Understanding Government and Railroad Strategy for Crude Oil Transportation in North America

by

S. Joel Carlson

Bachelor of Science in Civil Engineering, University of Alberta, 2006

Submitted to the Engineering Systems Division and the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degrees of

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Abstract

On July 6, 2013, an oil-laden unit train derailed and exploded in Lac-Mégantic, Quebec, Canada, killing 47 people, shocking and saddening many, and leading to significantly increased public scrutiny of crude oil transported by rail. Simultaneously, there has been intense scrutiny of proposed pipelines from the oil/tar sands in Alberta, most notably the TransCanada Keystone XL. Not only is there concern about the potential environmental impacts of the pipelines themselves, such as a potential spill of diluted bitumen, but there is also concern about the consequences of greenhouse gas emissions caused by the energy-intensiveness of bitumen production and refining.

Proponents argue that a denial of pipeline permits by governments in Canada and the United States would lead to more crude by rail, an outcome that pipeline supporters believe would not only be less cost-effective, less safe, and less environmentally-friendly, but would also ultimately lead to the same amount of greenhouse gas being emitted from the production and refining of oil sands bitumen. Railroads, with much of the required infrastructure already in place to transport crude, usually do not need to undergo the same environmental assessments as pipelines for modest capacity expansions. As a result, when pipelines are evaluated through political and regulatory processes in Canada and the US, much of the focus is on what railroads *might* do if a pipeline permit is not approved, rather than what they *should* do. This research emphasizes the latter.

The CLIOS Process, an approach for studying complex sociotechnical systems, is used to study the relationships between the oil sands production and transportation systems, the institutional actors that govern them, and the critical contemporary issues of economic development, energy security, climate change, and safety. Specifically, strategic alternatives – pipelines and railroads – for adding transportation capacity from the oil sands are identified and their performance along dimensions of societal concern are compared and contrasted. Additionally, recognizing that railroad safety is of particular concern, CAST, an accident investigation tool built on the STAMP accident causation model, is used to study the safety control structure of the Canadian railway industry that existed prior to the Lac-Mégantic accident.

This research describes how environmental acceptability is implicit in advancing energy security and economic development. The research also raises questions about the acceptability of safety risks associated with rail transport of crude oil and recommends that this issue be further debated at railway management, regulatory, and political levels. Both railroad and pipeline modes are environmentally efficient and safe, and the emphasis of the conclusions is that further *improving* environmental performance and further *improving* safety should be focused on, whenever possible, not only by looking inwardly at one organization or transport mode in isolation, but also by seeking broader system-level changes.

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Dedication

To the memory of grandma Evelyn, who passed away during my time at MIT, as a reminder to:

"always aim high"

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There are many individuals who have contributed to my success at MIT. I will be sure to thank you in person if you are not mentioned here.

To Joe, thank you for your encouragement to take on this topic and for your personal and professional guidance during these past three years. We never did have a 'normal' year – if such a thing exists – but your steadfast support helped me press on even when I wasn't sure about the path forward.

To members of my research group and lab mates in 1-151 over the past three years, thank you for the guidance you've shared. In particular:

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***

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Joel Carlson
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Biographical note

S. Joel Carlson holds a Bachelor of Science in Civil Engineering from the University of Alberta in Edmonton, Alberta, Canada. Upon his graduation in 2011, Joel was awarded the Governor General's Silver Academic Medal and the Right Honourable CD Howe Memorial Fellowship, the university's highest awards for graduating students. He was also a recipient of a Natural Sciences and Engineering Research Council of Canada Postgraduate Scholarship. Joel grew up in Prince Rupert, British Columbia, Canada where his family still resides.

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Glossary of terms and acronyms

AAR	Association of American Railroads
API	American Petroleum Institute
API Gravity	The API gravity is given as: API Gravity = 141.5/(Specific Gravity) - 131.5. Heavier oils, which contain a higher concentration of hydrocarbons with high molecular weights (Centre for Energy 2014), have a lower API gravity (and higher density).
ACRS	Advisory Council on Railway Safety
bbl	Barrel, a unit of measure containing 42 US gallons
bbl/d	Barrels per day
Bitumen	Bitumen is "[a] thick, sticky form of crude oil that is so heavy and viscous that it will not flow unless it is heated or diluted with lighter hydrocarbons" (Government of Alberta 2009).
BNSF	Burlington Northern Santa Fe Railroad
CAPP	Canadian Association of Petroleum Producers
CAST	Causal analysis based on STAMP, an accident investigation tool introduced in Leveson (2011a)
CCI	Critical contemporary issue
CERI	Canadian Energy Research Institute
CLIOS Process	A methodology for studying for studying complex sociotechnical systems described in Sussman et al. (2014).
CLIOS system	Complex, large-scale, interconnected, open, sociotechnical system (Sussman et al. 2014)
CN	Canadian National Railway Company
Condensate	"Light liquid hydrocarbons . . . [recovered following the production of natural gas] that [normally] [enter] the crude oil stream after production" (EIA 2014).
CP	Canadian Pacific Railway
Critical contemporary issues	"Issues . . . in contemporary society, which are very expensive on many dimensions and have substantial impact on the human condition on this planet" (Sussman et al. 2014)
CROR	Canadian Rail Operating Rules
CTA	Canadian Transportation Agency
DG	Dangerous good
Dilbit (diluted bitumen)	Bitumen that has been diluted using lighter hydrocarbon diluent to allow for pipeline transport, typically in a 70:30 ratio of bitumen to condensate.
Diluent	A lighter hydrocarbon such as condensate used to dilute bitumen for transport
DOT	US Department of Transportation
DRU	Diluent recovery unit
EIA	US Energy Information Administration
ERAP	Emergency Response Assistance Plans
Evaluative complexity	The complexity resulting from actors in the institutional sphere having differing definitions of desirable system performance (Sussman et al. 2014).
FERC	Federal Energy Regulatory Commission
FRA	US Federal Railroad Administration
Fracking	Hydraulic fracturing, an unconventional production technique used to extract shale oil

FSEIS	Final Supplemental Environmental Impact Statement
GHG	Greenhouse gas
Heavy oil	Oil with an API gravity of less than approximately 25 degrees.
IEA	International Energy Agency
Institutional actors	Individuals, organizations, and governments that can influence and be affected by the physical system (Sussman et al. 2014).
Institutional sphere	In the CLIOS Process, the institutional sphere refers to the system of actors that encapsulate the physical domain (Sussman et al. 2014).
IPCC	Intergovernmental Panel on Climate Change
Light oil	Oil with an API gravity less than about 25 degrees
MM&A	The Montreal, Maine and Atlantic Railway, the now-defunct railway company involved in the Lac-Mégantic accident
MMbbl/d	Million barrels per day
$MMTCO_2e$	Million metric tonnes of carbon dioxide equivalent
NEB	National Energy Board (of Canada)
Nested complexity	The complexity resulting from having a physical domain embedded within an institutional sphere composed of actors. Studies of the physical domain often require quantitative engineering and economic models, whereas studies of the institutional sphere often require qualitative management and social science methods (Sussman et al. 2014).
NTSB	National Transportation Safety Board
Oil sands	A deposit of bitumen infused sand and clay found in northern Alberta Canada. The oil sands comprise three deposits: the Athasbasca, the Peace River, and the Cold Lake oil sands.
OPEC	Organization of the Petroleum Exporting Countries
PADD	Petroleum Administration for Defense Districts
PHMSA	Pipeline and Hazardous Materials Administration
Physical domain	The set of subsystems in the CLIOS Representation, excluding the institutional sphere (Sussman et al. 2014).
Production	Product refers to either: (1) The act of removing (i.e. "extracting") the bitumen from the ground when used as a verb, or (2) the quantity of petroleum removed from the ground during a certain period when used as a noun (e.g. oil sands' production was 1.8 MMbbl/d last year).
PTC	Positive train control
RAC	Railway Association of Canada
Railbit	Railbit is similar to dilbit, but the mixture only contains approximately 15% diluent.
Rawbit (raw or undiluted bitumen)	Raw bitumen is bitumen that is not diluted for transport and does not flow at ambient temperatures. It can only be shipped by insulated (coiled) tank cars that be heated at the unloading facility to allow the bitumen to flow.
RSA	Railway Safety Act
SCO (Synthetic crude oil)	Heavy crude oil or bitumen that has been processed into lighter form of crude oil
Shale oil	Oil found in low-permeability rock formations typically produced using horizontal drilling and hydraulic fracturing
SMS	Safety management systems
STAMP	Systems-Theoretic Accident Model and Processes, an accident causation model developed in Leveson (2011a).

STB	US Surface Transportation Board
STPA	System-Theoretic Process Analysis, a hazard analysis tool (Leveson 2011a)
Strategic Alternatives	Deliberate physical or institutional changes designed to enhance the performance of the CLIOS system along one or more dimensions
Supply (of crude oil)	Supply refers to the volume of crude oil available for delivery to refining and other customers after the raw bitumen is initially processed ("upgraded") into a lighter product or blended with a diluent to allow for transport (CAPP 2013)
Tar sands	Refer to the definition of oil sands
TC	Transport Canada
TDGA	Transportation of Dangerous Goods Act
Tight oil	Refer to the definition of shale oil. The terms are not technically the same, but are used synonymously throughout this thesis.
TransCanada	The company proposing the Keystone XL pipeline
TSB	Transportation Safety Board of Canada
UN1267	A hazardous material marking referencing petroleum crude oil
Unconventional oil	Oil that is not conventional oil, which is defined as oil "produced by a well drilled into a geologic formation in which the reservoir and fluid characteristics permit the oil . . . to readily flow to the wellbore" (EIA 2014).
Unit train	A train composed of around 100 cars of one commodity circulating between a given origin and destination.
UP	Union Pacific Railroad
US	United States of America
USGC	US Gulf (of Mexico) Coast
WCS	Western Canadian Select, a crude oil stream from Canada
WTW	Well-to-wheel. In the context of this thesis, it is used to refer to the greenhouse gas emissions that are emitted during the production, transportation, refining, and combustion of petroleum products.

1 INTRODUCTION AND MOTIVATION

On July 6, 2013, an oil-laden unit train derailed and exploded in Lac-Mégantic, Quebec, levelling its downtown and killing 47 people (Transportation Safety Board of Canada [TSB] 2014c, Cairns 2013b).[1] Following a dramatic increase in crude oil shipments on US Class I[2] railroads[3] from just 9,500 carloads in 2008 to 234,000 in 2012 (Association of American Railroads [AAR] 2013b), this accident shocked and saddened many – including the author – and led to the increased public scrutiny of crude oil by rail.

The rapid growth in oil by rail shipments was initially driven by increased production of *tight* or *shale oil*: crude oil found in low-permeability rock formations, such as the Bakken in North Dakota, and the Eagle Ford in Texas. Horizontal drilling combined with hydraulic fracturing allowed oil producers to economically produce oil from these sources, resulting in 1.5 million barrels per day of shale oil being produced in 2012, up from almost no production in 2006 (Maugeri 2013). This growth "[surprised] most experts" (Maugeri 2013). Pipeline capacity has not been correspondingly expanded. With much of the necessary infrastructure already in place, railroads were able to respond quickly to these production increases.

Nearly simultaneously to the increasing in production from shale oil reserves, there has been intense scrutiny of several proposed pipelines from the oil/tar sands found in northern Alberta, Canada to the west and east coasts of Canada as well as to the US Gulf of Mexico Coast (USGC). These pipelines are proposed to accommodate increases in *bitumen* production, the form of petroleum produced from the oil sands. Pipeline opponents are concerned not only about negative potential environmental impacts from the pipelines themselves, such as a spill of diluted bitumen (a form of crude oil to be shipped), but also about the consequences of greenhouse gas (GHG) emissions caused by the energy-intensiveness of bitumen production and refining. Proponents counter that a denial of pipeline permits by the Canadian and US governments would lead to more crude by rail, which they argue would not only be less cost-effective, less safe, and less environmentally-friendly, but also ultimately lead to the same amount of GHG being emitted from

[1] The Wikipedia page for the Lac-Mégantic Derailment (http://en.wikipedia.org/wiki/Lac-M%C3%A9gantic_derailment) also provides a thorough literature review on the subject.

[2] Class I railroads are railroads with revenues exceeding approximately $433 million annually, figure adjusted annually by the US Surface Transportation Board [STB] (American Short Line and Regional Railroad Association 2014). Canadian regulations have a similar classification.

[3] Canadian nomenclature typically refers to railroads as railways. Both terms are used interchangeably throughout this thesis.

the production and refining of oil sands[4] bitumen (e.g. Krugel 2013). Therefore, much of the debate over proposed pipelines from the oil sands hinges on whether railroads could accommodate oil production increases economically and with comparable societal impacts.

Opposition to the construction of pipeline projects is not new; however, the nature of the controversy over their construction has evolved from a focus on *local* environmental issues[5] to include broader *global* issues. For example, in the early 1970s, there was debate over the proposed Trans-Alaska Pipeline (TAP), which now carries crude oil between the North Slope of Alaska and a port on the southern shore at Valdez. The opponents of this pipeline were concerned about the potential negative *local* environmental impacts from the pipeline itself, such as the consequences of potential spills, for example (Kashi 2013). The opponents of current pipeline proposals are also concerned about such issues, but in addition, are also concerned about the climate change impact of the GHG emissions from oil production and use. In other words, the question is no longer solely about the pipeline itself, but whether North American society should be expanding the capacity to produce and transport crude oil at all, especially from a "dirtier" source.

The ongoing debate over the proposed Keystone XL pipeline from Canada to the US is the highest profile example of this controversy. As shown in **Figure 1-1**, the Keystone XL pipeline is a proposed $5.3 billion, 1,179-mile crude oil pipeline capable of carrying 830,000 bbl/d of crude oil[6] from the oil sands in Alberta, Canada to heavy oil refineries on USGC (TransCanada 2014). The Keystone XL would become part of a larger Keystone pipeline system, which includes an existing pipeline called the Keystone. TransCanada, the publicly traded company proposing the Keystone XL and owner of the existing pipelines, submitted its initial application to the US Department of State for a Presidential Permit to construct the pipeline across an international border in September 2008, and

---

[4] Choosing whether to use "oil sands" or "tar sands" is challenging in the context of the scrutiny that this resource is receiving. Gailus (2012) notes that technically "bituminous sands" would be the correct term, though it is not used in practice. The oil sands industry, and the Governments of Alberta and Canada, use "oil sands," and US President Obama, as well as "critics of how the bitumen deposits are being developed [typically] use 'tar sands'" (Canadian Association of Petroleum Producers [CAPP] 2014a, Government of Alberta 2009, Gailus 2012, Dembicki 2011, *The New York Times* 2013). One exception is The Pembina Institute, an environmental think-tank that also works with industry (Gailus 2012). David Finch, a historian, in a post on CAPP (2014), finds that until 1960, tar sands was the exclusive term used. Around then the Alberta Government started using oil sands to give some indication as to the final product. The Government of Alberta (2007) argues, "while oil sand is a naturally occurring petrochemical, tar is a synthetically produced substance that is largely the last waste product of the destructive degradation of hydrocarbons." The author has chosen to use oil sands consistently throughout because it aligns more closely with the final use of the bitumen, but recognizes that tar sands is commonly used and reflects the consistency of the bitumen.

[5] This framing should not discount concerns over a pipeline spill, which is currently creating opposition from landowners in Nebraska to the Keystone XL (Elbein 2014).

[6] The Keystone XL will transport dilbit (diluted bitumen), which is bitumen that has been mixed with a diluent for transport, such as condensate (heavier hydrocarbons from natural gas that liquify once the gas is recovered). A typical ratio of bitumen to diluent is 70:30 (Canadian Association of Petroleum Producers [CAPP] 2013).

the environmental evaluation process associated with its construction is still ongoing as of May 2014.[7] By contrast, the time between the proposal and the final approval of the original Keystone pipeline in 2008 was only about three years (Al Jazeera America 2013).

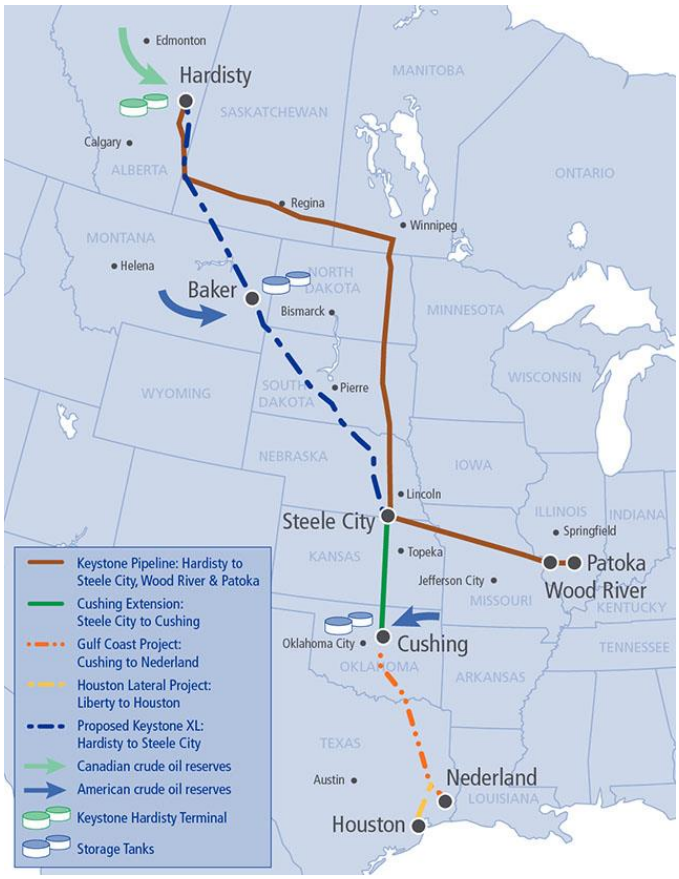

Figure 1-1: Route of the existing Keystone pipeline and proposed Keystone XL pipeline (Source: TransCanada 2014)

The debate over the Keystone XL has become symbolic of a larger clash between environmental and energy interests. Environmentalists view the Keystone XL as a "litmus test for President Obama's commitment to fighting climate change" (Davenport 2014). Renowned climate scientist James Hansen (2012) argued, "it will be game over for the climate" if oil sands production growth is encouraged by the approval of the Keystone XL permit (as well as failure to implement other climate policies).[8] By contrast, Canadian Prime Minister Stephen Harper as well as Republicans in

[7] After three years of evaluation, in December 2011, Congress passed a bill requiring a decision on the Keystone XL project within 60 days, which President Obama signed into law (US House of Representatives Energy and Commerce Committee 2013). President Obama subsequently denied a permit based on TransCanada's application in January 2012, stating that "[this decision is not a] judgment on the merits of the pipeline, but [on] the arbitrary nature of a deadline that prevented the State Department from gathering the information necessary to approve the project…," and invited TransCanada to reapply, which it did in May 2012 (Obama 2012, US House of Representatives Energy and Commerce Committee 2013).

[8] The entire editorial by Dr. Hansen only mentions the Keystone XL permit denial as one possible action among many.

US Congress have called approving the Keystone XL a "no brainer" for the energy security and economic benefits that the pipeline will provide in the US and Canada (McCarthy 2011, Needham 2013). Labor unions, which tend to support Democratic-Party candidates, also want the project to go ahead (Panetta 2014). The intense symbolism of the permitting Keystone XL has created a politically lose-lose scenario for President Obama. As Broder et al. (2013) puts it, Obama faces a "knotty decision . . . [in choosing] between alienating environmental advocates who overwhelmingly supported his candidacy or causing a deep and perhaps lasting rift with Canada," among others.

As this symbolic debate over the Keystone XL and other pipeline permits in Canada and the US continues, several existing pipelines, such as the Keystone, continue to transport oil sands bitumen to destinations in the US and Canada. Additionally, the two Canadian Class I railroads, the Canadian National (CN) and the Canadian Pacific (CP), have been shipping increasing amounts of oil from western Canada (including Alberta). By the end of 2013, these two railroads expected to transport approximately 150,000 carloads annually (about 216,000 to 267,000 barrels per day)[9] of crude oil (Domm 2013), a small but growing fraction.

Collectively, the oil sands bitumen rail traffic ending up in the US, as well as traffic from shale oil production, is helping US railroads make up for falling US domestic coal rail traffic. Coal is the railroads' most important existing revenue source. In 2012, US railroad revenues from coal transport, both for domestic and international markets, totalled $14.7 billion, or about 22% of their total revenues (AAR 2013a). However, in 2012, annual coal traffic was down by 1.51 million carloads from its peak of 7.71 million carloads in 2008 (AAR 2013a). Though coal export markets remain strong, a combination of low natural gas prices from shale gas production and stricter GHG emissions standards for coal-fired power plants are leading to coal consumption declines in the US (Stagl 2012). Crude oil by rail offers a potential new revenue source for railroads to make up for this decline in coal traffic.

Thus, the stakes – for governments and railroads – of this debate over whether to build more pipelines are high: shale oil production is expected to grow from 2.3 million barrels per day (MMbbl/d) in 2012 to 4.8 MMbbl/d in 2021 (US Energy Information Administration [EIA] 2013d), and oil sands production could increase from 1.8 MMbbl/d in 2012 to 5.0 MMbbl/d in 2035 (National Energy Board [NEB] 2013), with both positive and negative consequences for Canada and

[9] The capacity of a tank car to carry crude oil varies between about 525 barrels per car for higher-density heavy crudes to about 650 barrels per tank car for lower-density lighter crudes (Cairns 2013a).

the US. It would also have implications for the railroads: if all of the crude oil production growth were to be transported by railroads, approximately 3.5 million carloads per year would be originated on Canadian and American railroads, which is around 10% of 2012 carload traffic.[10,11] Given this potentially dramatic growth, it is thus critical to better understand the implications of how oil is transported in North America.

However, while proposed pipelines are subject to intense public scrutiny through national-level environmental reviews in Canada and the US, railroads, with most of the infrastructure in place to transport crude, usually do not need to undergo the same environmental assessments as pipelines. As a result, when pipelines are evaluated through political and regulatory processes in Canada and the US, much of the focus is on what the rail industry *might* do if a pipeline permit is not approved, rather that what railroad's role should be. As a result, much of the discussion thus far has focused on whether railroads could or would transport crude oil, rather than whether they *should* transport crude oil.

Thus, this thesis will focus on what the railroads' role should be in transporting crude oil. Should railroads transport more crude oil? If so, what concerns does this create and how should they be addressed? Because these two questions remain broadly stated, **Section 1.1** provides further background on the purpose of this thesis. Then, **Section 1.2** specifies the more precise questions this thesis raises and explains the methodologies used to address them. In **Section 1.3**, the distinction between shale oil and oil sands is provided. Finally, this opening chapter is concluded in **Section 1.4**.

1.1 THESIS PURPOSE

Initially, the aim of this thesis was to focus on railroad industry's ability to manage societal issues within their strategic decision-making process. When the Lac-Mégantic accident occurred, the author and his research group colleagues were not only shocked and saddened by the consequences of the accident, but also concerned by how the railroads – given their high-level of safety consciousness – became involved in the transport of this commodity. Some members of the industry expressed similar sentiments as well. Following the accident at Lac-Mégantic, the chairman of the railroad involved in the accident, the Montreal, Maine, and Atlantic (MM&A), indicated in an interview that with the benefit of hindsight, "[he's] asked [himself]. . . whether [his

[10]This calculation assumed an unweighted average tank car capacity of 588 barrels per tank car.

[11] US Class I railroads originated 28,374,746 carloads in 2012 (including intermodal, AAR 2013a) and Canadian railways originated 3,161,034 carloads (excluding intermodal).

company][12] should have been handling this oil at all," which suggests that his company did not give much consideration to any special precautions that are required (The Canadian Press 2013c). Although his comments have been highly controversial – in the rest of the interview, he discussed the financial implications of the accident for the railroad – this comment articulates the initial sentiment motivating this research.

However, while informing railroad strategy for managing the transport of new potentially hazardous energy commodities remains the ultimate aim of this research, it was also quickly realized that the actions of railroads are simultaneously driven by and constrained by regulations from and actions by Canadian and American governments. Without understanding these drivers and constraints, it is difficult to comprehend the behavior of the railroad industry. While railroads have almost always been a regulated industry, of concern in this market are not only the regulations on the industry itself, but also those on the pipeline industry, which, after the early days of oil exploration in the US starting in the late 1800s (Yergin 2009), has generally been the preferred mode by which crude oil has been shipped.

While the technological development that has allowed for the economic extraction of shale oil and oil sands bitumen is one key driver of crude oil by rail, another driver is the lack of pipeline expansion. As discussed regarding the Keystone XL, the environmental assessment has taken longer than expected due to the heightened level of public scrutiny. As production from the oil sands continues to expand, oil producers have had to resort to shipping by rail if they want to get their product to refining market; however, it is not necessarily because they view rail as a preferred mode. In essence, the market for rail transport of crude oil was created in part by government inaction thus far, and could be further reinforced if governments denied the permits necessary for pipeline construction.

Additionally, railroad actions are constrained by their common carrier requirements, which, under economic regulations in Canada and the US, require railroads to transport products upon a reasonable request by shippers. Regulators give shippers – the individuals and organizations requesting transport – deference in interpreting these requirements. For example, in 2009, the Union Pacific Railroad (UP) argued to the US Surface Transportation Board (STB, the economic regulator of railroads in the US) that it should not be required to transport certain chlorine shipments, because there were other sources of chlorine near the destination and the shipment

[12] It is unclear from the context of the quote whether he is referring to his company and/or the railroad industry collectively.

would transit through heavily populated areas (Quinlan 2009). Even though chlorine is very hazardous to transport, the UP was not successful in defending its argument to the STB, which ordered the railroad to transport the chlorine if requested by the shipper. Regulations on the railroads themselves as well as its competitors create opportunities and impose constraints on the industry.

Ultimately while the aim of this thesis is to provide insights into what railroads *should* do in response to increased North American oil production, the first step of this thesis is to understand the influence of government actors over railroad actions. Additionally, because an academic thesis cannot defend the response to a question requiring broad societal and management debate – i.e. whether railroads should transport crude oil – the emphasis of this thesis is on articulating the influence governments have over increasing or constraining capacity expansion from the oil sands, understanding the tradeoffs associated with increasing oil sands bitumen production and its transport by railroads, and posing questions for further reflection and thought. These overarching aims are addressed by responding to the three interrelated questions introduced in **Section 1.2**.

