Discussion Paper: Greenhouse Gas Emissions Resulting from the Energy East Pipeline Project

A Global Oil Market and Transportation Analysis

SUBMITTED TO

Ontario Energy Board
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SUBMITTED BY

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About Us

Navius Research Inc. ("Navius") is a private consulting firm with locations in Vancouver and Toronto. Our consultants specialize in analysing government and corporate policies designed to meet environmental goals, with a focus on energy and greenhouse gas emission policy. We also assist clients with stakeholder consultation and engagement processes, and with the development of clear and effective communication strategies and materials. This combination of quantitative forecasting expertise and communication and engagement capabilities allows Navius to provide a complete and integrated solution to clients working on climate change and energy planning.

Our consultants have been active in the energy and climate change field since 1996, and are recognized as some of Canada's leading experts in modeling the environmental and economic impacts of energy and climate policy initiatives. Navius is uniquely qualified to provide insightful and relevant analysis in this field because:

- We have a broad understanding of energy and environmental issues both within and outside of Canada.
- We use unique in-house models of the energy-economy system as principal analysis tools
- We have significant experience developing and implementing communication and engagement strategies on energy, climate change, and environmental topics.
- We have a strong network of experts in related fields with whom we work to produce detailed and integrated climate and energy analyses.
- We have gained national and international credibility for producing sound, unbiased analyses for clients from every sector, including all levels of government, industry, labor, the non-profit sector, and academia.

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Executive Summary

On October 30, 2014, the Energy East Pipeline Ltd., a wholly owned subsidiary of TransCanada Oil Pipelines (Canada) Ltd. (TransCanada), submitted its application to the National Energy Board for the proposed Energy East project. The Energy East project would connect oil producing regions in Western Canada with refineries and export terminals in Eastern Canada. As proposed in TransCanada's regulatory filing to the National Energy Board, the project would add pipeline capacity of 1,100 thousand barrels per day. The project would also add two export terminals: one in Cacouna, Québec and another in Saint John, New Brunswick. The project is expected to begin operation in 2019.

The Ontario Minister of Energy has asked the Ontario Energy Board (OEB) to examine the Energy East project from an Ontario perspective. As a part of the process, the OEB has undertaken consultations with various communities across Ontario to provide a forum for Ontarians to express their views on the proposed Energy East project.

During the consultation process, several stakeholders expressed concerns that the project's approval would lead to greater greenhouse gas (GHG) emissions. Specifically, they expressed concerns that the pipeline would enable greater activity from Alberta's oil sands, and this would lead to a net increase in Canada's and the world's GHGs. Additionally, greater supply for crude oil could increase the global consumption of refined petroleum products, further increasing GHG emissions and exacerbating global climate change.

The OEB wishes to inform the Ministry of Energy on how the project is likely to affect GHG emissions. The OEB has retained Navius Research Inc. to estimate how the approval of Energy East would affect GHG emissions. The OEB has asked that the analysis focus on all sources of GHG emissions – from extraction ("wells") to final consumption ("wheels") – that can be attributed to the project. Navius reviewed the available literature on how pipeline infrastructure affects GHG emissions. This paper also summarizes the results from original modeling using the OILTRANS model to quantify the impact of Energy East on global GHG emissions.

The objective of this paper is to inform the discussion on how pipeline projects from Alberta are likely to affect Canadian and global GHG emissions. The paper is also intended to elicit feedback from stakeholders, which will be considered before the report is finalized. The key findings from the review and analysis are summarized below.

The literature reports a wide range for the GHG impact from approving new pipelines.

The literature includes qualitative discussions and quantitative analyses of how new pipelines are likely to affect GHG emissions. To date, most of the literature has focused on another proposed pipeline project: the Keystone XL project that would connect Alberta with refineries in the United States Gulf Coast. However, strong parallels can be drawn between Keystone XL and the Energy East project.

The literature highlights several dynamics that affect how new pipelines affect GHG emissions. However, the various analyses place emphasis on different dynamics. By focusing on some of these dynamics, it can be argued that new pipelines are likely to have a small impact on GHG emissions, while focusing on others suggests the impact is large. Figure 1 summarizes the key dynamics highlighted in the literature, and illustrates whether they are likely to lead to small or large GHG impacts.

Figure 1: Key dynamics affecting how new pipelines affect GHG emissions

Dynamics Leading to Small Impacts:

- Easy Substitution between Global Resources
- Easy Substitution between Pipelines and Rail
- Easy Substitution between Pipeline Projects

Dynamics Leading to Large Impacts:

- Restrictions on other Transport Options
- Higher GHG Intensity for Oil Sands Relative to other Global Resources
- Impact on Consumption of Refined Products
- Global Climate Policy

On one side, new pipelines will have a small impact on GHG emissions if:

- *Any increase in oil production in Western Canada is offset with a decline in production elsewhere ("easy substitution between global resources").* In generating their GHG estimates for Keystone XL, the State Department focused primarily on the substitutability between Alberta crude oil and other global resources (i.e., from Venezuela or Middle Eastern crude). They estimated that Keystone XL would increase global emissions by between 1.3 and 27 million tonnes of carbon dioxide or equivalent (Mt CO_2e) annually. For perspective, Ontario's total emissions in 2012 were 167 Mt, while Canada's emissions were 700 Mt. IHS CERA focus on the substitutability between Alberta and Venezuelan Crude, and suggest the lower estimate from the State Department is likely correct. Michael Levi (a senior fellow for energy and environment at the Council on Foreign Relations) suggests that OPEC is likely to meet any gap in production from foregone Alberta production.[1]

- *Any oil not shipped by pipeline is shipped by rail.* Although pipelines offer lower costs for oil transport, oil can also be transported by rail if it is economic to do so. Andrew Leach (professor of Energy Policy at the University of Alberta) highlights that many oil sands resources would be economic even if oil has to be transported by rail. Therefore, restrictions on pipelines do not necessarily restrict oil sands production.

- *Any pipeline cancelation is offset with the approval of another pipeline.* There are several proposals for pipelines from Western Canada. As part of their review, the U.S. State Department contracted EnSys to conduct modeling of the Keystone XL project. In their analysis, EnSys suggests that other pipeline projects would offset the impact of not approving Keystone XL. Therefore, Keystone XL would have a negligible impact on GHG emissions.

On the other side, new pipelines can have a large impact on GHG emissions with:

- *Restrictions on other transport options.* The Pembina Institute's analysis suggests that new oil sands production is uneconomic without new pipelines. They also suggest that there is no guarantee that other pipeline projects from Alberta will be approved. Similarly, the Stockholm Institute conducted an analysis that did not account for rail as a transport option.

[1] References for all studies are provided in the body of the report

- *Higher GHG intensity for oil sands relative to other global resources*. Oil sands currently have higher GHG intensities relative to other global resources. Therefore, greater oil sands production relative to other resources will lead to an increase in GHG emissions. By focusing on the upstream emissions from the oil sands, Pembina estimates that the Energy East project will increase emissions in Canada's oil sector by between 30 and 32 Mt. For perspective, Canada's total emissions in 2012 were 700 Mt, so this would amount to an increase of about 4.5% in Canada's current emissions.

- *Greater global demand*. The Stockholm Institute highlights that the majority of emissions from the oil supply chain occur during the consumption of refined petroleum products. Therefore any increase in the global supply for crude oil, due to new pipelines, could lead to a large increase in global GHG emissions. They estimate that the approval of Keystone XL could increase emissions by up to 110 Mt.

- *Global climate policy.* Several authors have argued that new pipelines from Alberta would not be necessary if the global community enacts policies to mitigate the impact of climate change. They argue that a world that limits the rise in global temperatures to $2^{O}C$ from pre-industrial levels would demand significantly less oil. In this scenario, there would not be sufficient demand for oil sands to warrant a new pipeline or further oil sands development. Further, new pipelines may even lock-in GHG emitting infrastructure, and make it more difficult to reduce emissions later on. Lock-in occurs because once an oil sands project is built, it is likely to continue operating until the end of its useful life.

In sum, there is a wide range of GHG estimates reported in the literature. The impact of the Keystone XL project ranges from 1 Mt to 110 Mt. However, the width of the range is attributed to differing focuses on the dynamics above. Some analyses have focused on some dynamics while others have focused on others. The result is the literature offers little clarity on how new pipelines affect GHG emissions.

The wide range of impacts reported in the literature highlights the need for a comprehensive analysis that includes the major dynamics affecting GHG emissions from oil markets.

The wide range of impacts reported above is due to the inclusion and exclusion of different dynamics. Therefore, the range is wider than it would be if all dynamics were accounted for within a comprehensive framework.

The central objective of this report is to summarize the results from original modeling that provides a comprehensive framework with all the dynamics above. The analysis employs the OILTRANS model, which simulates the decisions for each agent in the global oil market. These agents include: oil producers, oil traders, oil transportation companies, refineries and final consumers. The model accounts for all major sources of GHG emissions in oil markets. These include emissions from the direct combustion of fossil fuels, emissions from venting/flaring, and indirect emissions associated with consuming electricity generated from fossil fuels.

To assess how the Energy East project is likely to affect global greenhouse gas emissions, OILTRANS was run under several scenarios. Each scenario is run twice, once with the Energy East project approved and once without. The difference between the scenarios with and without Energy East is directly attributed to the project as everything else is held constant.

The scenarios vary how the global oil market evolves from now until 2035. Specifically, the modeling explores the effect of:

- *The approval of other pipelines projects from Alberta.* These include TransCanada's Keystone XL, Enbridge's Northern Gateway and Kinder Morgan's TransMountain Expansion. As discussed above, the Keystone XL project would link western Canada with the United States Gulf Coast. The latter two projects would deliver crude oil to British Columbia's west coast.

- *The sensitivity of final consumption to prices for refined petroleum products.* The consumption for refined petroleum products (e.g., gasoline, diesel, heavy fuel oil, etc.) is sensitive to price. However, there is a wide range for estimates for the degree of sensitivity. The analysis examines the full range reported in the literature.

- *Global climate policy*. The analysis examines whether new pipelines will "lock-in" GHG emitting infrastructure in a low-GHG future. Specifically, the analysis examines the effect of Energy East in a world that limits the rise in temperatures to 2^{O}C from pre-industrial levels.

- *Advanced extraction technology for oil sands.* Although the current standard practice for extracting oil sands is greenhouse gas intensive relative to other resources, several technologies are being developed that would significantly reduce this impact. The analysis examines the impact of these technologies.

The Energy East project will increase global GHG emissions from "wells-to-tank", but the impact is modest as global GHGs increase by 0.01%.

The oil sector from "wells-to-tank" is comprised of:

1) Extraction of crude oil;

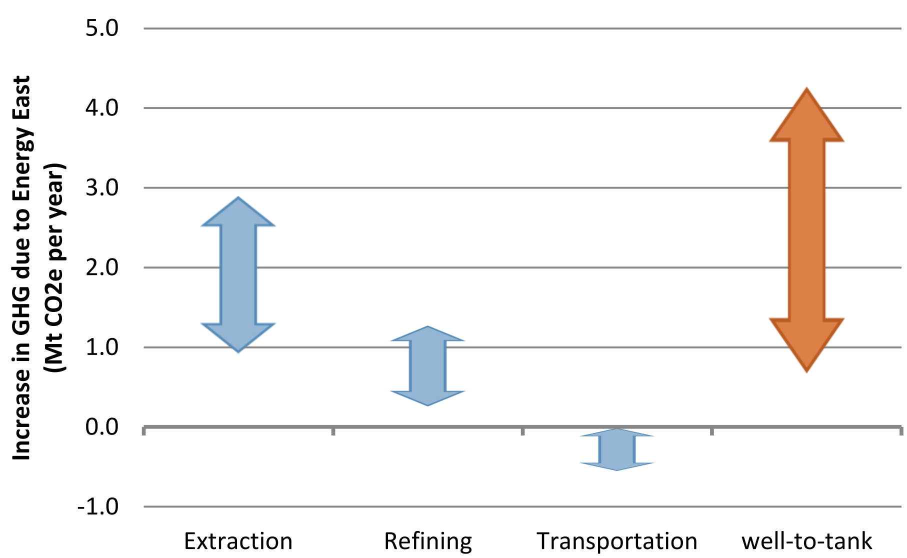
2) Refining of crude oil into refined petroleum products and "upgrading" bitumen into synthetic crude oil; and

3) Transportation of oil and refined products between regions.

In summary, this portion of the oil sector comprises all sources of emissions from the point of extraction ("wells") to right before refined products are consumed ("tank").

Figure 2 shows how the Energy East project is likely to affect global emissions from the "well-to-tank" in 2035. The results are reported as a range, with the bottom of each arrow showing the minimum impact and the top of each arrow showing the maximum impact.

Figure 2: The range of impact of the Energy East project on GHG emissions in 2035



From well-to-tank, global emissions increased by between 0.7 and 4.3 million tonnes of carbon dioxide or equivalent (Mt CO_2e) per year in 2035.[2] For context, total global

[2] Unless specified otherwise, all emission impacts are reported for 2035 in annual terms.

emissions in 2011 were about 34,000 Mt, so this would amount to a maximum increase of 0.01% from current levels of emissions.

The impact on GHG emissions from wells-to-tank are described below for each of the three participants introduced above.

Emissions from extraction increase due to the Energy East project. The project would reduce the costs of transporting oil to market, and therefore raise the price for oil in Western Canada. A higher price in Alberta induces greater development of marginal projects. In 2035, the approval of Energy East increases oil extraction from Western Canada by between 30 and 100 thousand barrels per day. This increase is significantly lower than the capacity of the pipeline, which is 1,100 thousand barrels per day.

A large portion of the pipeline capacity is filled with extraction that would have occurred regardless of the project's approval. This is because a large portion of Alberta's oil sands resource is economic even if it has to be exported by rail. As a result, the project's approval does not affect production from these resources. The pipeline simply changes the mode of transport for these resources (from rail to pipeline).

Petroleum refining is another source of new GHG emissions due to Energy East. The project would lead to a slight increase in the global supply for crude oil, and therefore increase total refining throughput. Furthermore, bitumen extracted from Alberta's oil sands requires more emissions intensive processes to produce refined petroleum products. Therefore, the emissions intensity of refining increases with greater bitumen supply. This impact amounts to between 0.3 and 1.0 Mt in 2035.

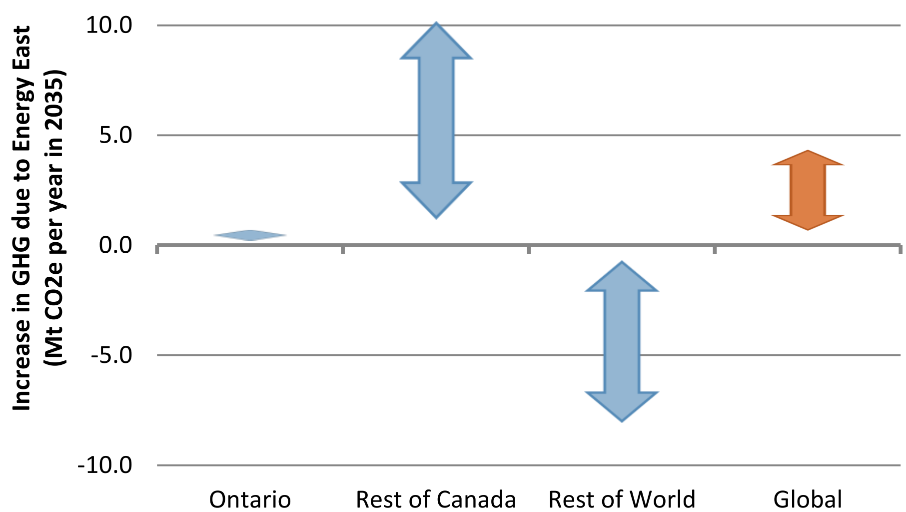
Emissions from oil transport actually decline due to the Energy East project. Pipelines typically consume electricity for transport, and the consumption of electricity can lead to emissions at the point of electricity generation. However, these emissions are offset by fewer emissions from rail transport, which consumes diesel. As the Energy East project would operate through several provinces with close to zero-emissions electricity generation (i.e., Ontario, Manitoba and Québec), greater pipeline transport reduces net transportation emissions.

The Energy East project would have a negligible impact on Ontario's GHG emissions.

As oil production in Ontario is negligible, the project only affects emissions from well-to-tank from two sources: petroleum refining and the operation of the pipeline.

As the pipeline would not connect with any refinery in the province, the project has a negligible impact on GHG emissions from petroleum refining. The main new source of emissions in Ontario due to the project would be due to the operation of the pipeline. In 2035, these emissions are estimated at between 0.2 and 0.6 Mt CO_2e (see Figure 2). For context, these emissions would amount to less than 0.5% of Ontario's GHGs in 2012.

Figure 3: Location of GHG impact from wells-to-tank in 2035



The increase in global GHG emissions from well-to-tank would be concentrated in Canada, with emissions declining in the rest of the world.

The entire global market for oil would readjust to the approval of the Energy East project. While the project would increase prices for oil in Alberta due to lower transportation costs, it would lower the average global price for oil. Therefore, producers in other regions would reduce extraction. Figure 2 shows where the impact on GHG emissions is located. The figure shows the range of impact to reflect the variation observed in different scenarios. The top of each arrow is the maximum impact, while the bottom of each arrow is the minimum impact.

The entire increase in GHGs from well-to-tank would occur in Canada, with emissions in the rest of the world declining. Emissions increase in Canada for two main reasons. First, production and associated emissions from the oil sands increase due the approval of the Energy East project. Second, the project's approval would lead to greater refining of bitumen in Eastern Canada (which is more emissions intensive to refine relative to light oil).

The increase in Canadian emissions would be partially offset by a decline in the rest of the world. The decline in emissions in the rest of the world is caused by the flip side of the increase in Canadian emissions. Greater production from Alberta reduces the average global oil price, and therefore production and associate emissions from extraction in other regions. With greater refining of bitumen in Canada, less is refined in other countries.

While emissions from well-to-tank decline in the rest of the world, this decline does not fully offset the increase in emissions from Canada. Overall, global emissions from wells-to-tank increase by between 0.7 and 4.3 Mt per year in 2035. The approval of the Energy East project leads to a net increase in global crude oil production, which comes mostly from the oil sands. Further, oil sands are more energy and emissions intensive to refine relative to many other sources of crude oil.

The Energy East project would increase global emissions from the consumption of refined petroleum products ("tank-to-wheels"). All of this impact would occur outside of Canadian regulatory control.

