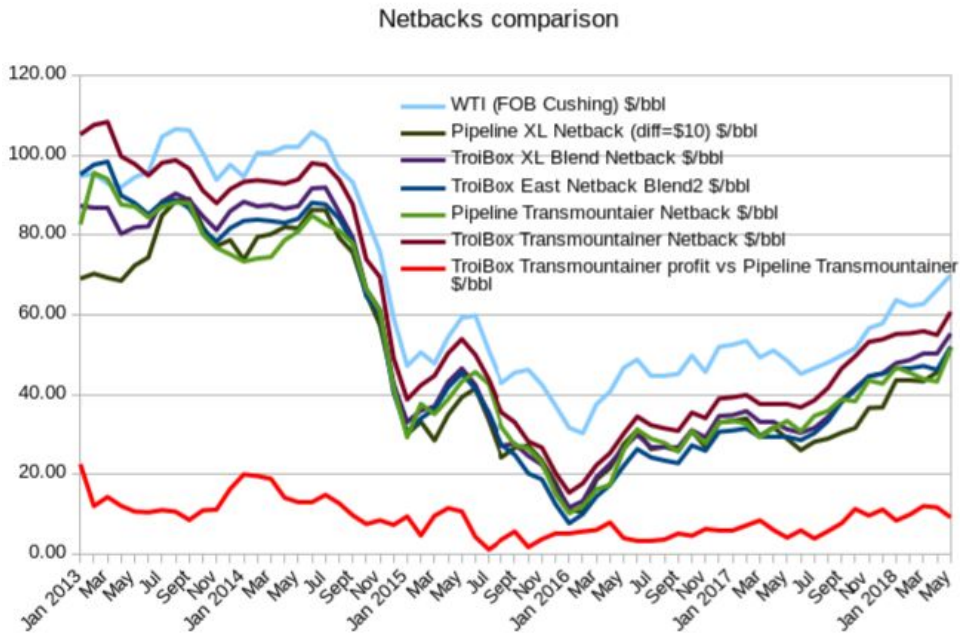


Figure 14 - Netbacks comparison

Figure 15 shows an imaginary world situation if TroiBox Transmountainer has been existing since 2013, and there is no Keystone XL built and there is no extension to Transmountain pipeline yet. The dark red area represents aggregate loss for crude oil producers since Jan 2013.