1.2 THESIS QUESTIONS AND APPROACHES

The conceptual framework used to generate the questions in this thesis is the *CLIOS Process*, an approach for studying *complex, large-scale, interconnected, open, sociotechnical (CLIOS) Systems,* and the *critical contemporary issues* (CCIs)that emerge from them (Sussman et al. 2014). CLIOS systems are a class of *complex sociotechnical systems* "characterized by a high degree of technical complexity, social intricacy, and elaborate processes" with wide-ranging social, political, economic, and environmental impacts (de Weck et al. 2011, Sussman et al. 2014). Critical Contemporary Issues are "issues . . . in contemporary society, which are very expensive on many dimensions and have substantial impact on the human condition on this planet." Critical contemporary issues result from these impacts (Sussman et al. 2014).

As this thesis will demonstrate, the oil sands production and transportation systems, including the institutional actors that govern these systems, are two subsystems forming part of a CLIOS System. There are also other subsystems of societal interest within the CLIOS system related to energy, the economy, and the environment. The interactions between the oil sands production and transportations systems impact these subsystems of societal interest. Thus, any changes to the oil sands transportation is likely intertwined with the critical contemporary issues of economic development, climate change, energy security, and safety considered in this thesis.

A related concept in the CLIOS Process that of *strategic alternatives*: deliberate physical or institutional changes designed to enhance the performance of the CLIOS system along one or more dimensions. Of concern in this thesis is how proposed strategic alternatives – pipelines and railroad capacity expansions – interact with the oil sands production system and impact the broader economic and environmental societal systems, and hence relate to the critical contemporary issues of economic development, climate change, energy security, and safety. In this research, the author is mainly interested in identifying and studying strategic alternatives already proposed by pipeline and railroad companies.

In order to identify and study strategic alternatives, the CLIOS Process is organized into three stages.

1. *Representation* of the CLIOS System structure and behavior
2. *Design, Evaluation, and Selection* of CLIOS System strategic alternatives
3. *Implementation and Adaptation* of the selected strategic alternatives

The first stage is descriptive and responds to the question: *what is the system*. In this stage, the researcher reviews the important characteristics of the system, and identifies its physical components and institutional actors of interest and the linkages between them. The second stage is evaluative and responds to the questions: *what are the criteria of good performance* and *how do the strategic alternatives perform*. In this stage, the researcher identifies relevant performance metrics and evaluates the strategic alternatives against them to determine how the strategic alternatives could affect the performance of the system. Sussman et al. (2014) recognize that multiple strategic alternatives may be necessary to achieve desired performance criteria, and therefore suggest that they be implemented as *bundles*. Finally, the third stage is practical, and responds to the question: *how to implement the selected bundle of strategic alternatives.* In this stage, the researcher is concerned with ensuring that the selected strategic alternatives perform as desired. These general questions posed by the CLIOS Process are used to organize the work in this thesis.

In response to the overarching question discussed in the introduction to this chapter – *should* railroads transport crude oil – three more specific questions are posed. In parallel with the CLIOS Process, the three questions in this thesis are descriptive, evaluative, and practical in nature, and progress from broadly considering the entire system definition in the first question to focusing more narrowly on the issue of railroad safety in the third question.

Question 1 describes the physical and institutional system for bitumen production and transportation:

> **(1) What is driving the demand for greater transportation capacity of crude oil in North America, what are the strategic alternatives for providing this transportation capacity, which institutional actors have influence over the implementation of these strategic alternatives, and what influence do these actors have?**

The response to this question describes why additional crude oil transportation capacity is being proposed and what strategic alternatives – e.g. pipelines and railroad service – are required to provide this capacity. The response then identifies the *institutional actors* – individuals, organizations, and governments with influence over the physical system – and explains their influence over the implementation of strategic alternatives.[13] This information provides the necessary context for **Question 2**, which questions the performance of the pipeline and railroad strategic alternatives:

> **(2) In the context of the strategies of the Canadian and US governments related to broader issues of public policy, how does the performance of rail transport compare to pipelines?**
>
> **a. Furthermore, how does uncertainty affect the strategies of the actors?**

This question is responded to in two levels: the first focusing on the oil sands' production system; the second focusing on the transportation system. First, the response identifies and describes the economic development, energy security, and climate change impacts of additional oil sands' production that crude oil transportation capacity would facilitate (related to the CCIs of interest). Second, the response discusses the relative performance of pipelines and railroads.

Because it would be unadvisable to suggest whether pipelines or railroads are preferred modes for transporting crude oil in a purely objective fashion – such a question *needs* to be resolved in the public sphere – the emphasis of this discussion is on (1) understanding the potential tradeoffs associated with increasing oil sands production (as opposed to relying on other sources of oil) and by using pipelines and railroads, and (2) understanding these tradeoffs in the context of strategies by the Canadian and American governments.

[13] Finally, as this thesis is written as part of a transportation program, a secondary purpose of this chapter is to define important terms related to oil production and transportation to a potentially unfamiliar audience.

One of the findings from **Question 2** is that there is ambiguity associated with comparing the historical performance data from pipelines and railroads. Motivated by this finding, as well as the accident at Lac-Mégantic**, Question 3** addresses the question of crude oil transportation safety:

> **(3) If railroads are to take a greater role in the transportation of crude oil, what considerations of safety at the railroad management and regulatory should be addressed?**

The response to this question will describe the railroad and regulatory safety control structure for crude oil transportation in North America and identify locations for potential improvement. This study will provide the necessary underpinnings for deeper study of the issue of railroad safety.

To address these three questions, additional methods are integrated into the CLIOS Process framework. Concepts from the *CLIOS Process* are used to organize the work to respond to **Question 1** and **Question 2**. Some results from a dynamic program are also integrated into the response for **Question 2**. *CAST*, a tool built on *STAMP*, a system safety model, is used to respond to **Question 3**. These approaches are now further discussed in **Section 1.2.1**.

1.2.1 Questions 1 and 2

The CLIOS Process is the primary tool used to respond to **Question 1** and **2**. As discussed, the CLIOS Process can be used as an organizing mechanism for understanding a CLIOS System's underlying structure and behavior, identifying and deploying strategic alternatives for improving the system's performance, and monitoring the performance of those strategic alternatives.

The crude oil transportation system and the associated oil production system is a CLIOS system. The system has the potential for broad societal economic, energy security, climate change, environmental, and other impacts. The system also exhibits high degrees of both technical and institutional complexity. Of particular interest in this thesis is *nested complexity* and *evaluative complexity*.

Nested Complexity occurs when a "'physical/technical' system [referred to as the *physical domain*] [is] embedded within an institutional system (which. . . [is referred] to as an *institutional sphere*)" (Sussman et al. 2014). The physical domain is composed of the physical subsystems of interest (e.g. the oil sands production system and its transportation system) and the institutional sphere is composed of actors. Predicting the behavior of either physical domain or institutional sphere separately is difficult. When these two systems are combined, they exhibit what Sussman et al. (2014) call nested complexity. For example, when considering only the physical domain, it is

uncertain whether railroads could expand sufficiently to transport all the crude oil production growth from the oil sands. Simultaneously, when considering only the institutional sphere, the political forces at play in both Canada and the US also make the specific criteria for the decision difficult to predict from a purely objective technical evaluation. Notably, President Obama may deny the Keystone XL pipeline permit as a way to ensure the continued support of his environmental base, even if objectively, a permit denial may not ultimately prevent crude oil from being shipped to the US. However, the fact that other pipeline and railroad capacity *might not* be able to expand may provide sufficient justification for this course of action. In other words, the ambiguity in predictions associated with the political system provides justification for different actions, which is difficult to understand by outside analyst.

The other, related, complexity exhibited by this system of interest is *evaluative complexity*: actors have varying definitions of "good" performance. For example, the Canadian and US government (may) have different priorities and values: Canada, with the oil sands on its territory, is likely going to be more concerned about the economic impacts of oil sands expansion facilitated by pipelines than the US, which would only receive indirect or induced benefits from oil sands production increases. The priorities between the two actors may further diverge due to the differences in government structures between the countries as well as different values prioritized by the individuals that comprise each government. While tools from political science and decision-theory can be used to study these issues, understanding the differences in values between the governments can be difficult. As a result, to the outside analyst, the nested and evaluative complexity present makes the behavior of the system difficult to predict.

Given the need to understand the system behavior faced with these complexities, the first stage of the CLIOS Process is to represent the overall system. In this stage, a diagrammatic and written description of the system is created to develop qualitative understanding of how it works, as shown conceptually in **Figure 1-2**. The physical domain consists of multiple subsystems.[14] In this thesis, the physical subsystems of particular interest are the crude oil transportation system and the oil sands production system. Similarly, the institutional sphere, composed of actors is represented. The interaction between the institutional actors and the physical domain is then considered. In this research, the study of these linkages is emphasized.

[14] The distinction between a "system" and a "subsystem" is somewhat arbitrary and depends on the definition of the system boundary. For example, the transportation "system" could be studied by itself, but because we are looking at other systems as well, such as the economy, we consider the transportation "system" to be a "subsystem" in the CLIOS representation.

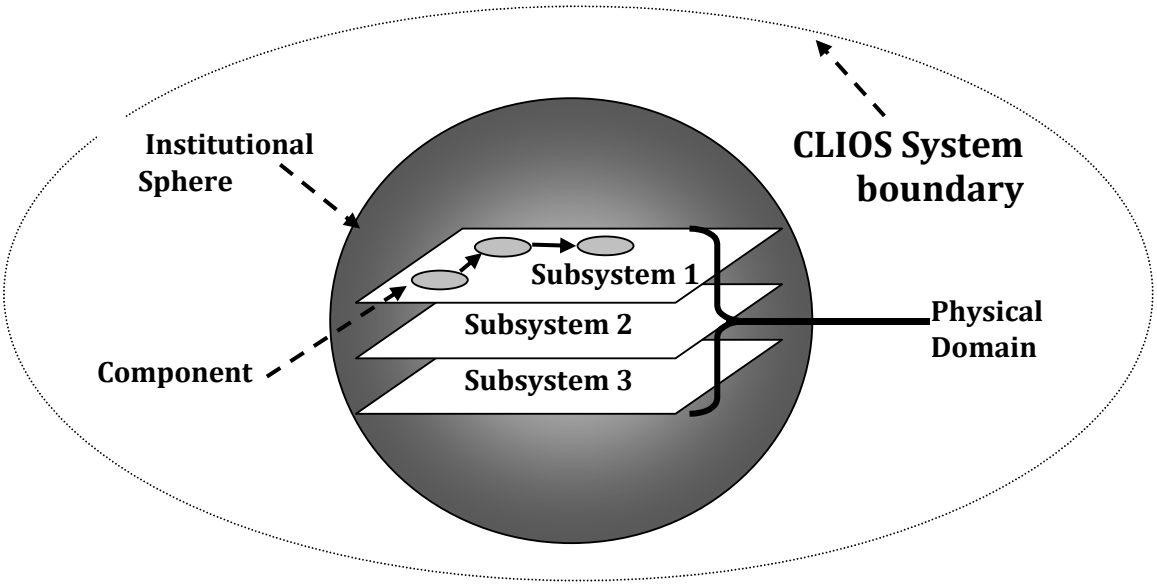

Figure 1-2: The conceptual representation of a CLIOS system with a physical domain embedded within an institutional sphere (Source: Sussman et al. 2014)

The representation is first presented in **Chapter 2**, and is used to respond to **Question 1**. First, this chapter describes important characteristics of oil sands production and transportation systems, and describes trends motivating the demand for increasing transfer of crude oil. Second, the chapter introduces the institutional actors who control and influence potential strategic alternatives. Third, it introduces the strategic alternatives being contemplated and more particularly describes how these actors can influence the strategic alternatives. By the end of the chapter, the reader should have a foundation for understanding the production and transportation of crude oil.

The work in the Representation stage underpins the work in the subsequent Design, Evaluation and Selection stage. In **Chapter 3**, the performance of the strategic alternatives, i.e. railroads and pipelines, are compared in the context of the strategies of the Canadian and American governments and the broader societal issues such as economic impacts, energy security, and climate change associated with oil sands production. These issues are first introduced and then the positions of the Canadian and American governments are discussed. The emphasis of this semi-qualitative discussion is on understanding the tradeoffs associated with oil sands development and between pipelines and railroads.

One of the challenges with doing this evaluation is that there is *uncertainty* affecting each of the actors. Notably, the ultimate decision by the Canadian and American governments whether to

approve pipeline permits in each of their respective territories is uncertain to the other actors. This uncertainty not only affects the other government, but also the railroad industry, as the uncertainty makes it difficult to plan long-term capacity investments if pipelines might be constructed. Additionally, there is the uncertainty over exactly how much capacity the railroad can provide and at what cost, which affects governments trying to decide whether to approve pipelines.

Therefore, in **Chapter 3** a dynamic programming model is used to determine the desirable capacity investments (at multiple time periods in the future)[15] for the railroad industry as a whole to transport bitumen from the Alberta oil sands. This information is useful to both the railroad industry and government decision-makers. The results from the model provide an indication of what the railroad industry's posture towards the transportation of crude oil should be: i.e. should railroads aggressively pursue the market or wait until more information is known about whether governments will approve pipelines in the US and Canada? The model results are also useful to government decision-makers, as it provides some indication of the railroad's investment strategy, particularly in the short term. The model will not be used to suggest specific actions, but rather should be interpreted with the other qualitative information discussed in this thesis.

The use of the dynamic program to consider rail capacity investments also represents the point at which the thesis turns to focus on the role of the railroad industry in transporting crude oil. **Question 3**, which is responded to in **Chapter 4**, focuses solely on railroad safety.

1.2.2 Question 3

The accident at Lac-Mégantic raises questions about how the railroad industry addresses major operational changes. Prior to the accident at Lac-Mégantic, the railroad industry appeared to view the transport of crude oil through their common carrier history: i.e. crude oil is " just . . . another" hazardous material that railroads need to transport.[16] Further, in the "gold rush" of demand for crude oil by rail (as, following the accident, CP CEO E. Hunter Harrison described the growth), railroads adapted existing transport approaches – i.e. unit trains – without major modifications to accommodate the unique characteristics of crude oil (Robertson and McNish 2013). Arguably, the system migrated to a higher level of risk – a common phenomenon described in MIT Professor Nancy Leveson's *Engineering a Safer World: Systems Thinking Applied to Safety* text on system safety – creating circumstances in which the accidents mentioned above were more likely to happen. Of

[15] The time periods are selected to approximately coincide with the expected time at which pipeline permitting decisions will be made by governments in Canada and the US.

[16] Glen Wilson, Vice-President, Safety, Environment and Regulatory Affairs, Canadian Pacific, presenting to the Standing (Canadian) Senate Committee on Energy, the Environment and Natural Resources, June 4, 2013.

course, this motivation does not suggest that railroad companies did not take precautions; however, given that this and other accidents occurred, the question is whether the precautions were sufficient.

Further motivating the consideration of safety is that in the literature reviewed for **Question 1** and **2**, there has been a reliance on the use of historical data and probabilistic risk assessments, even though the transportation of large volumes of crude oil is a new market for the railroad industry. Not only is transporting crude oil by unit trains an operational change for the railroads, but also, the behavior and characteristics of the oil being shipped is only now being fully understood. For example, in the case of the Lac-Mégantic accident, the volatility of the Bakken-formation sourced crude remains under investigation by hazardous material transport regulators in the US and Canada (Pipeline and Hazardous Materials Administration [PHMSA] 2014). In the case of oil sands diluted bitumen, there is concern over the environmental impact of a spill of diluted bitumen (Crosby et al. 2013). Because of the new situation, the applicability of existing data should be scrutinized, and new forward looking approaches to safety should be considered.

In order to address these concerns, STAMP (Systems-Theoretic Accident Model and Processes), an accident causation model that views system safety as a control problem (Leveson 2011a). STAMP assumes an hierarchical control structure, as shown in **Figure 1-3**, in which upper-level controllers impose constraints on lower-level subsystems (i.e. the downward arrows), and receive feedback in return (i.e. the upward arrows) and that the safe behavior of the overall system emerges as a result of these constraints. For example, in the case of the Lac-Mégantic accident, applying sufficient functioning air brakes in the train is perhaps a safety constraint that would have helped ensure that the system remained safe.

However, the tools based on STAMP do not assume that one "root cause" or specific "failure" caused an accident, but rather that there are multiple interacting causal factors – not necessarily failures – why an accident did or will occur. For example, the fact that the crude oil in question may not have been packaged (loaded into tank cars) correctly accounting for its volatility or the fact that the train was parked on the mainline (instead of a siding) also contributed to the accident. STAMP explicitly recognizes these multiple interacting levels may have or will contribute to an accident, and that it is not necessarily simply failures, in the traditional sense, that would contribute to an accident.

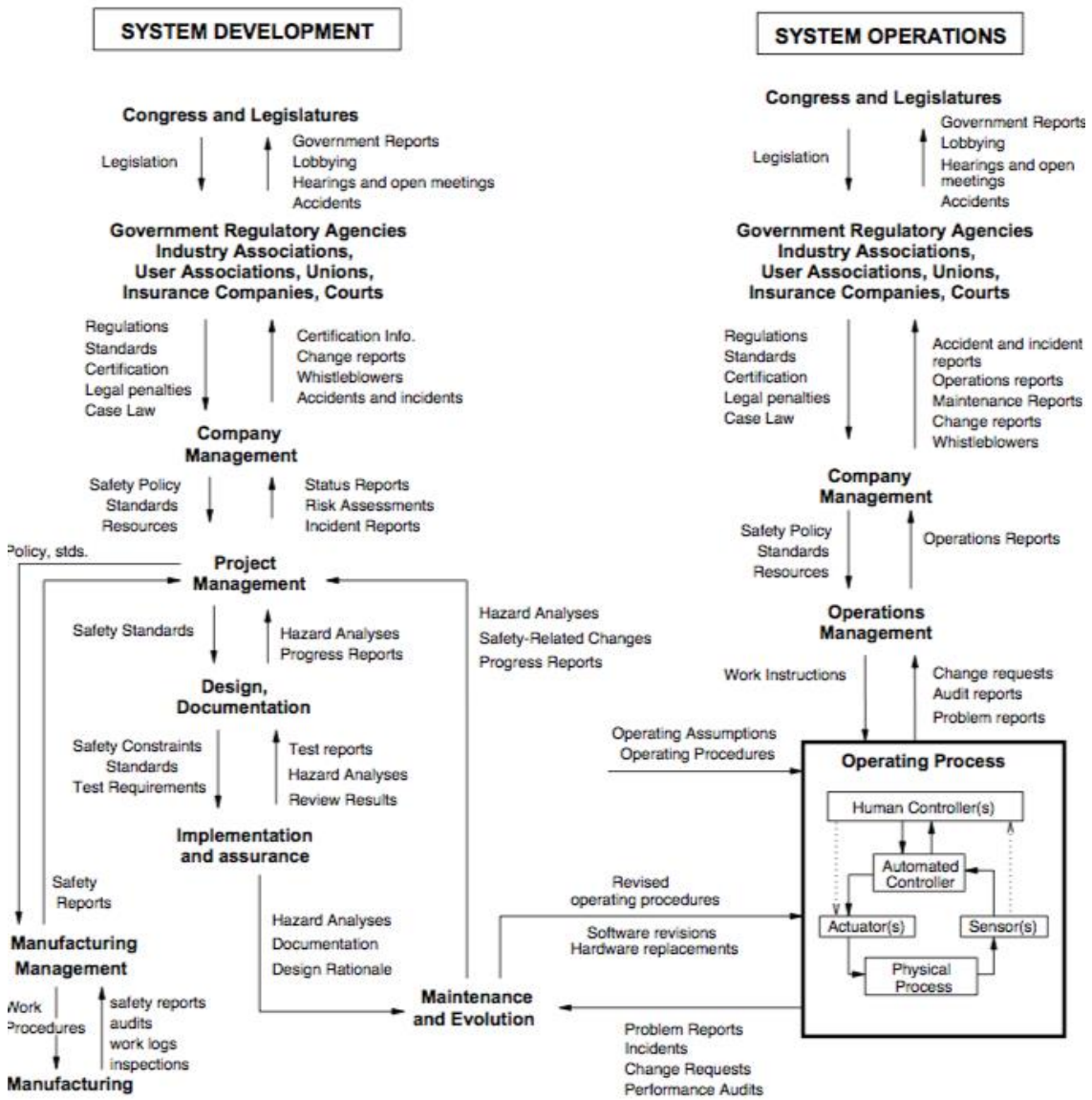

Figure 1-3: The hierarchical control structure assumed in STAMP (Source: Leveson 2011a)

More practically, STAMP, as operationalized in its two main tools, (1) CAST (Causal Analysis based on STAMP) for studying accidents that have occurred in the past, and (2) STPA (System-Theoretic Process Analysis) for identifying hazards when designing systems, allows the analyst to quickly identify many of the possible hazards that might contribute to an accident.

CAST analysis will be used to study the safety control structure that existed during the Lac-Mégantic accident. Specifically, CAST will be used to understand how a major strategic operational change resulting from new market opportunities occur without formal consideration of the potential consequences. This question addresses the third stage of the CLIOS Process – Implementation – in that it identifies areas of potential safety concerns and thus areas of future

research: i.e. if railroads are to take a greater role in transporting crude oil, what factors need to be considered to improve overall rail safety? CAST is explicitly not a tool to evaluate system safety probabilistically, but rather a tool focused on improving system safety qualitatively.

The results from the CAST analysis are presented in **Chapter 4**. As is found in this analysis and briefly motivated above, the type of oil produced has important implications for how oil is transported (notably safety considerations). Though most of the oil and gas terminology used in this thesis is provided in **Chapter 2**, **Section 1.3** introduces in more detail the two crude-by-rail markets growing in North America: shale oil and the oil sands.

1.3 Research Cases

As discussed in the opening of this chapter, there are in fact two markets of crude oil – shale oil and oil sands bitumen – in North America. Shale oil formations and the oil sands produce two distinct forms of oil that serve different markets, as summarized below in **Table 1-1**. The oil sands, which are located in Alberta as shown in **Figure 1-4**, contain deposits of bitumen, "a thick, sticky form of crude oil that is so heavy and viscous that it will not flow unless it is heated or diluted with lighter hydrocarbons" (Government of Alberta 2009), mixed with sand and clay. Tight or shale oil (often used interchangeably though not exactly the same [Maugeri 2013]) formations are located throughout the US and Canada as also shown in **Figure 1-4**, and the largest is the Bakken formation in North Dakota.[17] Tight or shale oil formations contain a lighter (in terms of density) form of crude oil. As a result of these very distinct physical properties, different refineries demand the crude oils from these two sources.

[17] This figure also shows formations in which shale (natural) gas is the primary resource being produced.

Figure 1-4: Map showing shale oil (and gas) formations in the US and Canada, along with the approximate location of the oil sands (Adapted from: EIA 2011)

Though the transportation of both sources of oil will be discussed, this research will focus on informing the debate over transportation capacity for bitumen from the Alberta oil sands. First, though hydraulic fracturing is not without controversy, the energy-intensiveness, and thus, environmental impacts of extracting and refining oil sands has, arguably, generated more societal debate over the merits of even extracting this resource. Second, given expected production growth from the oil sands, the development of transport capacity using pipelines and railroads is still very much subject to debate, leaving open greater opportunities to inform actors. Specifically, rail transport of crude oil from the oil sands developed later than rail transport from the Bakken-formation region; the first unit train facility in Alberta only opened in the fall of 2013 (Williams 2013).[18] Third, as is described in **Chapter 2**, due to the size of the oil sands bitumen reserves, there is less uncertainty over future production levels beyond 2020 than with shale oil. Finally, considering this resource provides greater opportunity to consider the interplay between the strategies of Canada and the US, resulting in greater potential for new insights. The energy systems of the two countries are highly interrelated, and in particular, a substantial amount of oil flows from Canada to the US. As the Canadian Association of Petroleum Producers [CAPP] (2013) further point

[18] As noted at the start of this chapter, rail traffic from North Dakota started growing in 2008.

out, "Canada is the top foreign supplier of crude oil to the US while the US is almost Canada's only market," making the strategies and relationship between the two countries important considerations. The emphasis of the research is thus on providing recommendations for the transport of bitumen from Alberta.

Table 1-1: Comparison of tight/shale oil and the oil sands (Source: compiled by author)

Characteristic	Tight/Shale oil	Oil sands
Deposit	Crude oil found in low-permeability rock formations.	Bitumen mixed with sand and clay.
Nomenclature	The terms, tight and shale oil, though not synonymous, are often used interchangeably. However, shale oil should not be confused with *oil shale*, which is a product with a different chemical composition (Maugeri 2013).	The oil sands are often referred to as the tar sands due to their similar consistency.
Extraction technique	Horizontal drilling and hydraulic fracturing are typically used to extract this oil from shale/tight oil deposits.	Mining and specialized steam injection techniques are used to extract this oil.
Oil density*	Usually a medium or light crude in terms of density (CSUR 2012).	Extra heavy crude in terms of density.
Deposit locations	Tight/shale oil deposits are located across the US and Canada. The largest producing area is the Bakken formation in North Dakota (Maugeri 2013).	Oil sand deposits (known as the oil sands) are located in northern Alberta.
Refining Markets	Located throughout the US and Canada. Many of the refineries on the east coast of Canada and US use light oil, and currently import it from abroad (CAPP 2013).	Heavy oil refineries in the US Midwest are currently used refine oil sands bitumen. The majority of heavy oil refining capacity in the US exists along the US Gulf of Mexico Coast. Additional complex refining processes are required to refine heavy oil and bitumen (US Department of State 2014).
*The API (American Petroleum Institute) gravity is used to classify crude oil as *light* or *heavy* based on its density. The API gravity is given as: API Gravity = 141.5/(Specific Gravity) - 131.5. Heavier oils, which contain a higher concentration of hydrocarbons with high molecular weights (Centre for Energy 2014), have a lower API gravity (and higher density). While the specific classifications can differ, a typical dividing line between a light and heavy crude oil is around 25 degrees (in API gravity). Bitumen, which is an extra-heavy oil found in the oil sands, has an API gravity of less than 10 degrees.		