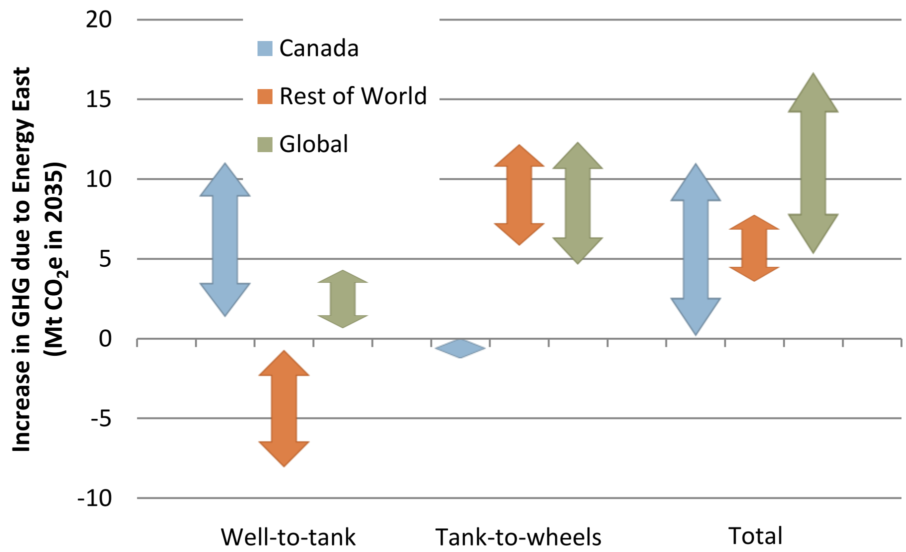
This analysis confirms that the Energy East project is likely to increase the global consumption of refined petroleum products and associated greenhouse gas emissions. The implication of the Energy East project is that the average global price for oil declines slightly, leading to lower prices for refined petroleum products.

In 2035, the Energy East project reduces the benchmark price for crude oil in Europe (the Brent price, which is the best representation of the global price) by between $0.2 and $0.6 per barrel (2010$). With lower prices, the emissions from the consumption of refined petroleum products (i.e., emissions from "tank-to-wheels") increase by between 4.7 and 12 Mt (see Figure 4).

The entire impact from tank-to-wheels occurs outside of Canada, and therefore outside of Canadian regulatory control. Emissions from the consumption of refined petroleum products increase by between 5.8 and 12 Mt in 2035 in the rest of the world.

Ontario and Canadian emissions from tank-to-wheels actually decline in most scenarios due to Energy East's approval. While the Energy East project would reduce the average global price for oil, it raises prices for oil and for refined petroleum in Western Canada. With higher prices, the consumption and associated GHG emissions decline in Western Canada.

Figure 4: Location of emissions due to Energy East in 2035



The total impact (from well-to-wheels) of the Energy East project would range from 5.3 to 17 Mt in 2035. This amounts to a maximum increase of 0.1% in the globe's projected emissions from well-to-tank. Of this increase, between 74 and 87% is from final demand while the remainder is upstream from final demand.

The majority of the increase in GHG emissions attributed to Energy East would occur outside of Canada. Figure 4 shows that the majority of the impact occurs outside Canada. The maximum increase in Canada is 11 Mt in 2035. For context, Canada's emissions were 700 Mt in 2012, so this would represent a maximum increase of 1.6% from current levels.

The Energy East project is unlikely to "lock-in" GHG emitting infrastructure in a GHG constrained world.

Experts have highlighted two concerns with new pipeline infrastructure from Alberta in the context of the objective to reduce global GHG emissions. The first is that new pipelines may not be needed in a world that achieves its goal of limiting the rise in global temperatures to 2^{O}C from pre-industrial levels. If this climate goal is achieved, the argument goes, the world would demand less oil and the remaining demand would not be sufficient to warrant a new pipeline.

While this concern is legitimate, in the context of GHG emissions it is largely a private concern. If the Energy East project turns out to be unprofitable, its construction and operation costs will be borne by TransCanada and its shareholders, not the public.

Therefore this analysis does not examine whether the project would be economic in a GHG constrained future.

The second concern is important from a public perspective. The concern is that new pipelines could make it more difficult to limit the rise in global temperatures to $2^{O}C$ from pre-industrial levels. If the project enables greater production from the oil sands, this production may not be needed and it would be difficult to close later on.

The modeling examined the degree to which new pipelines would "lock-in" GHG emitting infrastructure and make it more difficult to stabilize global temperatures at $2^{O}C$. To estimate the extent of lock-in, the analysis estimated whether a global policy to achieve $2^{O}C$ would have to be stronger if Energy East is approved. This analysis suggests the impact of lock-in is small.

There are two possibilities for the future of the oil sands in a $2^{O}C$ world. First, advanced technologies to extract bitumen will not become available. In this world, production from the oil sands will stagnate and eventually start to decline. The approval of the project would not reverse this trend.

The second possibility is that technologies for extracting bitumen from the oil sands, which are currently in a developmental phase, become commercial. These technologies include solvent-based extraction among others. If this occurs, the oil sands will have significantly lower GHG intensities (on par with other global resources in a GHG constrained world), and production will continue to grow (although less rapidly than in the absence of climate policy). As the emissions intensity of bitumen would be significantly lower with these technologies, the concerns about oil sands would be ameliorated.

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1. Introduction

On October 30, 2014, the Energy East Pipeline Ltd., a wholly owned subsidiary of TransCanada Oil Pipelines (Canada) Ltd. (TransCanada), submitted its application to the National Energy Board for the proposed Energy East project. The Energy East project would connect oil producing regions in Western Canada with refineries and export terminals in Eastern Canada (see Figure 5). As proposed in TransCanada's regulatory filing to the National Energy Board, the project would have:

- A capacity to deliver up to 1,100 thousand barrels per day of crude oil from Western Canada to Eastern Canada;
- Two shipping terminals, one in Cacouna, Québec and one in Saint John, New Brunswick;
- The pipeline would be available to ship crude oil by 2019; and
- A $12 billion upfront capital cost, which would be recovered over time through pipeline tolls.

Figure 5: Conceptual map of the Energy East project[3]

[3] TransCanada, 2014, *Energy East Pipeline*, available from: http://www.energyeastpipeline.com/; accessed November 17, 2014.

The Ontario Minister of Energy has asked the Ontario Energy Board (OEB) to examine the Energy East project from an Ontario perspective. As a part of the process, the OEB has undertaken consultations with various communities across Ontario to provide a forum for Ontarians to express their views on the proposed Energy East project.

During the consultation process, participants expressed concerns that the project's approval would lead to greater greenhouse gas (GHG) emissions. Specifically, they expressed concerns that the pipeline would enable greater activity from Alberta's oil sands, and this would lead to a net increase in Canada's and the world's GHGs. Additionally, greater supply for crude oil could increase the global consumption of refined petroleum products, further increasing GHG emissions and exacerbating global climate change.

The OEB wishes to inform the Ministry of Energy on how the project is likely to affect GHG emissions. The OEB has retained Navius Research Inc. to estimate how the approval of Energy East would affect GHG emissions. The OEB has asked that the analysis focus on all sources of GHG emissions – from extraction ("wells") to final consumption ("wheels") – that can be attributed to the project.

To provide insight into the impact of the project, Navius has reviewed the literature and conducted original modeling of the Energy East project to estimate its emissions impacts. The modeling uses the OILTRANS model, which accounts for all sources of greenhouse gas emissions from extraction to final consumption ("wells-to-wheels").

This report is structured as follows. The following section provides a review of the literature on how pipeline infrastructure is likely to affect greenhouse gas emissions. Section 3 provides a high level summary of how the OILTRANS model estimates the impact of pipeline infrastructure on global GHG emissions. The section further describes the scenarios under which the Energy East project is evaluated. Section 4 summarizes the modeling results. Section 5 concludes with a discussion of the results.

2. Literature Review and Conceptual Framework

Several authors have conducted qualitative and quantitative analyses of how oil transportation infrastructure affects GHG emissions. The body of literature focuses mostly on TransCanada's proposed Keystone XL pipeline that would connect Alberta with refineries in the Gulf Coast of the United States. However, strong parallels can be drawn between Keystones XL and the Energy East project.

The GHG impact of an oil pipeline includes emissions related to operation as well as indirect lifecycle GHG emissions resulting from changes in the global oil market (e.g., global emissions increase if high GHG intensity oil production is substituted for low GHG oil production). This review focuses on analyses of the global lifecycle GHG impact of Keystone XL, with one study that focuses directly on Energy East.

Based on this literature review, we have produced a framework to describe a complete methodology to evaluate the global GHG impact of oil transportation infrastructure. Finally, we compare the OILTRANS model against this framework to demonstrate its capacity to produce a rigorous analysis of the GHG impacts of the Energy East pipeline.

Literature Review

U.S. Department of State Keystone XL Environmental Impact Statements, Final Statement (2011), Final supplemental statement in (2014)

The U.S. Department of State is a branch of the United States government that was tasked with examining the impact of the Keystone XL project. The State Department produced a broad qualitative and quantitative analysis of the GHG impact from Keystone XL. They concluded that the Keystone XL pipeline will lead to a positive but modest increase in global lifecycle GHG emissions. The State Department's conclusions are informed by several individual analyses, including:

- An oil market study
- A lifecycle GHG analysis of crude oil production
- A review of crude oil transportation options between Canada and the United States
- A review of supply costs for different oil sands resources

Oil Market Study and Lifecycle GHG analysis

EnSys Inc. produced the oil market study using their World Oil Refining and Logistics Demand (WORLD) model. WORLD represents the global oil market and estimates regional crude oil and oil product prices as well as trade flows of these goods via multiple transportation modes. The WORLD model was used to estimate how building or not building Keystone XL would change:

- The source of crude oil and petroleum products used in the United States
- The volume and market destination of Canadian crude oil
- The price of crude oil and petroleum products at different trading hubs (e.g., the price at Hardisty in Edmonton that Albertan producers would experience)

These results were produced under several scenarios that defined US oil demand as well as other pipeline expansions from Alberta. Key results from this analysis are that:

- Keystone XL by itself will not change refining activity or petroleum product prices in the US. The pipeline will simply shift the source of crude oils used in the United States. A reduction in Canadian imports to the United States will be met by increased imports from other foreign sources such as the Middle East.
- Keystone XL by itself will not change the benchmark price of oil that Alberta producers receive (i.e., the price of Western Canadian Select, known as WCS). This price is more sensitive to a restriction on East/West pipelines from Alberta or a restriction on all new pipelines from Alberta. In these scenarios, the WCS price will be 10-20$/bbl lower than it would be without constraints on pipeline development.
- Canadian crude oil production will only be reduced if 1) no new pipelines from Alberta are built, 2) no new pipelines between the north-central US and the Gulf coast are built, and 3) if other transportation modes such as rail are restricted.

While the EnSys analysis sought to quantify some impacts of the Keystone XL project, it did not inform others.

The total demand for refined petroleum products was treated as fixed in the modelling. In other words, the consumption for refined petroleum products (e.g., gasoline or diesel) did not change in response to changes in the price for oil or refined products. As a result, this study does not inform how new pipeline infrastructure may affect emissions associated with changes in consumption.

Canadian oil or bitumen production was not explicitly modelled in any of the scenarios. Instead, the product mix (e.g., the fraction of total production that is bitumen versus synthetic crude oil) was held constant according to a forecast from the Canadian Association of Petroleum Producers. Therefore, the results of this study could not account for how emissions from refining and bitumen upgrading (i.e., the production of synthetic crude oil from bitumen) might change in response to market and policy drivers.

Most importantly, because Canadian production was not explicitly modelled, it appears that total production volumes did not respond to prices. For example, while the WORLD model could show that production can be constrained by a lack of export capacity (i.e., a physical limitation to production), it seems that it could not show how production might be reduced if oil sands projects became less profitable or unprofitable (i.e., an economic limitation to production).

In summary, the WORLD model provided a global representation of how Keystone XL would change the source and price of crude oil and petroleum products in the US and other regions, but it did not account for how a change in oil prices could change:

- Global oil consumption
- The oil sands product mix (e.g., bitumen vs. upgraded synthetic crude oil)
- Future investment and production in the oil sands

When paired with the US Department of Energy oil lifecycle GHG model, the analysis concluded that Keystone XL is unlikely to change the GHG emissions that result from global crude oil production and refining. Again this result is subject to the caveats that the WORLD model cannot quantify how fossil fuel infrastructure may change global consumption or how Canadian crude oil volumes or prices will respond to different oil prices.

Review of Crude Oil Transportation Options

The State Department analysis included a review of rail and pipeline options for transporting crude oil from Alberta into various regions in the US. The review indicated that there is a significant potential to move oil and bitumen out of Canada by rail. Furthermore, the cost premium of rail transport relative to pipeline will be modest because of the economies of scale and reduced diluent requirements achieved with dedicated bitumen transport trains. The implication of this result is that the WORLD model scenario where Canadian production is constrained by limited transportation options is unlikely.

Review of Oil Sands Supply Costs

The State Department paired the results of the EnSys modelling with an analysis of the oil sands supply curve (i.e., costs and volumes of each resource) to understand if and how constraints on oil transportation from Alberta would change oil sands production.

The supply curve included the cost and volume of current and announced oil sands production.

The State Department produced the supply curve using information from the Canadian Energy Research Institute,[4] the Oil Sands Development Group,[5] The Energy Conservation Resource Board[6] (now called Alberta Energy Regulator), the National Energy Board,[7] BMO[8] and Goldman Sachs.[9] The supply curve showed that all expected oil production from the oil sands is economically viable with a WSC price of $50-$60/bbl, corresponding to the cost of new in-situ bitumen extraction.

By comparing the EnSys results with this supply curve, the State Department concluded that constraints on pipelines and other oil transportation from Alberta are unlikely to render projects unprofitable, thereby changing oil sands production. In the WORLD model results, the WCS price does not fall below 80$/bbl in any scenario. At that price, all forecasted oil sands production is economically viable, albeit less profitable.

Conclusions on the Global Lifecycle GHG Impact of Keystone XL

Ultimately, the State Department did not directly use the above analyses to estimate the global lifecycle GHG impact of Keystone XL. The analyses within the Environmental Impact Statement suggest that Keystone XL is unlikely to affect global GHG emissions. In other words, the global lifecycle GHG impact is zero $MtCO_2e$/yr.

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[4] Canadian Energy Research Institute (CERI). 2012. Conventional Oil Supply Costs in Western Canada.

[5] Oil Sands Developers Group. 2013. Oil Sands Project List 2013—Updated July 2013.

[6] Energy Resources Conservation Board (ERCB). 2011. Alberta's Energy Reserves 2010 and Supply/Demand Outlook 2011-2020. June 2011. ISSN 1910-4235.

[7] National Energy Board (NEB). 2011. Canada's Energy Future: Energy Supply and Demand Projections to 2035.

[8] BMO Capital Markets. 2012. Oil and Gas Global Cost Study. August 2012.

[9] Goldman Sachs. 2013. 380 Projects to Change the World. From resource constraint to infrastructure constraint. Exhibit 47, page 31. April 12, 2013

Despite this conclusion, the State Department produced a GHG estimate bounded by two assumptions. The upper bound of the GHG impact assumes that without Keystone XL, a light, low-GHG intensity oil (e.g., Middle Eastern Sour) would substitute for Canadian bitumen. The lower bound of the GHG impact assumes that without the pipeline, Venezuelan heavy oil would substitute for Canadian bitumen. Based on these assumptions, the State Department estimated the indirect lifecycle GHG emissions of Keystone XL between 1.3 and 27.4 $MtCO_2e$/yr.

Pembina Institute

Flanagan, 2014, *Climate Implications of the Proposed Energy East Pipeline*

Lemphers, 2013, *the Climate Implications of the Proposed Keystone XL Oil Sands Pipeline*

Droitsch, 2011, *the Link between Keystone XL and Canadian Oil Sands Production*

The Pembina institute is a Canadian non-governmental organization that focuses on environmental protection. Pembina is one of the few organizations to offer commentary specific to the Energy East project (2014) and they have offered two critiques of the State Department's analysis of Keystone XL (2011 and 2013). The focus of their studies has been the impact of new pipeline infrastructure on upstream emissions in the oil sands. In their latest study, they indicate that the Energy East project would increase upstream emissions in Alberta's crude sector by between 30 and 32 Mt CO_2e on an annual basis. They indicate that this pipeline would therefore "cancel out most or all of the reductions generated by Canada's single most effective climate policy": "phasing out the use of coal power in Ontario" (2014).

In the 2011 and 2013 studies, Pembina argued that the State Department's analysis is flawed because it did not adequately assess how oil sands would evolve in the absence of new pipelines from Alberta. The EnSys analysis conducted for the State Department assumed that new pipelines would be built (e.g., Northern Gateway) if Keystone XL does not move forward. Therefore, oil sands would find markets regardless of Keystone XL.

Pembina argues, rightfully in our opinion, that there is no guarantee that new pipelines would be built. They cite complications with the approval of the Northern Gateway project due to public opposition, lack of approval among First Nations, among others. Similar challenges exist for approving the Keystone XL or Energy East project.

Pembina also argues that alternative means of transporting oil sands by rail or truck are "unlikely" (2011), "likely to be small" (2013) or cost prohibitive (2014). Although

Pembina's thoughts on rail have progressed since 2011, an underlying assumption behind their conclusions is that rail will fail to be a long-term option for Alberta producers to access markets. Therefore a 1 barrel increase in pipeline capacity leads to a 1 barrel increase in oil development in Alberta (mostly from oil sands) and an increase in associated GHG emissions.

Pembina's argument that transport by rail is unlikely or likely to be small is unconvincing. Pembina is right that transport by rail is more costly relative to transport by pipeline. Based on data from the EIA, rail transport is about three times more costly relative to pipeline transport.[10] However, the economic viability of transport by rail is based on whether the price for bitumen in Alberta is sufficiently strong to warrant the more costly option for transportation. A study by Andrew Leach (reviewed below) indicates that the price for bitumen is likely to be sufficiently high to warrant new oil sands developments and transport by rail.

Pembina's focus has been on how new pipeline infrastructure would affect upstream emissions in Western Canada's oil sector. However they note that any production displaced in Alberta could occur elsewhere, with emissions "leaking" to the other jurisdiction. They argue that these emissions are less important because oil sands are one of the most energy and emissions intensive crudes to extract and process. Therefore a relocation of extraction from Alberta to some other jurisdiction would yield a net reduction in GHG emissions. Pembina did not make any effort to quantify the degree to which emissions in other jurisdictions would increase with a decline in oil sands production.

Forrest and Brady, 2013, Keystone XL Pipeline: No Material Impact on US GHG Emissions, IHS CERA Insight

Jackie Forrest and Aaron Brady are senior directors at IHS CERA, an energy think-tank with a focus on the oil and gas industry. The authors affirm the State department's conclusions and indicate that the GHG impact of Keystone XL is at the lower bound of the State Department estimate (closer to 1 Mt per year).

The authors explain that there are multiple transportation options to move oil that would compensate for Keystone XL not being approved. They suggest that transporting bitumen by rail offers some economic advantages since less or no diluent is required.

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[10] Energy Information Administration, 2013, *Rail deliveries of oil and petroleum products up 38% in first half of 2012*, available from www.eia.gov.

They conclude that Keystone XL will not have a significant impact on Canadian production.

They further argue that because the US Gulf Coast refineries are designed to refine heavy oil and bitumen. Any shortfall in Canadian bitumen imports to the US would be compensated by increased imports of Venezuelan heavy oil, resulting in similar global GHG emissions.

Erickson and Lazarus, 2014, Impact of the Keystone XL pipeline on global oil markets and greenhouse gas emissions, Nature Climate Change

Erickson and Lazarus are senior scientists at the Stockholm Environmental Institute, which is a non-profit organization that focuses on research in environmental issues. Erickson and Lazarus developed a simple model of global oil supply and demand to demonstrate that global oil consumption and GHG emissions could be sensitive to development of fossil fuel transportation infrastructure. They argued that if Keystone XL increased production from Alberta, this would increase global oil supply. Increased supply would exert downward pressure on the price of oil which in turn would increase consumption.