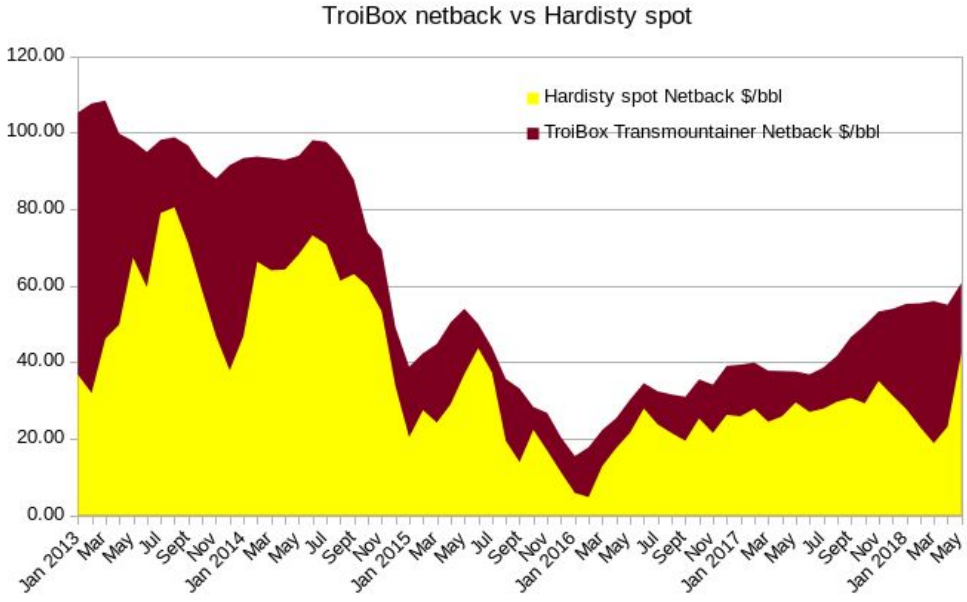
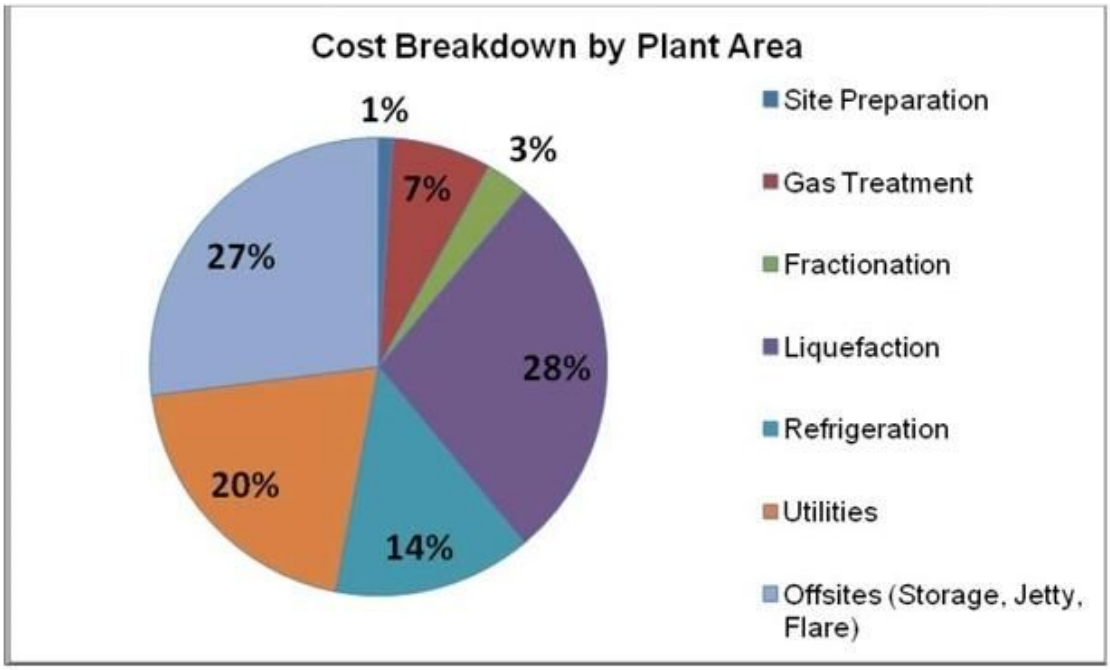


Figure 15 - TroiBox Transmountainer vs Hardisty spot netback

TroiBox LNG & LPG

The same transportation scheme can be also applied in the case of LNG and LPG export. Currently Canada is solving an acute problem with its natural gas production, since US growing shale plays are reducing opportunity for Canadian natural gas to be exported southward. The following paragraphs compare four LNG projects, in US and Canada, and two LPG projects existing or planned in Canada. Majority of costs estimation is extracted from the most actual CERI study Nr. 172 “Competitive analysis of Canadian LNG” from July 2018[69]. Since the nature of LNG and LPG transport is similar, the projects are compared as a group.

In the LNG group, there are two brownfield projects (Sabine Pass, LA and TroiBoxLNG) and two greenfield projects (Corpus Christi, TX and LNG Canada). Brownfields differ from greenfields in capital costs, since almost half of needed expenses have been already sunk in by previous plant function (Figure 16). For example, there are a number of existing regasification terminals in USGC, where making conversion and addition of liquefaction trains is faster and less financially intensive task. TroiBoxLNG is one of the brownfield projects, it utilizes existing straddle and fractionation facilities located inland throughout Western Canadian provinces.



Source: (Oxford Institute for Energy Studies 2014)

[69] "competitive analysis of canadian lng - Canadian Energy Research ...." 1 Jul. 2018, https://www.ceri.ca/assets/files/Study_172_Full_Report.pdf. Accessed 2 Sep. 2018.

Figure 16 - LNG plant capital cost breakdown. (Source: CERI)[70]

There are two projects in the LPG group, TroiBoxLPG and AltaGas Ridley Island in BC[71]. The AltaGas terminal is already being built and is expected to start operations in 2019. It is focused on propane export, has a planned capacity of 1.2mil tonnes/year with a capital cost of CAD 500 mil. TroiBoxLPG would contract feed gas from existing inland fractionators, limiting the project expenses to the tank container fleet costs of similar capacity and avoiding any operational cost. Cost of loading and unloading of TroiBoxLPGs is included in transportation expenses calculation.