However, information from the tight/shale crude oil market will inform this research. In **Chapter 2**, the growing supply of shale oil is considered as an important factor driving the demand for additional crude oil transportation capacity in the US. In **Chapter 4**, the events from the Lac-Mégantic accident, in which shale oil was being transported, will be used to inform the safety portion of this analysis. Thus, while the main emphasis of the conclusions and recommendations is

on the bitumen market, there will still be some general conclusions from this research that can inform the transportation of crude oil more generally.

1.4 CLOSING

All institutional actors – including the public, companies, and governments – are struggling with how to manage transportation capacity expansion strategic alternatives proposed in response to increases in oil production. The strategic alternatives will result in impacts on systems deeply intertwined critical contemporary issues such as economic development, energy security, climate change, and safety. Proponents are arguing that the economic, energy security, and safety benefits of expanding pipelines outweighs the detrimental effects (if any) on climate change. Opponents and those critical of pipeline expansions strongly disagree. Given the significant broader impacts of crude oil transportation infrastructure, and in the context of the significant scrutiny crude oil transportation by rail and pipeline, holistic approaches, such as the CLIOS Process and STAMP have the potential to reveal new insights about potential courses of action. In the very least, these approaches provide a useful way to organize the overall research about a new, complex, topic.

This chapter motivates and explains how the CLIOS Process and CAST are used to respond to the question: *should* railroads transport crude oil? In **Section 1.1**, the rationale for this overarching question is elaborated on. In **Section 1.2**, the conceptual framework for this thesis – the CLIOS Process – is introduced, which led to the development of three additional specific research questions. CAST, a novel accident investigation tool, is used exclusively to respond to the third question addressing railroad safety. In **Section 1.3**, further background on the two growing crude oil markets in North America: light tight oil and oil sands bitumen – is provided, which is used to define the research cases considered in this thesis. In closing, **Section 1.4** summarizes how the thesis and its conclusions are organized.

This thesis integrates the findings from the body chapters described in **Section 1.2** according to **Figure 1-5**. The findings in **Chapter 2** provide background with which to read the remainder of this thesis, but do not relate directly to any specific conclusions. For readers with background knowledge of the oil sands and its transportation system, this chapter could be skimmed. The thesis then diverges into two streams leading to two somewhat separate sets of conclusions. The findings from **Chapter 3** are used to suggest conclusions pertaining to the tradeoffs between pipelines and railroads. The findings from **Chapter 4**, though motivated by some of the findings in **Chapter 3**, are used to suggest conclusions pertaining to improving crude oil by rail safety. In the final chapter, **Chapter 5**, following the motivations of this thesis, the findings are assembled into two separate

sets of conclusions. The first set (which draw primarily from the findings in **Chapter 3**), addresses the ongoing evaluation of the Keystone XL, and the second set (which draw primarily from **Chapter 4**), addresses possible suggestions for improving the social responsibility of the railroad industry.

There is also an implicit time dimension in this thesis. While, following the previous paragraph, the thesis can be read as an integrated whole, readers progressing through the thesis may also see an evolution in the author's thinking. Because the topics addressed in this thesis remain on the political agendas in Canada and the US, there are new developments on a daily basis that shape the author's thinking. The author discusses some of these developments in the introduction to the conclusion chapter. First, however, the author invites the reader to begin with **Chapter 2**, which contains a representation of the oil sands production and transportation systems.

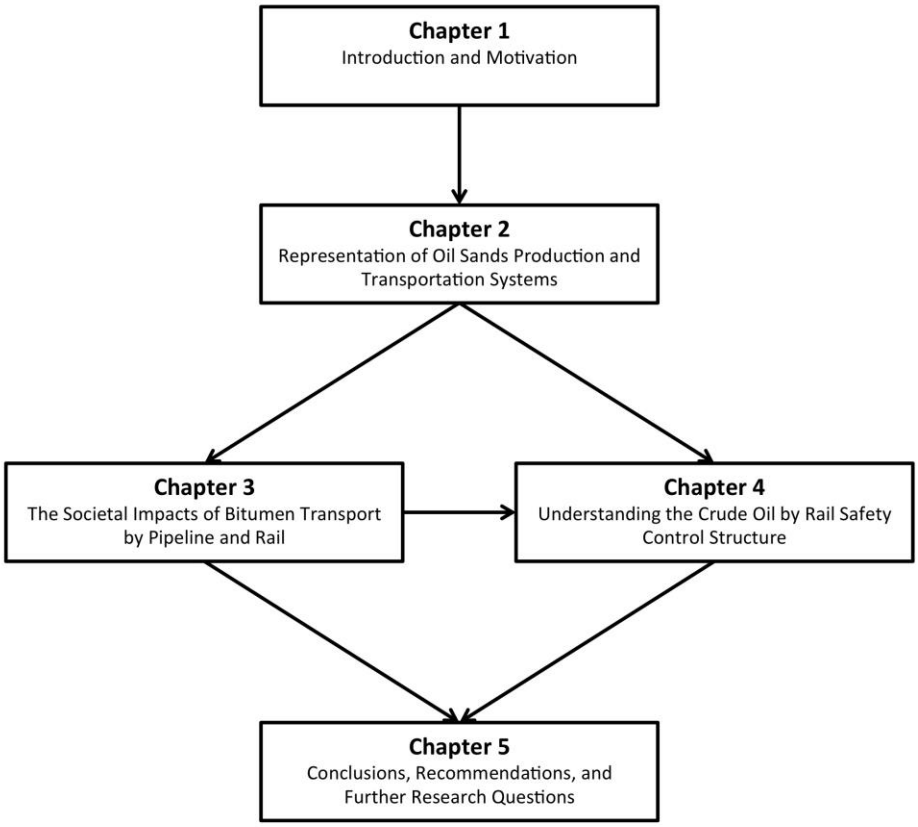

Figure 1-5: Thesis organization

2 REPRESENTATION OF OIL SANDS PRODUCTION AND TRANSPORTATION SYSTEMS

By responding to **Question 1** posed in **Chapter 1**, this chapter defines the CLIOS[19] system studied in **Chapter 3**, which includes the oil sands production system and its associated transportation system. First, the author describes important characteristics of the oil sands production and transportation systems, and describes trends motivating the demand for increasing transportation of *bitumen*, the petroleum product found in the oil sands. Second, the author identifies the institutional actors with influence over these two systems. Third, the author introduces the *strategic alternatives* being contemplated to add transportation capacity from the oil sands, and describes how the institutional actors can influence these strategic alternatives. By the end of the chapter, readers should understand key terminology and trends related to the production and transportation of bitumen from the oil sands.

The CLIOS Process Representation Stage and the concept of strategic alternatives are used to organize the research in this chapter.[20] The CLIOS Process representation is a structured approach to understand the behavior of a system, and includes both a graphical and written description of the system. The CLIOS Process views the system as including a physical domain encapsulated by an institutional sphere composed of actors, which is reflected in the discussion below. Strategic alternatives are deliberate physical or institutional changes to the system designed to enhance the performance of the CLIOS system along one or more dimensions. Readers should refer to **Chapter 1** for an in-depth discussion of these concepts.

Figure 2-1 contains the high-level[21] graphical representation created to describe the interaction between different subsystems, between the institutional actors and the subsystems, and between the institutional actors. Within the physical domain, the oil sands production system provides the input that spurs the need for transportation capacity, and the transportation system provides the necessary capacity with which to move that input. Both of these systems directly benefit and are controlled and/or influenced by oil producers (i.e. the shippers of oil), and pipeline and railroad

[19] CLIOS stands for complex, large-scale, interconnected, open, sociotechnical (Sussman et al. 2014).

[20] Please refer to Sussman et al. (2014) for more information.

[21] The representation is high-level because, though the institutional sphere is represented at the actor level, the representation of the physical domain remains at the subsystem level.

companies. These companies are regulated by governments in the US and Canada.. These interactions are further described in **Section 2.1**.

In **Section 2.2**, the strategic alternatives for providing additional oil transportation capacity in the US and Canada are introduced and described. In this case, the primary goal of the strategic alternatives is to provide transport capacity for bitumen from the oil sands using pipelines and/or railroad. There are also impacts of oil production and transportation of societal concern related to the critical contemporary issues of economic development, climate change, energy security, and safety that must be considered, which will be discussed in **Chapter 3**.

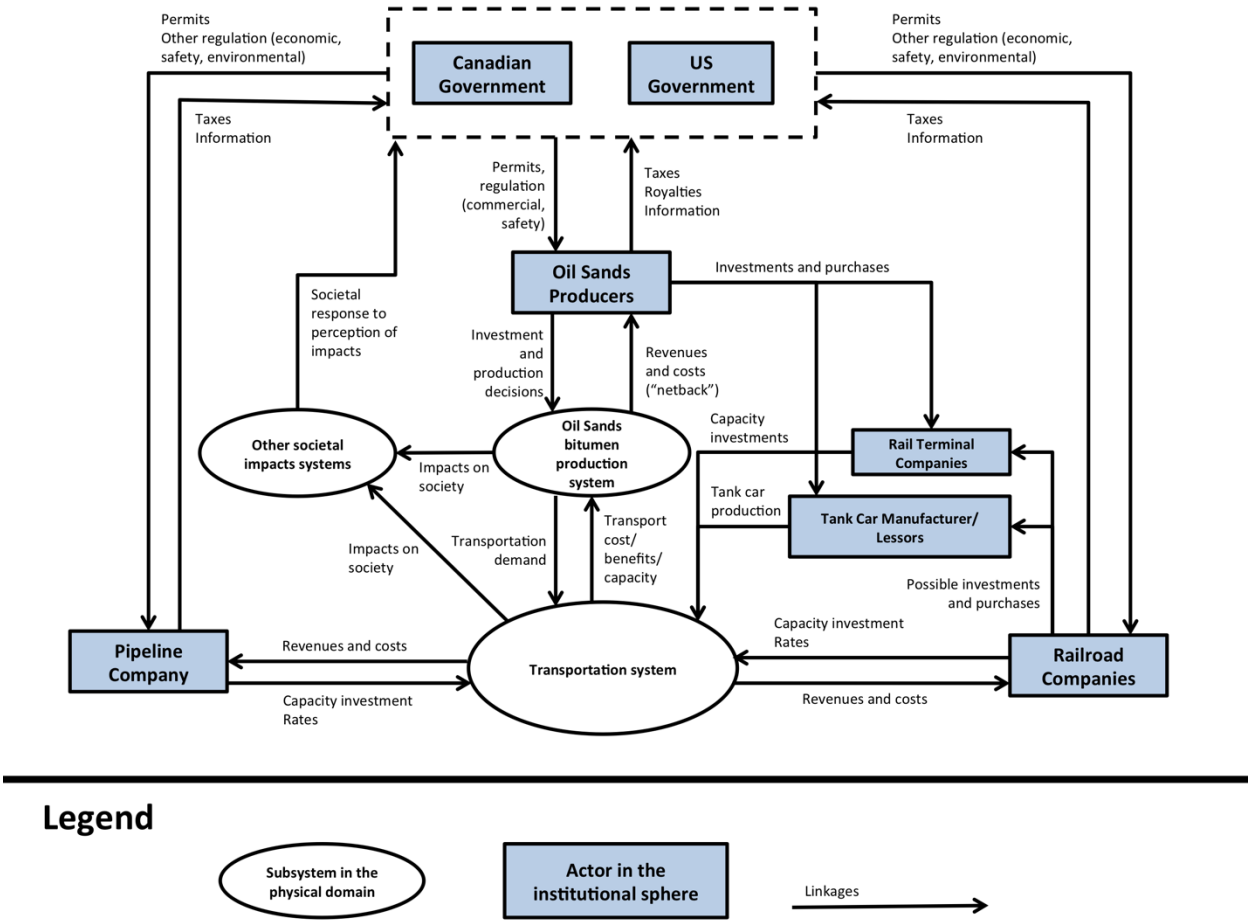

Figure 2-1: CLIOS Representation used to organize the discussion in this chapter

2.1 System Definition

2.1.1 The Canadian (Alberta) Oil Sands

As shown in **Figure 2-2,** the oil sands are located in northern Alberta, Canada, and are the source of over 98% of Canada's proven oil reserves of 173.6 billion barrels,[22] the third-largest proven reserves of in the world behind (US Energy Information Administration [EIA] 2012a).[23, 24] The oil sands are actually composed of multiple deposits, the largest being the Athabasca, but are often referred to as the *Canadian* or *Alberta* oil sands.

Figure 2-2: Map of oil sand deposits in Alberta relative to the rest of Canada (Source: Wikipedia.org)

[22] 1 Barrel = 42 US Gallons = 159 Liters

[23] According to the EIA (2014): "proved reserves are estimated volumes of hydrocarbon resources that analysis of geologic and engineering data demonstrates with reasonable certainty (greater than 90 percent probability) are recoverable under existing economic and operating conditions."

[24] Canada, with reserves of 173 billion barrels, falls behind Saudi Arabia (267.0 billion barrels) and Venezuela (211.2 billion barrels), and ahead of Iran (151.2 billion barrels), Iraq (143.1 billion barrels), and Kuwait (104.0 billion barrels) (EIA 2012e).

The particular form of crude oil found in these deposits is known as bitumen, which is "a thick, sticky form of crude oil that is so heavy and viscous that it will not flow unless it is heated or diluted with lighter hydrocarbons" (Government of Alberta 2009). Mixed with sand, it forms the sticky substance shown in **Figure 2-3**, and is often referred to as the *tar sands* because of its consistency.

The high density and viscosity of the bitumen has implications for how the bitumen is produced, transported, and refined. *Producing* and *production* refers to: (1) The act of removing (i.e. "extracting") the bitumen from the ground when used as a verb, or (2) the quantity of petroleum removed from the ground during a certain period when used as a noun (e.g. oil sands' production was 1.8 million barrels per day last year). Production falls under the *upstream* sector of the oil and gas industry. *Transportation* refers to moving the crude oil derived from the bitumen from the production area to a refinery. Transportation falls under the *midstream* sector of the oil and gas industry. Finally, *refining* refers to processing crude oil into higher-value products, such as gasoline or diesel, for example. Refining is part of the *downstream* sector of the oil and gas industry.

Figure 2-3: A photo of the oil sands (Source: Canadian Association of Petroleum Producers [CAPP])

Oil sands bitumen is considered an *unconventional* source of oil because it cannot be extracted from the ground by using traditional techniques (Gordon 2012). Two techniques are used to produce bitumen. The first is surface mining, which involves pulling back the overburden, excavating the sand and bitumen mixture, bringing it to a processing plant, and separating the bitumen from the sand using water. This technique can only be used to remove bitumen close to the surface because it becomes uneconomical to mine to deeper depths, so only about 20% of current reserves are recoverable using this technique (Dunbar 2012). The other broad category of techniques that is used is called "in-situ," in which steam is injected down a well to heat the bitumen and allow it to

flow. Once the bitumen is flowing, another nearby well is used to pump out the heated bitumen. Approximately 80% of the bitumen reserves are recoverable using these techniques according to current estimates because they can be used to produce oil from deeper deposits (Dunbar 2012).

One of the implications of having to use these energy-intensive techniques is that bitumen production is relatively expensive and at the upper end of the global crude oil supply curve, as shown in **Figure 2-4**. The different color boxes represent the volume (by width) and production cost range (by height and position on the y-axis) of various sources of crude oil, including bitumen. This figure is consistent with the results of the analysis by the US Department of State for the Keystone XL pipeline Final Supplemental Environmental Impact Statement (FSEIS), which finds that much of oil production in the oil sands has a supply cost of $65 to $75 per barrel.[25] Given that other sources of oil might have similar production costs (e.g. light tight oil as found in the US) in which producers could plausibly invest, this figure suggests that oil sands producers may be sensitive to cost.

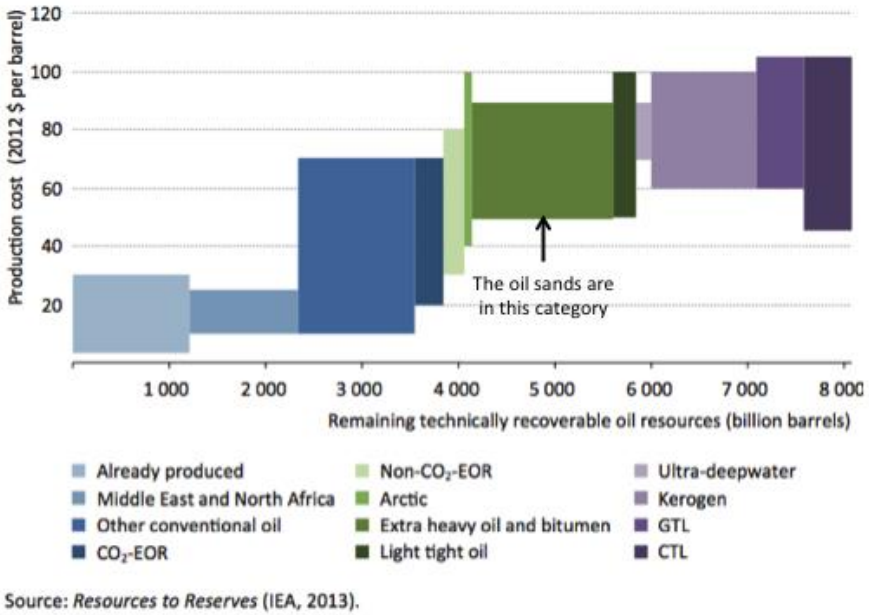

Figure 2-4: Production costs of various sources of crude oil (Source: International Energy Agency [IEA] 2013)

After the raw bitumen (*rawbit*) is taken out of the ground, it typically requires additional processing or special handling in order to be shipped. The resulting products, listed in **Table 2-1**,

[25] In early 2014, the price of West Texas Intermediate, a commonly used oil price benchmark in the US for crude oil delivered to Cushing, Oklahoma, is around $100.

are often generically called "crude oil." This distinction suggests a difference between oil sands *production* and *supply*. Production, previously defined, refers to the volume of bitumen (or other crude oil) removed from the ground. Supply refers to the volume of crude oil available for delivery to refining and other customers after the raw bitumen is initially processed ("upgraded") into a lighter product or blended with a diluent to allow for pipeline transport (Canadian Association of Petroleum Producers [CAPP] 2013). Currently, the ratio of oil sands bitumen production to oil sands supply is approximately 1:1.12 (according to figures in CAPP 2013); the specific ratio depends on the fractions of bitumen upgraded and shipped before shipping. To the first order, because production and supply move in lock-step, they will be considered as synonymous unless otherwise noted.

In order to be transported by pipeline, bitumen either needs to be upgraded into a lighter form of crude oil that can flow at ambient temperatures called *synthetic crude oil (SCO)*, or diluted with a lighter (less-dense) hydrocarbon, such as condensate. The product resulting from the latter is referred to as *dilbit (diluted bitumen)*. Rail tank cars can be used to ship these two products. Tank cars can also be used to ship rawbit and *railbit* (a less diluted form of bitumen as compared to dilbit) but special equipment, such as insulated tank cars and heating facilities at terminals are required (Fielden 2013a, Cairns 2013a). Additionally, because feeder pipeline are used to ship dilbit from the oil production areas to the rail car loading facilities, a diluent recovery unit (DRU) at the loading facility is also required if rawbit or railbit is to be shipped. The type of oil to be shipped has noteworthy implications on transport costs as well as safety, issues that are discussed in **Chapter 3**.

All of these additional requirements generally makes bitumen more costly to ship than light crude oil. Building an upgrader requires capital costs on the order of billions of dollars, and can only be justified by oil companies if there is a large spread between the price of bitumen (the input) and the lighter oil (the output) (Forrest 2012, Choquette-Levy 2013). Adding condensate to the bitumen adds cost because it is less desirable to refiners and expensive to transport to Alberta (Canexus 2013). It also reduces the capacity of the pipeline or tank car to ship bitumen (the desired product), which also increases per barrel transportation costs (Fielden 2013b). Finally, while no condensate and less processing is generally required to ship rawbit, the insulated tank cars reduce the effective capacity that can be shipped and the additional heating required at the loading and unloading

facilities add to the costs. Therefore, regardless of the mode, shipping bitumen is generally more complicated and costly than shipping lighter crudes.[26]

Table 2-1: Oil sands products (Source: compiled by author)

Product	Description	Transport modes	Bitumen : Crude Oil Volume Ratio
SCO (synthetic crude oil)	SCO is bitumen that has been processed ("upgraded") into a lighter crude oil.	Pipeline tank car (regular)	1.0 : 0.83
Dilbit (diluted bitumen)	Dilbit is bitumen that has been mixed with a diluent for transport, such as condensate (heavier hydrocarbons from natural gas that liquify once the gas is recovered).	Pipeline tank car (regular)	1.0 : 1.43
Railbit	Railbit is similar to dilbit, but having only approximately 15 percent diluent in the mix.	Pipeline tank car (insulated)	1.0 : 1.18
Rawbit (raw bitumen)	Raw bitumen is bitumen that is not diluted for transport and does not flow at ambient temperatures. It can only be shipped by insulated (coiled) tank cars that be heated at the unloading facility to allow the bitumen to flow.	Pipeline tank car (insulated)	1.0 : 1.0
Sources:	CAPP 2013, Choquette-Levy et al. 2013		

Finally, specialized refinery processes are required in order to make use of in order to make best use of the heavier hydrocarbons contained in bitumen. Notably, a process known as coking is often used to convert heavy oil into lighter hydrocarbons (e.g. gasoline) (EIA 2013a), and results in a coal-like co-product known as petroleum coke, which can release more carbon if it is burned, or can be a nuisance if stockpiled due to the dust it can produce (CBC News 2014a). Specialized equipment is required for this process, and the majority of this capacity in the US is located along the US Gulf of Mexico Coast (USGC) (US Department of State 2013a).[27] This capacity along the USGC is one of the drivers the construction of pipelines from Canada to the USGC, such as the Keystone XL, designed to transport bitumen.

Once crude oil is refined, the ultimate characteristics of the product do not vary depending on the source of the oil. As shown in **Figure 2-5**, most oil in the US is ultimately used as transportation fuels, primarily for road vehicles. However, the specific mix of refined products does change depending on the input crude oil and the refinery process. Heavier oils, such as the bitumen from

[26] Shipping lighter crude oils also presents challenges. For example, the crude oil produced from the Bakken-formation in North Dakota is highly volatile, which ultimately appears to have contributed to the explosion in Lac-Mégantic.
[27] The US's total refinery capacity is about 17.7 MMbbl/d (EIA 2013c).

Alberta, results in more "heavier" products; for example, it produces more diesel (less volatile) than gasoline (more volatile). Bitumen also produces more petroleum coke as discussed above above.

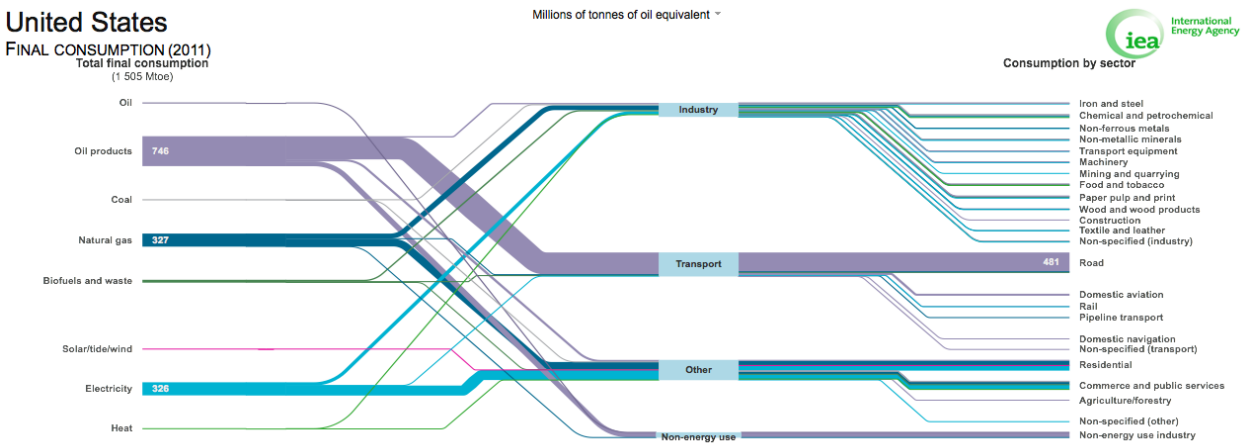

Figure 2-5: Sankey diagram of US energy consumption (Source: IEA[28])

Crude oil production trends will now be used to provide context for the discussion of North American crude oil transportation capacity.

Oil Sands' Production Trends in the Context of North American Crude Oil Production

Forecasts by Canadian government agencies and other industry and research groups predict major growth in oil sands bitumen production, which will make it an even larger fraction of total Canadian production. Canada's National Energy Board's (NEB's) reference forecast, shown in **Figure 2-6**, predicts that oil sand bitumen production is expected to rise from 1.8 MMbbl/d in 2012 to 5.0 MMbbl/d in 2035. The NEB also provides high and low forecasts, all of which predict significant growth by 2035. Forecasts by other groups, notably the CAPP (Canadian Association of Petroleum Producers [2013]) and CERI (Canadian Energy Research Institute, [Millington and Murillo 2013]), predict higher growth in production levels under each of their reference (base) forecasts. Because conventional oil production is expected to remain relatively constant over the same period, the oil sands are expected to make up over three-quarters of Canadian oil production by 2030, up from slightly over 50% now. These figures provide insight into why the current Canadian government is strongly supporting the development of new transportation infrastructure.

[28] Created using the IEA's Sankey Diagram tool available at: http://www.iea.org/Sankey/.