They concluded that this price/demand feedback could have a much larger GHG impact than the upstream impact assessed by the State Department. Their results put the upper bound at 110 $MtCO_2e$/yr. Specifically, this impact would only result *if* Keystone XL enabled bitumen production in production that would not otherwise occur without the pipeline.

It is important to highlight that their methodology only represented the global relationships between oil prices, production and consumption. Therefore, it could not actually determine whether the pipeline would change production in Alberta.

Andrew Leach, 2014, critiques of Erickson and Lazarus[11]

Andrew Leach is a professor of Energy Policy at the University of Alberta. Leach does not negate the price/demand dynamic that Erickson and Lazarus proposed, he suggests that it would only be relevant under specific circumstances. These would be dictated by the relative cost of transporting Albertan Bitumen to market by pipeline versus rail. He

[11] Accessed Sept 9th from www.macleans.ca/economy/economicanalysis/econ-101-is-great-but-get-it-right/ and www.macleans.ca/economy/economicanalysis/kxl-econ-101-lecture-2/

argues that global oil supply would only be changed if the approval of Keystone XL affected global marginal oil production (i.e., the most expensive production, or the production that would not occur if demand fell). To demonstrate that condition, one would need to show that the incremental cost of rail transportation relative to pipeline transportation makes otherwise viable oils sands production unviable. If not, then Keystone XL will only affect profit margins and not the quantity of bitumen extracted; there would be no real change in global GHG emissions driven by a change in oil consumption.

Michael Levi, 2014, critique of Erickson and Lazarus[12]

Michael Levi is a senior fellow at the Council of Foreign Relations, which focuses on foreign policy analysis. Levi also argues that the size of the price/demand impact proposed by Erickson and Lazarus is unlikely. He suggests that even if Canadian production changed, the demand response would only occur if other suppliers did not adjust production to maximize the value of their resource. For example, cartel behaviour (e.g., OPEC) could result in production constraints elsewhere that would yield a small net-change to global oil supply. Similarly, major producers might restrain production on their own accord to maximize the value of their resource over time. Therefore, the change in oil price and demand would be small and the GHG impact would likely be within or close to the range estimated by the State Department.

Palen, Sisk, Ryan, Árvai, Jaccard, Salomon, Homer-Dixon, Lertzman, 2014, *Consider the Global Impacts of Oil Pipelines*, Nature, vol. 510

The authors state that the policies governing oil sands expansion should have a scope that is wider than approving or denying a given pipeline proposal. They argue that good policy must account for the consequence of carbon emissions, look at cumulative environmental impacts and consider the trade-offs between the multiple factors affected by oil sands growth (e.g., economic benefit, impact on climate, impact on land and water resources). They suggest adopting a moratorium on all oil sands projects, not just a specific export route, until that development can be reconciled with national and international GHG emissions targets.

An underlying theme of their commentary is that expanding the oil sands and building new pipelines is at odds with Canada's national GHG emissions targets. It is also at odds

[12] Accessed Sept 9th from http://blogs.cfr.org/levi/2014/08/13/a-new-keystone-xl-paper-is-probably-wrong/#

with the global reduction in GHG emissions that will reduce the risk of anthropogenic climate change.

Summary of the literature

In conclusion, all of the analyses ask whether a pipeline will increase GHG emissions within a region or globally. Palen *et al* (2014) come at this issue from another angle, asking whether investment in the oil sands fits within a world with constrained GHG emissions. Essentially, is there a business case for expanding our oil infrastructure if we also want to avoid climate change? A complete analysis of the GHG implications of a pipeline should be able to answer both questions.

Conceptual Framework

The literature review demonstrates that that there are many different dynamics that influence how fossil fuel infrastructure affects GHG emissions. The difference in the conclusions of the analyses is less to do with whether an author has accurately represented a dynamic, and more do to with which dynamics were included in the analysis.

This review highlights a need for a fully integrated analysis which accounts for all major dynamics that affect oil markets and associated greenhouse gas emissions. Broadly speaking, these could be changes to production, transportation and processing infrastructure, or even GHG reduction policies applied to the sector in various regions. Therefore, we believe a complete analysis of the GHG impact of these factors must include a detailed representation of technologies, resources, market feedbacks and policy impacts.

In the Canadian Context, a complete analysis must answer the following questions:

- **Does the project change Canadian oil production and GHG emissions?** To answer this question, the methodology needs to account for:
  - Canadian supply costs and GHG emissions intensity by product and technology. For example, bitumen can be extracted using several different processes, including mining and in-situ. Even within the in-situ bitumen resource, technology choice affects greenhouse gas emissions.
  - Canadian oil price and how it changes under different assumptions
  - Cost and emissions of pipeline transportation

- Cost and emissions of rail transportation

- **Does the project change global oil production and/or consumption?** To answer this question, the methodology must include:
  - Global supply costs and GHG emissions intensity
  - Global transportation costs and emissions (i.e., Marine transport)
  - Price sensitivity of demand
  - Regional oil prices
  - Behaviour of other agents to maximize the value of their resource (e.g., a cartel such as OPEC or major producer restraining production to increase prices)

- **How does energy and climate policy change supply costs and emissions intensities over time?** The cost and GHG intensity of oil production is not static. The relative production and emissions by region, product or extraction method can be altered by policy. Therefore, the ultimate GHG impact of any change to the oil market will be influenced by energy and emissions polices. Conversely, a methodology cannot assess the need for new oil sector infrastructure in a GHG constrained future unless it can represent the impact of energy and emissions policies.

Comparison of Methodologies

In Table 1, we evaluate the analyses described above against the elements that constitute a complete methodology. The State Department's analysis is shown twice: once to show the issues covered in their analysis, and once to show the dynamics used to estimate the GHG impact of Keystone XL. We also compare these to the OILTRANS model, showing that it provides the most comprehensive coverage of dynamics affecting GHG emissions in the global oil market.

Table 1: Comparison of OILTRANS with the methodologies and critiques review above

	Change in Canadian Oil Production?				Change in Global Oil Production?					Policy Impact?
	Canadian production cost/GHG	Pipeline transport cost/GHG	Rail transport cost/GHG	Canadian regional oil price	Regional production cost/GHG	Marine transport cost/GHG	Regional oil prices	Demand sensitive to price	Cartel behavior	Dynamic GHG/barrel over time
State Dept. (2014)	✓	✓	✓	✓	✓	✓	✓			
GHG estimates from State Dept. (2014)	✓				✓					
Pembina Institute (2011, 2013, 2014)	✓			✓						
Forest & Brady (2013)		✓	✓		✓					
Erickson & Lazarus, (2014)								✓		
Leach (2014)	✓	✓	✓	✓						
Levi (2014)									✓	
OILTRANS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

3. Methodology

This section introduces the OILTRANS model, which is used to estimate how the Energy East project affects global greenhouse gas emissions. The section further describes the scenarios uses to assess the impact of Energy East.

The OILTRANS model

OILTRANS is an equilibrium model of the global oil market. The model represents the full supply chain for crude oil from extraction ("wells") to the final consumption of refined petroleum products ("wheels").[13] The model simulates how the global oil market adjusts under different economic conditions or constraints (e.g., whether Energy East is approved). The model solves for the price for every grade of crude oil, the price for refined petroleum products and refinery services such that the entire global oil market arrives at an equilibrium.

OILTRANS is unique in that it is an "agent" based model. This means that the model simulates the behavior of specific agents within the global oil market and can distinguish between the behaviours of different agents (e.g., OPEC decision making versus oil producers operating in a competitive environment). The model does not "optimize" for how the market "should" evolve if there were a single agent minimizing the costs of producing refined petroleum products (i.e., the typical approach of optimization models). Rather it simulates "how" the market is likely to evolve with each agent pursuing their own objectives.

Box 1 presents the key highlights of the model.

[13] "Wheels" and "tank" are used throughout the study as analogies for different points in the supply chain. However, they are imperfect analogies for representing consumption because refined petroleum products are used for non-transportation purposes, in addition to transportation. Non-transportation uses include feedstock into petrochemical manufacturing, demand for direct heat, electricity generation, among others. The model accounts for the consumption of each of these. However, refined petroleum products are primarily used for transportation.

Box 1: OILTRANS at a glance

OILTRANS represents:

- The evolution of the global oil market from 2015 to 2035 in 5 year increments.
- 27 regions/trading hubs, with 10 in Canada and 6 in the United States.
- 11 grades of crude oil, which vary by API gravity and sulfur concentration.
- 54 oil resources represented throughout the world. Each resource varies by extraction cost, greenhouse gas intensity, grade of crude oil and well decline rate.
- The ability to upgrade bitumen to synthetic crude oil.
- 3 modes of transporting crude oil (pipeline, rail and tanker), which have unique costs, greenhouse gas intensities and constraints.
- 13 refining processes required to refine different grades of crude oil into refined petroleum products.
- 35 refining technologies/decisions available to meet the demand for refining processes, each with a unique cost and greenhouse gas intensity.
- 6 types of refined petroleum products that are consumed by final consumers.

The following sections describe each agent in detail, starting upstream ("wells") and moving downstream to the final consumer ("wheels").

Oil producers

The objective of an oil producer is to maximize their profits by extracting and selling crude oil. Oil producers are assumed to make several decisions in order to maximize profits:

- *Extraction decisions:* Oil producers must decide whether and when to develop specific resources. For example, if a resource is not economic to develop in a given year, producers can delay extraction until a following year. Producers can also decide to forgo development altogether (i.e., leave the oil in the ground) if it is uneconomic to extract.

- *Technology choice:* Extraction decisions are partially based on the availability of technology. All resources can employ different technologies, which have different emissions intensities and costs. For example, in-situ oil producers in Alberta have the option of using six technologies for extraction. These include Cyclic Steam Stimulation (CSS), Steam-Assisted Gravity Drainage (SAGD), more efficient SAGD (SAGD+EFF), SAGD plus carbon capture and storage (SAGD+CCS) and a few advanced technologies such as solvent based extraction (SOLV) and SOLV+CCS. Each of these technologies has a unique cost and a unique GHG intensity.

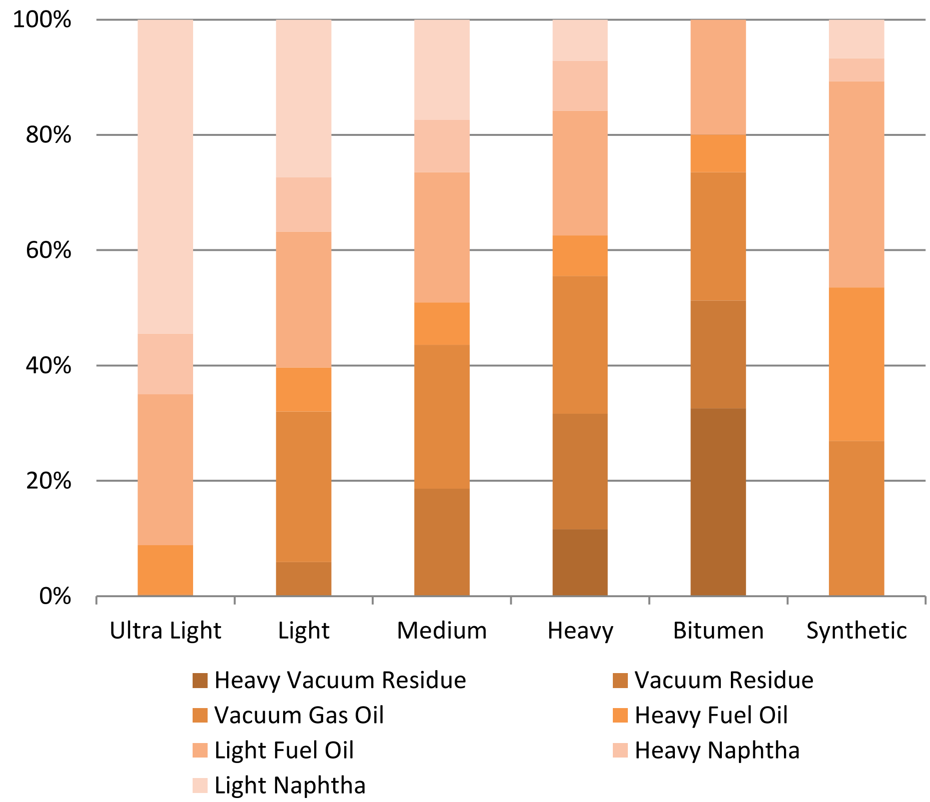
Oil producers are constrained in several ways:

- *Resource constraints:* Extraction from some resources is limited by the availability of the resource. The extraction of oil by conventional means is declining in many regions due to resource depletion. Other resources (e.g., Saudi Arabia, Venezuela bitumen and Alberta bitumen) are mostly unconstrained.

- *Well decline rates:* Most wells experience a decline in production once they are first tapped. These decline rates affect the economics of extraction, as producers will consider the decline rate in advance of making an upfront capital investment. Well decline rates vary by resource. In-situ bitumen extraction, for example, operates at a 75% capacity over a thirty year period, while tight oil experiences a rapid decline in production following its first year of production. In OILTRANS, well decline rates are based on five resource types: conventional, offshore, tight, in-situ thermal and mined bitumen extraction.

- *Crude oil grade:* Resources also vary by the quality of crude oil in the reservoir. The model represents eleven grades of crude oil that vary by API gravity and sulfur content. Figure 6 shows the fractions by grade of crude oil. The distillation of crude oils with high API gravities (e.g., an ultra-light or light oil) produces greater fractions of straight-run gasoline and light fuel oil, which are more valuable. The distillation of crude oils with low API gravities (e.g., bitumen) produces relatively little straight-run gasoline or light fuel oil. These crude oils have greater quantities of vacuum residue, which require more complicated refining processes. Crude oils that are high in sulfur (i.e., sour crudes) also require more complicated refining relative to low-sulfur oil (i.e., sweet crude).

Figure 6: Fractions by crude oil grade



Note: Synthetic crude oil is not "extracted". It is the result of upgrading bitumen (see Page 18).

Organization of the Petroleum Exporting Countries (OPEC)

Oil markets are not perfectly competitive. They are influenced by specific producers (e.g., Saudi Arabia) and/or OPEC which exert market power. These producers can increase their profits by restricting output and thereby increasing the global price for oil. In OILTRANS, producers that exert market power know that they can manipulate their production in order to increase their profits. In economic terms, these producers decide how much to produce by ensuring the marginal cost of production equals the marginal revenue from selling an additional barrel.

Output decisions for producers with market power (in this case OPEC) are determined by solving for Q_{OPEC} in the equation below.

$$MC_{OPEC} = MR_{OPEC} = P_0 \times \left(\frac{Q_{OPEC} + Q_{NOPEC}}{Q_0}\right)^{\frac{1}{\sigma}} \times \left(\frac{1}{\sigma} \times \frac{Q_{OPEC}}{Q_{OPEC} + Q_{NOPEC}} + 1\right)$$

Where: OPEC's marginal revenue (*MR_{OPEC}*) is a function of its output (*Q_{OPEC}*) and the output of non-OPEC members (*Q_{NOPEC}*); σ is the elasticity of demand for crude oil; and P_o and Q_o are constants representing the base price and consumption for oil.

Several commentators have enquired into the impact of pipeline infrastructure in a market that is not fully competitive. Levi (2014) suggests that restricting pipelines from Alberta would lead cartels or other countries to restrict output in order to maintain prices.

It is impossible to conclusively determine what OPEC will ultimately do, as OPEC members may make decisions for non-economic reasons in addition to economic reasons. However, the economics of cartel activity would contradict Levi's intuition. On an economic basis, greater production from non-OPEC producers should increase production from OPEC producers. This occurs because greater non-OPEC production erodes OPEC's market power and OPEC becomes more competitive. Appendix A: describes this dynamic in more detail.

In OILTRANS, once OPEC output has been determined, it is allocated via quotas to each of the OPEC regions.

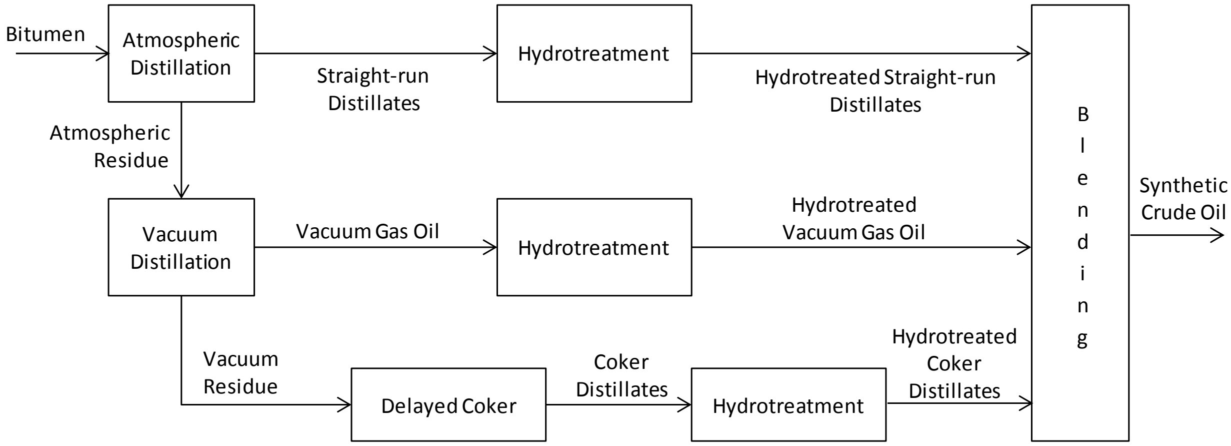
Bitumen upgraders

Bitumen upgrading is most akin to a refinery that produces synthetic crude oil, as opposed to refined petroleum products. Synthetic crude oil is lighter than bitumen, more easily transported by pipelines and requires less refining at the petroleum refining stage.

It is important to distinguish between bitumen extraction and bitumen upgrading. The decision on whether to build new upgrading capacity is distinct from the decision on whether to extract bitumen. The objective of a bitumen upgrader is to convert bitumen into synthetic crude if it is profitable to do so. However, if upgrading is not profitable, bitumen can be exported in its raw form.

OILTRANS represents the individual processes and technologies required to upgrade bitumen into synthetic crude. These are shown in Figure 7 (the auxiliary processes for bitumen upgrading are the same as for the refining section on page 22). Each of these processes and technologies has a specific cost and energy requirement.

Figure 7: Schematic for key processes in bitumen upgrading



Oil traders

The objective of oil traders is to arbitrage price differentials between oil trading hubs. In other words, if the price for oil at one hub is greater than the price at another hub plus the cost of transporting it, oil transporters will transport crude oil.

OILTRANS represents three options for transporting crude oil. Each of these three options has unique costs and constraints:

- *Pipeline:* Offers the cheapest option for transporting crude oil over land. However, the volume of oil which can be transported between hubs is constrained by available capacity. For example, existing capacity available to transport oil from Western Canada to the northern part of PADD II is about 3.1 million barrels per day.[14] And there is very little pipeline capacity available to transport crude oil from Alberta to PADD V (currently there is a single pipeline that carries crude from British Columbia to Washington state).