The LNG rail transport is done in a cryogenic tank container, TroiBoxLNG. Since it is necessary to utilize the maximum of available train car weight capacity, the tank container gross weight is 50 tonnes. The tank itself is made of special metal alloy and has a double shell. Length is 53ft and tare weight is assumed about 15 tonnes (extrapolating to 53ft from specification of 40ft LNG ISO tank container[72]) with cargo capacity 35 tonnes. TroiBoxLPG share the same weight specifications. There is opportunity to improve the transport economy of LPG, since butane can be transported using the standard light composite TroiBoxes (4 tonnes tare weight per 40ft) inside the refined petroleum compartment. Propane has way higher vapour pressure[73] and would require a stronger composite tank wall.

TroiBoxLNG logistic is built on calculation that it is equally expensive to transport unit of BTU via pipeline in gaseous form and via train in the cryogenic liquid state. TransCanada, the owner of the planned Coastal Link 650 km long pipeline, which should bring natural gas to LNG Canada facility, is expected to charge minimum $0.92 per mmBTU. Excluding loading and unloading cost (lifting cost), to transfer the same mmBTU via rail would cost $0.42 per mmBTU ((130[tonnes per car]x 406[650 km in miles] x 0.037[tariff per tonne-mile] x 0.75[unit train discount])/ 3500[mmBTU per car, calculated as 35 cargo tonnes per TroiBoxLNG x 2[two stacked containers] x 50[mmBTU per tonne of LNG]]). With lifting cost included the total would be $0.95 per mmBTU of LNG. The lifting costs are assumed the same as in the case of standard crude oil TroiBox, $3 (per barrel, $1.5 loading + $1.5 unloading) x 620 (total oil barrels in two TroiBoxes) = $1860 per well car.

[70] "Competitive Analysis of Canadian LNG :: CERI." https://www.ceri.ca/studies/competitive-analysis-of-canadian-lng. Accessed 8 Sep. 2018.
[71] "Ridley Island Propane Export Terminal | AltaGas." https://www.altagas.ca/infrastructure/projects/ridley-island-propane-export-terminal. Accessed 10 Sep. 2018.
[72] "lng iso intermodal containers - Chart Industries." http://files.chartindustries.com/14732510_LNG_ISO.pdf. Accessed 9 Sep. 2018.
[73] "Propane Butane Mixtures - Evaporation Pressures - Engineering ToolBox." https://www.engineeringtoolbox.com/propane-butane-mix-d_1043.html. Accessed 10 Sep. 2018.

TroiBoxLNG supports modularization concept of LNG liquefaction plants[74]. Such modules can be moved and integrated into any suitable gas plant located in the Western Canada. The full TroiBoxes travel via intermodal double stack trains to a seaport container terminal and get exported via TroiShipLNG vessels. TroiShipLNG vessel has the same design as regular TroiShip, it is just suited to liquefied gases loading/unloading and on spot blending. There is also the possibility to integrate both concepts together and build one single supership with complete liquid hydrocarbon transport capabilities.

The project's economic comparison is in Table 6.

US$ per mmBTU	USGC Sabine Pass (brownfield)	USGC Corpus Christi	LNG Canada	TroiBox LNG (inland brownfield)	TroiBox LPG	AltaGas Ridley Island LPG
Capital cost	1.85	2.86	3.42	1.98	0.15	0.35
Feed gas cost	4.52	4.52	2.51	2.51	5.76	5.76
Transportation cost	0.1	0.42	1.09	1.29	1.38	0.95
Operating cost	0.91	0.91	0.69	0.35	0	0.45
Taxes	0.32	0.37	0.69	0.69	0.69	0.69
Shipping to Japan	1.63	1.63	0.64	0.32	0.32	0.64
Total	9.33	10.71	9.04	**7.14**	**8.3**	8.84

Table 6 - LNG and LPG export projects comparison.