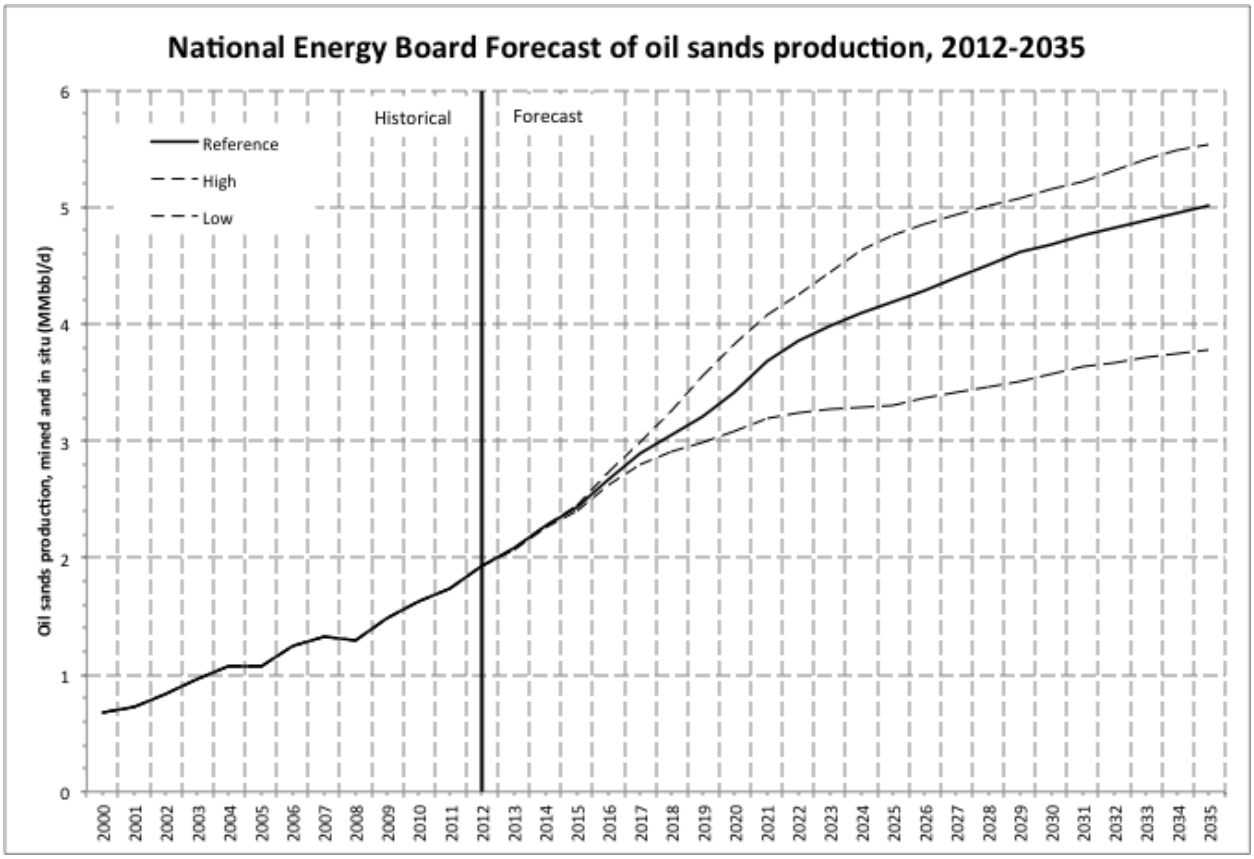

Figure 2-6: Oil sands production forecasts from the NEB (Source: NEB 2013)

However, as discussed by Millington and Murillo (2013) in their documentation of the CERI forecast, there are many assumptions that go into forecasts of future oil production, including that sufficient transportation infrastructure will be available to accommodate the growing supply from the oil sands. Additionally, the implementation of worldwide carbon constraints could also result in *reductions* in oil production. Chan et al. (2012), using MIT's Emissions Prediction and Policy Analysis (EPPA) model, a computable general equilibrium model of the world economy, found several plausible scenarios in which oil sands production would decline if worldwide climate policies were implemented. While the CERI forecast does consider some impacts of carbon pricing, none of the official forecasts appear to consider the longer term potential for such aggressive climate action. As a result, the high-low forecasts provided by the NEB are likely not representative of the true range of uncertainty, particularly in the long run.

Currently, most of Canada's oil production is transported to the US. Of Canada's total production of 3.2 MMbbl/d in 2012, Canada exported approximately 2.6 MMbbl/d to the US, which represents 97

percent of Canada's crude oil exports.[29] (Specifically, of these total exports, approximately 0.6 MMbbl/d was synthetic crude oil[30] and 0.7 MMbbl/d was blended bitumen.) For comparison, 2.6 MMbbl/d is approximately 14% of US oil consumption and about 33% of US oil imports in 2012 (based on EIA 2013c), a minority but important fraction. Although Canada itself is self-sufficient in terms of oil production, it imported approximately 0.7 MMbbl/d of crude oil into Eastern Canadian (Ontario, Quebec, New Brunswick, and Nova Scotia) from the US and abroad (CAPP 2013). As a result, oil production from the oil sands flows almost exclusively south into the US, and the desire to increase production is further creating the demand for transportation capacity to transport bitumen into the US.

In addition to rising Canadian production from the oil sands, there are two other important trends in the upstream sector that are driving the need for changes to the crude oil transportation system oil within Canada and the US:

1. US oil production is rising from the use of horizontal drilling and hydraulic fracturing ("fracking") to extract tight oil, notably in the Bakken formation found primarily in North Dakota, as well as in Western Texas;

2. Production from two major oil exporting countries to the US, Mexico and Venezuela, is decreasing partly due to insufficient investment in their oil sector;

Petroleum Administration for Defense Districts (PADD) are used to aggregate energy statistics in the US. PADDs will be referred to in the subsequent discussion and are shown in shown in **Figure 2-7**.

[29] Calculations based on data from: NEB – "Estimated Canadian Crude Oil Exports by Type and Destination (2013, Quarter 4)" available at http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/sttstc/crdlndptrlmprdct/stmtdcndncrdlxprttpdstn-eng.html.

[30] Synthetic crude oil includes both upgraded bitumen and conventional heavy oil.

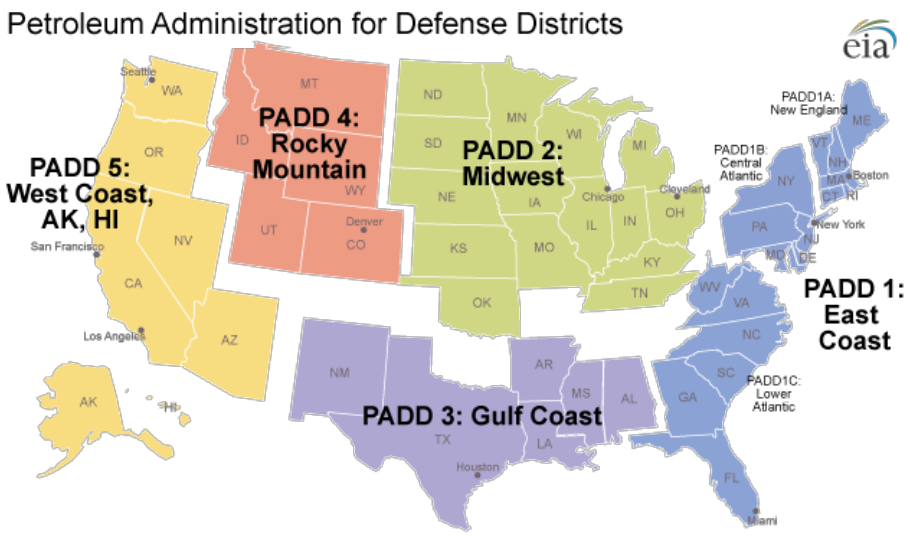

Figure 2-7: Map of Petroleum Administration for Defense Districts (PADD) (Source: EIA)

As shown in **Figure 2-8**, US oil production rapidly increased after several decades of decline. Notably, oil production in North Dakota, which is contained in PADD 2, has increased by 259 percent since 2008 (authors calculations based on EIA data). There has also been an 81 percent increased in oil production in Texas, which is contained in PADD 3, over the same period. Both states production increases have been driven by the production of shale oil wells. Texas and North Dakota are now the largest and second largest oil producing states in the US (excluding offshore production in the Gulf of Mexico). Collectively, rising production in Canada and the US Midwest means that more oil is trying to get to refineries, primarily on the USGC (CAPP 2013).

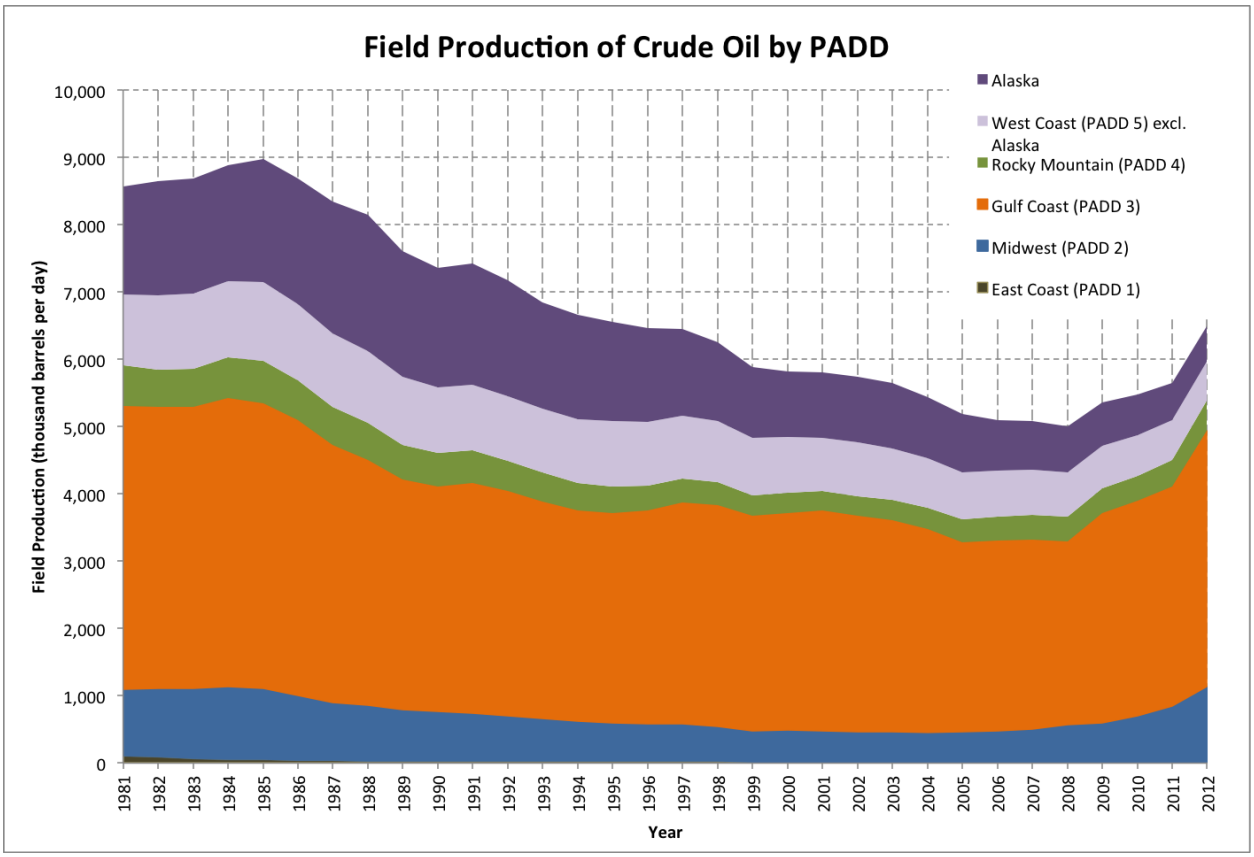

Figure 2-8: US oil production from 1981-2012 by PADD (Source: author, from EIA US oil production data)

Oil production from shale oil formations is even more uncertain given the relative inexperience exploiting this resource. The EIA (2012d) forecasts that that tight oil production will continue to increase over the next decade, before beginning to taper off after 2020, as shown in **Figure 2-9**. Some[31], however, have argued that it is plausible that shale oil production could continue to grow past 2020. This uncertainty makes it difficult to decide whether investments in capital-intensive pipelines should be pursued to serve shale oil production sites; as a result, rail transport, which has much of the necessary fixed infrastructure already in place, is being used extensively to serve these production areas.

[31] Amy Myers Jaffe, Executive Director of the Energy and Sustainability at University of California, Davis, made comments to this effect in a presentation at the Transportation Research Board's Annual Meeting on January 15, 2014.

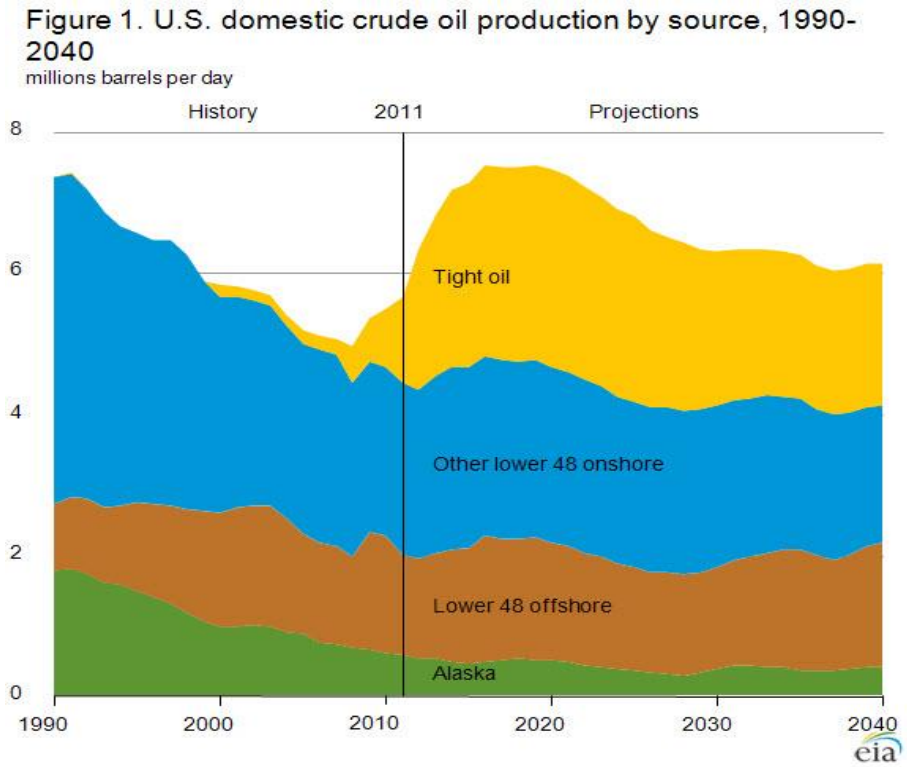

Figure 2-9: US crude oil production from 1990 to 2040 (Source: EIA 2012d)

Reducing US oil imports from Mexico and Venezuela due to the declining production in those countries is also motivating a reconfiguration of North American crude oil transportation infrastructure.[32] The industry structure can make it more challenging to attract the necessary investment and expertise required to maintain oil production. In contrast to the US and Canada, which do not have a nationally-owned petroleum producer, state-owned Petróleos Mexicanos (PEMEX) and Petroleos de Venezuela S.A. (PdVSA) control oil production in Mexico and Venezuela, respectively. Mexico is currently taking steps to liberalize organization of their oil sector to encourage more foreign investment, as well as to bring in foreign expertise to drill deeper wells in the Gulf of Mexico and produce from shale oil resources (The Economist 2013). Some of these reforms have been put in place in December 2013, which may ultimately stem the decline in the production of oil from Mexico (The Economist 2014). As of writing this thesis, Venezuela is currently embroiled in major political turmoil. Therefore, while there appears to be potential for Mexican oil production shipped to the US to recover, the situation in Venezuela is much less clear.

[32] Both countries produce similar quantities of crude oil (i.e. 2.55 MMbbl/d compared to 2.24 MMbbl/d, respectively) but Venezuela has proven oil reserves an order of magnitude greater than those of Mexico, i.e. 211 billion barrel versus 10.2 billion barrels, respectively (EIA 2012b, 2012c).

Currently, the net result of increasing US and Canadian oil production and decreasing foreign production is twofold: US imports of crude oil have decreased, and the Canada's share of US crude oil imports have increased. First, from 2005 to 2012, U.S. imports of crude oil decreased from its peak of 10.1 MMbbl/d to 8.5 MMbbd/d – a decrease of 15.8% – and as of January 2014 has been as low as 7 MMbbl/d. Imports of refined products (such as gasoline and diesel) also decreased during this period such that now the US exports more refined products than it imports (3.2 MMbbl/d versus 2.1 MMbbl/d).[33] Second, during the same period from 2005 to 2012, crude oil imports from Canada increased by 47.5 percent, resulting in a 12.3 percentage point increase in Canada's share of US crude oil imports, as shown in **Table 2-2**. By contrast, the US's other three largest sources of crude oil, Saudi Arabia, Mexico, and Venezuela, had their exports decrease to the US.

Table 2-2: Originating country of US crude oil imports summarized by percentage of total imports (Source: author, from EIA data)

	Canada	Saudi Arabia	Mexico	Venezuela
2005	16.1	14.2	15.4	12.3
2012	28.4	16.0	11.4	10.7
Point change	+12.3	+1.8	-4.0	-1.6

Collectively, these trends mean that more crude oil is trying to flow from the (landlocked) interior of the US and Canada outward to refineries, notably to PADD 3 refineries on the USGC, instead of flowing from import terminals on the USGC into the center of the continent. However, the current oil transportation infrastructure in the US and Canada is not well equipped to support these flows.

As a result of this increasing oil production in the US, there have been calls to remove an export ban, in place in the US since the 1970s,[34] which prevents US companies from exporting crude oil. Currently, companies must receive an export license from the US Department of Commerce, which must find that such exports are in the "national interest". Thus far, only a small fraction of crude oil produced in the US has been allowed to be exported to Canada (Businessweek 2013); otherwise, export licenses have been denied. While further consideration of this issue is beyond the scope of this thesis, changes to the export restriction resulting from the increase in domestic production

[33] All calculations based on data from the EIA – "Petroleum and Other Liquids: US imports by Country of Origin" available at http://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbl_m.htm.

[34] The restrictions were passed into law in the Energy Policy and Conservation Act shortly following the Arab oil embargo in 1974-1975 (Oil & Gas Journal [OGJ] 2013)

could have further implications for the energy transportation system, which is now introduction in **Section 2.1.2**.

2.1.2 The Oil Sands Transportation System

After the early days of oil production until 2008, pipelines were the almost exclusively used to transport crude oil overland. The pipeline network, including proposed new pipelines, is shown in **Figure 2-10**. PADD 2, 4, and Western Canada (i.e. the provinces west of Ontario), source most of their oil from domestic US or Western Canadian sources (CAPP 2013). These areas are largely landlocked, as there is currently only one pipeline from Alberta to refineries West Coast, and no pipelines flowing from west to east. Most existing crude oil pipelines transport crude oil from Western Canada into PADD 2 and 4, picking up oil along the way, converging in Oklahoma and Illinois. Cushing, Oklahoma is a particularly important trans-shipment point, as it is the price settlement point for a type of crude oil known as West Texas Intermediate (WTI), a commonly used benchmark for the price of light oil in the US.[35] As can be seen in **Figure 2-10**, once oil reaches these points, there are few pipelines outwards, which has created a bottleneck for crude oil transport in light of the recent growth in crude oil production from the Bakken-formation region as well as the oil sands. As a result, there are ongoing efforts to construct new pipelines or reverse the flow of existing ones to ship oil from Cushing to the USGC, as also shown in **Figure 2-10**, such as the Seaway Reversal and Twin Line, and the TransCanada Gulf Coast.

[35] E.g. see http://www.investopedia.com/terms/w/wti.asp

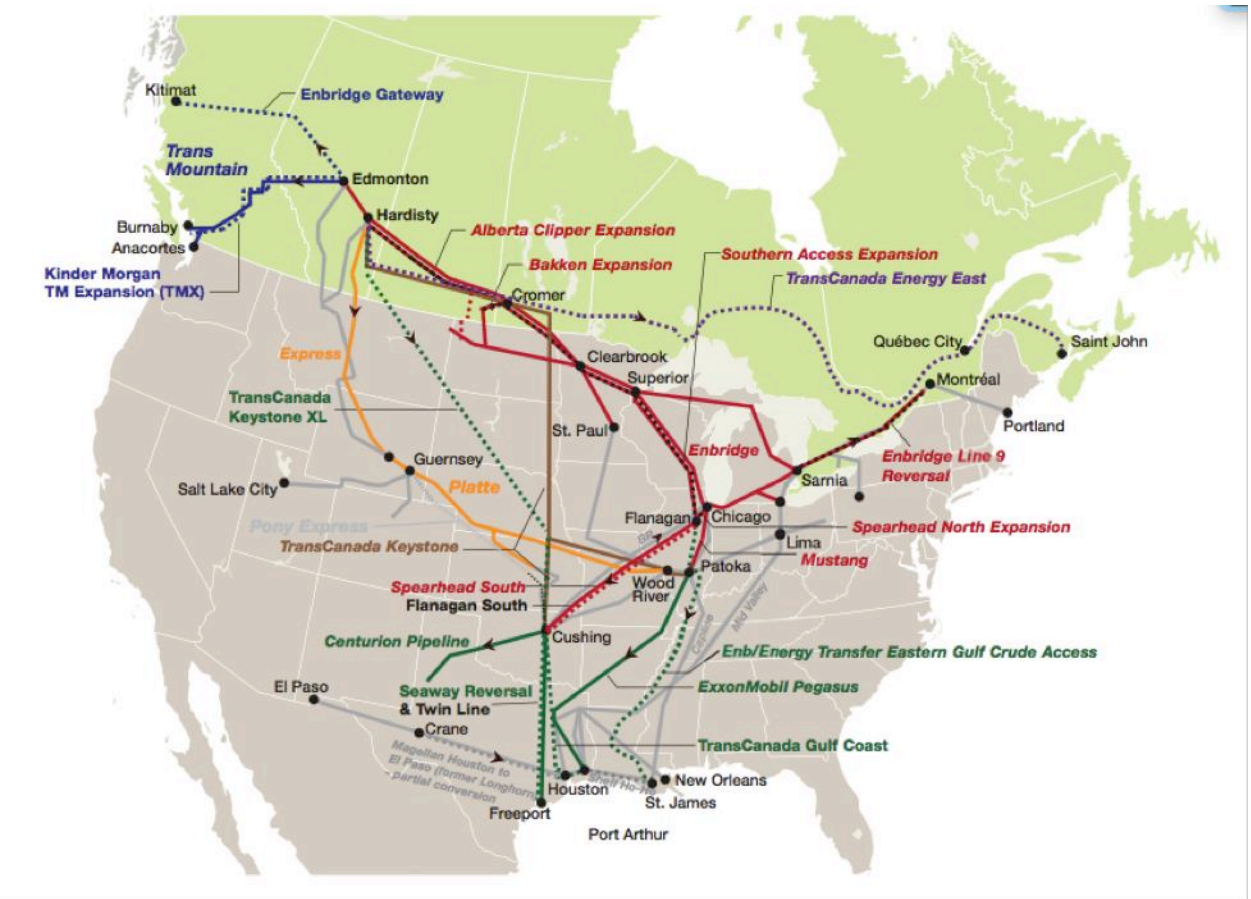

Figure 2-10: Existing and proposed pipelines in Canada and the US (Source: CAPP 2013)

In general, prior to the increasing use of rail cars to transport oil, most oil refined on the periphery of the continent in states and provinces that touch the ocean (i.e. PADD 1, 3, 5, Atlantic Canada, and Quebec [QC]) were from imports of crude oil, which is evident from the pipeline configuration in **Figure 2-10**.[36] However, unlike PADD 3 refineries, which are configured to process heavy oil from nearby heavy oil sources in Venezuela and Mexico (US Department of State 2014), East Coast refineries (i.e. those refineries in PADD 1, Atlantic Canada, and Quebec) typically source light crude oil due to their refinery configuration (e.g. Demerse and Partington 2014). Therefore, these refineries are generally more interested in receiving light oil from the Bakken-formation region as this production grows as compared to oil sands bitumen.

As shown in **Figure 2-11**, North American railroads already have the ability to serve coastal regions through their extensive network. However, one of the key pre-requisites for shipping by train is having suitable bitumen loading and unloading facilities, which are still under development. The

[36] The exception to this statement occurs on the West coast (PADD 5), where, based on EIA data, domestic production, including from Alaska, provides the majority of the crude oil refined; however, imported crude oil still makes up a large fraction of refinery demand.

first unit train (defined below) loading facility in Alberta only opened in October 2013 (Williams 2013). However, these facilities can be built in fairly rapidly, i.e. in 12 to 18 months (Carey 2013), making it less of a constraint than building a new pipeline.

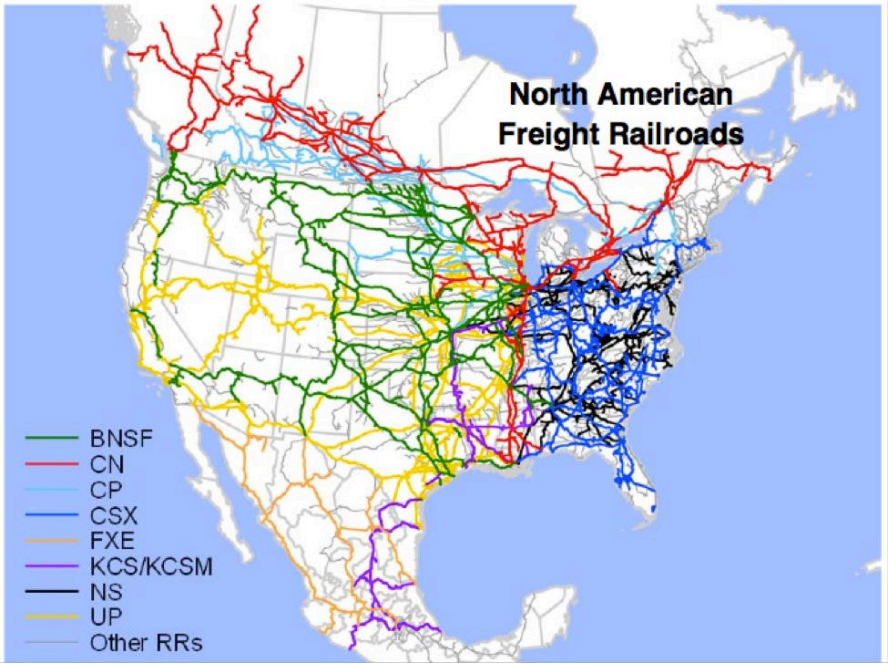

Figure 2-11: The North American railroad network (Source: AAR)

Railroads are using unit trains which are usually about 100-car long trains carrying the same commodity between a certain origin and destination, to transport large quantities of oil. Railroads also continue to use manifest trains to ship crude oil, which are trains hauling multiple commodities. However, because unit trains are more economically competitive with pipelines for large shipments of crude oil,[37] unit trains are the focus of this study. As shown in **Figure 2-12**, partly due to their resemblance to pipelines, some companies have marketed crude oil unit train service as a "pipeline on rails".