- *Rail:* In the absence of pipeline capacity, oil can be transported over land by rail. While rail offers greater flexibility (all hubs in North America, except Newfoundland Labrador, can be connected via the rail network), it comes at a higher cost relative to pipeline transport.

[14] PADD stands for Petroleum Administration for Defense Districts. The United States is divided into five PADD districts. OILTRANS further distinguishes between the northern part of PADD II and the southern part. West Texas Intermediate is priced in Cushing Oklahoma, which is in the southern part of PADD II, so this additional disaggregation enables OILTRANS to forecast impacts on this benchmark for crude oil.

- *Ship:* Transport is also available via tanker transport. Tanker transport is constrained to hubs with water access and to export and import terminal capacity. For some routes, transport is constrained by tanker size, with smaller tankers being more costly to operate. Transport through the Panama Canal and the St. Lawrence Seaway to Montreal can only occur with a Panamax size tanker (about 500 thousand barrels). Transport through the Suez Canal or from Cacouna Québec can use up to a Suezmax size tanker (about 1,100 thousand barrels). Other routes allow for the largest (and cheapest) Very Large Crude Carrier (VLCC) tanker (about 2,100 thousand barrels).

Oil transportation companies

The model distinguishes between oil trading and firms responsible for transportation infrastructure. While traders must use installed transportation capacity, transportation companies decide whether to build new capacity. Transportation companies will add new capacity under two conditions:

- *Sufficient price differential:* The price differentials between two regions are sufficient to offset the costs of building new infrastructure (e.g., a pipeline) to carry oil between regions.

- *Infrastructure approval:* New pipelines can only be built if they are approved by the relevant regulatory agencies. As discussed below, scenarios vary whether pipelines from Western Canada are approved.

To assess the impact of Energy East, we override the model's ability to determine when and if new pipelines are built. For every scenario examined, we look at one scenario where Energy East is fully built and one where it is not built at all.

Oil refineries

The objective of an oil refinery is to maximize profits by transforming crude oil into valuable products, like gasoline, diesel, petrochemical naphtha and heavy fuel oil. Similar to bitumen upgraders, OILTRANS represents the individual processes and technologies required for petroleum refining (see Figure 8 and Figure 9). Each process and technology has a specific cost and energy requirement.

Refineries can alter their configurations, and will do so in order to:

- *Alter their oil feedstock:* Different grades of crude oil require different processes. Heavy oils typically require more delayed coking capacity, while sour crudes require greater hydrogen production and hydrotreatment.

- *Change the suite of products produced:* Refineries can produce greater quantities of gasoline through fluid catalytic cracking (FCC), while they can produce greater quantities of light fuel oils (e.g., diesel) by installing a hydrocracker.

- *Reduce costs:* The cost for operating different units can vary over time, due to changes in fuel prices or costs imposed through greenhouse gas policies. For example, carbon capture and storage is an available abatement option for petroleum refining and becomes economic if greenhouse gas policies reach certain strength.

Figure 8: Schematic for key processes in petroleum refining

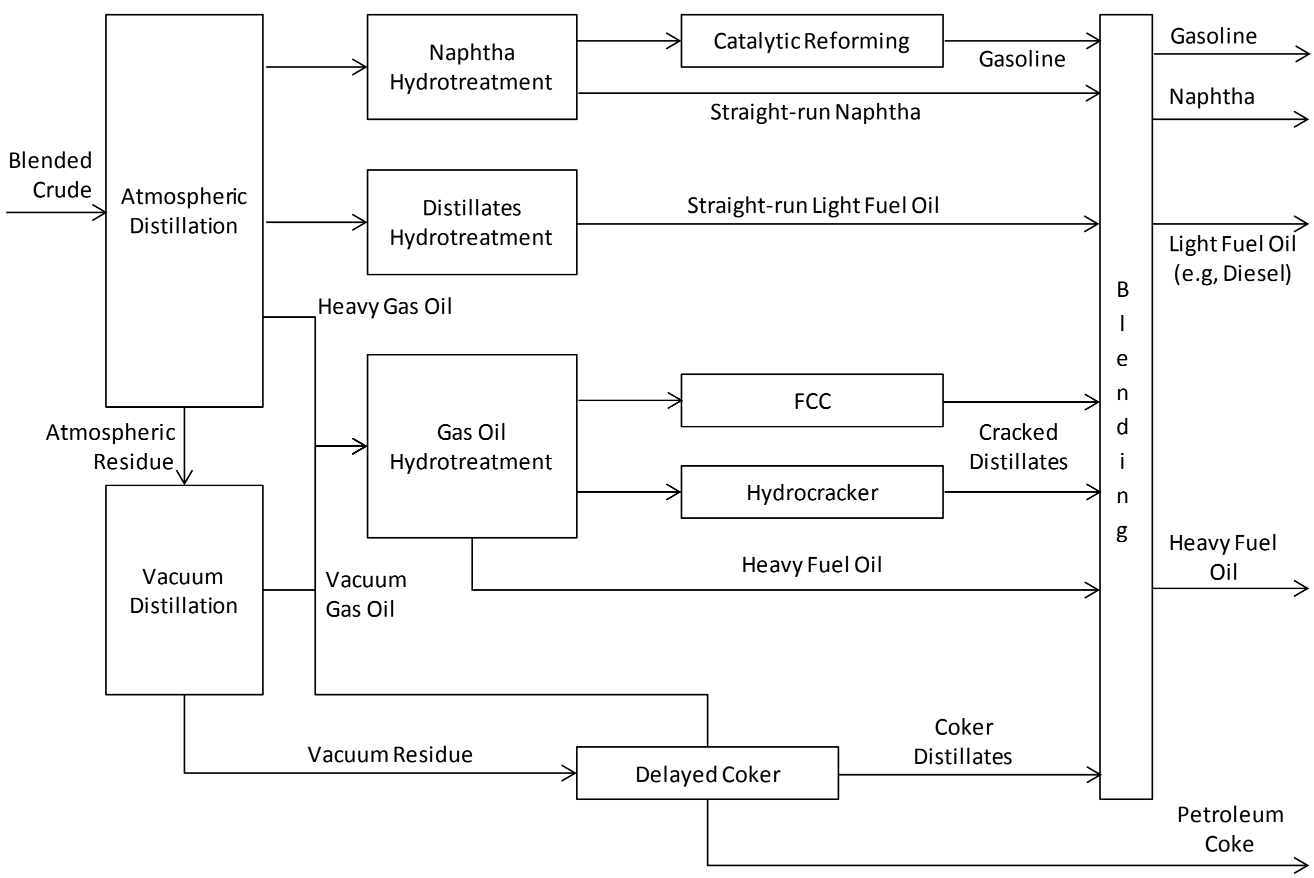
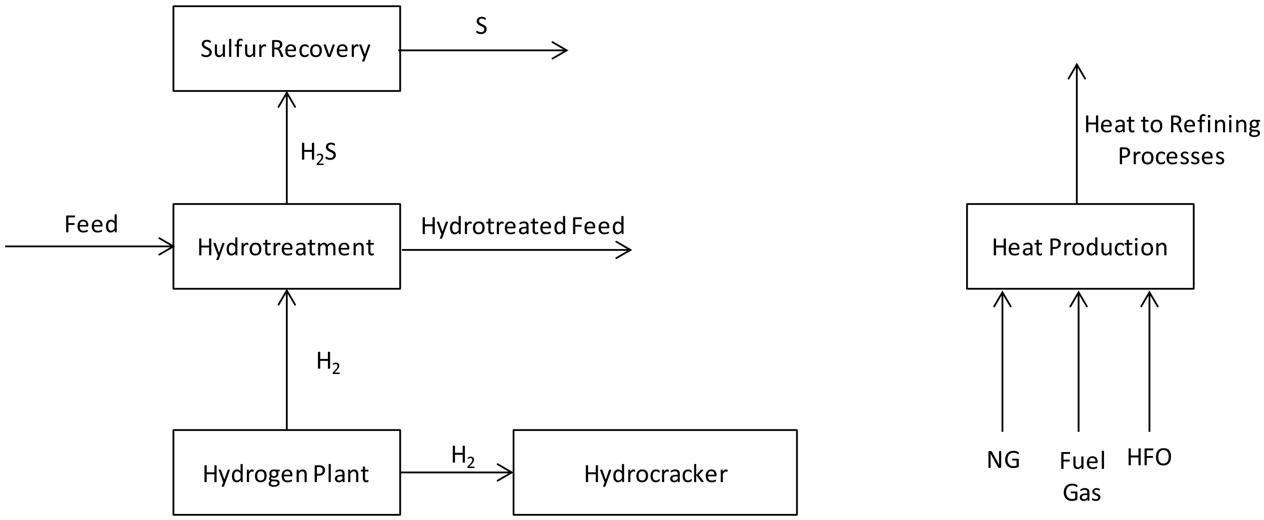


Figure 9: Auxiliary processes for petroleum refining and upgrading



Refined petroleum traders

Similar to oil traders, refined petroleum can be traded using the same or similar transportation infrastructure. Note that the volume of trade for refined product trade is significantly lower than for crude oil.

Final consumers

The purpose of the supply chain for crude oil is to meet the final demand for refined petroleum products. In the model, the demand for refined products is responsive to price. Using empirical estimates of the "elasticity of demand", we inform this sensitivity to price.

Government

Government influences several points along the supply chain for crude oil and refined products:

- *Royalties and oil and gas taxation:* Governments can collect royalties and taxes on crude oil extraction. OILTRANS represents both the gross and net royalty regimes for Western Canadian oil producers. Note that the representation of royalties and taxation is only important if government is not directly involved in extraction. For state owned oil companies (e.g., Saudi Aramco), the objectives for the oil producer match the objective for government (i.e., to maximize profits from the extraction of crude oil).

- *Taxation of refined petroleum products:* Governments impose both excise and *ad valorem* (e.g., provincial sales) taxes on the consumption of refined petroleum products. These, in turn, influence the final consumption for these products.
- *Subsidies for refined products:* In some regions, governments subsidize the consumption of refined products. These subsidies are most notable in Venezuela and the Middle East. These subsidies are captured as negative *ad valorem* taxes.
- *Approval for infrastructure projects:* For this project, any new pipelines must be approved before their construction. All other infrastructure investments are made on economic grounds.

Labor markets

The extraction of crude oil in some regions (particularly Alberta) is constrained by labor availability. Constrained labor availability limits how rapidly a resource can expand its capacity.

Data on how investment in specific resources affects labor availability and labor costs are limited. To inform how labor markets work in Alberta, we estimated the parameters for labor supply that would yield a production profile similar to the Canadian Association of Petroleum Producer's projection.[15]

Capital markets

Capital markets are assumed to be fully open globally to allocate capital towards the most profitable projects.

Scenarios

Scenario design process

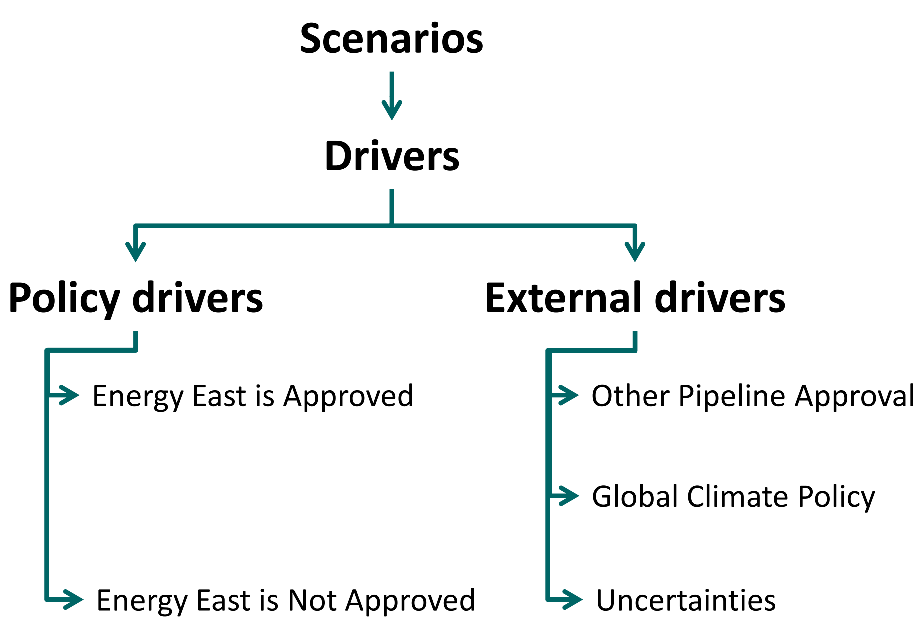
Scenarios are internally consistent views of the future that vary one or more drivers (key assumptions that affect scenario outcomes). Scenarios enable modeling to isolate the

[15] Canadian Association of Petroleum Producers, 2014, *2014 crude oil forecast, markets and transportation*, available from www.capp.ca, accessed November 2014.

effect of specific drivers. For example, if two scenarios are identical in every way but vary approval of TransCanada's Energy East project, the difference between the two scenarios can be directly attributed to the project.

Figure 1 illustrates how varying different drivers define a scenario. Policy drivers represent decisions for policy makers (in this case, the approval of the Energy East project). By varying policy drivers, scenarios can help identify the impact of policy choices. Alternatively, external drivers represent factors outside the control of policy makers. These could include policies from other jurisdictions (such as the approval of other pipelines or global climate policy), but also other factors like changes in energy prices or market conditions.

Figure 10: Defining scenarios and scenario drivers



The objective for the scenario design process is to select scenarios that will inform the range of impacts from the Energy East project.

Scenario choices

Working with the Ontario Energy Board, we identified six scenarios to inform the impact of the Energy East project. Each of these scenarios is designed to answer specific questions about the project.

For every set of external drivers, the analysis varies whether the Energy East project is approved or not. The difference between the two drivers is attributed to the Energy East project.

The scenarios vary four external drivers:

- *The approval of other pipelines from Western Canada:* Several other pipeline projects have been proposed to deliver crude oil from Western Canada to markets. These include: 1) TransCanada's Keystone XL project, which would transport crude to the United States gulf coast; 2) Kinder Morgan's Trans Mountain Expansion project would expand capacity between Alberta and British Columbia; and 3) Enbridge's Northern Gateway project would build a new pipeline between Alberta and British Columbia's coast. The analysis examines two possibilities for other pipeline approval:

    1) *No pipelines*: None of these pipelines are approved.

    2) *Pipelines approved*: Other pipelines are approved, and will be constructed if they are economic.

- *The sensitivity of demand to price:* There is substantial uncertainty on how sensitive demand will be to prices for refined petroleum products. The literature provides a range of estimates of the "elasticity of demand". The elasticity of demand represents the percent change in consumption for a percent change in price. We explore the full range reported in the literature:

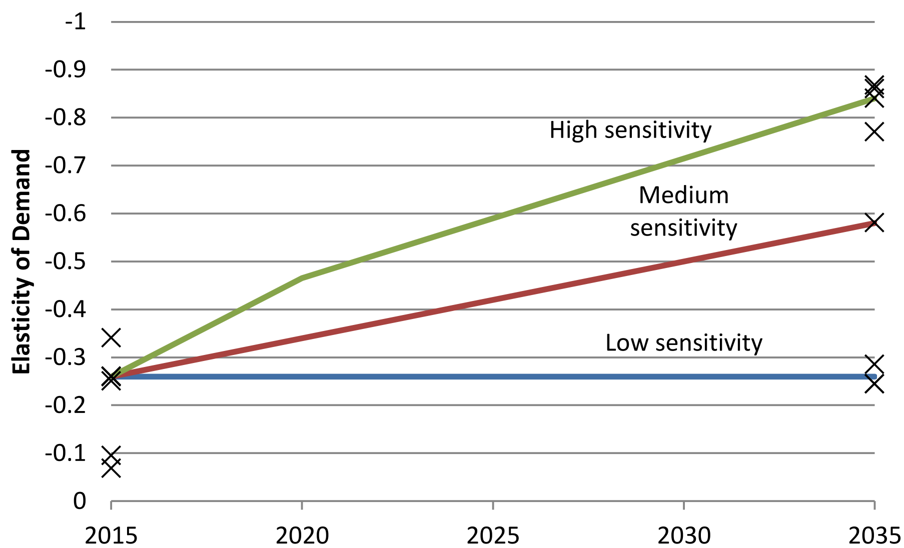
    1) *Low sensitivity:* The elasticity of demand is assumed to be in the lower end of the reported range. In this case, the long-run elasticity for demand is -0.26.

    2) *Medium sensitivity:* The elasticity of demand is in the middle of the reported range, and reaches -0.58 in the long-run.

    3) *High sensitivity:* The elasticity of demand is in at the high end of the reported range, and reaches -0.84.

    Figure 11 shows the elasticities of demand for refined petroleum products used in the scenarios. The "x"s on the left- and right-hands sides of the figure are empirical estimates of the short- and long-run elasticities, respectively, reported in the literature.[16]

Figure 11: Elasticities of demand



- *Global climate policy:* The level of effort to reduce global greenhouse gas emissions is highly uncertain. The analysis examines two possibilities:

  1) *Current policies:* Policy makers maintain current and expected policies from now until 2035. This leads to a demand for oil based on the International Energy Agency's *new policies* scenario.[17]

  2) *450 ppm:* The global community implements policies to limit the concentration of GHGs to 450 parts per million (ppm). This is the concentration of GHGs emissions that offers a 50% chance of limiting the rise in global temperatures to 2^{O}C from pre-industrial levels. GHG emissions align with the forecast for oil emissions from the IEA.

- *Advanced technology for oil sands production:* The cost and emissions associated with oil sands extraction are sensitive to the availability of technology. There are currently several new technologies in development that could potentially reduce the cost and emissions associated with extraction. Of these, we examine the

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[16] Hamilton J, 2009, "Understanding crude oil prices", *Energy Journal*, 30(2):179-206.

[17] International Energy Agency, 2013, *World Energy Outlook 2013*.

impact solvent based extraction, as it appears to have specific advantages. Specifically, solvent-based extraction significantly reduces energy requirements and slightly upgrades bitumen directly in the well (heavier fractions and some sulfur are left in the well). The analysis examines two possibilities:

1) *No advanced technology:* Advanced technologies are not available.

2) *Advanced technology:* Advanced technologies are available after 2020.

In total, we examine six scenarios, as shown in Table 2. Drivers that differ from the reference case are bolded.

Table 2: Scenarios

Scenario	Other Pipeline Approval	Elasticity of Demand	Global Climate Policy	Advanced Technology
S1-Ref	No	Medium	Current Policies	No
S2-NewPipe	**Yes**	Medium	Current Policies	No
S3-lowSens	No	**Low**	Current Policies	No
S4-highSens	No	**High**	Current Policies	No
S5-450	No	**High**	**Policies to achieve 450 ppm**	No
S6-450+adv	No	**High**	**Policies to achieve 450 ppm**	**Yes**

The focus of the analysis changes slightly between the first four and last two scenarios. For the first four scenarios, the analysis quantifies the incremental GHG impact due to the Energy East project. The final two scenarios explore whether it becomes more difficult to achieve climate targets with Energy East's approval. Estimating the GHG impact of Energy East is not relevant for the final two scenarios, because global GHG emissions are fixed. Rather, the analysis focuses of policy stringency to achieve the GHG target.