Values for the USGC and LNG Canada projects are derived from CERI study Nr. 172 “Competitive analysis of Canadian LNG” from July 2018[75]. They also form base for the synthesized values of TroiBoxLNG and TroiBoxLPG. TroiBoxLNG has capital cost advantage, consisting of the same 1.85 as Sabine Pass (also brownfield, assuming similar costs) and added 0.13 for capital cost for the tank containers fleet ($25000 each). There would be need for about 18000 TroiBoxLNGs a day to transport 13 mil tonnes LNG a year (expected production of LNG Canada) and assuming 18 days round trip to Japan. Total cost $450 mil divided to 6 years (expected service life) gives $205000 daily payment. 32900 (12 mm/365) tonnes of LNG delivered daily represent 1645000 mmBTU(32900 x 50 mmBTU per tonne of LNG). Dividing 205000 by 1645000 gives approximately 0.13. Same logic is applied in LPG case, just the mmBTUs are slightly lower for propane, 47 mmBTU per tonne, giving value of 0.15 (This is just very simple and rough approximation, depending on the financing conditions the value might even double). Since the liquefaction modules are integrated into existing facilities, the operating

[74] "LNG on the Go: GE's Modular Liquefied Natural Gas Facility Offers ...." https://gereports.ca/lng-go-ges-modular-liquefied-natural-gas-facility-offers-field-flexibility/. Accessed 2 Sep. 2018.
[75] "competitive analysis of canadian lng - Canadian Energy Research ...." 1 Jul. 2018, https://www.ceri.ca/assets/files/Study_172_Full_Report.pdf. Accessed 2 Sep. 2018.

cost for TroiBoxLNG are halved. Feed gas costs are derived from current prices of natural gas and propane[76] (August 2018) and are similar for all the Canadian projects. TroiBoxLPG operating cost is 0 since the propane is sourced from existing third party fractionation facilities.

In comparison to LNG Canada and Ridley Island, the transportation cost is higher since the TroiBoxLNGs and TroiBoxLPGs travel a longer way from Fort Saskatchewan. If the LNG would be sourced from the same spot where LNG Canada begins its pipeline, the cost would be the same. AltaGas has the advantage of existing train loading facilities. It minimizes the transportation cost to sole railway tariff calculation without the loading and unloading expenses.

The Ridley Island operating costs are lower than in case of LNG Canada, since the scale of the operations is smaller, but must include the railway unloading terminal manpower. Taxes are assumed the same as for LNG Canada, but very likely would be considerably lower. TroiShipLNG design lacks refined petroleum backhaul option since the TroiBoxLNGs and TroiBoxLPGs are not designed for dual use. But there is still opportunity to partially cover the shipping cost with the profit from cargo container transport business, same way as classic TroiShip does. 50% share of the shipping cost is assumed, 0.32 versus 0.64 for LNG Canada.

The base and semi-calculated values are further summarized in Appendix II.

As in the case of crude oil blending, there is a need to customize the delivered LNG to a particular customer requirements. There are two important terms used, Gross Calorific Value (GCV) and Wobbe Index (WI)[77]. WI is an indicator of the combustion properties of a given natural gas and is important value for UK and European LNG import facilities. GCV is also known as the high heating value and is measured in million Joules per cubic meter. Usual values are 38-42 in the US and 43-46 in Asia. This represents a challenge for standard LNG liquefaction terminals since the GCV value must be incorporated in the facility train design. Not every LNG export terminal can supply all import countries. For example in Japan, where higher GCV is required, the problem is solved by injecting butane into LNG stream at a regasification import point. TroiBoxLNG concept solves the problem by blending the LNG stream with appropriate amounts of LPG liquids coming from TroiBoxLPG tank containers. It is all done on the TroiShipLNG deck before the LNG liquid leaves the vessel. The blending ratio is specific for every importing terminal and can be changed any time according to the needs of the inland natural gas distribution company.

[76] "NEB - Commodity Prices and Trade Updates." 17 Aug. 2018, https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/prcstrdrtcl/index-eng.html. Accessed 11 Sep. 2018.
[77] "Differing market quality specs challenge LNG producers - Oil & Gas ...." 11 Oct. 2004, https://www.ogj.com/articles/print/volume-102/issue-38/processing/differing-market-quality-specs-challenge-lng-producers.html. Accessed 10 Sep. 2018.