[37] Fielden (2014) notes that smaller oil companies do not produce sufficient bitumen to warrant the use of a unit train, making manifest shipments economic alternatives.

Figure 2-12: Unit train (left) and pipeline (right) (Source: Delmarva Railfan Guide[38] and Canadian Energy Pipeline Association)

Both of these modes are considered as potential strategic alternatives, which will be discussed in **Section 2.2**. First, however, the institutional structure is introduced to provide some background on which actors have control over which strategic alternatives.

2.1.3 Institutional Actors

The goal of this section is to describe some of the institutional actors in Canada and the US concerned with the transport of bitumen from the oil sands and discuss how they can control the development of infrastructure or the operation of the existing system. These actors are shown in **Figure 2-1** and include railroad companies, pipeline companies, oil producers, tank car manufacturers, terminal companies, and government actors.

There are three major pipeline companies proposing large trunk pipelines from the oil sands: Kinder Morgan, Enbridge, and TransCanada. These private pipeline companies propose, design, construct, and operate pipelines in response to demand from potential shippers, the oil producers and other midstream companies. After securing interest in the pipeline capacity from shippers, the pipeline company submits the plan to regulators for an environmental review. If the necessary permits are issued by governments, then the pipeline can be constructed and operate. Pipeline companies, backed by their potential customers, are therefore the proponents of new pipeline.

In the US and Canada, railroads are generally vertically integrated, owning their own infrastructure and operating their own trains. In the US, there are 7 Class I railroads in the US (which includes the US operations of the two Canadian Class I's, CN and CP), and 561 shortline (non-Class-I) according to the AAR. Because the oil sands are in Canada, any traffic coming from the oil sands would originate on CP and CN trains.

[38] http://www.delmarvarails.com/NorthernDE/

While locomotives are typically owned or leased by the railroad companies, most crude oil tank cars are not owned by the railroads. Instead they are owned by the shippers or are leased to them by tank car leasing companies. Additionally, most loading and unloading facilities are not owned by railroad companies, but by oil producers and transloading companies, including some pipeline operators (see Table 1.4-13 of the US Department of State 2014). However, in either case, there are no government or other restrictions precluding the railroads from being responsible for this rolling stock or this infrastructure. Notably, BNSF recently indicated that it is purchasing its own fleet of the latest tank cars for customer use (Hays and Podkul 2014). This action is facilitated by the fact that BNSF's parent company Berkshire Hathaway also owns Union Tank Car, a car producer.

There are many governmental actors involved in the transportation of energy resources. In the case of pipelines, the governmental actors concerned with the development of *new* pipelines are mainly of interest. In the case of railroads, as much of the necessary line infrastructure for hauling additional crude oil is already in place, at issue is mainly the operation of the *existing* system, both from safety and economic perspectives. Additionally, because the constitutions of the US And Canada generally assign federal governments in both countries the responsibility to regulate interstate, interprovincial, and international commerce, the focus of this representation is at the federal level.

Energy transport infrastructure and operations are regulated by agencies across the federal governments in Canada and the US, as listed in **Table 2-3**. Where possible, the agencies and departments with similar responsibilities in each country have been listed side-by-side. In Canada, the three main agencies with regulatory oversight of rail and pipeline transport of crude oil are Transport Canada (TC), which is the safety regulator for railroads and hazardous material (dangerous goods) transport; the National Energy Board (NEB), which is the economic and safety regulator for existing and proposed interprovincial and international pipelines; and the Canadian Transportation Agency (CTA), which is the economic regulator of rail transport in Canada. In the US, the Federal Railroad Administration (FRA) is the safety regulator, and the Surface Transportation Board (STB) is the economic regulator of rail transport. Economic and safety regulations of existing and new pipelines is, however, scattered across several agencies, including Pipeline and Hazardous Materials Safety Administration (PHMSA), the Department of State, and Federal Energy Regulatory Commission (FERC). There are also several other agencies interested in the economic, environmental, and safety impacts of the transport of crude oil in both countries.

Table 2-3: Roles of federal regulatory agencies in the US and Canada relevant to the provision of energy transport infrastructure (Source: author, from agency web sites).

Canada	United States
Transport Canada (TC) TC is the safety regulator for railroads in Canada. It also regulates the transport of hazardous materials in Canada.	**Federal Railroad Administration (FRA)** The FRA is the safety regulator for railroads in the US.
	Pipeline and Hazardous Materials Safety Administration (PHMSA) PHMSA is the safety regulator for pipelines and for hazardous material transport (both intrastate and interstate).
National Energy Board (NEB) The NEB is the economic and safety regulator for interprovincial and international pipelines. For proposed pipelines, the NEB is also responsible for completing an Environmental Assessment (EA) for proposed in accordance with the Canadian Environmental Assessment Act. If the Governor in Council (cabinet) approves the pipeline, the NEB is responsible for issuing issue certificates of public convenience and necessity. The NEB also regulates the approval of energy resource exports from Canada, as well as the rates charged by pipeline operators.	**Department of State (DoS)** The DoS has the responsibility for evaluating applications for permits to construct international pipelines, including acting as the lead agency for preparing an Environmental Impact Statement (EIS) under the National Environmental Protection Act (NEPA).
	Department of Commerce (DoC) The DoC is responsible for evaluating requests for crude oil export licenses from US domestic production.
	Federal Energy Regulatory Commission (FERC) FERC regulates interstate pipeline rates.
Canadian Environmental Assessment Agency (CEAA) The CEAA is responsible for the preparation of most Environmental Assessments (EAs) that are required under the under the Canadian Environmental Assessment Act (CEAA). In the case of pipeline projects, however, the NEB is the lead agency.	In the case of international pipeline projects (or railroad projects), the responsibility for environmental assessments is delegated to the **DoS** (see above). The lead agency for performing the Environmental Impact Statement of a railroad project entirely within the US is the Surface Transportation Board (STB – see below).
Canadian Transportation Agency (CTA) The CTA is the economic regulator for rail transport in Canada. One of its main responsibilities is helping to resolve rate disputes between shippers and the railroads. Additionally, it also issues certificates of fitness to railroad companies provided they are judged to have sufficient third-party liability coverage.	**Surface Transportation Board (STB)** The STB is the economic regulator for rail transport in US. One of its main responsibilities is helping to resolve rate disputes between shippers and the railroads. It also issues Certificates of Public Convenience and Necessity for the "construction, acquisition, operation and abandonment of railways"; however, unlike Canada, does not review third-party liability coverage (CTA 2013b).
Natural Resources Canada (NRCan) NRCan helps support the development of Canada's energy resources.	**Department of Energy (DoE)** The DoE regulates the development of oil and gas development in the US and maintains the US's petroleum reserves. In many cases, federal responsibilities have been delegated to state governments (e.g. Department of Energy, Office of Fossil Fuels 2014; PBPA 2011)
Environment Canada (EC) EC is the regulator for environmental issues (e.g. air, water, wildlife, climate change, etc.) in Canada.	**Environmental Protection Agency (EPA)** The EPA is the regulator for environmental issues (e.g. air, water, nature, climate change, etc.) in the US. The EPA also reviews and comments on EIS's prepared by other federal agencies (such as the DoS).
	Department of the Interior (DoI) The DOI is responsible for protecting land, water, wildlife, and energy resources in the US.
Transportation Safety Board of Canada (TSB) The TSB investigates railroad and pipeline transportation accidents in the US.	**National Transportation Safety Board (NTSB)** The NTSB investigates railroad and pipeline transportation accidents in the US.

2.2 STRATEGIC ALTERNATIVES AND THE INFLUENCE OF ACTORS

2.2.1 Strategic Alternatives Overview

In order to allow greater quantities of crude oil from the midcontinent to coastal areas, there are several strategic alternatives possible. As shown in **Figure 2-13**, the strategic alternatives can be classified at the highest levels by route (i.e. ultimate destination) and transport mode (e.g. by rail or pipeline). The type of oil shipped is not as high-level of strategic alternative, but it has important economic implications particularly for rail transport, which will be discussed in **Chapter 3**. Each actor in the institutional has different level of influence over the implementation of the various strategic alternatives.[39]

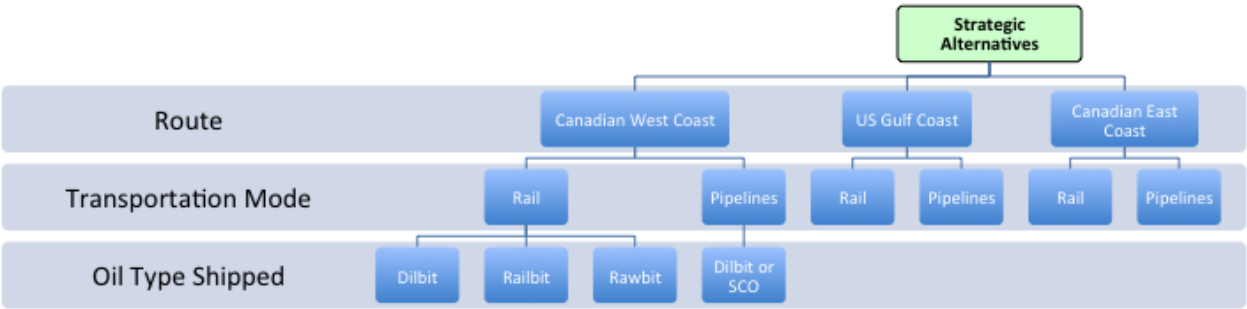

Figure 2-13: Strategic alternatives for crude oil transportation capacity from the oil sands (Source: author)

There are several proposals to build new pipelines directly from Alberta to the West and East Coast of Canada and US Gulf of Mexico Coast (USGC) to accommodate additional oil sands production. These projects would not only allow Canadian producers to sell increasing amounts of bitumen to Asian markets by shipping oil via tankers, but also allow refineries on the East Coast of Canada reduce the amount of oil they import from abroad. Currently, as of March 2014, as listed in **Table 2-4**, there is approximately 3.4 MMbbl/d of pipeline capacity proposed to handle increased oil sands production.

[39] There are some strategic alternatives that the author has not explicitly considered in the analytical work in this thesis, either because they were proposed after the work was substantially completed or that few details are publicly available about the feasibility of the projects. Enbridge is proposing a replacement and expansion of its mainline pipeline from Alberta to Wisconsin (Jones 2014). This existing pipeline is shown in **Figure 2-10**. Media reports suggest there is debate over whether this expansion would require a revised presidential permit to enter the US and thus be subject to a similar process as the Keystone XL (Jones 2014). A First Nation's (aboriginal) company called G7G Railway Corp. is proposing a new rail line from Alberta to Alaska via British Columbia that could transport up to 1.5 MMbbl/d according to media reports. This project is in the pre-feasibility stage (Canfield 2014). There is also a recent proposal from the Aquilini Group, a Vancouver, BC-based company, backed by First Nations, to build a pipeline from Alberta to the West Coast of Canada (Lee 2014). The ongoing development of new proposals to transport crude oil from the oil sands suggests that there is strong economic benefits to expanding oil sands production.

Table 2-4: Proposed pipeline projects originating from the Alberta oil sands (Source: compiled by author)

Pipeline (Company name and pipeline name)	Capacity Expansion (bbl/d)	Expected Regulatory Decision-Date *Canada – National Energy Board* *US – Department of State*	Proposed Operational date
Enbridge Alberta Clipper (AC) – Line 67 (Phase 1)*	120,000	Approved Mid-/late-2014	Q3, 2014
Enbridge Alberta Clipper (AC) – Line 67 (Phase 2)*	230,000	Mid-/late-2014 Mid-/late-2014	Q1, 2016
TransCanada Keystone XL (KXL)	830,000	Approved Q1 2014 (US)	Q4, 2015
Enbridge Northern Gateway (NG)	525,000	Mid-2014 Not required – pipeline in Canada	Q1, 2018
Kinder Morgan Trans Mountain Expansion (TMX)**	590,000	Not yet filed; expected Q4, 2015 Not required – pipeline in Canada	Q4, 2017
TransCanada Energy East (EE)***	1,100,000	Not yet filed; expected Q4, 2015 Not required – pipeline in Canada	2017-2018
Total (Canada only)	**2,215,000**	**Expansion solely within Canada**	
Total (Canada and US)	**3,395,000**	**Expansion in Canada and the US**	

***The Alberta Clipper expansions involve adding capacity to an existing pipeline through pump station and other upgrades, in order for the pipeline to reach its originally intended design capacity of 800,000 bbl/d.
**A new pipeline to transport heavy bitumen would be constructed in an existing pipeline right-of-way.
***The EE project uses an existing natural gas pipeline for much of the route.
NB: The purpose of this table is to provide some insight into the expected regulatory decision-date for pipelines originating in Alberta. The author recognizes that there are plausibly going to be delays associated with the approval dates suggested by the pipeline companies and reported in the media.
Sources: Compiled from CAPP (2013), Penty (2013), US Department of State (2013b, 2013c), Kinder Morgan – Canada (2013), TransCanada (2013), Snyder and Penty (2013).

As shown in **Figure 2-11**, North American railroads already have the ability to serve coastal regions through their extensive network. However, whether railroads have the ability to handle the expected around 3 MMbbl/d growth in oil production expected by 2030 is unclear. Cairns (2013a) notes, for example, that it might be a "stretch too far" for rail to ship an additional 3.0 MMbbl/d, given the *significant* capacity expansion that would be required by railroads.[40] The US Department of State (2014, Section 1.4), in its environmental review of the Keystone XL, suggests that such capacity expansion would be consistent with the historical capacity expansion by the railroads to serve the Powder River Basin, a major coal producing area. Therefore, while railroads can currently

[40] If the cycle time, the time it took for the train to go from its origin (near the oil sands) to its destination (need the refinery) and back, were 15 days, adding one additional train per day to transport bitumen would require 15 train sets (locomotives and cars). If each train had two locomotives and 120 cars, then adding one train start per day would require an addition to the fleet of approximately 30 locomotives and 1,800 cars. As a result, assuming a car capacity of approximately 525 bbl/car (typical for heavy crude), adding 3.0 MMbbl/d of rail capacity would require the addition of approximately 1500 locomotives and 90,000 cars. Currently, the combined fleet of Canadian Pacific and Canadian National is 2,400 locomotives and 65,000 freight cars in 2011 (Cairns 2013a), meaning that the possible expansion of rail capacity could be significant.

serve most geographic markets in the US, the specific capacity they would have to ship crude oil is uncertain.

2.2.2 Pipeline and Railroad Permitting and Regulations

For pipeline projects, the NEB and Department of State are responsible for preparing the Environment Assessments (EAs) and Environmental Impact Statements (EISs) for proposed pipelines in the Canada and the US, respectively, and for issuing the necessary permits. Once these documents are complete, final approvals of new interprovincial and international pipeline projects are provided by the Governor-in-Council (i.e. cabinet) in Canada and the president in the US, as explained in **Table 2-5**. Provincial and state governments have limited power to stop these projects due to the division of powers within the Canadian and American constitutions. However, in the US, state governments can legislate around issues of local concern, such as pipeline siting. This power has become apparent with the ongoing (as of May 2014) court case related to Nebraska's approval of the Keystone XL route (Bernstein 2014). Because the ultimate decision-making authority is vested in the executive branch of both countries, governmental actors at the federal level have control over the development of pipeline capacity to transport oil sands products.

Table 2-5: Roles of governments for the approval of new pipeline projects (Source: compiled by author)

Canada	United States
Federal Government Under the most recent update of the Canadian Environmental Assessment Act (CEAA) in 2012, the Governor-in-Council (i.e. the prime minister and his/her cabinet) has ultimate authority to approve or deny a permit for a project following the completion of an Environmental Assessment under the act (CEAA 2012).	**Federal Government** The president of the US has ultimate authority to approve a permit for international pipelines if he/she finds the project in the "national interest", which is not explicitly defined (Parformak et al. 2013). However, there are currently questions as to whether Congress could override the president's decision regarding the approval of the Keystone XL using Congress' legislative authority.[41]
Provincial Governments While pipeline projects cross across provincial land, their governments may not have any "legal basis" to stop pipeline projects should they object to their construction, as interprovincial and international pipeline projects are under federal jurisdiction (Centre for Constitutional Studies 2012)	**State Governments** The federal government, as the regulator of interstate commerce, has ultimate authority over the approval of interstate pipelines. States generally have the authority over the particular route ("siting") that a pipeline will take, provided the actions that they take do not overly harm interstate commerce. However, states "are given significant deference by courts to establish environmental, public health, and safety standards" that may harm interstate commerce (Vann et al. 2012).

[41] Vann et al. (2012) of the Congressional Research Service observes that ". . . legislation altering the pipeline border crossing approval process appears likely to be a legitimate exercise of Congress's constitutional authority to regulate foreign commerce . . ." However, overruling the President's decision would require a veto-proof (two-thirds) majority in both the House of Representatives and Senate; both the House and the Senate have supported the construction of the KXL in the past, but it is unclear whether they could reach this threshold (Eilperin 2013).

By contrast, because much of the necessary infrastructure to transport additional bitumen by rail is already in place, governmental actors, particularly at the federal level, have fewer mechanisms to control the capacity of crude oil by rail (as compared to pipelines). In Canada, where much of the necessary loading facilities might be built, approval by the Canadian Transportation Agency (CTA) of new railway lines is generally only required when the new line is over 100 meters away from the centerline of an existing rail line, and then only if the rail line is longer than three kilometers. Furthermore, environmental assessments are only required for new rail construction over 32 kilometers (20 miles) long (CTA 2011). In the US, the Surface Transportation Board (STB) has exclusive jurisdiction over the approval of new railroad construction, and thus the need to perform an environmental review (STB 2014), but "the STB does not have authority under this chapter over construction, acquisition, operation, abandonment, or discontinuance of spur, industrial, team, switching, or side tracks" (49 United States Code 10906), and thus the STB does not conduct an environmental review on these works. Additionally, the absence of a review by the STB "does not mean that a project is open to environmental review at the state or local level" (STB 2001). Therefore, the government actors have limited mechanisms to prevent the construction of additional line capacity needed to support the transportation of crude oil, unless a new rail line is proposed.

State actors may have some success at limiting the construction of crude oil unloading and loading facilities for unit trains should they choose to do so. Where state or provincial environmental assessments of these projects are required, opponents of oil sands expansion are "having some success" at blocking these facilities in states such as Washington (Snyder 2013). However, it is unlikely that environmental activists would have as much success in blocking these facilities in oil producing states and provinces such as Alberta, North Dakota, and Texas that are heavily dependent on the oil industry. Therefore, again, it is unlikely that regulatory action to stop terminals will be a major constraint on the development of rail capacity.

Federal railroad safety regulation could be used to discourage the transport of crude oil by rail. Notably, tank car supply is currently a shorter-term constraint to growing crude oil by rail traffic, which could be exacerbated by federal-level regulatory safety action. There is a large order backlog of 48,000 tank cars as of the beginning of 2013, of which 80% are estimated to be capable of carrying crude oil. The current production rate is approximately 16,000 to 24,000 cars per year (Lehlbach 2013), which means that backlog of tank cars will not be cleared until 2015.

Relatedly, contemplated tank car safety regulations would exacerbate this shortage. Following the accident at Lac-Mégantic, there has been scrutiny of the DOT-111 tank car design used to ship the most volatile crude oil.[42] While tank cars since 2011 have been built to a new AAR standard (P-1577), older tank cars, of which there are approximately 140,000, have not been phased out (Vantuano 2014). These cars correspond to approximately 51% of the DOT-111 fleet of 272,000, or 82% of the fleet used to ship hazardous materials (Vantuano 2014). There is (as of February 2014) ongoing debate as to whether these cars should be retrofitted or phased out as part of PHMSA (Pipeline and Hazardous Material Safety Administration) rulemaking Docket No. PHMSA-2012-0082 (and a similar process by Transport Canada to revise Safety Standard TP14877), the outcome of which could reduce the tank car fleet available for crude oil. The Railway Supply Institute (RSI), representing tank car manufacturers, argues that any phase-out/retrofit program with a deadline in less than ten years could have the effect of "[extending tank car] out-of-service times" and thus lowering tank car capacity (RSI 2013). Environmental advocates are thus supportive of enhanced tank car regulations (Snyder 2013).

Safety-related regulation of tank cars is therefore one possible policy lever that governments could take to reduce the capacity of crude oil by rail. There are other safety-related regulations that could discourage the transport of crude oil by rail. By contrast, the existing economic regulatory framework in Canada and the US does not appear conducive to discouraging the transport of crude oil by rail.

Current economic regulation in North America requires railroads to ship crude oil or other hazardous materials if requested by shippers under the railroads' common carrier requirements. The CTA in Canada and the STB in the US administer these regulations in each agency's respective country. The railroads thus have limited commercial responses possible to a shipment request, and government agencies in both countries are unlikely to change these regulations to prevent railroads from transporting crude oil. The US Department of Transportation (DOT) notes:

> *While the railroads have expressed concern over [their common carrier obligations], particularly with respect to their potential liability exposure arising from train accidents involving the release of poisonous by inhalation hazard or toxic inhalation hazard (referred to as PIH or TIH) materials, DOT believes that there is no reason to change this common carrier obligation (DOT 2008).*

[42] The most volatile crude oil is referred in the US and Canada as a Class 3 PG (Packing Group) I and II material (Vantuono 2014).

Because removing the railroad's common carrier requirements to ship crude oil would create a precedent to do so for TIH and PIH (toxic and poisonous inhalation hazards, respectively) chemicals, which are more hazardous than crude oil, it is unlikely that the DOT would make changes to the railroads' common carrier requirements.

Therefore, unlike with new pipelines, in which the federal governments have authority over their construction through permitting processes, governments in the US and Canada may only have indirect mechanisms, primarily through safety related legislation, to influence the flow of crude oil by rail.

2.3 FINDINGS AND INITIAL CONCLUSIONS

This chapter introduced the Canadian oil sands and its associated transportation system. It then used oil production trends to motivate the need for new strategic alternatives for adding transportation capacity for crude oil. Finally, it introduced some of the actors in the institutional sphere and discussed their influence over the strategic alternatives.

While it would be premature to draw conclusions based on this initial system representation, there are several findings that stand out.

- Oil sands bitumen is relatively energy intensive and costly to produce as compared to other forms of crude oil. This finding would suggest that oil producers are potentially cost sensitive, given that they may have alternative sources of oil that they could pursue.

- All Canadian government and industry forecasts suggest that oil sands production will grow significantly in the next 20 years. Similarly, shale oil production in the US is also growing. Oil imports to the US from other traditional suppliers (Venezuela and Mexico) are currently declining. To support the increase in crude oil production from the midcontinent, more crude oil transportation capacity would be required on refineries and potential export terminals on the coasts of Canada and the US.

- Specifically, over 3.0 MMbbl/d of additional oil sands production is expected between now (2014) and 2035, which would require significant capacity expansion by pipelines and/or railroad. Approximately four new pipelines or additional capacity for about 50 trains per day would be required.

- There is uncertainty about future oil production levels that are not necessarily reflected in government forecasts. In the case of the oil sands, while the reserves are large, production forecasts are predicated on there will be sufficient transport capacity to ship out all of the increases in production. Forecasts, though they usually consider carbon prices, also do not necessarily consider worldwide carbon constraints. Shale oil production levels are also uncertain given the relative inexperience with the hydraulic fracturing approach.

- Approval authority of interprovincial and international pipelines is vested in the executive branch of government in Canada. Similarly, approval authority of international pipelines in the US is vested in the president of the US. In the US, it is unclear whether Congress could force a decision by the president. Additionally, states in the US are allowed to legislate around issues of local concern such as pipeline siting decisions, which can delay pipeline construction.

- New construction required accommodating modest capacity expansions are not subject to environmental reviews in both Canada and the US. Additionally, railroads, as common carriers, are required to transport goods upon a reasonable request, and regulators are reluctant to change this framework. Safety-related regulations are one way to control the flow of crude oil by rail, at least in the short term, given that most rail infrastructure is already in place. This finding is another motivation for the specific consideration of safety in **Chapter 5**.

Now that a fundamental definition of the crude oil transportation system has been established, **Chapter 3** will turn to discussing the broader impacts of the strategic alternatives being contemplated along economic, energy security, and environmental dimensions of interest.

3 THE SOCIETAL IMPACTS OF BITUMEN TRANSPORT BY PIPELINE AND RAIL

The [Keystone XL Final Supplemental Environmental Impact Statement] is a Rorschach [inkblot] test; you can read it anyway you like.

Mark Bittman, *The New York Times*, 2014

Pipelines make good politics, they just do. There is so very much to sink your teeth into: energy, environment, money, Canada-US relations. The list is almost endless.

Rosemary Barton, CBC News, 2013

There is the potential for significant growth in oil sands production – 3 MMbbl/d or about 150% of *current* production – provided adequate transportation capacity is provided. To serve this expected growth, on the order of 50 trains per day or several new pipelines would be required. Because of this potential growth in bitumen production and transportation, proponents, opponents, and other stakeholders critical of transportation capacity expansion are concerned about a range of impacts, including economic benefits, energy security benefits, and climate change impacts, and safety concerns which to first order, vary with the amount of oil produced and transported.

Conceptually, the impacts of concern are shown in the representation introduced in **Chapter 2,** which is provided again for the reader's convenience as **Figure 3-1**. Each system (i.e. the oil sands production and transportation systems) produces a range of societal impacts to which the public – including individuals and other non-government actors – respond. The interaction between the two systems is essential to produce these positive and negative impacts. Oil producers make investments in production capacity, which creates demand for transportation capacity to get oil to refinery markets. Simultaneously, pipeline and railroad companies provide transportation capacity at a certain price to transport the oil produced to market. The availability and cost of transportation capacity thus affects the profitability of the oil producers, and thus their investment decisions.