4. Results

This section begins by describing the reference case projection from OILTRANS. The following section describes how the Energy East project is expected to affect global greenhouse gas emissions. The comparison section shows how the results compare to other research, and explains why the results are similar or different.

Reference case without Energy East

OILTRANS provides an internally consistent projection of the global oil market from 2015 until 2035. It accounts for all major factors affecting the market, including how prices are determined, how supply comes on-line, how crude oil is transported between hubs, how it is refined and finally how it is consumed.

This section describes the reference case projection for the Canadian and global oil market from OILTRANS. The projection here uses the assumption that the Energy East project does not proceed.

The data provided here are results from the modeling, not assumptions used in the modeling. For example, each oil price benchmark shown below is the result of all agents characterized in the model interacting together. Further these results change when the scenario assumptions (e.g., whether Energy East is approved) change.

Oil price benchmarks

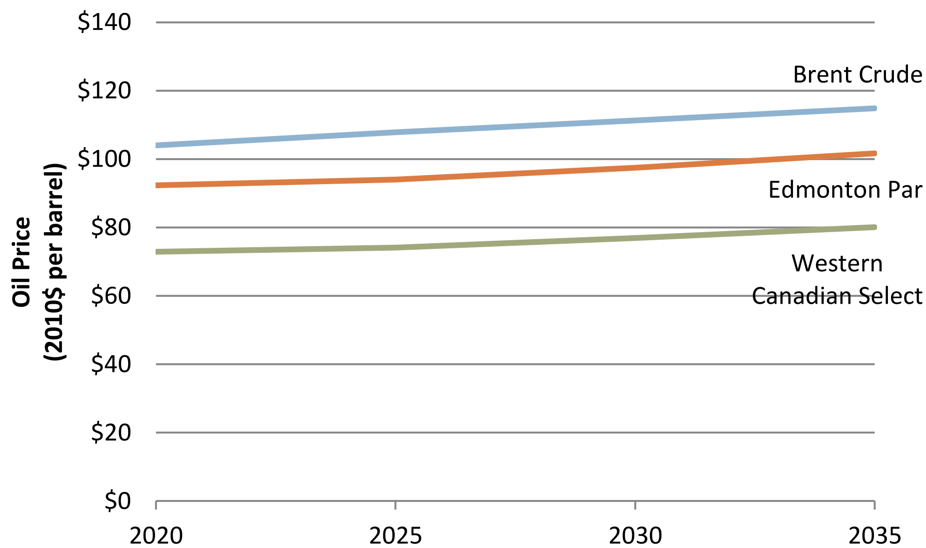
OILTRANS generates a forecast for the price of every grade of crude oil in every region. From this, it is possible to infer the price for key benchmarks throughout the world. For example, the price for light sweet crude in PADD II South is the benchmark for West Texas Intermediate.

The price for every crude oil benchmark is predicted to increase over the forecast period (see Figure 12). By 2035, the price for Brent crude oil trades at $115 per barrel (2010$).

While the price for crude oils in Western Canada (e.g., the price for Edmonton Par and Western Canadian Select) generally follow the global benchmark, they trade at a discount. Even though Edmonton Par and Brent are both light sweet crude oils, the additional cost of transporting from Alberta to market leads to a lower price in Alberta. The spread between the two crude benchmarks also grows after 2015, reflecting the effect of pipelines reaching full capacity, and the shift towards more costly rail transport.

Western Canadian Select trades at a further discount to the Edmonton Par.[18] Western Canadian Select is less valuable than light oil because heavier and/or sour crudes require greater refining or upgrading before they produce valuable products such as gasoline, diesel, etc. The additional cost associated with these refining processes leads to a discount on heavy/sour relative to light/sweet crude oils.

Figure 12: Crude oil benchmark prices (2015-2035)



Benchmark	Product Type	2020	2025	2030	2035
Brent Crude	Light Sweet	$104	$108	$111	$115
West Texas Intermediate	Light Sweet	$102	$105	$109	$113
Edmonton Par	Light Sweet	$92	$94	$97	$102
Western Canadian Select	Blended Bitumen	$73	$74	$77	$80
Alberta Synthetic Crude	Synthetic Crude Oil	$97	$99	$102	$106

Extraction of crude oil in Western Canada

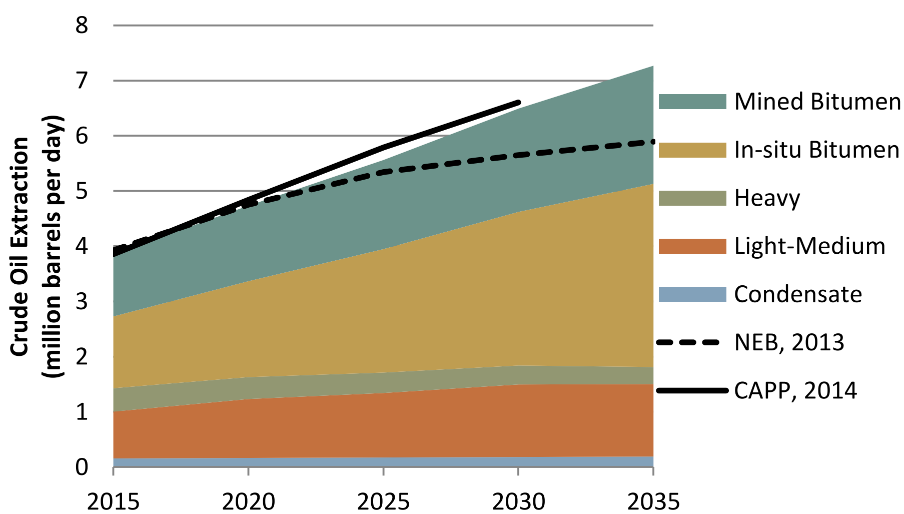
Western Canada experiences a significant increase in crude oil extraction under the reference case, even without the Energy East project. Oil extraction increases from 3.9 million barrels per day in 2015 to 7.3 million barrels per day in 2035 (see Figure 13).

18 Western Canadian Select (WCS) is a blended crude oil comprised of bitumen and a diluent. Although bitumen can be blended with different products, for this figure we calculate WCS as 75% bitumen and 25% ultra light sweet oil. Note that bitumen can also be blended in equal parts with a light or synthetic crude. The price for vary slightly depending on the diluent used.

Most production growth in Western Canadian occurs in Alberta's oil sands sector as production from other resources remains fairly stable due to resource constraints. Oil sands production increases by 3.0 million barrels per day from 2015 to 2035. Production also rises more rapidly from in-situ resources, while production from mining operations increases more modestly. By 2035, 75% of extraction of Western Canadian oil is from the oil sands.

Figure 13 further compares the forecast for crude oil production from OILTRANS to the latest forecast from CAPP (2014) and the National Energy Board (2013).[19] The forecast used here is based mostly on the forecast from CAPP; however the forecast is slightly lower. This is because of slightly different assumptions with respect to available transportation options.

Figure 13: Western Canadian crude oil extraction



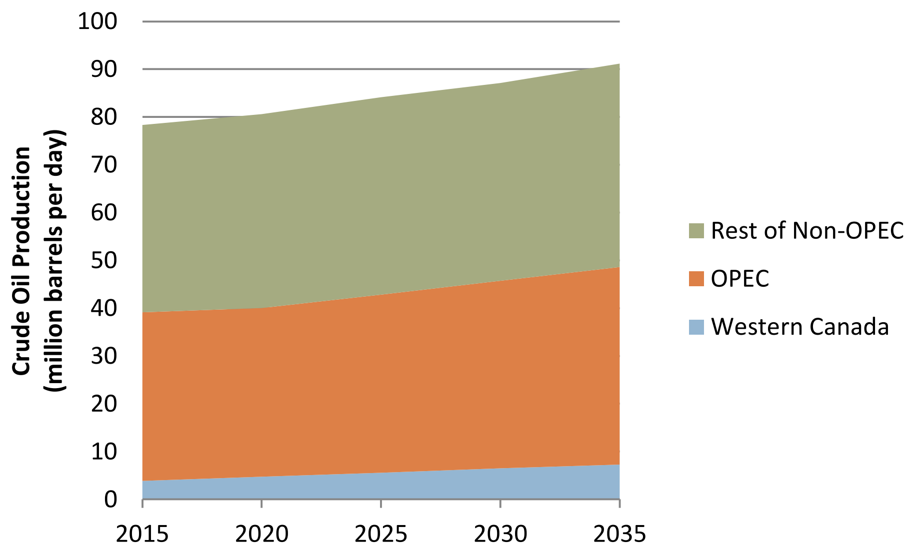
Global extraction of crude oil

The results from the analysis are sensitive to the production of crude oil from the rest of the world. Figure 14 shows the projection of global crude oil production from 2015 to 2035. Total production rises from 78 million barrels per day in 2015 to 91 million barrels per day in 2035.

[19] Canadian Association of Petroleum Producers, 2014, *Crude oil: Forecast, markets & transportation*, available from www.capp.ca, accessed November 2014; National Energy Board, 2013, *Canada's energy future 2013*, available from www.neb-one.gc.ca, accessed November 2014.

Canada's share of global production increases over time, from 4.9% in 2015 to 8.0% in 2035. OPEC's share remains fairly constant, while other non-OPEC declines.

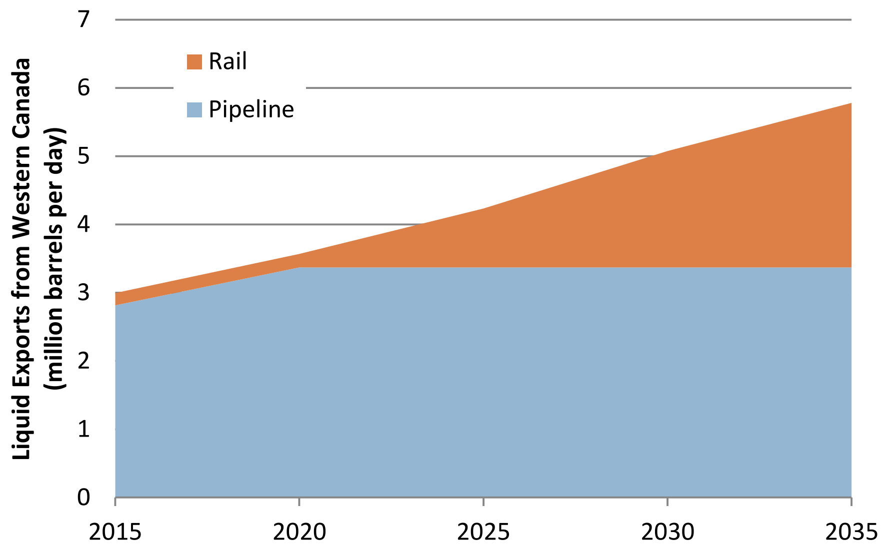
Figure 14: Global crude oil extraction



Liquids transport from Western Canada

The existing pipeline network available to transport Western Canadian crude oil has a limited capacity at approximately 3.4 million barrels per day. As production continues to grow past the available capacity after 2020, an increasing amount of crude oil and refined petroleum products are exported by rail. In 2015, rail transport is relatively small, but rises to 2.4 million barrels by 2035 (see Figure 15).

Figure 15: Liquid exports by mode of transportation



As will be discussed below, the most important difference between this analysis and the analyses conducted by Pembina and the Stockholm Institute is that this analysis allows for oil to be transported by rail if it is economic to do so. As rail is an important component of the analysis, Box 2 discusses whether the increase of rail exports from Western Canada is realistic.

Box 2: Is the growth in rail transport realistic?

This analysis indicates that exports of crude oil by rail are likely to increase to unprecedented levels in the absence of new pipelines. Based on historic data from 2013, shipments of rail from Western Canada were approximately 200 thousand barrels per day.[20] This analysis indicates that rail exports would increase to 2,400 thousand barrels per day by 2035 in the absence of new pipelines (over a 1000% increase).

To examine whether this level of increase is reasonable, this subsection examines:

1. How this increase compares to the experience in other jurisdictions; and
2. How this increase compares to the near-term forecast for rail exports from the Canadian Association of Petroleum Producers.[21]

[20] Canadian Association of Petroleum Producers, 2014, *Crude oil forecast, markets & transportation*; available from www.capp.ca; accessed November, 2014.

[21] *Ibid*.

This review indicates that the increase in rail exports shown here is likely to be easily accommodated by the rail network.

How the increase in rail shipments compares to the experience in other jurisdictions

The experience in other jurisdictions provides insight into what is possible for rail. North Dakota has recently experienced a large increase in crude oil extraction and currently has limited pipeline capacity. The result is that in three years (between 2010 and 2013), exports by rail have increased by 800 thousand barrels per day.[22] OILTRANS is predicting an increase in rail exports of 2,200 thousand barrels per day in 20 years.

On an annual basis, OILTRANS is forecasting an increase of 110 thousand per day per year, whereas North Dakota managed to increase exports by 270 thousand barrels per day per year.

How the increase in rail shipments compares to the near-term forecast from CAPP

CAPP (2014) indicates that much of the capacity required to meet the growth in rail shipments will already be added by 2016. CAPP indicates that between 2013 and 2016, rail loading capacity will increase from 200 thousand barrels per day to 1,400 thousand barrels per day. To accommodate the forecast from OILTRANS, rail capacity would only have to increase a further 1,000 thousand barrels per day in 19 years.

Summary: Rail is likely to be available

Historically, crude oil and other liquids have not been transported by rail because there has been sufficient pipeline capacity. If restrictions on new pipelines become permanent, total shipments by rail are likely to increase substantially. The level of effort required to accommodate the increase in rail shipments forecasted by OILTRANS is well within what has occurred in other jurisdictions and what is expected to occur in the near-term in Western Canada.

Global greenhouse gas emissions

Activities at all points on the supply chain for petroleum products emit greenhouse gases. The supply chain can be roughly divided into all activities up to the point where refined products are finally used ("well-to-tank") and the final consumption of refined products ("tank-to-wheels").[23] Greenhouse gases are emitted during the direct

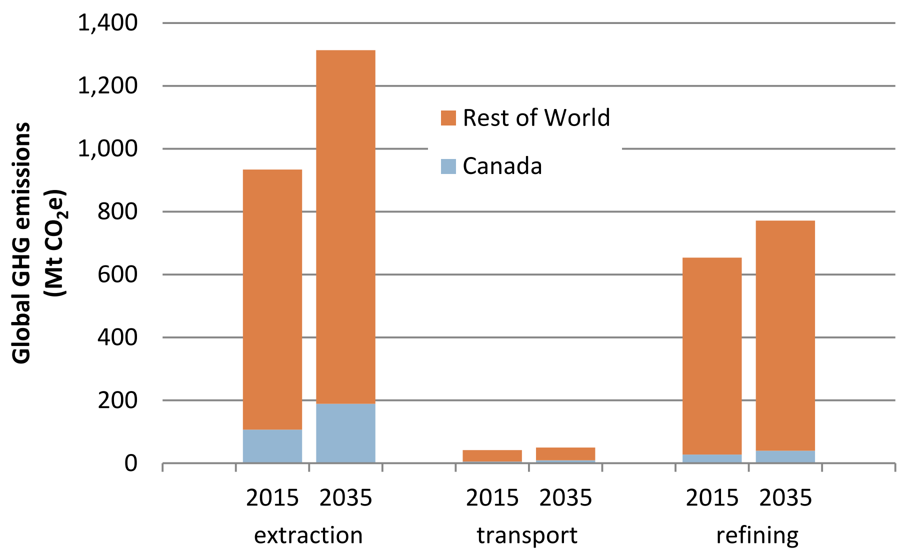
[22] Energy Information Administration, 2013, *Rail delivery of U.S. oil and petroleum products to increase, but pace slows*, available from www.eia.gov, accessed November 2014.

[23] Note that the "tank" and "wheels" analogies are imperfect as refined petroleum products are used for non-transportation purposes as well. OILTRANS accounts for all uses, including petrochemical feedstocks, direct heat production, etc.

combustion of fuels for energy purposes (e.g., direct heating in petroleum refining or for transportation use), electricity consumption (i.e., emissions occur at the point of electricity supply), and venting and flaring gas during crude oil extraction.

From well-to-tank, extraction and petroleum refining contribute most significantly to global greenhouse gas emissions. By 2035, extraction is projected to lead to about 1,300 Mt CO_2e, while petroleum refining leads to 770 Mt CO_2e. In 2035 Canada accounts for about 11% of emissions from well-to-tank, with a more significant contribution from extraction. Canadian total direct and indirect emissions from well-to-tank will rise to 189 Mt by 2035.

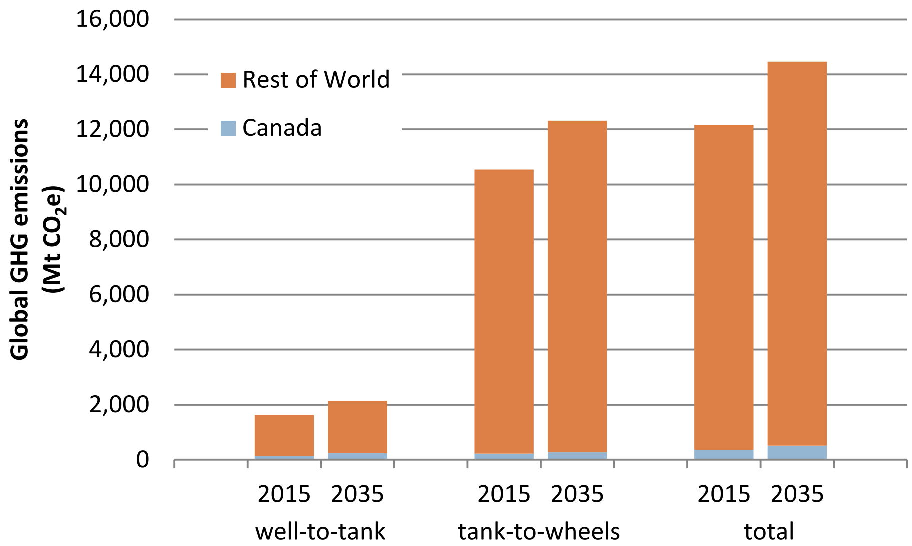
Figure 16: Global emissions from well-to-tank



While emissions from well-to-tank are important, they are small in comparison to the emissions from final consumption (see Figure 17). In total, emissions from well-to-tank account for about 2,100 Mt in 2035. Emissions from tank-to-wheels account for 12,000 Mt, or 85% of total emissions from the oil sector from well-to-wheels. This confirms the suspicion, but not the estimates, from the Stockholm Institute[24] that the most important impact of pipeline infrastructure could be on final demand, rather than emissions from well-to-tank.

[24] Erickson and Lazarus, 2014, "Impact of the Keystone XL pipeline on global oil markets and greenhouse gas emissions", Nature Climate Change.

Figure 17: Global emissions from oil sector



Modeling results for the impact of Energy East

The following sections explore the impact of the Energy East project on global greenhouse gas emissions in each of the scenarios described in Table 2 (on page 27). Each scenario is run with and without the Energy East project. As all other dynamics are held constant, the difference is directly attributed to approving the Energy East project.