There is LNG glut expected around 2020-21 and phase of strong demand around 2025[78]. It is also the time when Shell company, the major owner of the LNG Canada project, targets potential finalization and start of the liquefaction plant. FID solely depends on calculations of Canadian LNG competitiveness versus USGC LNG exporting plants. Canada has two major advantages in this game. One is lower price of natural gas and second is transporting proximity to Asian markets. The same advantages are valid for LPG export as well. 40% of US LPG production is directed at the export market[79], and the number is expected to grow.

In 2017 TransCanada introduced a new long term fixed price toll for its mainline natural gas pipeline running from Empress, AB to the Dawn hub in Ontario. The new toll is CAD 0.77/GJ and 23 producers have commited to ship 1.5 PJ/day for a maximum of 10 years[80]. The discount is a clear attempt to preserve market share for Western Canadian natural gas producers. Compared to the previous firm toll of CAD 1.86/GJ, it represents daily loss of CAD 1,635,000. There is a long term viability question of this approach, since the transferred natural gas will have to compete with the closer shale gas plays in Ohio and Pennsylvania and simple tariff sponsoring doesn't address the underlying problem. It is reasonable to believe that the NGL plants cluster in Empress, AB is one of the sponsors since the gas stream is vitally important for the existence of these facilities and critically important for the associated petrochemical industry in Alberta. TroiBox is the perfect solution for this long term problem. The additional liquefaction trains can be added to the existing NGL stripping plants which are already equipped with railway access for LPG export. The discounted 1.5 PJ/day stream represents about 80% of the planned first stage of LNG Canada plant.

Safety

The current methods of crude oil transportation involve large amounts of fluid transfers, which itself generates a number of possible unsafe situations. By storing the fluid in a pressurized vessel, which travels itself to the destination, lots of friction points get removed. The viscous fluid requires a low amount of diluent, possibly attaining status of combustible liquid instead of flammable. Such cargo moves faster on a railway and doesn't involve sour gas risks for workers. Tank containers are daily moved across the country using existing infrastructure and there is a large base of skilled workers who have experience with moving containerized cargo.

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[78] "Olly Spinks - Flame 18 - Timera Energy." https://timera-energy.com/wp-content/uploads/2018/05/US-Exports-EU-Hubs-Olly-Spinks-May18A.pdf. Accessed 2 Sep. 2018.
[79] "Very large gas carriers in the global LPG spotlight - LNG World Shipping." 2 Sep. 2018, https://www.lngworldshipping.com/news/view,very-large-gas-carriers-in-the-global-lpg-spotlight_54043.htm. Accessed 3 Sep. 2018.
[80] "Western Canada gas in jeopardy without new TransCanada toll: CAPP." 14 Sep. 2017, https://www.jwnenergy.com/article/2017/9/western-canada-gas-jeopardy-without-new-transcanada-toll-capp/. Accessed 13 Sep. 2018.

Compared to DOT117 tank cars, TroiBox tank containers are divided by diaphragm into 2 compartments, together, in case of crude oil (dirty side), dividing the usual tank car 600 barrel load into 4x150 barrels. TroiBoxes are transferred on well cars, which themself form a solid frame around their bottom. In case of CBR, the car frame is formed by the tank body itself and thus is more suspect to deformation[81]. Since they are transported together with regular cargo containers, their frame must withstand the same compressional forces. The insulation space between frame and vessel body serves as a deformation zone, designed the same way as it is in cars and trucks. Operated in slight overpressure and equipped with tank gauges, there is an instant warning information system in case of a vessel leak.

Rail well cars act as carriers for containers, and in case of failure, they are replaceable without need to do any fluid transfer. Way cheaper to build, they are widely available and can be always used to carry standard cargo containers instead of TroiBoxes. Multi-unit articulated well cars connected by common platforms (Jacob bogies) are safer than regular single unit cars[82] and tank containers have very good impact resistance[83].

People involved in transport of TroiBoxes do not get in contact with the fluid inside. Loading and unloading is automated, thanks to the design of TroiPump. Drivers just drive a trailer with a TroiBox in, wait for green light signalling completion of loading/unloading task, and then drive away. The process is simplified, preparing ground for future automated driving systems.

Environmental impact

TroiBox integration into the existing flow of cargo containers utilizes existing infrastructure and transhipment ports. Since world containerized traffic rises every year, any requirement for extra capacity resulting from the TroiBox use, would be needed later anyway. There are projected container handling capacity increases in Vancouver, BC and Sydney, NS terminal ports, which eventually will require alterations of the current transport routes. TroiBox has minimal infrastructure footprint effect and fully integrates into the existing intermodal transport. It also reduces traffic by utilizing existing railway weight limits.