However, providing transportation capacity is only a necessary – but not sufficient – for oil production to occur. As discussed in **Chapter 1**, the demand for crude oil by refiners, which is driven largely by oil's final use in transportation vehicles, also drives oil producers to make investments. These economic forces operate at a global scale due to the "relative ease" – i.e. low cost – of transporting oil around the world using large crude tankers (Rosenberg 2014, US Department

of State 2014, p. 1.4-8).[43] The ease of transport means an oil refinery on the United States Gulf of Mexico Coast (USGC) could purchase crude oil from the Middle East, refine it, and then ship the resulting fuel to Europe for consumption by motorists there.

As a result, global marketplace for crude oil makes it is difficult to predict the impact of one project, the Keystone XL, on oil sands production. Other issues further compound this challenge. As discussed in **Chapter 1** and **2**, oil sands' crude could be shipped by railroads, which are not subject to the same environmental reviews necessary for modest capacity upgrades. However, while railroad capacity expansion cannot be constrained as easily pipelines by government actors, ultimate railroad capacity expansion is uncertain. Additionally, the Canadian government can independently issue pipeline permits to allow additional capacity from the oil sands wholly in Canadian territory. Thus, the intertwinement of the two systems – oil sands production and transportation – of different scales, and the ability for independent action by governments and railroads leads to ambiguity in the predicted consequences of the Keystone XL construction. Bittman (2014), above, likens this ambiguity to individual interpretations of the inkblots in Rorschach test.

[43] Rodrigue (2013) notes that the cost of shipping oil from the Middle East only works out to about a penny at the gasoline pump per liter (i.e. around four cents per gallon).

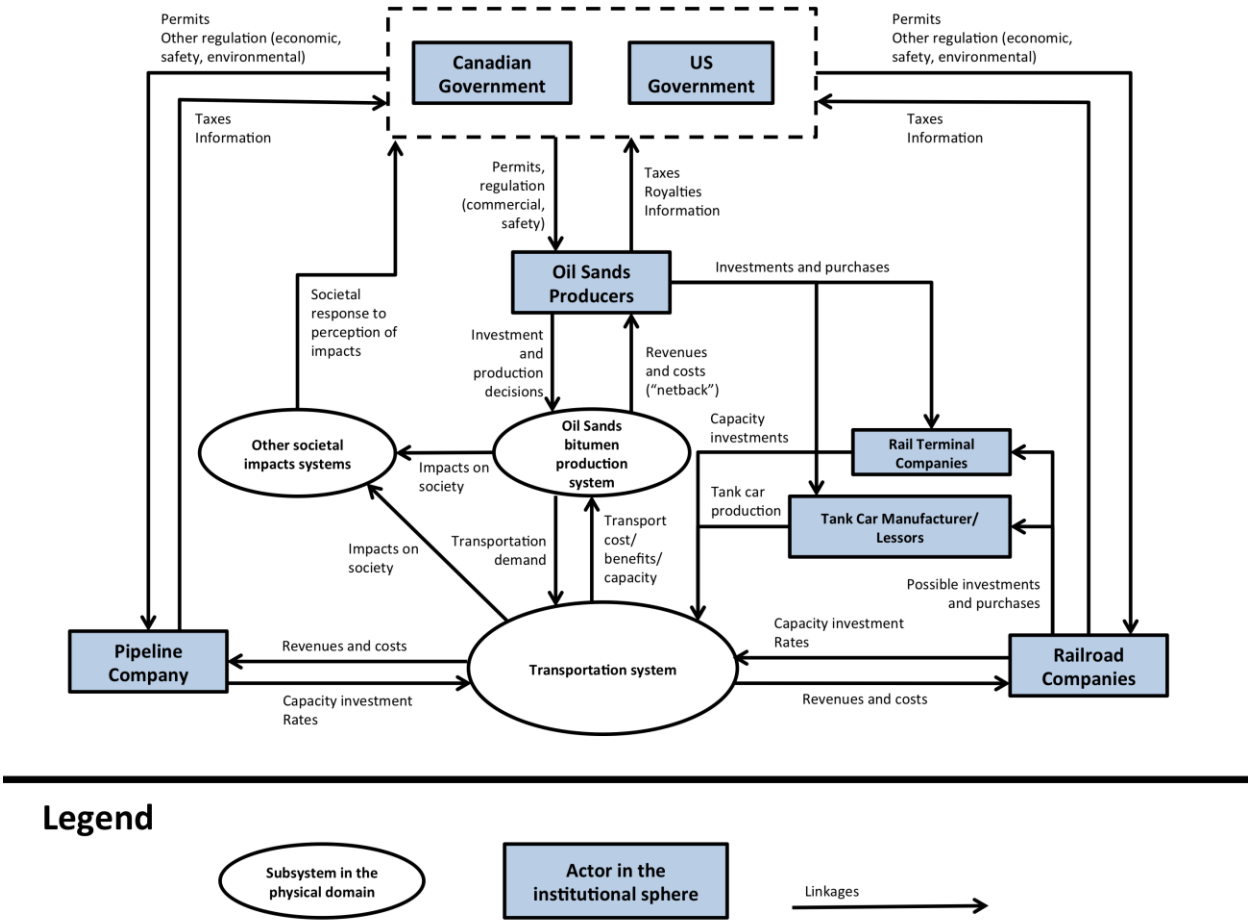

Figure 3-1: CLIOS Representation used to organize the discussion in this chapter

In the case of the Keystone XL, proponents and opponents of the pipeline have responded to this ambiguity with conflicting arguments. Proponents of pipeline expansion argue that because railroads would be able to transport all of the additional oil sands crude oil production expected, that denying a pipeline permit to prevent oil production is ineffective and would lead to additional negative consequences from rail transportation. Findings by the US Department of State (2014), though not a proponent, suggest a similar conclusion. Implicitly, these arguments downplay the importance of climate change in the evaluation of transportation infrastructure. By contrast, individuals and organizations critical of and/or opposed to oil sands expansion argue that because impacts from the pipeline expansion and oil production are deeply intertwined, that governments must consider the consequences of oil production along with the evaluation of the pipeline itself (e.g. Demerse and Flanagan 2014, discussing the proposed TransCanada Energy East pipeline entirely within Canada). Implicitly, these arguments make a value judgment that addressing climate change is of utmost importance. Because of these conflicting values, evaluating transportation

capacity becomes a highly political exercise, as Barton (2013) well-articulates in the quote leading into this chapter.

As a result, not only is there technical complexity associated with evaluating the Keystone XL, there is also evaluative complexity as well. This chapter addresses both by responding to **Question 2** posed in **Chapter 1**:

(2) In the context of the strategies of the Canadian and US governments related to broader issues of public policy, how does the performance rail transport compare to pipelines?
    a. Furthermore, how does uncertainty affect the strategies of the actors?

In this chapter, the author disaggregates the impacts from the oil sands and its transportation system in order. First, he considers the question: regardless of how oil sands bitumen is transported, what are the impacts from oil sands bitumen being taken out of the ground, transported, refined, and used? In other words, what would happen in the alternative if oil sands bitumen were to stay in the ground? In subsections under **Section 3.1**, three impacts of concern – economic development, climate change, and energy security – are defined and explained. Then the tradeoffs associated with these impacts from oil production are considered in the context of the positions of the Canadian and US government.

Second, assuming that the bitumen would be produced, what are the tradeoffs associated with transportation by pipeline or rail modes? This question is responded in both a static and dynamic way. In **Section 3.2**, in the static sense, the actual tradeoffs – transport cost, direct economic benefits, greenhouse gas emissions, and safety – associated with each mode are reviewed. In **Section 3.3**, in the dynamic sense, a dynamic programming model is used to study the plausible response of the rail industry to the construction (or not) of pipelines. Railroads are faced with uncertainty over the approval of pipelines, which affects their actions. Simultaneously, governments in the US and Canada are ensure about the expected response of railroads, which could affect government actions. This study, recognizing this interplay, helps to inform both government and railroad strategy.

Finally, in the **Section 3.4**, conclusions and recommendations supported by the findings in previous sections are posited in order to respond to **Question 2**. In other words, it re-aggregates the impacts from the oil sands' production and transportation systems to support recommendations specific to

the American and Canadian governments, and to the railroads, to ensure that they account for the specific strategies of the different actors.[44]

For this study, the Keystone XL, introduced in **Chapter 1**, will be used as the central discussion. While the Keystone XL has been well studied, as Bittman (2014) suggests, ambiguity remains. Additionally, much has been made of the belief that rail *could* transport crude oil in the absence of pipeline capacity, but less work has been done to understand what the railroads' role *should* be. The author hopes this chapter provides a new ways to consider the tradeoffs involved in decision making for governments in the US and Canada as well as the railroad industry.

3.1 Impacts of Bitumen Production

Before discussing the impacts of the transportation system, the purpose of this section is to understand the impacts oil the oil sands production itself. This section will focus on three issues of North American and global scale – economic impacts, greenhouse gas (GHG) emissions, and energy security – and the tradeoffs involved in deciding whether to support the continued production of oil sands crude oil. These issues will be discussed both from the perspective of governments in Canada and the US.

This discussion assumes that if oil is not produced from the oil sands, that oil from another location will be used to satisfy demand. MIT economist Christopher Knittel (2013) argues that the effect of any one pipeline, such as the Keystone XL, will not result in any "appreciable change in the **world** price of oil, certainly not enough to base policy decisions on." Additionally, because transport costs only make up around five to 10% of the total cost of the refined products, final consumption is likely relatively insensitive to the cost of transport (Rodrigue 2013). Therefore, this discussion assumes that the same amount of oil will be consumed (demanded) regardless of whether a particular transportation project goes ahead.

3.1.1 Economic Impacts

Production from the oil sands is a major economic driver in Canada. Currently, in Alberta, one out of 14 jobs is in the oil and gas sector (Government of Alberta 2013), and assuming plausible growth in oil sands production, oil sands jobs could grow from 75,000 jobs (direct, indirect and induced)[45] in

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[44] As discussed in Chapter 1, the multiple objectives of the different actors is what Sussman et al. (2014) term *evaluative complexity*.

[45] Honarvar et al. (2011) define direct, indirect and induced impacts as follow. The direct impacts are the "employment and financial effects immediately associated with the development of new projects in the oil sands industry" and are located only in Alberta. The indirect effects impact the industries that "supply goods and services for the development of new oil sands projects." Induced effects are the resulting "employment and financial effects that occur in a region due to

2010 to 905,000 jobs in 2035. Over the next 25 years, given plausible oil sands growth, the Government of Alberta and the Government of Canada could expect to receive $455 billion (in tax revenue and royalties) and $311 billion (in tax revenue), respectively, over this period (Honarvar et al. 2011).

The economic development potential of the oil sands is so significant that all major Canadian federal political parties support some continued expansion of the oil sands and some of the necessary transportation capacity to support it. In addition to the current Conservative government, which strongly supports pipeline development, the centrist federal Liberal Party also appears to support some pipeline development, with leader Justin Trudeau praising former Alberta Premier Alison Redford for her lobbying efforts in the US supporting the Keystone XL (The Canadian Press 2013a). The more left-wing federal New Democratic Party (currently the official opposition) is supportive of pipelines that would allow bitumen to be refined in Canada, such as the TransCanada Energy East, instead of exported, such as with the Keystone XL, Enbridge Northern Gateway, and the Kinder Morgan Trans Mountain Expansion (Barton 2013).[46] While each political party has a different strategy, they all recognize the economic potential of the oil sands.

Production from the oil sands also benefits the economy of the US through its trade relationship with Canada. The same study cited above found that the oil sands sector could contribute to the creation and preservation of 465,000 jobs (indirect and induced)[47] in the US in 2035, up from 21,000 in 2010, as well as an increase in US GDP $521 billion over the same period. These benefits would be accrued as a result of the economic activity generated in the US through the investments required to increase oil sands capacity (i.e. the manufacturing of components) as well as the ongoing operations of this added capacity (i.e. through the input of oil it provides to US refineries) (Honarvar et al. 2011). Therefore, the oil sands do have the potential for significant indirect and induced economic effects in the US.

However, some benefits from investment in oil sands would likely be received in the US regardless of where the oil is ultimately transported. The indirect economic benefits from oil sands *investment* would be received in the US regardless of whether the bitumen itself were transported to US,

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the economic activity in a particular sector, [such as when] . . . an oil sands project worker . . . spend[s] money in the economy by purchasing meals, clothes, and other various goods and services."

[46] The author refers readers to Hoberg (2013) for a further discussion of the response by Canadian political parties to proposed pipelines.

[47] In the main text, Honarvar et al. (2011) state that these are "direct, indirect, and induced," but by the report's own definition of these impact, these jobs can only be indirect and induced.

because any suppliers to the oil sands located in the US would benefit regardless of where the oil is shipped to. Only the indirect economic impacts from oil sands *operations* received by the US would depend on whether the oil sands were transported to the US, because refineries along the USGC and elsewhere in the US may be required to seek other sources of oil from other sources. If this oil were slightly more expensive or less reliably received than bitumen from Canada, then refineries on the US would have higher input costs, negatively impacting the US economy. While the impacts of the US receiving less Canadian oil (and more oil from abroad) may be modest because the price of oil is set at the global level, the inability to quantify this impact well – which is closely related to the issue of energy security – creates room for debate in the US over the economic impacts of the oil sands and more specifically, the impact of one project such as the Keystone XL.

Based on the above discussion, if oil sands production were to grow, it would benefit the Canadian and, to a lesser extent, the American economies. However, there are several uncertainties that could affect production levels, including the potential for climate change policies, which would decrease demand for oil sands bitumen. The decrease in demand would come partly from a decrease in oil consumption world wide, but is also a result of the relative disadvantage of bitumen due to its higher carbon intensity (Chan et al. 2012), which is discussed subsequently in **Section 3.1.2**.

3.1.2 Greenhouse Gas Emissions and Climate Change

As motivated in **Section 3.1.1**, production and refining of crude oil derived from bitumen from Alberta results in more climate-change causing greenhouse gas (GHG) emissions as compared to crude oil from most other sources refined in the US. Specifically, according to Lattanzio (2013):

1. *oil sands [bitumen is] heavier and more viscous than lighter crude oil types on average, and thus [requires] more energy- and resource-intensive activities to extract [from the ground]; and*

2. *oil sands [bitumen is] chemically deficient in hydrogen, and [has] a higher carbon, sulfur, and heavy metal content than lighter crude oil types on average, and thus [requires] more processing to yield consumable fuels by U.S. standards.*

In addition to the incremental GHG emissions produced during production and refining of bitumen, refining the heavier bitumen also results in a coal-like co-product[48] called petroleum coke, which is not present in abundant quantities with lighter crude oils; when petroleum coke is burned, it

[48] According to the Draft SEIS, "co-products are two or more products that are outputs from a process or product system" (US Department of State 2013a).

releases GHG emissions.[49] As a result of these three factors, the total well-to-wheel (WTW)[50] GHG emissions of a barrel of bitumen from the oil sands is generally higher than a barrel of other crude oils refined in the US (Lattanzio 2013).

The amount of incremental carbon emissions depends on the crude oil source that oil sands bitumen would replace in refinery inputs. In the context of the Keystone XL pipeline, a representative mix of bitumen from the oil sands produces 2% to 19% more WTW emissions than comparable heavy oils imported in the US, such as Mexican Maya,[51] Middle Eastern Sour, and some Venezuelan streams. However, there are some heavy crude streams, such as Venezuelan Bachaquero and Californian Kern River, and lighter crude streams where natural gas is burnt off at the well, such as Nigerian Bonny, which produce comparable WTW emissions as bitumen from the oil sands (Lattanzio 2013).

Ultimately, depending on what crude oil bitumen from the oil sands would replace, the incremental emissions from the oil sands bitumen shipped by the Keystone XL (assuming the full 830,000 bbl/d capacity were used) would be between be 1.3 to 27.4 $MMTCO_2e$ (million metric tons carbon dioxide equivalent) annually (US Department of State 2014, p. 4.14-36), equivalent to between 4,391 to 90,444 gCO_2e per barrel. Thus, 27.4 $MMTCO_2e$ per year of emissions would be the upper bound of "incremental" emissions attributable to the Keystone XL.

President Obama has previously stated that "[he is] going to evaluate [the Keystone XL] based on whether or not [it] is going to significantly contribute to carbon in [the] atmosphere" (cited in *The New York Times* 2013).[52] If the results conveyed in the previous paragraph are the upper bound of potential emissions, are they "significant"? When viewed in relative terms, the potential incremental emissions from the oil sands bitumen transported on the Keystone XL could be 0.06% to 0.3% of the total annual GHG emissions for the United States, which does not appear to be much. However, from a more absolute perspective, the Final SEIS notes that this amount of emissions equates to the additional emissions from 270,883 to 5,708,333 passenger vehicles (0.1 to 2.3% of

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[49] This product can be stockpiled, which while creating local environmental impacts, does not result in greenhouse gas emissions. However, the stockpiled petroleum coke is also coming under scrutiny (CBC News 2014a, Goodyear 2014).

[50] WTW refers to the lifecycle of a barrel of oil from the time it is extracted to the time it is combusted in a vehicle (most crude oil is used in transportation). The combustion of the products resulting from crude oil produces most of the greenhouse gas emissions (70-80%) (Lattanzio 2013).

[51] According the US Department of State (2013a, Appendix W): "Most [life-cycle assessments] refer to reference crudes in terms of their country of origin (e.g., Mexico) and the name of the crude (e.g., Maya). The crude's name is meant to indicate a crude oil with specific properties."

[52] The original quote used first person pronouns.

the current vehicle stock),[53] 64,935 to 1,368,631 homes, or up to 8 coal-fired power plants (Department of State 2014), certainly not inconsequential. While President Obama has indicated that he going to prioritize the issue of climate change, the ambiguity he leaves in his definition of "significant" gives him the leeway to approve or deny the Keystone XL permit or delay his decision.

By contrast, Prime Minister Stephen Harper downplays the issue: "[emissions from oil sands production are] almost nothing globally" (Fitzpatrick 2013). Furthermore, although Canada has a GHG emissions reduction target for 2020, Canada does not have any federal policy for GHG emissions reductions from the oil sector. Combined with expected oil sands production growth, Canada is currently poised to *increase* carbon emissions by 2020 from the baseline year (2005) used in the proposed target. Though the US is also not on track to meet the same GHG emissions-reduction goal as Canada, Canada's oil and gas sector emissions is a critical component to meeting that goal, because it represents 23% of Canadian GHG emissions in 2011 (Demerse and Partington 2013).

The resistance by Canadian government to implementing carbon pricing for the oil sector suggests that the government is very concerned about the negative economic impact of a carbon tax on the industry, particularly when such a policy is not only critical for meeting Canada's climate goal Furthermore, proposed carbon taxes are within the range of the price differential between pipeline and rail transportation costs. For example, one proposal by The Pembina Institute (an environmentally-inclined think tank) for a $150 per tonne carbon tax – which is much higher than most government carbon tax proposals – would result in an effective cost of $2.87 per barrel (Partington et al. 2013). This cost is within the price differential between pipelines and rail that the US Department of State finds would have no significant impact on oil production (which will be discussed in **Section 3.2**). Furthermore, government proposals for carbon taxes have typically been much more modest at $40 per tonne or less, yet even so, have not yet been implemented. This information, combined with the discussion about the flat world supply curve for oil (as discussed in **Chapter 2**), suggest that: (1) there is tradeoff between strategies to reduce the incremental GHG emissions from the oil sands and economic development, and (2) that the Canadian government is emphasizing economic development goals above all else.

[53]Assuming that there are 253 million vehicles in the US based on data from the US Department of Transportation (http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_11.html).

Unlike with issues of economic development (discussed previously in **Section 3.1.1**) and energy security (discussed subsequently in **Section 3.1.3**), which are issues primarily of *national* concern, climate change is a *global* issue.[54] While the concerns over the impacts of climate change are growing with reports increasingly indicating that climate change is happening now (see e.g. Intergovernmental Panel on Climate Change [IPCC] 2014, US Global Change Research Program 2014), political action remains difficult. However, while political action on climate change may be difficult in the short term, it is nonetheless an issue that is interconnected with economic development and energy security, as will be explained.

3.1.3 Energy Security

Energy security is achieved when there is sufficient energy supply at an affordable price (The Global Energy Assessment [GEA] Writing Team 2012). The US and Canada have different strategies vis-à-vis energy security given their respective position as importer of crude oil versus exporter of crude oil.[55]

The US wants to ensure that it has an adequate supply of crude oil. Since the presidency of Nixon, presidents have had the goal of reducing the US's dependence on foreign-sourced oil (Freudenburg and Gramling 2012). Notably, in 1980, President Carter stated that the US would us military force if necessary to protect its oil interests in the Persian Gulf (Carter 1980). More recently and specific to the Keystone XL, the US House of Representatives have highlighted the potential energy security benefits of the Keystone XL in its page on the subject (US House of Representatives Energy and Commerce Committee 2013). However, President Obama's prioritization of energy security in regard to his decision of the Keystone XL is unclear. Energy security has previously been on President Obama's agenda during his first term in office; it was his strategy in 2010 to reduce the amount of oil imported from the Middle East and Venezuela through increasing domestic supplies and by improving vehicle fuel efficiency (e.g. CNN Wire Staff 2010, Hale 2011). However, he does not appear to have made any public comments regarding the energy security benefits of the Keystone XL.

By contrast, the strategy of the Canadian Government is ensure that the oil sector has sufficient oil transport capacity to transport its production to world markets. Currently, Canada is heavily dependent on the US as its primary crude oil export market, and is thus highly subject to the

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[54] Of course, climate change also has many local implications, such as the potential for sea-level rise to impact low-lying coastal areas.

[55] See e.g. EIA country data at http://www.eia.gov/countries/, accessed April 3, 2014.

political situation in the US (e.g. Hale 2011). Therefore, regardless of whether pipeline projects such as the Keystone XL are approved, the Canadian government's current strategy is to diversify its energy markets through where it ships its oil (Babad 2012), primarily through the construction of other energy pipelines. However, because Canada is a net exporter of crude oil, it is not concerned with energy security in the sense of the definition given above.

With the context of the two government's initial positions in mind, the energy security implications of greater oil sands production can be further described along multiple dimensions of energy security of " 'availability' (physical availability of resources), 'accessibility' (geopolitical aspects associated with accessing resources), 'affordability' (economic costs of energy), and 'acceptability' (social and often environmental stewardship aspects of energy) (Kruyt et al. 2009)." This commonly used framework is known as the four A's, and is one of many frameworks used to consider energy security (GEA 2012). This framework will be used to consider the energy security implications of greater oil sands production from the US and Canadian perspective.

Along dimensions of *availability* and *accessibility*, allowing oil sands production to increase by providing more transport capacity to the US would increase the US's energy security. The oil sands are available: they are one of the largest crude oil reserves in the world. They are accessible to the US: While they are in Canada, there are strong trade and diplomatic relationships between Canada and the US. The oil sands are strongly available and accessible for the US as compared to other sources in the world, and additional pipeline or rail capacity would enhance this position.

Additional transport capacity to the US would not only increase the availability of oil sands bitumen to the US, but also make it more available other world markets; oil imported from Canada is not subject to the US's export restriction on domestically produced crude oil. On one hand, providing more access for Canadian oil exports means that the US would have to compete with other countries for Canada's oil. There has already been an increase in non-US foreign investment in Canada from Asian and Oceanic sources, which now make up 27.5 percent of foreign direct investment stock in the Canadian oil and gas industry (Burt et al. 2012), reducing the US's influence over Canada's oil and gas sector. However, on the other hand, as discussed in the **Section 3.1.1**, the US benefits economically from oil sands *investments* regardless of whom the ultimate customer is. Additionally, even though other countries have access to the oil sands, the US can work cooperatively with Canada, using Canada's resource if necessary, as a tool for international diplomacy. For example, the US could deploy its strategic petroleum reserve in support of an ally,

knowing that the US *could* access Canada's oil supply if necessary (Rosenberg 2014). Furthermore, Canada, which has mechanisms to block foreign investments into the oil sector under the Investment Canada Act, has been reluctant to allow foreign investment by state-owned oil companies, particularly as China seeks to expand its reach in the energy market (see e.g. O'Brien 2013). Therefore, there is less tension between US and Canada energy security goals than is often suggested.

Along the energy security dimension of *affordability*, greater transportation capacity from the oil sands also provides an affordable source of crude oil to the US. First, some of the expense of purchasing Canadian oil flows back into the US economy through Canada's trade relationship with the US; the exact amount is subject to debate, as discussed in the section on economic impacts. More importantly though, the funds from purchasing the oil from Canada would not go to an "adversarial" government (Levi 2009). Second, having a reliable supply of oil in Canada helps lower the market power of OPEC (Organization of the Petroleum Exporting Countries) countries, a cartel producing 41%[56] of world oil production, and thus with market power. Combined, the US and Canada could grow their market share from about 17% of world oil supply in 2012, eroding the market power of OPEC. This increase in market share could help prevent price shocks if OPEC tries to restrict its supply.[57] Finally, the diplomatic and military costs associated with maintaining oil supplies from Canada as opposed to another country are arguably smaller. As the US Department of State points out, "the US-Canada alliance is a cornerstone of both countries' national security" (US Department of State 2012).

However, based on the arguments of Levi (2009), these affordability benefits may not necessarily be as large as first thought because: (1) the US would receive many of the economic benefits from oil sands production expansion regardless of the ultimate destination of the oil from the capital investments required for production; (2) the growth in oil sands production would not "significantly [diminish]" the ability of OPEC countries to manipulate prices (as the Canada's oil production is only about 4.4% of world oil production as compared to OPEC's 41% share[58]); and (3) the "[US's] military commitments in the Middle East. . . [would not] decline" as a result of importing

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[56] Based on 2012 EIA data of oil production.(http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=53&aid=1&cid=ww,r1,&syid=2008&eyid=2012&unit=TBPD)

[57] Greene (2010) describes economic aspects of energy security and OPEC's ability to affect world oil prices.