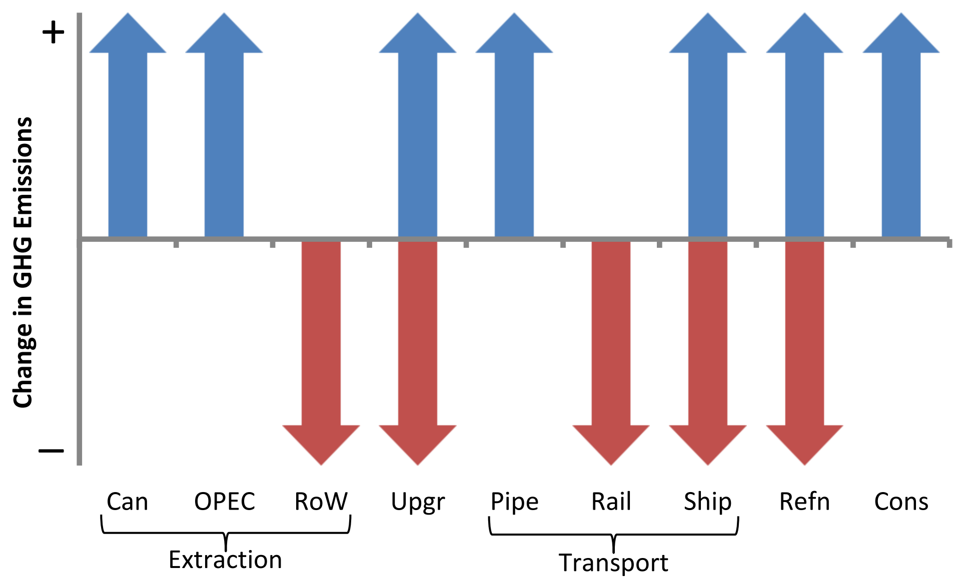
This section begins with describing our expectations for the direction of the results, and follows with a detailed discussion of how the Energy East project is projected to affect global greenhouse gas emissions.

Review of key dynamics that affect GHG emissions due to the Energy East project

Many dynamics interact to determine how a pipeline project will affect global greenhouse gas emissions. The approval of a new pipeline is likely to increase GHG emissions in some areas, but reduce emissions in other areas. Some analysts have focused on some dynamics and argued that new pipelines from Alberta would have a large impact on emissions (e.g., Pembina and Stockholm Institute); while others have focused on other dynamics to argue that new pipelines have a negligible impact on emissions (e.g., IHS CERA). This section reviews the key dynamics affecting GHG emissions in the oil market.

Although the "magnitude" of each impact varies by scenario, in many cases the "direction" of the impact does not. Figure 18 shows the expected direction for emissions due to approving Energy East. Entities with arrows above the x-axis indicate that their emissions are likely to increase with Energy East's approval. Likewise, entities with arrows below the x-axis indicate that their emissions are likely to decrease. Entities with arrows in both directions indicate that the direction of Energy East's approval varies by scenario.

Figure 18: Expected direction for GHG impacts due to Energy East's approval



Canadian oil extraction (labelled "CAN" in Figure 18): Emissions from crude oil extraction in Canada increase due to Energy East's approval. By approving Energy East, the netback price (the price for oil wherever it is consumed minus the cost of getting the oil there) for crude oil increases in Alberta, therefore inducing greater investment in more marginal resources. Greater production leads to greater energy consumption and emissions.

OPEC extraction ("OPEC"): Emissions from crude oil extraction in OPEC also increase due to Energy East's approval. Greater supply from Western Canada erodes the market power for OPEC, leading to greater supply from these countries. This increase occurs despite a lower average global price for oil.

Rest of world extraction ("RoW"): Emissions from crude oil extraction in the rest of the world decline due to Energy East's approval. Greater supply from Western Canada and

OPEC reduce the average global price for oil. With a lower oil price, extraction from more marginal resources in these countries declines.

Bitumen upgrading in Alberta ("Upgr"): The direction for emissions from bitumen upgrading changes between the scenarios. Several factors affect upgrading activity in Alberta:

1. *Refinery access:* By upgrading bitumen in Alberta, oil can be exported to refineries that are not already configured to accept heavy-sour crudes. On the other hand, if new pipeline infrastructure links Alberta to regions with existing heavy oil processing capacity (e.g., PADD III or PADD IV), upgrading may not be needed.

2. *Pipeline transport:* Synthetic crude oil does not require diluent for pipeline transport and can also act as diluent for transporting raw bitumen. As condensate and conventional light oil extraction declines in Western Canada, diluent must either be imported or bitumen must be upgraded.

3. *Labor constraints:* In Alberta's tight labor market, greater upgrading activity diverts labor from extraction. With everything else equal, greater upgrading would reduce extraction.

4. *Total system efficiency:* With everything else equal, upgrading bitumen and then refining synthetic crude is less efficient and more costly than straight refining bitumen. Upgrading bitumen leads to a duplication of the atmospheric and vacuum distillation processes. Bitumen is first heated for atmospheric and vacuum distillation in the upgrader; the resulting fractions are then cooled and reblended into synthetic crude; synthetic crude is exported to a refinery where it is re-heated for atmospheric and vacuum distillation. Straight refining bitumen eliminates this duplication.

Overall, there are reasons why Energy East's approval could increase upgrading activity, but also reasons why it could reduce upgrading activity.

Pipeline transport ("Pipe"): Pipelines typically do not produce emissions directly from fossil fuels, but consume electricity. Therefore, pipelines can lead to "indirect" emissions at the point of electricity generation. However, several pumping stations in Ontario are expected to consume natural gas directly. Emissions from pipeline transport increase due to Energy East's approval.

Rail transport ("Rail"): With greater transport by pipeline, less oil is transported by rail and rail emissions decline.

Shipping transport ("Ship"): The direction on shipping emissions is unclear, and the results vary by scenario. The entire global market adjusts due to Energy East's approval, and leads to oil exports to different destinations.

Refining ("Refn"): Refining emissions typically increase with greater global supply. The exception to this is that greater upgrading activity in Alberta reduces the need for specific processes at the refining stage. If delayed coking and hydrotreatment occur at the upgrading stage, these processes are not required to refine synthetic crude oil.

Final consumption ("Cons"): Total global consumption of refined petroleum products increases due to a net increase in global oil supply. While global consumption increases, in some regions it should be noted that consumption is likely to decline due to Energy East. Specifically, oil prices increase in Western Canada and the United States Midwest due to new pipelines. In turn, the consumption of refined products declines in these regions.

Impact of Energy East on the Reference case

The reference case explores a scenario in which the world does not enact climate policies beyond those already committed to. It also assumes that no pipelines other than the Energy East project will be approved (see S1-Ref in Table 2 for scenario details).

To estimate the impact of the Energy East project, the reference case was simulated twice in OILTRANS: once without the project and once with the project. As all other assumptions are held the same, the difference between the two cases is directly attributed to the project's approval.

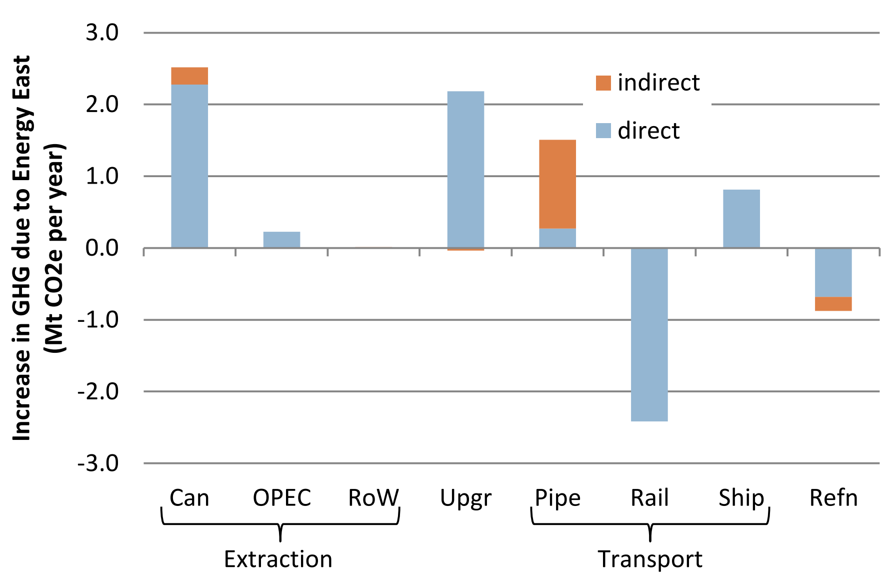
As discussed above, the emissions associated with Energy East's approval can be divided into emissions from well-to-tank (i.e., everything up to final consumption) and from tank-to-wheels (i.e., final consumption). Figure 19 shows how Energy East's approval affects emissions from well-to-tank in 2035 (the analysis focuses mostly on 2035 because it shows the long-term impact of the pipeline).

In Western Canada, GHG emissions increase due to Energy East's approval. In 2035, emissions from Western Canadian oil extraction are 2.5 Mt higher than they would have been without the pipeline. This increase amounts to a 0.4% increase in Canada's emissions from 2012 levels. The increase is driven by a 90 thousand barrel per day increase in oil sands production by 2035.

The other significant rise in emissions is attributed to the bitumen upgrading sector. This increase accounts for an additional 2.2 Mt due to Energy East. Bitumen upgrading serves two purposes in this scenario. Greater bitumen exports by pipeline increases the demand for diluent. Upgraded bitumen (or synthetic crude) can serve as diluent for pipeline transport. Second, synthetic crude oil can be accepted at a wider range of refineries. Therefore, greater bitumen upgrading reduces the need to re-configure refineries in other regions. However, greater bitumen upgrading reduces the refining of bitumen, which reduces the emissions from petroleum refining by 0.9 Mt in 2035.

Finally, net transportation emissions (from pipelines, rail and shipping) decline slightly by 0.1 Mt. In most cases, pipelines consume electricity, potentially leading to an increase in emissions at the point of electricity generation. Therefore, the increase in crude oil shipments by pipeline leads to greater emissions during electricity generation. On the other hand, shipments by rail fall leading to a decline in associated emissions. As the Energy East pipeline would operate through several provinces where electricity generation has low GHG intensity (Ontario, Manitoba and Québec), the increase in emissions due to pipeline operation are smaller than the reduction in emissions from rail.

Figure 19: Well-to-tank emissions due to Energy East (reference case assumptions)

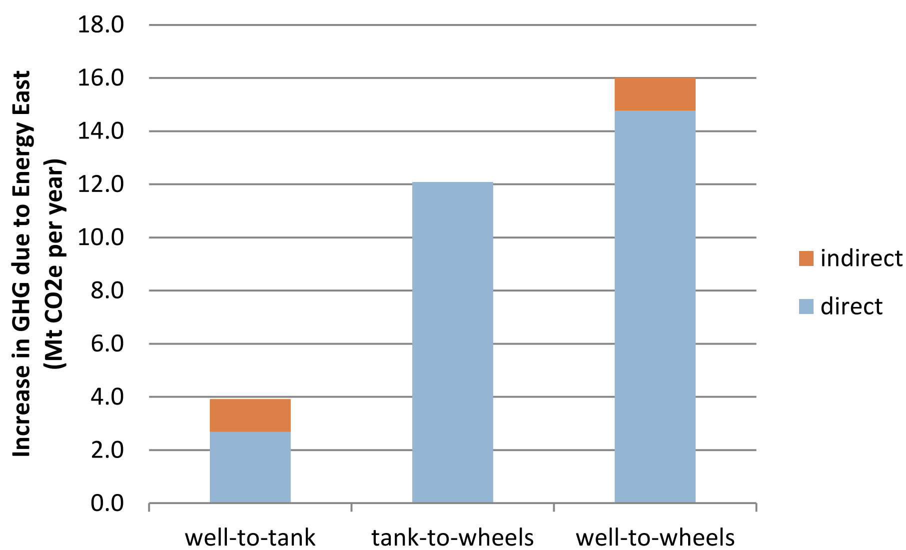


Note: the labels in this figure are defined on page 35

While the Energy East project is likely to increase emissions from well-to-tank, the largest impact occurs from tank-to-wheels (final consumption). The average global price for oil declines slightly due to the Energy East project. The price for Brent crude and the landed price for light sweet crude in China are about $0.39 per barrel lower due to Energy East. This decline is driven by slightly greater global oil supply induced by the pipeline.

The price for refined petroleum products declines slightly with the decline in average global oil prices. This leads to a small increase in the global consumption of refined petroleum products and a corresponding increase in emissions (see Figure 20). In 2035, this increase amounts to 12 Mt. Relative to the globe's total emissions in 2011, this would amount to an increase of 0.04%.

Figure 20: Well-to-wheels emissions due to Energy East (reference case assumptions)

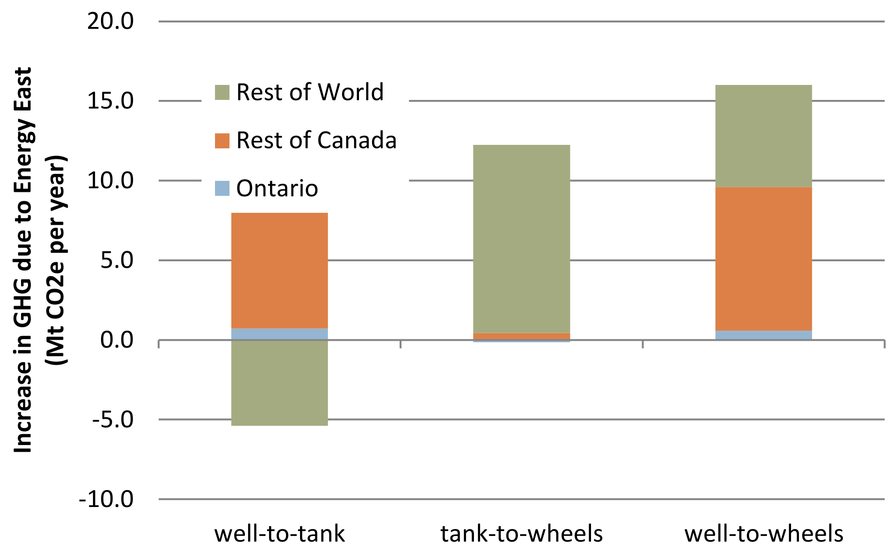


It should be noted that while Energy East is likely to increase global emissions, the majority of these emissions occur outside of Canada and the pipeline has a negligible impact on Ontario's emissions (see Figure 21).

In total, emissions in Canada increase by 9.6 Mt in 2035. This accounts for 60% of the global increase in GHG emissions. The majority of this increase occurs from wells-to-tank due to greater oil sands activity and greater emissions from refining heavier crude oils in Canada.

The impact on Ontario is negligible. The pipeline does not connect with any refineries in Ontario, so refining emissions are mostly unaffected. The most significant new source of emissions comes from pipeline transport (about 0.6 Mt in 2035), but this increase is negligible compared to the rest of the world. As Ontario's electricity sector has largely decarbonized due to other policies, greater pipeline transport does not yield significant impacts on emissions. About half of this emissions impact is from the pumping stations that will use natural gas.

Figure 21: Emissions due to Energy East in Ontario, Rest of Canada and the Rest of the World



Impact of Energy East if other pipelines are approved

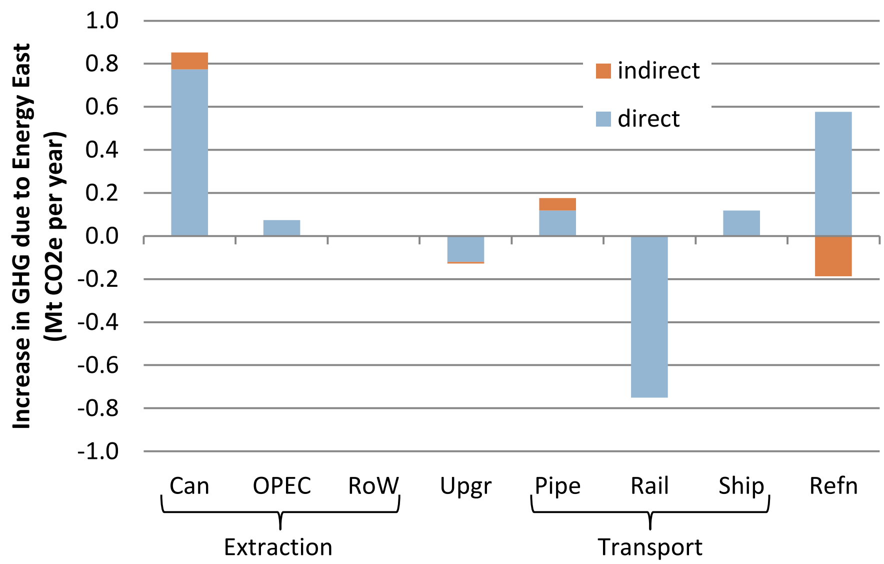
This scenario offers a variation to the reference case in which other pipelines from Western Canada are approved and will be built if they are economic (see S2-NewPipe in Table 2 for scenario details). These other pipelines include Keystone XL, which would link Alberta with the United States Gulf Coast (PADD III); Northern Gateway and the TransMountain Expansion, which would link Alberta with British Columbia's coast.

This analysis suggests that the impact of Energy East is much less significant if other pipelines are approved. In 2035, Energy East would only increase emissions by 5.4 Mt if these other pipelines are approved. Figure 22 shows the impact from well-to-tank (0.7 Mt) and Figure 23 shows the impact from tank-to-wheels (4.7 Mt).

The benefit of the Energy East project to oil sands producers would be significantly muted if other pipelines are approved. The modeling indicates that these other pipelines offer superior routes for crude oil producers in Western Canada. These pipelines are both shorter (i.e., they have fewer transport costs) and offer higher netback prices for Alberta oil. Therefore, these pipelines are built regardless of the decision on Energy East. For example, if Energy East is built by 2020 and all other pipelines are approved in 2021, each of these other pipelines would be built.

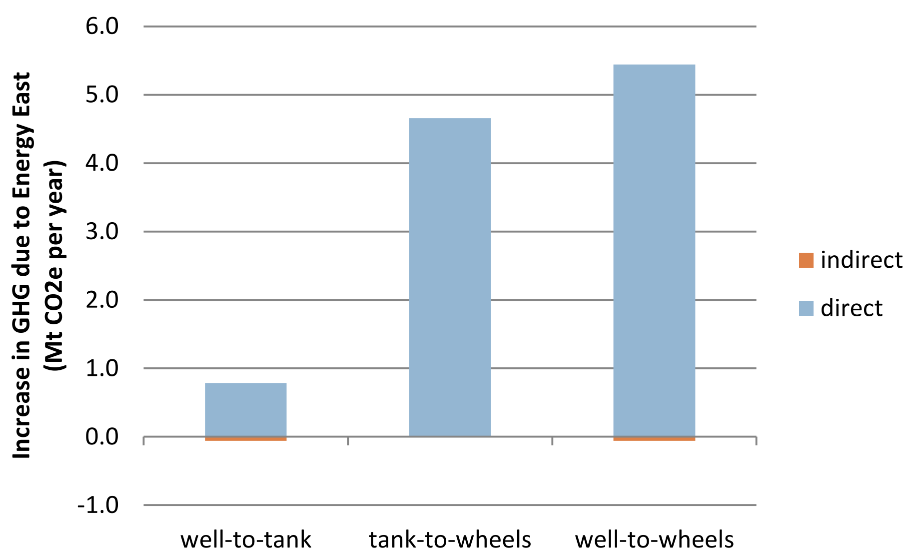
With all proposed pipelines built by 2025, there would be excess pipeline capacity until 2035 and the Energy East project would have little impact on global oil markets until the other pipelines reach full capacity.