In June 2017, the Alberta government set up a 100 Mt/year carbon emission cap on oil sand development. The industry currently emits roughly 70 Mt/year. Upgraders themself emit 20

[81] "Railway Investigation Report R01M0061 - Transportation Safety Board ...." http://www.tsb.gc.ca/ENG/rapports-reports/rail/2001/r01m0061/r01m0061.asp. Accessed 31 Aug. 2018.
[82] "On the Influence of Rail Vehicle Parameters on the Derailment ... - KTH." https://www.kth.se/polopoly_fs/1.157846!/Menu/general/column-content/attachment/Licentiate_thesis_Brabie.pdf. Accessed 20 Aug. 2018.
[83] "HAZMAT EMERGENCIES INVOLVING INTERMODAL CONTAINERS ...." https://www.fireengineering.com/articles/print/volume-150/issue-12/departments/haz-mat-on-the-line/haz-mat-emergencies-involving-intermodal-containers.html. Accessed 20 Aug. 2018.

Mt/year[84]. They process mined bitumen which is preprocessed using NFT technology and thus is not suitable for pipeline transport. TroiBox can transport these barrels and free 20 Mt/year of the emission quota for future oil sands development. Just this single step would render oil sand emissions per produced barrel equal if not lower than the majority of world crude oils. Marine and rail backhaul options represent another case of emission reduction. Electrification of the Fort McMurray - Edmonton railway track can create another outlet for cogenerated power from steam generation plants.

Challenges

The proposed TroiBox weight of 50 tonnes can represent a challenge in certain cases since the standard gross weight limit for 40ft containers is 30 tonnes. Reach stackers are often rated up to 45 tonnes[85], but can be overloaded[86]. There are also versions with capacity up to 500 tonnes[87]. Such equipment can transload TroiBoxes by two already stacked up and tied by twistlocks[88]. In case of gantry cranes there are versions with rubber tires, allowing quick installation without need to set up rails. They can lift up to 65 tonnes[89] and some versions are set up for automatic function[90].

By far the biggest capital investition would flow into the TroiShip vessels. It is a challenge to estimate a price tag for such an integrated ship, since this market segment isn't much discussed. But there are few pieces of information available which can give a hint of the pricing mechanism. In case of RoRo ships the typical ratio of work hours per lightweight ton is 60-80. Normal tanker requires 30-60 and passenger ship, as the most expensive, requires 80-120[91]. This would imply a rough ratio of 70:45 RoRo vs tanker capital cost. In 2017 a new suezmax

[84] "Will the Trans Mountain Pipeline and tidewater access boost prices ...." 31 May. 2017, https://www.policyalternatives.ca/tidewater-access. Accessed 13 Sep. 2018.
[85] "View the full line of Konecranes reach stackers. - Leavitt Machinery." https://www.leavittmachinery.com/docs/default-source/Spec-Sheets/konecranes-reach-stacker-brochure.pdf. Accessed 14 Sep. 2018.
[86] "Konecranes Weighing System - YouTube." 20 Jul. 2016, https://www.youtube.com/watch?v=OFP5ayBu9Yo. Accessed 14 Sep. 2018.
[87] "Reach Stacker: Heavy Duty Series up to 500t - CES - ces-vrs.eu." http://ces-vrs.eu/vrs-versatile-reach-stacker-heavy-duty-series. Accessed 14 Sep. 2018.
[88] "Twistlock - Wikipedia." https://en.wikipedia.org/wiki/Twistlock. Accessed 14 Sep. 2018.
[89] "Konecranes Noell Rubber-Tired Gantry Cranes." https://www.konecranes.com/equipment/container-handling-equipment/rubber-tired-gantry-cranes/konecranes-noell-rtg. Accessed 14 Sep. 2018.
[90] "Automated RTG (ARTG) System | Konecranes Canada (English)." https://en.konecranes.ca/equipment/container-handling-equipment/rubber-tired-gantry-cranes/automated-rtg-artg-system. Accessed 14 Sep. 2018.
[91] "7 Cost and price estimation 7.1 Cost estimation by Nallikari-Nieminen ...." 17 Nov. 2014, https://wiki.aalto.fi/download/attachments/100219980/Cost%20and%20price%20estimation.pdf?version=1&modificationDate=1416327800310&api=v2. Accessed 14 Sep. 2018.