[58] Based on 2012 EIA data of oil production. (http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=53&aid=1&cid=ww,r1,&syid=2008&eyid=2012&unit=TBPD)

more oil from Canada. In regard to the second point, as premised in the introduction of **Section 3.1**, the expansion of one pipeline would not have significant effects on world oil prices. Parfomak et al. (2013) echo this statement. In regard to the third point, the Internation Energy Agency notes that "The Middle East, the only large source of low-cost oil, remains at the centre of the longer-term oil outlook." In 2011, about 17 MMbbl/d flowed through the Strait of Hormuz between Oman and Iran, and the EIA (2012f) notes "[the] blockage of a chokepoint, even temporarily, can lead to substantial increases in total energy costs." Ensuring the continued free flow of oil through this and other chokepoints in geopolitically volatile areas is thus going to remain a concern of the US. Therefore, while additional imports of Canadian oil would improve US energy security, energy security will remain a concern.

Along the energy security dimension of *acceptability*, providing additional using oil sands bitumen as part of the US and Canada's energy mix could, arguably, reduce energy security over time due to the negative social and environmental impacts of the oil sands supply. As discussed in **Section 3.1.3**, opponents of the Keystone XL have been concerned in particular with the additional greenhouse gas emissions emitted during the production and refining of oil sands bitumen. Chan et al. (2012) found that oil sands production would be particular sensitive to any worldwide climate policy due to its higher carbon intensity. Additionally, as Greene (2010) argues, reaching an energy secure state can result in complacency with taking the other actions necessary to maintain that energy security, such as improving vehicle fuel efficiency. Therefore, in the long term, the potentially growing unacceptability of the oil sands bitumen due to its carbon intensity, combined with the complacency of having the perception of a secure supply, could ultimately reinforce in the long term to result in lower energy security.

Therefore, on balance, increasing oil production from the oil sands appears to modestly support energy security; however, the results are ambiguous in the long term due to the potential for growing unacceptability of oil sands production due to its climate impacts.

3.1.4 Summary and Transition

The four A's of energy security suggest that there is an indirect interconnection between economic development, climate change, and energy security. The author proposes the following representation, as shown in **Figure 3-2**, to represent the interconnections between these three impacts. It is somewhat analogous to the "planner's triangle," a representation of the conflicts between economic development, social equity, and environmental protection, but unlike the proposal by Campbell (1996), the four A's are focused on the issue of energy security. Ideally, when

considering a project using both representations, the goal would be to improve all three concerns simultaneously and end up in the center of the triangle (Campbell 1996); however, in practice, there are tradeoffs among the issues in the short and long term.

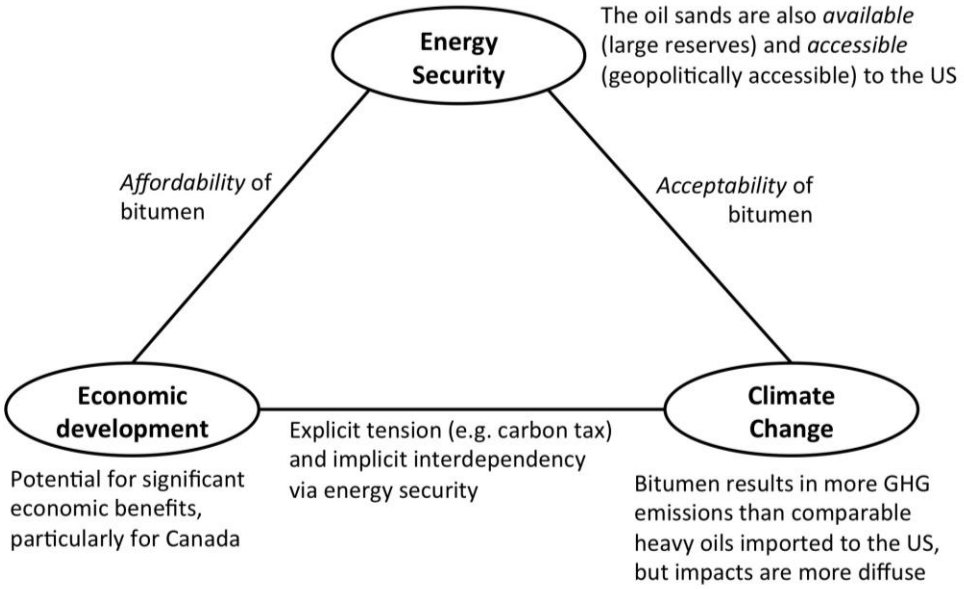

Figure 3-2: Interdependencies between economic development, climate change, and energy security (Source: author)

In the case of energy transport capacity from the oil sands, the three nodes on the triangle are not necessarily in conflict. Increasing oil production provides economic benefits and increase energy security – both of which align through the affordability of energy dimension – but that the oil sands produce greater GHG emissions than other heavy crude oils refined in the US. In the short term, there are clearly tradeoffs between change and the other nodes: one cannot expand oil production, creating economic and energy security benefits, without simultaneously creating carbon emissions given current production and refining technology. In other words, if one argues that the Keystone XL should be built because it supports North American economic development and energy security, one must also accept that it creates more GHG emissions. Another way to look at this tension is that if one wished to reduce the impact of the GHG goals, a climate change policy (e.g. carbon tax) could be implemented, but this policy creates a tension between economic development and climate change by slowing down oil sands production increases.

In practice, individual actors are generally concerned primarily about one of the impacts. Canada is particularly concerned with the economic potential of the oil sands. The US is generally concerned with energy security benefits. These benefits, particularly the economic benefits accrued in Canada,

are received by government through taxation and royalties and thus motivate action. By contrast, given the relatively diffuse benefits from addressing climate change, there is limited political support in the US or Canada to address the issue. Though President Obama has expressed concern over climate change, more so than the current Canadian government, it remains politically difficult issue for him to advance. In one poll taken in April 2013, a majority of American respondents oppose or strongly oppose taxation policies (either a gas tax increase or carbon tax implementation) that would result in higher cost for households. While 42% of respondents indicated that "global warming should be a . . .[high or very high] priority for the president and Congress" as compared 28% a low priority (Leiserowitz 2013), the overall results suggest that any policy that raises household costs is politically difficult at the national level.[59] By contrast, of those who have "heard" of the Keystone XL (i.e. about 50% of respondents), 63% support or strongly support the pipeline, (though only 18% of respondents follow the Keystone XL "very" or "somewhat" closely).[60] As a result, the results suggest that Americans remain more concerned with economic development and energy security. Along similar lines, Levi (2009) argues "[for] the near future, the economic and security value of oil sands expansion will likely outweigh the climate damages that the oil sands create." Though it unclear whether Levi is providing his own opinion of the value tradeoffs or his opinion of what political decision-makers perceive to be the value tradeoffs, the poll data and Levi's underlying message suggest that dealing with climate change is politically challenging the short term.

However, while addressing climate change is politically perilous, it continues to be a growing concern. The IPCC has stated that "[human] interference with the climate system is occurring, and climate change poses risks for human and natural systems" (IPCC Working Group II 2014). The US Global Change Program issued a report in May 2014 finding that climate change is happening now. In the longer term, if, or arguably, when addressing climate change becomes a more pressing issue, then the economic and energy security benefits upon which expanded oil production and associated transportation is premised might be lost. For example, one of the key dimensions of energy security is that is that the source of the energy is acceptable from a societal standpoint. If a climate price or constraint were put into place, oil sands bitumen would be less acceptable. However, these conflicts are not necessarily as critical if action is taken to lower the GHG footprint on oil sands production. The specific approach that should be taken is beyond the scope of this

[59] In the results, respondents seem more supportive of technological policies (e.g. clean energy) or policies that target corporations and industry.

[60] There is potential for self-selection bias in these results; i.e. that supporters tend to follow the developments of the Keystone XL at a higher rate than opponents.

thesis, but it could include a carbon tax, cap-and-trade approach, or prescriptive regulation, for example.[61]

In light of these tradeoffs, because expanded transportation capacity is being considered to support expanded oil production, tying any transportation capacity expansion – which facilitates production expansion – to climate goals, particularly in the case of long-lasting pipelines, seems reasonable. However, proponents of pipelines have argued that if pipelines are not permitted, that railroads will be able to transport crude oil regardless, rendering above discussion oil sands impacts moot. Can railroads transport similar quantities at a competitive cost and with comparable societal impacts? To respond to this question, **Section 3.2** considers the performance of railroad and pipelines along economic and other dimensions of societal importance.

3.2 IMPACTS OF THE TRANSPORTATION SYSTEM

3.2.1 Economic Relationship Between Transportation and Oil Production

Transportation capacity and cost affects the investment decisions by oil producers. Canada's oil sector is fundamentally market driven, though it does intervene through taxation, royalty collection, and regulation.[62] Canada does not have a national oil company controlled by government. Therefore, as represented in **Figure 3-1** (the CLIOS Representation in the introduction to this chapter), oil producers invest in oil production capacity if they feel that they can make an acceptable return on investment or profit. In the oil industry, the profit from a barrel of oil is defined as the netback, which is given as:

Netback = Revenue from sale – Cost to market

Where:

Revenue from sale: the price at which the producer sells the oil

Cost to market: The sum of production costs (i.e. taking the oil out of the ground), transportation costs (i.e. the price charged by the pipeline or railroad company), loading and unloading costs, and any other logistics costs associated with transporting the oil (e.g. the cost of purchasing diluent to allow the oil to flow through the pipelines)

[61] Similar to the conclusion of this research, though not with the same rationale, Levi (2009) further argues "climate concerns cannot and must not be ignored, and will become more important over time. US policymakers should balance the two goals by working with Canada to promote strong incentives to cut the emissions associated with each barrel produced from the oil sands, without directly discouraging production itself." He provides several examples of approaches that could be taken.

[62] EIA (2012) notes that the Canadian oil and gas sector is comprised of private domestic and international companies.

Transportation services affect both the revenue and cost side of the netback equation for producers, thus influencing their investment decisions. On the revenue side, constrained transportation capacity can result in producers having to discount the price of the oil they sell, as otherwise they would have to put it in storage tanks while they wait for pipeline capacity, thus incurring holding charges. Oil sands producers have recently faced this issue, which also reduces the revenues received by governments through royalties, which are tied to oil prices. In 2013, as shown in **Figure 3-3**, there was a larger discount of bitumen from Canada (e.g. WCS – Western Canadian Select) as compared to similar other heavy oils imported to the USGC[63] (e.g. Mexican Maya – a comparable heavy crude oil imported from Mexico).[64] Such a discount could be evidence of constrained transportation supply.

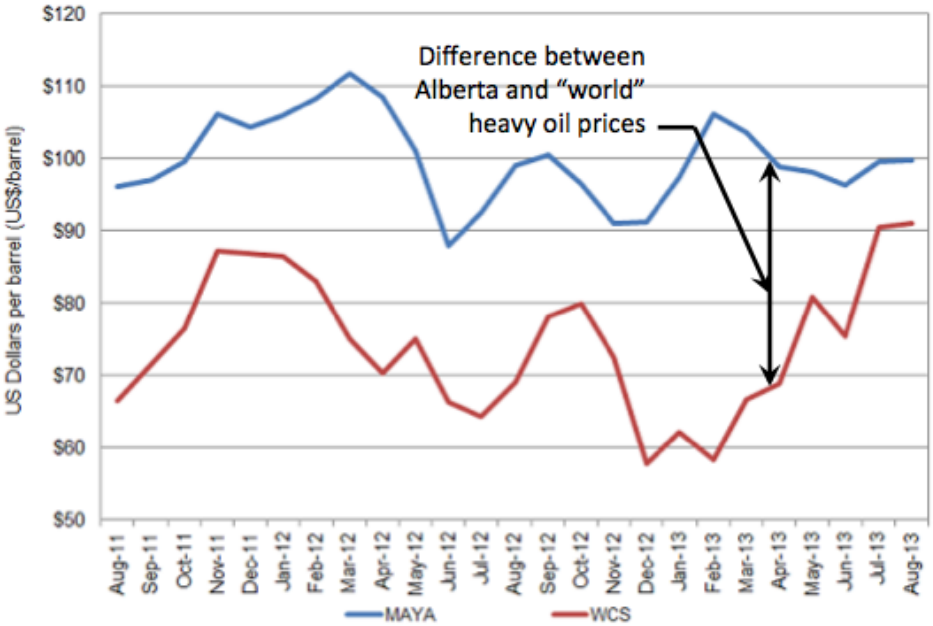

Figure 3-3: Prices of Mexican Maya and Western Canadian Select (Source: Government of Alberta, Office of Information and Statistics 2013).

The geographic flexibility of the transportation mode can also affect the revenue received by oil producers. Unlike pipelines, provided there is suitable loading and unloading facilities, railroads can ship crude oil almost anywhere in the US. Producers can therefore respond to the highest bidder for their product, and redirect shipments. However, the author is not aware of any publically available quantification of this optionality.

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[63] As noted in Chapter 1, the USGC is a significant refining center for heavy crude oil.

[64] Prices for WCS are usually less than the Maya due to the additional cost of transport from Alberta to the USGC as compared to transport from Mexico to the USGC.

On the cost side, in addition to the rates charged by the pipeline and railroad companies, producers incur other logistics costs associated with transporting bitumen. These costs are of the same order of magnitude as the rates charged by the railroad and pipeline companies themselves and can make either railroads or pipelines more desirable depending on the particular circumstances. These costs include:

- Railcar lease (for rail only)
- Loading and unloading costs (for rail)
- The holding cost (i.e. value of time) of the shipment
- The cost of shipping diluent (a product that allows oil to flow)

Examples of these costs to ship by rail (left) and by pipeline (right) from Alberta to the USGC are shown in **Figure 3-4**. The rail cost in this example assumes that bitumen goes in its raw, undiluted form, which requires heating upon loading and unloading. The pipeline cost assumes that the bitumen is shipped in a diluted form known as dilbit.

Other than the pipeline or railroad rate, the largest component of the logistics cost is for diluent transport when bitumen is being shipped by pipeline. Unless bitumen is initially processed into a lighter crude oil, it must be diluted with a lighter hydrocarbon in order to flow or heated (if being shipped by tank car). A mixture of 30% diluent, called dilbit, is used to transport oil by pipelines. Because refiners do not desire the diluent, it must be transported, recycled and returned to Alberta, all of which represents a loss (Canexus 2013). According to the costs in **Figure 3-4** for dilbit transport by pipeline from Alberta to the USGC (right), the cost of diluent transportation is approximately 43% of the total cost of pipeline transportation.

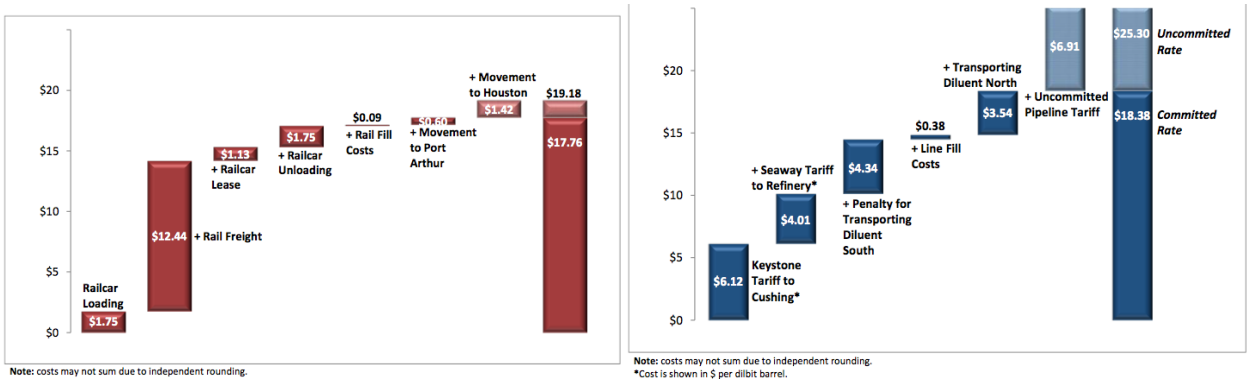

Figure 3-4: Cost components of oil shipments by rail (left) and pipeline (right) from Alberta to the USGC (Source: US Department of State 2014, Appendix C)

Ultimately, as shown in **Table 3-1**, the fact that bitumen could be shipped without dilution as rawbit means that railroads are nearly comparable with pipelines in terms of shipping costs. These

figures in the US Department of State (2014) FSEIS for the Keystone XL,[65] which concludes that the incremental cost to transport by unit trains is "less than $3.00 per barrel ([and] perhaps even more economic than dilbit by pipeline) [for rawbit]; $5 to $7 per barrel [for railbit]; and $7 to $9 per barrel [for dilbit]." Railroads are particularly competitive with pipelines if the perspectives of small oil producers (shippers) are considered. These shippers "do not produce enough bitumen and/or do not have enough capital to enable them to obtain long-term *committed* rates on pipelines" (US Department of State 2014). As a result, their cost for shipping from Alberta to the USGC is closer to $25 per barrel by pipeline, as opposed to $16 to $18 if they are able to sign a long-term contract with the pipeline companies. This higher rate for pipeline transportation makes railroads a particularly viable alternative for these small shippers.

Table 3-1: Logistics cost of bitumen shipping from Alberta to the USGC

	Unit Train	Pipeline
US Department of State (2014)	Rawbit: $17.76/bbl Railbit: $21.69/bbl	Committed: $16.14/bbl Uncommitted: $25.30/bbl

Based on analysis in the Keystone XL FSEIS, assuming that the cost estimates for rail transport of bitumen were to hold, a rejection of the Keystone XL pipeline (and thus the greater use of rail to ship oil sands bitumen) would not significantly alter the amount of bitumen being sent to the US, and may not affect the total amount of oil being produced. According to modeling by EnSys for the US Department of State (2014, Figure 1.4.4-1), in its reference scenario, preventing all cross-border pipeline construction would reduce the amount of oil being shipped to the US by 0.21 MMbbl/d in 2035, but that total production would remain unchanged. Using same model, under a reference scenario in which pipeline capacity is completely constrained and railroads cannot transport bitumen to the West Coast of Canada (presumably because export facilities are not constructed), EnSys finds that there would be around a 0.2 MMbbl/d reduction in oil sands' production in 2035 as compared to if transportation capacity is completely unconstrained. In other words, the model results suggest that oil sands' production would largely be unaffected if pipeline permits are not granted because, railroads could transport most of the bitumen at rates that oil producers find competitive. The analyst uses these and other results to conclude that "[permitting] or denying one particular pipeline project alone, such as Keystone XL, is unlikely to have a significant impact on oil sands economics if similar new pipelines are permitted in the future [including pipelines entirely

[65] The Keystone XL FSEIS is the most comprehensive review to date of pipeline and rail costs to ship bitumen from Alberta to the USGC.

within Canada] or if existing cross-border pipelines are allowed to expand" (Department of State 2014, p. 1.4-132).

Some of the assumptions used in the analysis are conservative with respect to the oil production implications of greater transport of crude oil by rail and thus help in supporting this conclusion. The analysis assumes the least economic way of shipping bitumen by rail, i.e. using dilbit instead of rawbit (Department of State 2014, p. 1.4-128). In reality, more shippers, if they expected to use rail to ship bitumen over a long-term, would likely choose to make the necessary investments to ship rawbit, thus making it unlikely that there would be a significant difference in the amount of oil sands crude ending up in the US as compared to if pipelines are approved.

However, there are several uncertainties associated with rail transport costs that could result in the analysis understating the implications of pipeline permit denials. First, the economics of rail transport by unit train from Alberta are primarily *estimates* at this point; the use of unit trains to ship bitumen from Alberta only started in October 2013 (Williams 2013). Furthermore, because bitumen coming from the oil sands is initially shipped in feeder pipelines and must be diluted right at the mine, a diluent recovery unit (DRU) is required at the rail transload facility to remove the diluent before loading in the railcars. As this equipment requires a five-year payback period, oil producers are only going to make this investment if they believe that pipelines will not be built in the near term (Forrest and Brady 2013). Therefore, even though shipping raw bitumen by rail is competitive with pipelines, it has not yet taken off because of limited infrastructure. Therefore, there is uncertainty regarding the costs of transporting bitumen, particularly in its raw form.

Second, there is uncertainty about whether the railroad companies could make the capacity investments necessary to transport all of the production growth between now and 2035, which is approximately 3 MMbbl/d. The US Department of State (2014) finds that such growth would be consistent with the capacity expansion that took place to accommodate the growth of coal exports from the Power River Basin coal mining area. However, Cairns (2013a) opines that "the handling of the full 3 million b/d anticipated by 2035 is probably a stretch too far" for the railroads to handle. As discussed in **Chapter 2**, assuming that the capacity expansion necessary would not offset by displacing or reducing other traffic levels, the expansion necessary would increase the Canadian railroads' (CN and CP) locomotive fleet by over 50%, which is a substantial expansion! Therefore, the implications of the unconstrained scenario in which no pipelines are constructed and railroads cannot expand to the west coast, the implications on oil production are potentially understated.

Third, related to the first two uncertainties, there is no guarantee that rail rates will hold at their current levels, an issue not discussed by the US Department of State. As railroads gain more market power in the crude oil market and as their capacity becomes increasingly constrained, it is plausible that railroads would exercise their market power and raise their rates. Rail rates above 1.8 times the railroads' variable cost can be challenged by shippers to the US Surface Transportation Board, but nonetheless, railroad rates remain uncertain. Higher rates would discourage oil sands' production.

Therefore, as compared to using railroads, approving the Keystone XL supports further oil sands' production expansion by providing assured capacity at a given competitive cost. While railroads could likely handle crude oil traffic from just Keystone XL alone at nearly competitive rates – particularly if rawbit is transported – it is unclear whether it could replace the full capacity provided by the Keystone XL *and* the other proposed pipelines entirely within Canada if they were not approved.

3.2.2 Other Impacts of the Transportation System

The discussion in **Section 3.2.1** only considers the economic tradeoffs between pipelines and railroads. Even if railroads are nearly competitive in terms of cost to pipelines, one could still argue that railroads could have worse impacts along other societal dimensions such as economic benefits, energy security, climate change and safety. There this section discusses these impacts by reviewing available literature.

Direct Economic Impacts from the Transportation System

Because the issue of economic impact and job creation of the oil sands is a more contentious issue in the US than in Canada, the debate over the Keystone XL tends to focus on the short-term construction from the pipeline infrastructure itself. For example, many in Congress support the Keystone XL partly because of the construction jobs that the Keystone XL would create (see e.g. US House of Representatives, Energy and Commerce Committee 2013). However, President Obama has downplayed the economic benefits from Keystone XL, indicating in one interview that its construction would only 2,000 construction jobs, which is lower than the estimate given in the Department of State's DSEIS of 3,900 person-years in direct construction jobs, and 42,100 person-year in indirect jobs throughout the US (*The New York Times* 2013, US Department of State 2013a). While the number of short-term jobs are modest, they can have longer-term stimulus effects. MIT economist Christopher Knittel (2013) notes in testimony to Congress that these jobs have longer-term stimulus effects as the US economy is operating at less than full employment.

However, transporting crude oil by rail would also result in more jobs through infrastructure investments, tank car construction, and ongoing operations. Though not specific to transporting crude oil, the US railroad industry spends $20 billion per year on maintaining and expanding capacity (AAR 2014b). Furthermore, based on approximate figures, the locomotive and tank car investment costs (i.e. not including any infrastructure) would be on the order of up to $6.3 billion to replace the volumes of the Keystone XL (830,000 bbl/d),[66] as compared to the Keystone XL's $5.3 billion cost. Much of this cost would be expended in the US: General Electric (GE) and Caterpillar Electromotive Division (EMD) produce many of the locomotives used in the North American freight industry in plants in Fort Worth, Texas (GE); Erie, Pennsylvania (GE); and Muncie, Indiana (EMD) (Hagerty and Linebaugh 2012). Therefore, transportation jobs would be created regardless of the mode of transport, making it a poor metric by which to distinguish the performance of the two modes.

Energy Security

The geographic scale of the pipeline and rail network is a potential consideration in terms of the tradeoffs between the two modes, because it has energy security implications. As discussed in the section on economic impacts, pipelines rates are generally less than railroad rates, which improve the *affordability* of the oil. Additionally, pipelines, as they are used only for the purposes of shipping crude oil, are likely more reliable in terms of ensuring that a particular refinery receives a continuous supply of oil (Frittelli et al. 2014), thus also enhancing energy security by making the oil supply more *available* and *affordable* to refiners. Railroads though are advantageous in terms of energy security as they can serve more refineries than pipelines due to the geographic scope of the railroads, in particularly refineries on the east and west coasts of Canada and the US, which are not served by pipelines from Alberta or the Midwest and thus currently import oil from abroad (CAPP 2013). Therefore, when considering a national or North American scale, pipelines and railroads are complementary to energy security. However, in the case of the Keystone XL proposal, where the goal were to ship a continuous supply of oil between one origin and one destination, i.e. from Alberta and the USGC, then pipelines are somewhat advantageous in terms of energy security, particularly for those refineries along the USGC. However, as discussed in **Section 3.1.3** on energy security, these benefits are modest.

[66] In coming up with this figure, the author assumed a cycle time of 21 days, a tank car capacity of 525 bbl/car, and a requirement for two locomotives per 100 car train. These assumptions are detailed in Table A-6 of Appendix A. The approximate cost of a locomotive and tank car is $2 million and $0.15 million, respectively (Hagerty and Linebaugh 2012, Stevens 2014). The total cost figure also assumes that entirely new investments would be required to transport the crude oil.

Greenhouse Gas Emissions

Generally, pipelines produce fewer GHG emissions per barrel than pipelines, but in the case of the Keystone XL and its associated rail route, there are conflicting findings. As shown in **Table 3-2**, the US Department of State finds that rail transport of diluted bitumen produces 41% more GHG emissions per barrel than pipelines. However, one study found the opposite to be the case when shipping oil from Alberta to the USGC. According to Tarnoczi (2013), because the power grid in the US Midwest relies on fossil fuels, as shown in **Table 3-2**, unit trains produce less GHG emissions for shipping the Alberta to the USGC. While the GHG emissions produced by pipelines seem high (i.e. about 46 kg per barrel shipped), there is no theoretical upper bound to this value. As a result, given the range of uncertainty associated with the two studies, it is not possible to tell whether pipelines or railroads produce fewer GHG emissions when transporting bitumen from Alberta to the USGC.