Figure 22: Well-to-tank emissions due to Energy East (other pipelines are approved)



Note: the labels in this figure are defined on page 35

Figure 23: Well-to-wheels emissions due to Energy East (other pipelines are approved)

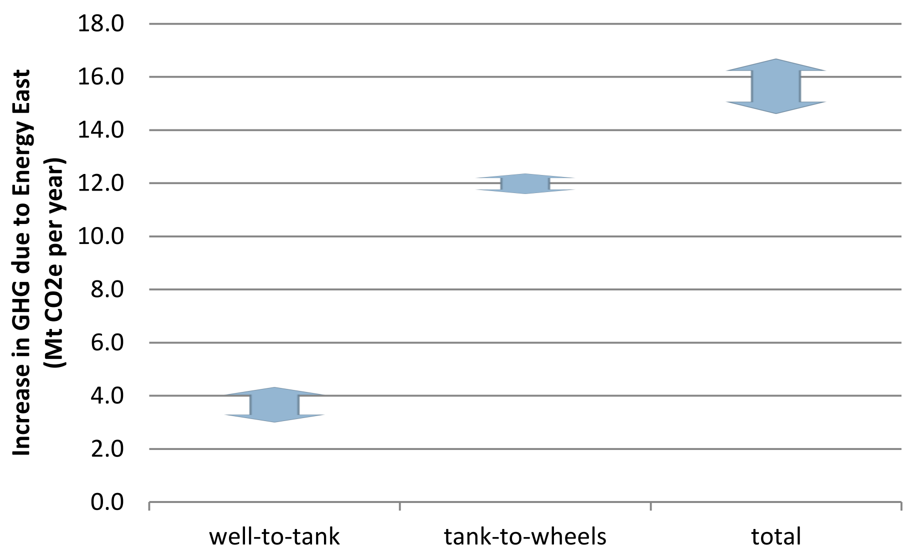


Impact of Energy East under different assumptions about the sensitivity of demand to prices

The modeling presented above uses an assumption to describe how the final consumption of refined petroleum products is affected by prices. The reference case examined a scenario in which this sensitivity falls in the middle of published estimates. However, this assumption is uncertain as displayed by the range of estimates in the literature. Furthermore, the analysis above indicates that the results are likely to be sensitive to these assumptions because final consumption is responsible for the most significant increase in GHG emissions.

Figure 24 shows the range of GHG impacts under different assumptions for this sensitivity. The top of each column indicates the largest GHG impact, while the bottom of each column indicates the smallest. When considering the full range of elasticity estimates, the GHG from well-to-wheels (total) impact from Energy East varies by 2 Mt in 2035. The impact from well-to-tank varies by 1.3 Mt, while the impact from tank-to-wheels varies by 0.8 Mt.

Figure 24: Range of emissions impacts with different elasticities



Impact of global climate policy

A critical question surrounding the Energy East project is whether this infrastructure may "lock-in" greenhouse gas emissions and make it more difficult to achieve climate stabilization. Several analysts have argued that new pipelines would enable greater oil sands production, which would be unneeded and costly to close under an aggressive climate policy.[25]

To examine the impact lock-in, the analysis examines a scenario in which the global community enacts policies to achieve climate stabilization at 2^{O}C. The model was rerun with a constraint to limit the total greenhouse gas emissions from the global oil market (from wells-to-wheels). The constraint is set to match the GHG emissions from oil consumption projected by the IEA in their 450 ppm scenario. Limiting atmospheric concentrations of GHGs to 450 ppm is believed to offer a 50% chance of stabilising the rise in global temperatures to 2^{O}C from pre-industrial levels.[26]

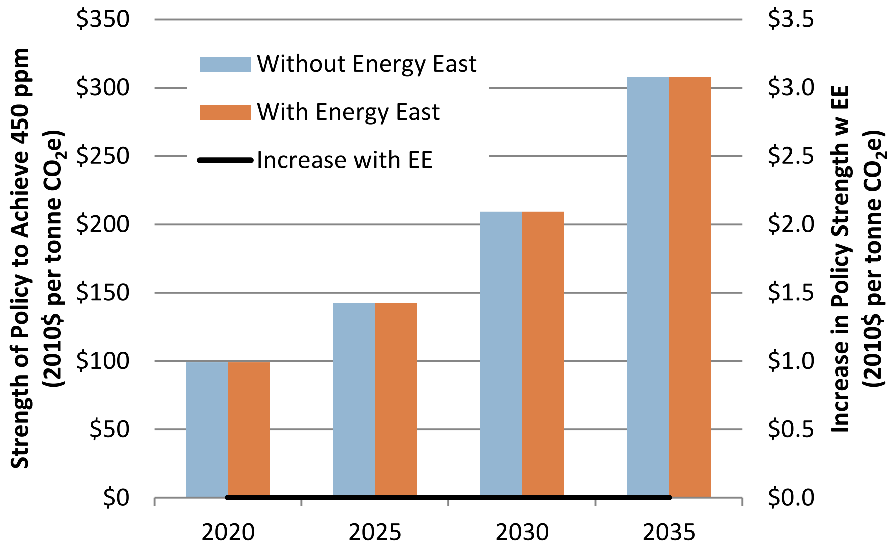
The focus of this section differs slightly from the previous sections. The previous sections estimated the increase in GHG emissions attributed to the Energy East project. In these scenarios, global GHG emissions are fixed at the constraint to achieve a 450 ppm concentration of emissions, so approving the Energy East project would not increase global emissions. Instead, this analysis examines the strength of policy (as represented by a carbon price) required to achieve the constraint for emissions. If the carbon price is higher due to Energy East's approval, the project would lock-in GHG-emitting infrastructure and make it more difficult to achieve climate stabilisation.

Figure 25 shows the projected strength of policy required to achieve climate stabilization at 2^{O}C. Approving the Energy East project has no effect on the stringency of the policy required to achieve climate stabilization. There are several reasons for this.

[25] Palen, Sisk, Ryan, Árvai, Jaccard, Salomon, Homer-Dixon, Lertzman, 2014, "Consider the Global Impacts of Oil Pipelines", *Nature*, vol. 510.

[26] International Energy Agency, 2013, *World Energy Outlook, 2013*.

Figure 25: Carbon price required to achieve climate stabilization at 2^{O}C

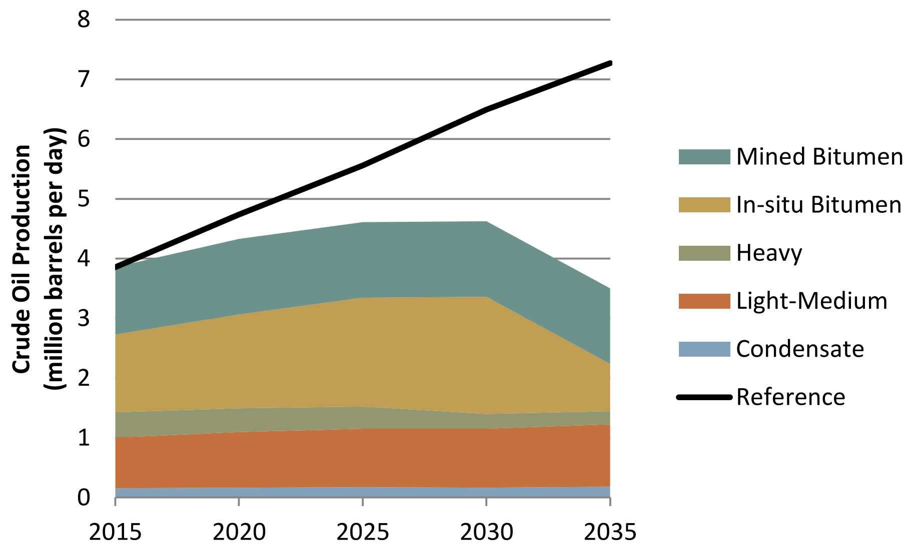


Most importantly, the potential benefit of the Energy East project to oil producers is dwarfed by the impact of the policy to reduce emissions. This policy has two important effects. First, the policy to achieve 450 ppm would reduce the demand for oil and therefore the price. In the reference case, the price for Brent crude rises to $115 per barrel by 2035, but actually declines to $70 per barrel with the policy. The price for Western Canadian Select (the benchmark for heavy oil in Alberta) is $80 per barrel in the reference case in 2035, while it is $55 per barrel with the policy.

In addition to a lower price for oil, the policy imposes costs on Alberta's oil sector. These costs are imposed by adopting lower emissions technologies, which in this scenario come at a greater cost. The policy examined here employs a carbon price, which oil producers are required to pay on any unabated GHG emissions. This would impose a further cost on oil producers.

The impact of a lower oil price and greater costs on oil producers would lead to a stagnation of oil output from Western Canada (see Figure 26). The implication of this stagnation is that the Energy East pipeline would operate significantly below capacity with aggressive climate policy. The pipeline would not provide enough of a benefit to compensate for the larger impact of the climate policy.

Figure 26: Oil extraction in Western Canada under climate stabilization at 2°C



This scenario indicates that without advanced technologies for the oil sands, new pipelines from Alberta are only marginally needed with aggressive climate policy. However, it does not confirm the theory that new pipelines may "lock-in" GHG emitting infrastructure. Simply, the impact of climate policy would be too large for lock-in to occur.

The implication of this scenario being correct is that the Energy East project would be a poor investment decision. However, the approval of the pipeline does not make it more difficult to stabilize the rise in global temperatures to 2°C.

Impact of global climate policy with advanced technologies

Similar to other sectors of the economy, technology to extract bitumen from the oil sands is continuously evolving. While the standard technology used today is energy and emissions intensive, producers are constantly developing new and more efficient ways of extracting bitumen. If these technologies become commercial, they could have a significant impact on the emissions and costs associated with developing the oil sands.

Solvent-based extraction offers several advantages over Steam Assisted Gravity Drainage (SAGD) for in-situ wells. The SAGD process requires the production of steam (which is energy and capital intensive). Steam is then injected into the well where it reduces the viscosity of bitumen and allows it to be pumped to the surface.

Solvent-based extraction injects a warm solvent (e.g., a natural gas liquid like propane) to "dissolve" bitumen so that it can be pumped to the surface. This option is expected to significantly reduce the energy and emissions intensity of in-situ extraction, in addition to lower capital costs (a steam plant is not required). Solvent-based extraction has an additional advantage by leaving the lower quality fractions of bitumen (i.e., heavy vacuum residue and associated sulfur) in the well. Therefore, the technology slightly upgrades bitumen in the extraction process, and requires less refining.[27]

Other potential technologies include Direct Contact Steam Generation, which would inject the entire combustion stream from the boiler plant (steam and flue gases such as carbon dioxide) into the well. A portion of the carbon dioxide would remain in the well.

While these technologies are expected to reduce the emissions intensity of extraction, it should be noted that bitumen must still be refined or upgraded once extracted. Bitumen using either technology is a heavy-sour crude and requires heavy oil refining capacity.

These technologies are currently in a demonstration phase, but could aid oil sands development in a low GHG world. Furthermore, global climate policy may accelerate the commercialization of these technologies, as the incentives to reduce the emissions intensity of oil sands would increase. This section revisits how global climate policy would affect the impact of Energy East with these advanced technologies.

As the previous section showed, oil sands production would be stagnate and start to decline with global climate policy to achieve 2^{O}C. However, these advanced technologies would enable oil sands to continue growing.

Figure 27 shows oil extraction in Western Canada under climate stabilization and advanced technology. These advanced technologies would allow the oil sands to remain competitive in a low GHG environment. While oil production does not increase at the same rate as in the reference case, is still grows to 5.2 million barrels per day by 2035.

While the oil sands are currently challenged by high GHG intensities, these technologies would largely offset some of these challenges. Solvent based extraction, for example, would reduce the emissions intensity of oil sands by 85%. Advanced technologies also benefit from leaving the heaviest portions of bitumen in the well. The slightly upgraded bitumen then requires less upgrading/refining after it has been extracted, further improving its competitiveness.

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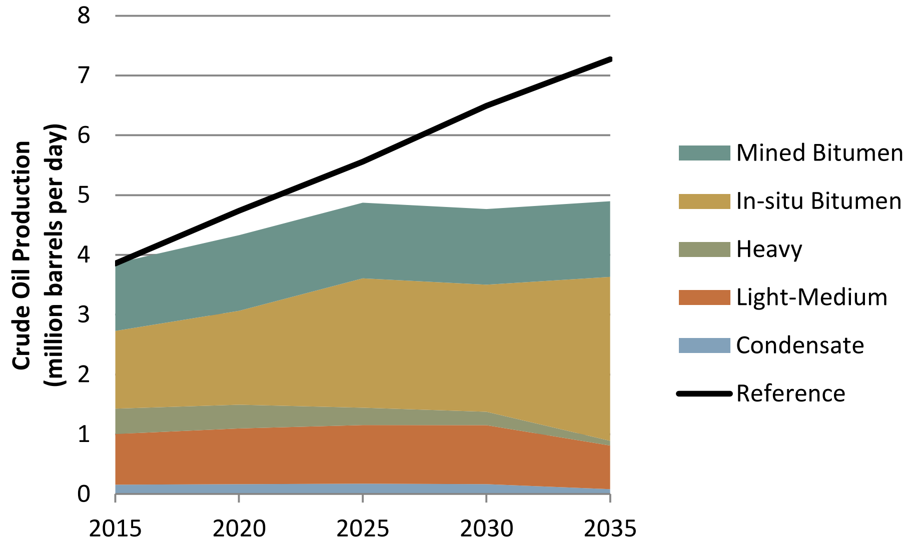
[27] N-Solv Corporation, 2014, www.n-solv.com.

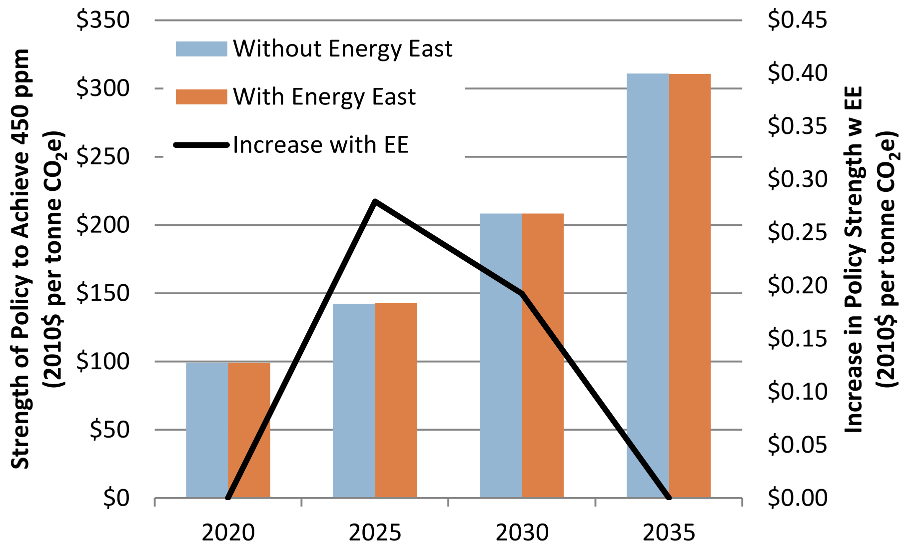
Figure 27: Oil extraction in Western Canada under climate stabilization at 2^{O}C with advanced technology



If these technologies become commercial, there would be a need for the Energy East pipeline in a low GHG future. As the Energy East project affects the oil market in this scenario, we can revaluate whether it would exacerbate the lock-in of GHG emitting infrastructure.

Figure 28 shows the carbon price required to achieve climate stabilization at 2^{O}C with advanced oil sands technologies. As shown, the project still has a negligible impact on carbon prices, meaning that it does not make it significantly more difficult to achieve climate stabilization. In the long-run, the policy would not have to be more stringent to climate stabilization with Energy East.

Figure 28: Carbon price required to achieve climate stabilization at 2^{O}C with advanced technology



Comparison of results to other research

This section compares the results from this analysis to other published estimates and explains the reasons for the discrepancies.

The results reported here are significantly lower than Pembina's estimates.

Pembina estimated that Energy East's approval would increase upstream emissions in Western Canada's oil sector by between 30 and 32 Mt, annually. In contrast, this analysis suggests a significantly lower value of between 0.7 and 4.3 Mt in 2035 (from wells-to-tank).

The difference between the results is due to three factors.

First, Pembina assumed that oil transport by rail was not an option, or that it would be prohibitively costly. With rail unavailable, oil sands are unable to develop beyond the available capacity of pipelines. In other words, one barrel of pipeline capacity would lead to one barrel of incremental oil production in Western Canada.[28]

[28] Flanagan, 2014, "Climate Implications of the Proposed Energy East Pipeline", *Pembina Institute*, available from www.pembina.org, accessed November 2014; Lemphers, 2013, "The Climate Implications of the Proposed Keystone XL Oil Sands Pipeline", *Pembina Institute*, available from www.pembina.org, accessed November 2014; Droitsch, 2011, "The Link

A more detailed look at the economics of rail and the oil sands indicates that rail is likely to be economic for many oil sands producers. New pipeline infrastructure induces greater activity in the oil sands by reducing transportation costs to market and therefore increasing the Alberta price for bitumen. Rather than increasing oil production by the full capacity of the pipeline, the Energy East project increases oil extraction by up to 9% of the pipeline's capacity in 2035.

Second, the higher netback price for oil in Alberta due to Energy East is temporary. If new pipelines are not built, pipelines from Western Canada reach full capacity by 2020 (in the model).[29] Energy East alleviates this constraint temporarily, but pipelines reach full capacity again by 2030. Therefore, Energy East only provides about 10 years of higher netback prices. While this temporary increase in price is sufficient to induce the more development in oil sands, development is more modest than it would be if higher prices persisted indefinitely.

Third, the analysis conducted here has a wider scope. Pembina focused exclusively on the emissions upstream from the pipeline in Western Canada. This analysis includes these emissions, but also considers how the pipeline will affect emissions downstream as well. Downstream from the pipeline, greater oil production from Western Canada can reduce production from other global sources. And greater bitumen upgrading in Alberta reduces emissions in the refining sector.

The results are more in the lower range of estimates provided by the U.S. State Departments' assessment of the Keystone XL.

It should be noted that comparing the results reported here to the U.S. State department is imperfect because the analyses examine different pipelines. However, the U.S. State Department estimated that Keystone XL would increase emissions by between 1 and 27 Mt from well-to-tank. This assessment indicates that the Energy East project would increase emissions by between 0.7 and 4.3 Mt.