(120,000 DWT) tanker cost was in average about $58 mil[92]. Multiplying 58 by 70/45 gives about $90 mil per ship. Recent order from Grimaldi group gives sum of $120 mil for a Roro ship of a same tonnage[93]. Including all the plumbing work, power wiring, modular pumps and blending mechanism, the final price tag for a TroiShip could be about $200 mil. To secure 600,000 bbl/day the export channel would require 18 TroiShips for the route Vancouver - South Korea and back, totaling $3.6 BN. Not a small investition but still a fraction of the cost of the Transmountain pipeline or the LNG Canada plant.

Currently the biggest ship in the RoRo category is MV Tønsberg[94] with capacity of 76,500 DWT and cargo volume 138,000 m³. In the same ratio a capacity of 120,000 DWT would allow loading 215,000 m^3 of cargo. The 40ft container has a volume of 67m^3. Allowing for 30% service space, there would be more than enough room to place the proposed 2000 TroiBoxes.

For a seamless operation it would be necessary to implement a tracking system to guide the ingredients of each batch to the final destination. This would introduce a new trading platform where customers could prepare and track their own blends using the available most actual crude oil essays. After confirmation and accepted quote from the sales department the delivery process would start by contracting the producers directly or through the futures market.

Conclusions

Pipelines are great in transporting light liquids with minimal maintenance requirements. But from a systemic point of view they create a single point of failure. They don't fail often, but when they do there is no way around how to economically substitute their function. The effect on oil prices is immediate, just as it happened when TransCanada reported spill on Keystone pipeline in November 2017[95] and had to temporarily shut down. Throughput problems on a railway, either due to accident or natural causes, can be solved or sidetracked within days or even hours. This is the power of a distributed system, consisting of many streams and distribution channels working together without a central element. All the proposed petroleum export projects on B.C. coast favor permanent centralised solutions. The low footprint and regulatory requirements of TroiBox solution form a bold contrast in comparison with any pipeline project. Formal Energy East pipeline project application, when arrived in NEB office, counted 38885 pages and took two trucks to deliver in five copies.

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[92] "Shipbuilding." http://www.brsbrokers.com/assets/review_splits/BRS-Review2018-01-Shipbuilding.pdf. Accessed 14 Sep. 2018.
[93] "THE GRIMALDI GROUP ORDERS SIX HYBRID RO/RO VESSELS." 27 Apr. 2018, https://www.grimaldi.napoli.it/en/read_123.html. Accessed 14 Sep. 2018.
[94] "MV Tønsberg - Wikipedia." https://en.wikipedia.org/wiki/MV_T%C3%B8nsberg. Accessed 14 Sep. 2018.
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In 2017 port of Vancouver handled 3,252,000 TEU in 809 vessel arrivals[96], which translates to 8900 TEU a day. Divided by 2 for import and export move, there is average arrival and leave of 4450 TEU a day on a board of a ship. This amount of containers can be easily handled by a pair of TroiShips and would lead to 10% decrease in container vessel traffic, while additionally exporting 1.2 mil barrels of crude oil. TroiShip loading system doesn't build any permanent structures at a terminal. It is completely compatible with existing cargo handling processes and can be moved to a different suitable place within days.

In South Korea, and the whole Asia region respectively, diversification of crude oil imports is a problem with national priority and can help to achieve a favorable price tag for the TroiShips fleet, given that the country is shipbuilding world power. The backhaul opportunity opens the South Korean refiners access to the West Coast market where they currently import 70,000 bbl/day of petroleum products[97]. The diversification problem is closely connected to an even more critical issue, the strait of Malacca. The inlet, 1.7 mile wide at the narrowest point, forms the second-largest oil trade choke point in the world after the Strait of Hormuz. Vessels passing through carry 16 mil bbl a day of crude oil and refined petroleum liquids[98]. The geopolitical problem has even its own term, the Malacca dilemma. It is so important to the future growth of the regional economies that it is one of the main reasons why China introduced its extremely expensive New Silk Road initiative[99].