In generating their estimates, the State Department, like the Pembina Institute, implicitly assumed that rail would not be an option. They appear to make this assumption despite their extensive review that indicates that rail is a viable option. Their estimate instead focuses on the substitutability between different crudes. If bitumen is extracted in Alberta to meet the demand from Keystone XL, it either displaces a Middle

between Keystone XL and Canadian Oil Sands Production", *Pembina Institute*, available from www.pembina.org, accessed November 2014.

[29] Note that the model solves in 5-year increments. So pipelines may reach full capacity before 2020.

Eastern or Venezuelan crude. The GHG impact is therefore based on the difference in GHG intensity between Alberta bitumen and Middle Eastern or Venezuelan crude.

As discussed in the section above, the availability of rail as an option for transporting crude oil from Alberta significantly reduces the GHG impact of new pipelines. As opposed to the pipeline increasing output by 1 barrel for every 1 barrel of capacity, it leads to an increase of up to 0.09 barrels (by 2035). Therefore, there is less opportunity for resource substitution than indicated by the State Department's analysis.

The range of impacts for Energy East reported is significantly smaller than reported by the Stockholm Institute for Keystone XL.

The Stockholm Institute indicated that the most significant GHG impact from Keystone XL is likely to be due to greater consumption of refined petroleum products. They argue that new pipelines from Alberta would enable greater global oil supply, therefore enabling greater consumption. As the majority of emissions occur during final consumption, greater supply could lead to significantly greater emissions. They estimate these emissions between 0 and 110 Mt (annually).

This analysis confirms that the most significant impact from new pipelines is from final consumption. Greater final consumption accounts for between 74% and 86% of the total GHG impact.

However, the range shown here is significantly smaller than reported by the Stockholm Institute. Here final consumption only accounts for between a 4.7 and 12 Mt increase in emissions.

The explanation for the difference follows Andrew Leach's criticism of the Stockholm Institute's study.[30] A large portion of the bitumen exported using the Energy East pipeline would have been extracted regardless of whether the pipeline is built. Therefore, the pipeline's impact on global supply is much more muted than reported by the Stockholm Institute.

This analysis accounted for the key dynamics that determine how pipelines affect GHG emissions.

In our view, this analysis is the first comprehensive quantitative analysis of how pipeline infrastructure is likely to affect global GHG emissions. By conducting a comprehensive

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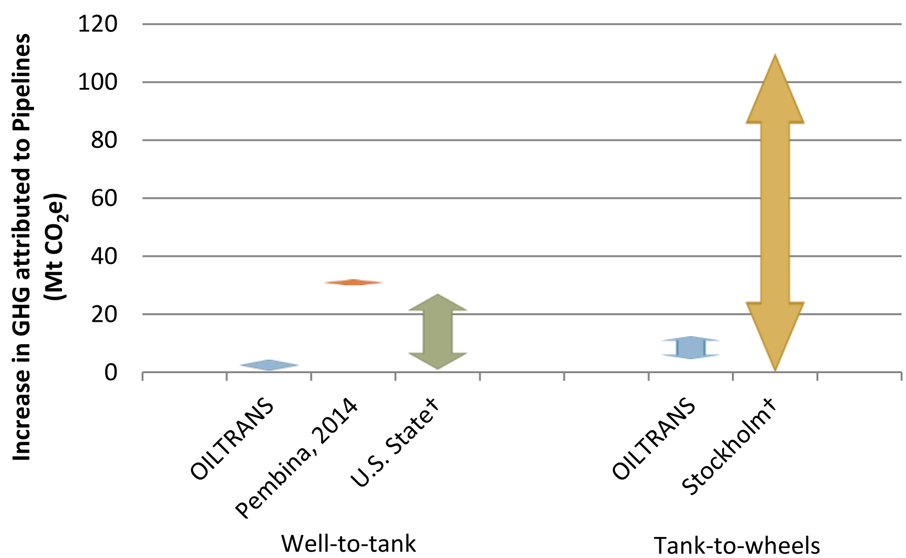
[30] Andrew Leach, 2014, "A paper on Keystone's climate impacts would fail Econ 101", *Macleans* Magazine, available from: www.macleans.ca., accessed November 2014.

analysis, the range of GHG impacts is significantly smaller than reported in the other analyses, which were not comprehensive.

Figure 29 shows the range of impacts reported in other analyses against the impacts shown here. Note that the three other analyses with quantitative estimates differ on whether they focus on emissions from well-to-tank or from tank-to-wheels. Pembina and the State Department focus on the former, while the Stockholm Institute focuses on the latter.

Figure 29: Comparison between OILTRANS and other GHG estimates



Note: † The U.S. State Department and the Stockholm Institute are analyses of another pipeline: the Keystone XL pipeline.

5. Discussion

This report summarizes the analysis of how TransCanada's Energy East project is likely to affect global GHG emissions. They key findings from the analysis are as follows.

The literature highlights the need for a comprehensive analysis of how pipeline infrastructure affects GHG emissions.

The literature reports a wide range in possible GHG impacts due to building new pipeline infrastructure from Alberta. On one side, IHS CERA estimates that the GHG impact of new pipelines is small or negligible. On the other side, the Stockholm Institute suggests that approving new pipelines could increase GHG emissions by up to 110 Mt per year.[31]

The challenge with analyzing the GHG impact of pipeline infrastructure is oil markets are complicated with many interacting dynamics. By focusing on some of these dynamics, it can be argued that pipelines will have a small impact on GHG emissions. For example, IHS CERA focuses on the competitive interaction between producers in Alberta and other countries to suggest that any production that does not occur in Alberta will be "leaked" to Venezuela, where extraction is also emissions intensive. By focusing on this dynamic, it can be argued that new pipelines will have a small impact on global emissions.

By focusing on other dynamics, it can be argued that pipelines will have a large impact on emissions. The Stockholm Institute focused on how new pipelines would increase in global supply and therefore consumption. As the majority of emissions from the oil supply chain occur during final consumption, new pipelines could increase emissions by 110 Mt.

While each of the dynamics highlighted in the literature are important, in isolation they cannot provide full insight into the impact of new pipelines on GHG emissions. This highlights the need for a comprehensive analysis that captures the major dynamics affecting the evolution of oil markets. This report summarizes the results from the OILTRANS model, which simulates the major dynamics affecting GHG emissions in oil markets from now until 2035.

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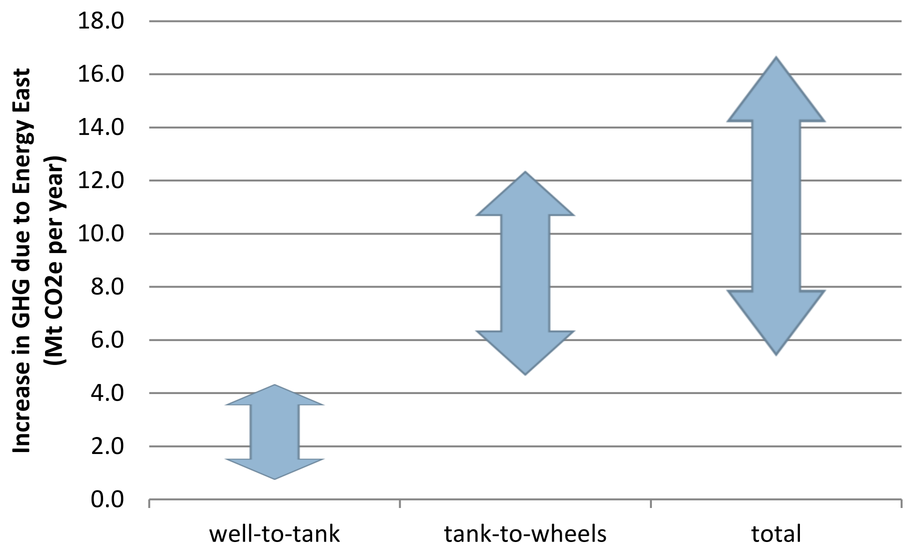
[31] Forrest and Brady, 2013, "Keystone XL Pipeline: No Material Impact on US GHG Emissions", IHS CERA Insight; Erickson and Lazarus, 2014, "Impact of the Keystone XL pipeline on global oil markets and greenhouse gas emissions", Nature Climate Change.

The Energy East project is likely to increase global well-to-tank emissions, with a range of impacts from 0.7 to 4.3 Mt (in 2035).

This analysis examines Energy East's approval under four scenarios for how oil markets are likely to evolve until 2035 if global climate policies are not implemented. The scenarios vary the approval of other pipelines from Western Canada (e.g., Keystone XL) and assumptions around the sensitivity of consumption to prices for refined products.

The total impact on GHG emissions can be divided between all emissions up to final consumption ("wells-to-tank") and final consumption ("tank-to-wheels"). Figure 30 shows that the Energy East project is likely to increase emissions from well-to-tank by between 0.7 and 4.3 Mt annually in 2035.

Figure 30: Summary of global GHG impacts



The Energy East project is likely to increase global consumption of refined petroleum products, leading to an additional 4.7 to 12 Mt (in 2035).

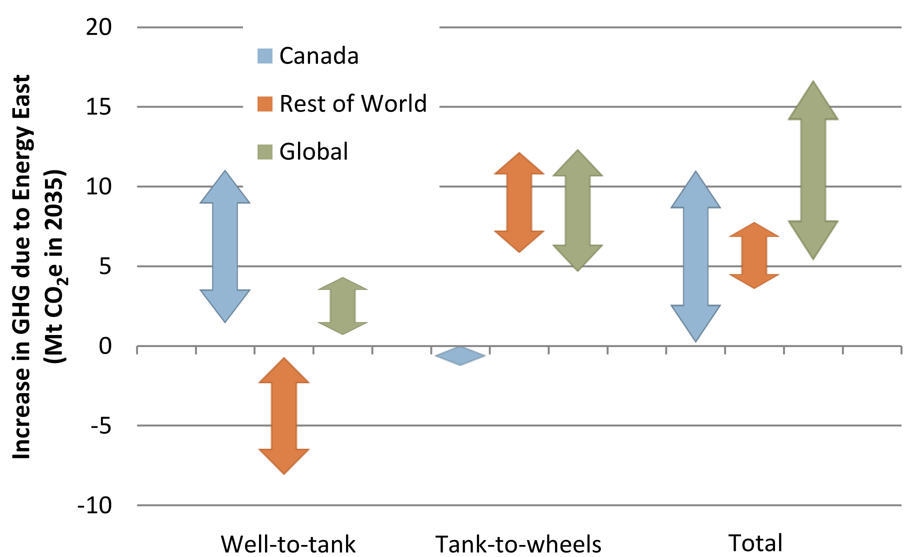
The majority of the impact occurs at the point of final consumption. This impact accounts for between 74 and 86% of the total increase in emissions. This confirms the intuition but not the magnitude from the Stockholm Institute, which indicates the increase in final consumption is likely to be the most significant impact of new pipeline infrastructure. The approval of Energy East leads to a small increase in global supply and therefore a small reduction in the average global oil price. This leads to a small increase in the final consumption of refined petroleum products.

The majority of the increase in emissions due to Energy East's approval would occur outside of Canada.

The increase in Canadian GHG emissions due to the Energy East project is significantly lower than the global increase. Figure 31 shows the range of impacts on Canadian, the Rest of the World and global GHG emissions. The "Global" columns match the range shown in Figure 30 above.

In 2035, Canadian GHG emissions increase by between 0.2 to 11 Mt (see Figure 31). This represents up to 66% of the global increase.

Figure 31: Summary of Canadian and Rest of World GHG impacts



As discussed above, the majority of the increase in global emissions is due to an increase in final demand (tank-to-wheels). These emissions occur predominately outside of Canada. In fact, consumption is lower in Canada due to the Energy East project, as the prices for crude oil and refined petroleum products increase in Western Canada.

Energy East's approval is unlikely to "lock-in" GHG emissions.

Some have argued that pipelines would enable greater oil sands production and therefore "lock-in" GHG emitting infrastructure. This analysis does not refute that this is a possibility, but it is likely to be a negligible concern.

There are largely two possibilities for Canada's oil sands in a GHG constrained world to limit the rise in temperatures to $2^{O}C$ from pre-industrial levels. First, oil sands producers do not succeed at developing technologies that enable it to be competitive in a low GHG environment. In this scenario, oil sands activity stops growing and begins to decline after 2030. A new pipeline route has little to no effect on this decline.

Second, oil sands commercialize low-emissions technologies that are currently under development. These technologies would enable the oil sands to stay competitive regardless of climate policy. In this scenario, oil sands could remain as a global supplier for crude oil and in fact gain market share, over its competitors. Here the pipeline has a greater impact, but it remains small as the oil sands would have significantly low GHG intensities.

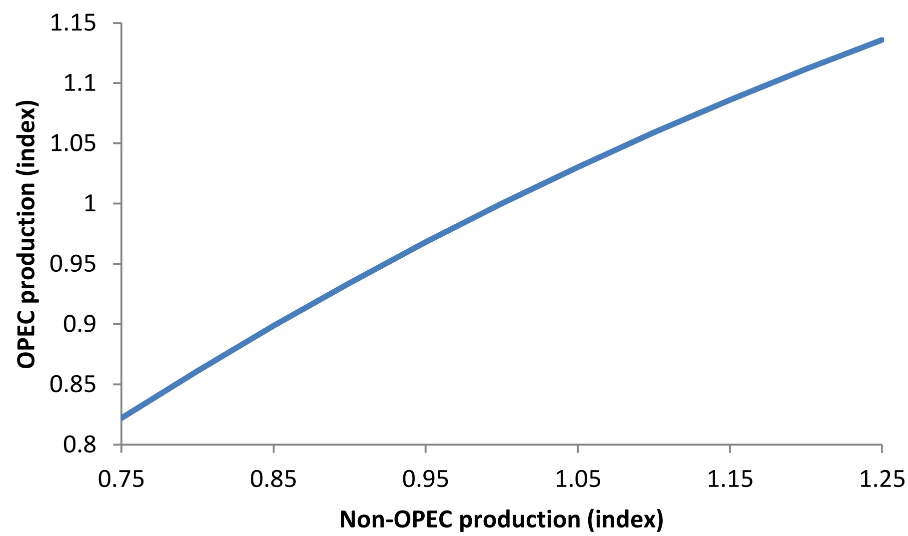
Appendix A: OPEC decision making

OILTRANS uses an algorithm to describe how OPEC responds to changes the production from non-OPEC oil producers. This algorithm is shown and described in The OILTRANS model.

The implication of this function is that OPEC production is positively correlated with non-OPEC production. Although the authors tried and failed at re-writing this function to describe OPEC production as a function of non-OPEC production, a simple example can demonstrate the outcome of this relationship.

Figure 32 shows the results from a simple model to solve for OPEC production under different production levels for non-OPEC producers. The figure shows that OPEC production is positively correlated with non-OPEC production.

Figure 32: OPEC production as a function of non-OPEC production



Appendix B: Glossary

API gravity: A measure of the density of crude oil. Less dense crude oils are called "light" and have relatively high API gravities (e.g., API gravity above 35O). More dense crude oils are called "heavy" and have lower API gravities.

Atmospheric distillation: The first stage in petroleum refining. The process separates crude oil into its various fractions (e.g., straight-run gasoline, straight-run fuel oils). Fractions that do not distill during atmospheric distillation are sent to the vacuum distillation process or sold as heavy fuel oil.

Bitumen upgrading: Processing bitumen to remove the contaminants and to "crack" the heavier fractions into lighter components. A bitumen upgrader employs several refinery processes, but produces a synthetic crude oil which is then sent to a refinery.

Brent crude: The benchmark for light sweet crude oil priced in Europe.

Carbon dioxide or equivalent (CO_2e): The sum of carbon dioxide and other greenhouse gases that have been weighted by their global warming potentials. For example, the global warming potential for methane is assumed to be 21 times that of carbon dioxide.

Delayed coking: The thermal cracking of vacuum residue to produce distillates (i.e., lighter petroleum products) and petroleum coke.

Diluent: A lighter crude oil which is required to dilute bitumen before it can be transported by pipeline.

Hydrotreatment: A process in petroleum refining or bitumen upgrading to remove contaminants (e.g., sulfur) from crude oil.

Naphtha: The lightest fraction of crude oil. This fraction is most commonly used to produce gasoline. Heavier naphtha can be blended with heavier fractions to produce light fuel oils or diesel.

Organization of the Petroleum Exporting Countries (OPEC): A cartel of major oil exporting countries whose key objective is to maximize the value of their exports by manipulating the price for oil.

Parts-per-million (ppm): In the context of this analysis, ppm refers to the concentration of greenhouse gases in carbon dioxide or equivalent in the atmosphere.

Synthetic crude oil: Bitumen that has been processed in a bitumen upgrader to remove contaminants (e.g., sulfur) and the heavier (less desirable) fractions.

Tank-to-wheels: The final consumption of refined petroleum products (e.g., gasoline, diesel, etc).

Vacuum distillation: The fractions of crude oil that do not distill during atmospheric distillation can be sent to the vacuum distillation unit, where they are further distilled. The portion of crude oil that does not distill during vacuum distillation is called vacuum residue.

Well-to-tank: The portion of the oil market responsible for extracting, transporting and refining crude oil into final refined petroleum products.

Well-to-wheels: The entire global oil market from extraction to consumption.

West Texas Intermediate: The benchmark for light sweet crude oil priced at Cushing Oklahoma.

Western Canadian Select (WCS): The benchmark for heavy crude oil in Western Canada. WCS consists of bitumen and a diluent such that it is ready for pipeline transport. WCS is priced at Hardisty Alberta, but this analysis uses Edmonton as a surrogate for Hardisty.

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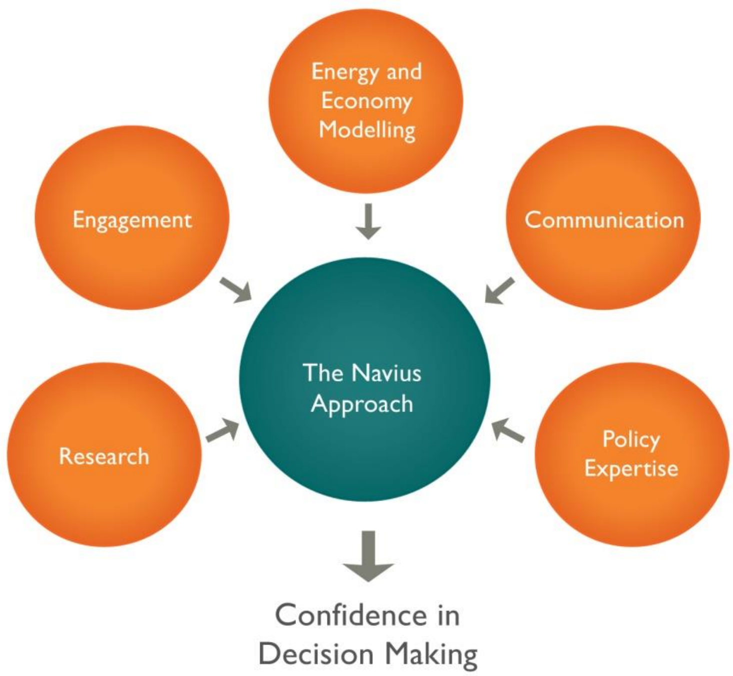

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