There is a long time crisis ongoing in the Western Canada since the current pipeline takeaway capacity is not sufficient to export produced barrels to the most lucrative markets. But every crisis brings opportunity. This is the perfect time for Canadian petroleum industry to step out from the traditional mindset and introduce a completely different transportation concept.

[96] "Statistics Overview - Port of Vancouver." https://www.portvancouver.com/wp-content/uploads/2018/03/2017-Stats-Overview-1.pdf. Accessed 13 Sep. 2018.
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Appendix I - Heat loss calculation

Heat loss calculation

City	Avg Jan deg F	Windchill deg F	Transit time (hrs)	Heat loss BTU/hrs	Cargo temp deg F	Cargo temp deg C
Fort McMurray	-10	-48	48	557676	129	54
Edmonton	3	-29	24	234752	125	51
Winnipeg	0	-33	24	234392	120	49
Chicago	21	-3	48	364986	113	45
Memphis	32	13	24	148288	110	43
New Orleans	46	33	24	113920	108	42

specific heat of petroleum is 0.51 BTU / (lb F), 2.13 (kJ/(kg K), BTU per deg F per 300 barrels of 959 kg/m3 is 51320 (171 BTU/bbl)

adding 10% for convection and radiation losses

Polyurethane spray foam R = 6/in (k=0.16), 4 inch thick insulation

Thickness (in)	4
k value	0.16
BTU per bbl oil	171
bbls	300
Wind speed mph (v)	60
Initial temp (F)	140
A - Area (sqft)	1408

Windchill

$$T_{\mathrm{wc}} = 35.74 + 0.6215T_{\mathrm{a}} - 35.75v^{+0.16} + 0.4275T_{\mathrm{a}}v^{+0.16}$$

Heat loss

$$Q = \frac{(k)(A)(\Delta T)(1.1)}{L} \text{ Heat Loss, BTU/hr}$$

Formulas source: https://www.process-heating.com/articles/87988-calculating-heat-loss ; Wikipedia https://en.m.wikipedia.org/wiki/Wind_chill

Appendix II - TroiBoxLNG

US$ per mmBTU	USGC Sabine Pass (brownfield)	USGC Corpus Christi	LNG Canada	TroiBox LNG (inland brownfield)	TroiBox LPG	AltaGas Ridley Island LPG
Capital cost	1.85	2.86	3.42	1.98	0.15	0.35
Feed gas cost	4.52	4.52	2.51	2.51	5.76	5.76
Transportation cost	0.1	0.42	1.09	1.29	1.38	0.95
Operating cost	0.91	0.91	0.69	0.35	0**	0.45
Taxes	0.32	0.37	0.69	0.69	0.69	0.69
Shipping to Japan	1.63	1.63	0.64	0.32	0.32	0.64
Total	9.33	10.71	9.04	**7.14**	**8.3**	8.84

Ridley Island capital cost is calculated basically just as the ratio of yearly cost vs yearly production mmBTU, 500mil / 25 years = 20 mil, 20 mil / 1.2mil = 16.6 per tonne of production, 16.6 / 47 (mmBTU in tonne) = 0.35. Including an interest rate the cost can easily double.

Lease cost per car not included, roundtrip 4 days, assuming 0.1 per mmbtu, negligible, but certainly lower in case of TroiBox since it shares the platform with cargo containers.

*AltaGas lifting costs are 0 since both ends of the transfer chain end in existing facilities thus the variable costs are already sunk in the previous capital expenditures.

**TroiBoxLPG operating costs are 0 since there are no facilities required outside regular loading and unloading premises. It operates in the spot market and delivers directly to a TroiShipLNG.

TroiBoxLNG capital cost is sum of 1.85 (Sabine Pass brownfield) + 0.13 (relative capital cost of the tank container fleet vs delivered mmBTU - in case of TroiBoxLPG the cost is slightly higher since propane has less mmBTU per tonne, 47 vs 50 as in case of LNG)

	TroiBox LPG	Standard LPG	TroiBox LNG			
cost per car	2673	3230	2673			
cargo tonne per car	70	72	70			
miles	741	962	741			
cost per mmbtu	0.81	0.95	0.76			
lifting cost	0.57	0*	0.53			
car weight tonnes	130	121	130			
tonne per mile tariff	0.037	0.037	0.037	x0.75 discount per unit train		
Propane mmbtu/tonne	47					
LNG mmbtu/tonne	50					