Additionally, the US Department of State's appears to overestimate incremental GHG emissions from rail transport compared to pipelines. The US Department of State assumes that dilbit is transported by rail.[67] In Section 2.2 of the FSEIS (Description of Reasonable Alternatives), the Department of State assumes:

> *For the purposes of the analysis in this Final Supplemental EIS, it has been assumed that dilbit would be delivered to the Gulf Coast,* ***although it is likely that other forms of crude oil would be shipped.*** *(Department of State 2014, p. 2.2-30, emphasis added)*

As discussed in **Section 3.2.1**, refineries desire the bitumen but not the diluent used; thus transporting railbit or rawbit by rail is economically preferred. Tarnoczi (2013) finds that, if the functional unit of interest is bitumen, then decreasing the diluent added would reduce the GHG emissions per barrel of bitumen. Because, the US Department of State assumed the least efficient approach to transport bitumen by rail, the GHG emissions that they calculate are perhaps overestimates GHG emissions.

Collectively, these findings suggest that the GHG emissions produced by rail are comparable, if not lower than pipelines (particularly if the Tarnoczi [2013] results are confirmed). The incremental emissions of railroads or pipelines are modest compared to the incremental emissions produced by oil sands production as compared to other crude oils. As discussed in **Section 3.1.2**, the incremental emissions produced by oil sands bitumen as compared to other heavy crude oils imported into the US range between 4,391 to 90,444 gCO_2e per barrel. In the worst case for railroads, the US Department of State (2014) finds that railroads produce 4,308 gCO_2e per barrel

[67] By comparison, Tarnoczi (2013) assumes that railbit (15% diluent) will be shipped.

more than pipelines, which is less than the lower bound of incremental emissions from oil sands bitumen.

Table 3-2: Greenhouse gas emissions from transport modes for shipping Alberta diluted bitumen to the USGC (Source: compiled by author)

	Greenhouse gas emissions for shipping (gCO_2e per barrel)		
	Unit Train	**Pipeline**	**(Rail – Pipeline) Absolute Difference**
Tarnoczi (2013)	13,000	46,000	-33,000
US Department of State (2014, Section 5.3)	14,619	10,311	4,308

However, if railroads were to emit more GHG per barrel transported than pipelines, because the incremental emissions of railroads are produced on all barrels of crude oil transported, but that the "saved" incremental emissions from oil sands production would only be on those barrels of oil that are not produced due to transportation constraints, the incremental emissions from rail transport could be an important consideration. Assuming:

- Total incremental production from the oil sands is approximately 3.0 MMbbl/d between 2014 and 2035;
- Completely constraining pipeline capacity would result in a 0.2 MMbbl/d reduction in production in 2035 to 2.8 MMbbl/d (as per the discussion in **Section 3.2.1**);
- Production and refining of oil sands bitumen results in 47,376 gCO_2e per barrel more emissions than other heavy oils refined in the US; and
- Railroads produce 4,308 gCO_2e per barrel more than pipelines;

Then the incremental GHG emissions produced by rail transport *exceed* the emissions saved from oil sands' production and refining by about 0.94 $MMTCO_2e$/year. If railroads produced approximately 21.4% less emissions than predicted by the US Department of State then there is no net difference in the emissions produced. Thus, even a modest increase in the GHG emissions from transportation component would outweigh the benefits from reduced oil sands production. However, within the range of uncertainty of GHG emissions of bitumen transportation by rail and pipeline as calculated by the conflicting studies, the GHG emissions performance of crude oil transport itself is not a distinguishing factor between pipelines and railroads in the absence of further evidence.

Transportation Safety

Following the accident at Lac-Mégantic involving a crude oil unit train (Transportation Safety Board [TSB] 2014c),[68] there has been particular concern over the issue of transportation safety. Both the AAR (2013b) and the Manhattan Institute for Policy Research (Furchtgott-Roth 2013) analyzed historical safety data for the transport of crude oil by pipelines and railway. A selection of "per barrel" metrics calculated in these analyses are provided in **Table 3-3**.[69] As shown in the table, railroads typically have a higher incident rate than pipelines. In the analysis by Furchtgott-Roth (2013), the railroads had an incident rate about 3.5 times higher than pipelines (i.e. 2.08 incidents per billion ton-miles for rail versus 0.58 for pipelines). However, in these historical data, railroads have a lower rate of amount released per incident, and as a result, railroads have a lower spill rate per ton-mile than pipelines (in barrels per million ton-miles). Therefore, if one were to consider only the environmental implications based on the amount of oil spilled, one could argue that the railroads perform modestly better than pipelines. However, Frittelli et al. (2014) find "location matters more: a major spill away from shore will likely cost considerably less to abate than a minor spill in a populated location or sensitive ecosystem." As a result, detailed route risk assessments would be needed to draw any further conclusions from these findings.

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[68] The Wikipedia entry on the accident also provides a comprehensive summary of the events: http://en.wikipedia.org/wiki/Lac-M%C3%A9gantic_derailment. Of course, it should be read critically.

[69] Some of the values in **Table 3-3** are inconsistent with the calculations in the Final Supplemental Environmental Impact Statement (FSEIS) of the Keystone XL project. In Section 5.3 of the FSEIS, the US Department of State (2014) conducts a risk assessment of rail and pipeline alternatives using historical data. Notably, in contrast to the AAR and Furchtgott-Roth studies, the Department of State finds that shipping by rail will result in greater quantities of crude oil released than shipping by pipelines. The analysis finds that the two exclusively rail routes would be expected release between 1,335 and 1,606 barrels per year (depending on the specific origins and destinations chosen for the analysis) whereas the proposed Keystone XL route would release on average 518 barrels per year (FSEIS Table 5.3-3). The higher rate of spills from rail can partly be explained due to the longer routes required for rail transport from Alberta to the USGC; however, there also appear to be some numerical discrepancies in the results presented. Notably, it is unclear how the State Department calculated the number of incidents per ton-mile of crude oil transported for pipelines. The values for the expected number of releases for rail transport appear in the same order of magnitude with the values found in **Table 3-3** above: i.e. the State Department finds that there are likely to be 3.06 to 3.22 releases per billion ton-miles for rail[69] (as compared to 0.81 to 2.08 incidents per billion ton-miles). However, the incident rate for pipeline transport appears to be several orders of magnitude lower at 0.00543 releases per year per billion ton-miles, as compared to 0.56 to 0.58 incidents per billion ton-miles by Furchtgott-Roth and the AAR. The value of 0.00543 releases per year also appears inconsistent with the values provided in Figure 5.3.3-2 "Number of Releases Per Million Ton-Miles Transported, Crude Oil: Pipeline, Rail, and Marine" of the FSEIS, which suggests that the release rate should be on the order of 0.5 releases per billion ton-miles. The author believes that the State Department did not convert the units from "releases per *million* ton-miles" in the figure and "releases per *billion* ton-miles" in the table. Regardless, these possible numerical discrepancies make it difficult to confirm accuracy of the final estimates of pipeline and rail spills. Therefore, the author is inclined to ascribe more weight the first two results by the AAR and Furchtgott-Roth.

While rail transport may result in less absolute quantities of crude oil spilled, pipelines are safer in terms of risk of injury or fatalities on average. Furchtgott-Roth (2013) finds that railroads have a much higher injury rate than pipelines for the transport of petroleum products, i.e. 0.1925 versus 0.0068 incidents per billion ton-miles, respectively. In other words, railroads appear to have an injury rate that is close to 30 times higher than that of pipelines when one looks specifically at the transport of petroleum products. From Figure 5.3.3-3 of the FSEIS, rail appears to have an injury rate between one and two order of magnitudes greater than that of pipelines, which is consistent with the analysis in Furchtgott-Roth.

Table 3-3: Historical safety record of trains and pipelines in transporting crude oil (Source: compiled by author)

	Railways	Hazardous Material Pipelines
Frequency:	0.81 – 2.08 incidents per billion ton-miles	0.56 – 0.58 incidents per billion ton-miles
Magnitude:	16.4 – 65.7 bbl per incident	266 – 269 bbl per incident
Spill rate:	2.2 – 3.5 bbl per million ton-miles	6.3 - 11.3 bbl per million ton-miles
Injuries:*	0.1925 incidents per billion ton-miles	0.0068 incidents per billion ton-miles
*Requiring hospitalization. These figures were only available from Furchtgott-Roth (2013) **Sources:** AAR (2013), Furchtgott-Roth (2013)		

This conclusion is consistent with the results in an MS thesis from Texas A&M. Shelton-Davis (2007) compared the risk of transporting ethanol by pipeline, road, and rail. After selecting plausible routes for the ethanol to take by each mode from producing areas (i.e. the Midwest) to destination areas along the coasts of the US, she locates accident frequency data by county from PHMSA's Incident Report Database (for pipeline), the FRA Office of Safety Analysis (for rail), and National Large Truck Crash Facts Database (for road). Based on these data, she performs a quantitative risk assessment and developed F-N curves for each mode, which plots the number of casualties (N) on the x-axis and the frequency of events causing more than N casualties (F) on the y-axis. Based on this analysis, she concludes that "pipeline transportation poses the least societal risk" – as she hypothesizes – and rail poses the largest risk. She notes, "both road and rail transportation have higher incidents and fatalities in densely populated areas," which suggests that that the particular routing of rail lines and highways is a key driver of these modes' higher risk.

However, while the AAR does not proffer similar calculations for comparison, both the Railway Association of Canada (RAC) (2013) and the AAR (2014c) critique past analyses of historical data. Along similar lines, an article in *Railway Age*, a trade publication, critiques the statistics used in the Department of State (2014) analysis, suggesting that the data used makes rail appear less safe as

compared to pipelines (Thomas 2014). The article has four concerns in particular with the Department of State analysis:

1. The data used by the State Department includes accident figures for all railroad traffic, not just crude oil or hazardous materials in general;
2. Most deaths on railroads are attributable to trespassing and grade crossing accidents, which, again, are not specific to crude oil transport;
3. Rail traffic has been increasing while trespasser deaths have been decreasing, i.e. there is no positive correlation between the two; and
4. Railroads are required to report every accident, regardless of the size of the spill, whereas pipelines are only required to report incidents involving a spill of greater than five gallons of crude oil.

The second, third and fourth issues raised by Thomas (2014) mean that the historical data available unfairly gives the *appearance* that railroads have a worse safety record than pipelines. Though one could alternatively argue that any death, regardless of how it occurs, is important, the fact that there is no correlation between trespassing injuries and rail traffic means that crude oil traffic increases themselves would not cause more injuries or deaths. Additionally, the fact that railroads have to report any incident, regardless of size, means that their incident rate is going to appear higher than pipelines (which it does in **Table 3-3**) even if the railroads had similar rates of larger spills. Therefore, based on these considerations of the historical data, the safety of pipelines and railroads may be closer than what is predicted by the other studies.

However, the first issue – that the data includes railroad traffic from all commodities – does not suggest that railroad safety is closer to pipeline safety than it appears. In fact, the same issue could be used to suggest that the historical data for railroads underestimates the spill rate. Recent accidents involving crude oil trains suggest that rail accidents involving crude oil have potentially greater *consequences* than previous accidents. The Lac-Mégantic accident released approximately 38,000 barrels of oil (Beaudin 2013), more than the oil released (20,600 barrels) in the largest pipeline spill since the start of Bakken shale oil production in 2006 (Sider 2013) and approximately the same size as the largest onshore pipeline spill in the US (40,000 barrels) (Frittelli et al. 2014).[70] Two other large railroad spills also occurred in 2013, as listed in **Table 3-4**, which, due to their size, call into question the applicability of historical spill consequence data. Heretofore, railroads had not used unit trains to transport crude oil, making judgments based on this historical data difficult because of potential interactive affects between tank cars. For example, in the case of the accident at Lac-Mégantic, the TSB (2014a) found almost all of the tank cars on the train were punctured,

[70] Frittelli et al. (2014) note that they could not conclusively say that this spill was the largest, but that it was the largest that "[they] can document."

thus potentially contributing a fuel source. With full unit trains carrying crude oil, there is the potential for accidents with greater consequences.

Thomas (2014) counters "[the] explosion of illegally classified cargo, *not the runaway derailment*, was the cause of the Lac-Mégantic fatalities" [emphasis added]. However, the initial recommendations by the Transportation Safety Board of Canada (2014a, discussed in **Chapter 5**) suggest that a range of factors, not just the volatility of product itself, contributed to the accident.

However, the above conclusion is not to suggest that characteristics of the crude oil itself do not play a role in the safety of transport. Bitumen does not have the same volatility as the light crude oil from the Bakken formation (Standing Senate Committee on Energy, the Environment and Natural Resources 2013). According to PHMSA (2014) crude oil from the Bakken region "may be more flammable than traditional heavy crude oil." Additionally, according to a Transportation Research Board study, there is no evidence that diluted bitumen increases the likelihood of a pipeline spill (Barteau et al. 2013). In the case of other research, the injury rate is calculated for all petroleum products in the case of Furchtgott-Roth (2013) and the Department of State (2014), and ethanol transport in the case of Shelton-Davis (2007). Petroleum products include potentially more hazardous materials (Furchgott-Roth 2013). The differences between the products shipped are not accounted for in average values and thus further complicate the comparison between modes.

Table 3-4: Major crude oil unit train accidents – January 2013 to January 2014 (Source: compiled by author)

2013 December 30	Casselton, ND	BNSF	9,500 barrels 20 tank cars	Collision with derailed grain train fouling main track	1
2013 November 08	Aliceville, AL	Alabama & Gulf Coast Railway	<9,000 barrels* 26 tank cars	Derailment	2
2013 July 06	Lac-Mégantic, QC	MM&A	38,000 barrels	Runaway and derailment	3

1. NTSB 2014
2. PHMSA Incident Reports Database Search, McAllister 2013, and Karlamangla 2013. The PHMSA Database indicates that 26 tank cars released 685 barrels of crude oil each, which is the approximate capacity of a tank car, but an emergency responder indicated that "most" of the crude oil remained in the tank cars (Karlamangla 2013). Therefore, *at most* 9,000 barrels of crude oil was released, and is the actual amount is likely smaller.
3. Beaudin 2013

In the case of oil sands bitumen, there are concerns regarding the environmental consequences of a diluted bitumen spill. A pipeline spill in Kalamazoo, Michigan in involving diluted bitumen has proven to be particularly difficult to clean-up and is currently costing upwards of $1 billion, the

costliest on-shore spill in US history (National Transportation Safety Board [NTSB] 2012. Railroad transport thus *may* be advantage from a safety perspective because the bitumen can be transported in its raw form (rawbit), which does not flow at ambient temperatures (Fielden 2013a). As a result, it does not require the addition of diluent, which can be highly flammable and its evaporation caused adverse health impacts following a pipeline release in Michigan (Crosby et al. 2013). Thus, it has been argued that shipping bitumen can be safer (e.g. Fielden 2013a); however, the author has not located any paper clearly articulating the potential tradeoffs of shipping bitumen in its diluted versus undiluted form. As a result, it is not possible to say at this point how this consideration might affect the choice between the two modes.

Overall though, given that the proposed rail route from Alberta to the USGC would come within two-miles of 669 communities versus 17 for pipelines (US Department of State 2014, Table 5.3-1), the actual and perceived consequences of transporting crude oil appear higher based on the three studies reviewed. While railroads' historical data safety has more stringent reporting standards for the railroad industry than on the pipeline industry, one cannot use this fact alone to argue that railroads have a comparable safety to pipelines. Other operational changes, such as the use of unit trains, means that historical consequence may in fact underestimate crude oil by rail safety. The author recognizes that there are broader system considerations related to the product being shipped that are not necessarily in the railroads' control, the author believes that the railroads and its regulators will need to address concerns regarding railroad safety if rail is to take a greater role in transporting crude oil. The results from a study of the safety structure of the railroad industry are presented in **Chapter 5**. Having said the above, railroads are a very safe mode of transport overall.

3.2.3 Summary and Transition

Along several dimensions, rail transport of crude oil is more comparable to pipelines than the symbolic debate over the Keystone XL suggests. Rail transport of rawbit by rail is almost comparable in cost to pipeline transport (i.e. within about $0 to $3 more per barrel), and can sometimes be less expensive than shipping by pipelines when small shippers are considered. Additionally, within a range of uncertainty suggested by two conflicting studies, the one cannot conclude that the GHG emissions from railroads are higher than pipelines; in fact, the opposite may be the case. Railroads also have a comparable spill rate to pipelines. However, because of the close proximity of railroads to communities, and the historical data suggesting that railroads have a higher incident rate, public safety is of concern if railroads are to take a greater role in transporting

crude oil. Although railroads have much more stringent reporting criteria than railroads, the potential the use of unit trains means that the consequences may be greater than the historical data suggests. Therefore, though railroads are very safe overall, further study of safety controls for crude oil by rail transport should be considered. Safety of rail transport is addressed in **Chapter 4**.

The above discussion compared and contrasted the performance of pipelines and railroads from a static perspective, yet uncertainty remains over whether railroads could sufficient add capacity to transport all of the expected production increase from the oil sands. Similarly, from the railroads' viewpoint, the question remains whether they should invest in capacity given the uncertainty over permitting decisions by the American and Canadian governments. Before concluding this chapter in **Section 3.4**, a modeling approach is used in **Section 3.3** to understand the this uncertainty and the implications for railroads and governments.

3.3 UNDERSTANDING THE UNCERTAINTY: A DYNAMIC PROGRAMMING APPROACH

A dynamic program is used to determine if and when railroads would invest in capacity to transport crude oil from Alberta to the USGC, the route of the Keystone XL. Dynamic programming models a situation in which a decision-maker can take actions at various points in time in the future in order to maximize his or her objective function. Of interest in this thesis is how the railroad industry reacts to the growing supply of crude oil from the oil sands. Given their objective function to maximize profit, if and when should railroads invest in capacity to transport crude oil from the oil sands?

The specific problem formulation is given in **Appendix A**. The problem horizon is 20 years starting in 2014. In total, there are five two-year periods and a final 10-year period. At each decision period, the railroad industry can decide whether to invest in capacity (infrastructure and rolling stock) to transport crude oil. Between the first and second, and second and third decision period, governments in the US and Canada will make decisions regarding whether to approve or deny pipeline capacity for exports from the Canadian oil sands. The probability functions used are discussed in **Appendix A**. Railroads can invest now before pipeline-permitting decisions are made, or defer their decision until it is certain that pipelines will not be approved. If the former decisions are made, railroads can make more profits in the short term, but may not be able to recover their investments if pipelines are approved. If the latter decision is made, railroads forgo short-term revenue, but do not run the risk of not being able to recover their investment.

The goal of this research is not to suggest a specific strategy for the railroad industry; it is an aggregate model with all railroads using reasonable assumptions about costs and benefits (the specific numeric values are not publicly available from the railroad industry. Rather, the goal of the model is twofold. First, in conjunction with the other information in this chapter, its purpose is to understand whether the railroad industry, faced with uncertainty over pipeline approvals, should adopt a more cautious posture in this industry or aggressively pursue market opportunities. Second, the results of the model also provide some insights for governments as to the plausible actions of the railroad industry, assuming that the railroads follow the resulting implications from the model. The model thus provides a useful way to study how the uncertainty that governments create over pipeline approvals interacts with the behavior of the railroad industry.

3.3.1 Results and Discussion

Figure 3-5 contains the optimal policy matrices – the mapping between the amount of railroad capacity (*RC*), pipeline capacity (*PLC*) and oil sands supply (*OSS*) in period *t* and the best capacity investment action to take – calculated for the base assumptions used in the analysis. The matrices for time periods 1 (2014), 2 (2016), and 3 (2018) are stacked vertically, and for pipeline capacities of 0.0 and 1.2 MMbbl/d are arranged horizontally. Within each policy matrix, the rows correspond with the railroad capacity (*RC*) and the columns correspond with the oil sands supply that exists that exists at the beginning of the corresponding time period. The cells contain the optimal railroad capacity investment.

		Pipeline Capacity = 0.0							Pipeline Capacity = 1.2						
	RC \ OSS	0.0	0.2	0.4	0.6	0.8	1.0	1.2	0.0	0.2	0.4	0.6	0.8	1.0	1.2
t = 1	0.0	0.0													
t = 2	0.0	0.0							0.0	0.0	0.0	0.0			
	0.2	0.0	0.0						0.0	0.0	0.0	0.0			
	0.4	0.0	0.0	0.0					0.0	0.0	0.0	0.0			
	0.6	0.0	0.0	0.0	0.0				0.0	0.0	0.0	0.0			
t = 3	0.0	**0.6**							0.0	0.0	0.0	0.0	**0.2**	**0.4**	**0.6**
	0.2	**0.4**	**0.6**						0.0	0.0	0.0	0.0	0.0	**0.2**	**0.4**
	0.4	**0.2**	**0.4**	**0.6**					0.0	0.0	0.0	0.0	0.0	0.0	**0.2**
	0.6	0.0	**0.2**	**0.4**	**0.6**				0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.8	0.0	0.0	**0.2**	**0.4**	**0.6**			0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1.0	0.0	0.0	0.0	**0.2**	**0.4**	**0.6**		0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1.2	0.0	0.0	0.0	0.0	**0.2**	**0.4**	**0.6**	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 3-5: Policy matrices for the "base" scenario (MMbbl/d).

Assuming that railroads are operating at capacity, the results imply that they should not invest in capacity in 2014 (t = 1), nor in 2016 (t = 2), even if the Keystone XL and Enbridge Alberta Clipper Expansion are *not* approved. Railroads should only invest in capacity in 2018 (t = 3) if pipelines are

nearing capacity, which implies that in the absence of uncertainty, the market is lucrative for railroads. Of course, there are going to be some specific geographic markets not served by pipelines in which rail transport is desirable regardless of whether pipelines are approved, which the model does not account for. However, on the whole, the base results suggest railroads should be cautious in terms of making any long-term capacity investments in competition with pipelines.

Figure 3-6 compares the policy matrices for the "low" (left) and "high" (high) scenarios (discussed in **Appendix A**). Only under a scenario in which there are *low* probabilities of pipeline approvals should railroads begin investing in capacity in periods t = 1 and t = 2. The results suggest that 0.4 MMbbl/d of capacity could be invested now (in 2014), and an additional up to 0.4 MMbbl/d could be invested in 2016, depending on oil sands supply growth; if growth were large in period 1, then more railroad capacity could built in period 2.

		Low likelihood of pipeline appr.							High likelihood of pipeline appr.						
		Pipeline Capacity = 0.0							Pipeline Capacity = 0.0						
	RC \ OSS	0.0	0.2	0.4	0.6	0.8	1.0	1.2	0.0	0.2	0.4	0.6	0.8	1.0	1.2
t = 1	0.0	0.4							0.0						
t = 2	0.0	0.4							0.0						
	0.2	0.2	0.4						0.0	0.0					
	0.4	0.0	0.2	0.4					0.0	0.0	0.0				
	0.6	0.0	0.0	0.2	0.4				0.0	0.0	0.0	0.0			
t = 3	0.0	0.6							0.6						
	0.2	0.4	0.6						0.4	0.6					
	0.4	0.2	0.4	0.6					0.2	0.4	0.6				
	0.6	0.0	0.2	0.4	0.6				0.0	0.2	0.4	0.6			
	0.8	0.0	0.0	0.2	0.4	0.6			0.0	0.0	0.2	0.4	0.6		
	1.0	0.0	0.0	0.0	0.2	0.4	0.6		0.0	0.0	0.0	0.2	0.4	0.6	
	1.2	0.0	0.0	0.0	0.0	0.2	0.4	0.6	0.0	0.0	0.0	0.0	0.2	0.4	0.6

Figure 3-6: Policy matrices for "low" and "high" scenarios (MMbbl/d).

There is also sensitivity to capital costs. If capital costs were lower than the assumed values by 25%, then it is optimal for railroads to invest 0.4 MMbbl/d in time period 1, presumably because there would be time to recoup the capital costs before any pipelines are built. If the capital costs were in fact 50% lower than predicted, then a similar policy to what applies in the "low" probability case would apply.

Collectively, this analysis reveals that in the short term (until uncertainty over pipeline permit approvals is resolved), railroads should be cautious about making investments for routes where they would be in direct competition with pipelines. The risk that the pipelines could be approved dominates the fact that the market would be lucrative for the railroads in the absence of uncertainty.

However, because of the assumptions in this analysis, this conclusion does not suggest that railroads will not transport crude oil. As noted in **Chapter 1**, the growth of the crude oil market in terms of carloads per year is still less than the decline in the coal carloads between 2008 and 2012, meaning that railroads still have additional capacity available to transport crude oil on their networks. Additionally, there may be markets segments in which railroads still compete well even if pipelines are approved, such as with small shippers transporting raw bitumen.

For governments, these results suggest that any hesitation by the railroads in transporting crude oil is partly as a result of the uncertainty over pipeline approval. From the perspective of President Obama in the US, this uncertainty may be desirable in terms of slowing down possible production expansion in the oil sands, thus decreasing GHG emissions. It also maintains pressure on the Canadian government to implement its own federal policy to manage GHG emissions in the oil and gas sector. From the Canadian perspective, they wish to remove this uncertainty by approving proposed pipelines as soon as possible.

3.4 Findings, Conclusions, and Initial Recommendations

In the introduction to this chapter, the author posed the following overarching question from **Chapter 1**:

> In the context of the strategies of the Canadian and US governments related to broader issues of public policy, how does the performance rail transport compare to pipelines? Furthermore, how does uncertainty affect the strategies of the actors?

This chapter addresses this question by first considering the impacts from oil sands bitumen being taken out of the ground, transported, refined, and used in **Section 3.1**. Then, in **Sections 3.2**, the tradeoffs between pipeline and rail transport along economic and other dimensions of societal importance are considered, how this performance might affect oil sands production. Finally, in Section 3.3, the implications of uncertainty on the railroad industry actions are considered, and how the industry's response might affect government actions.

This section synthesizes the information gathered in **Sections 3.1**, **3.2**, and **3.3**. As suggested by the phrasing of the overarching question posed in this chapter, it is not possible to draw conclusions about the performance of pipelines and railroads without considering the specific strategies of the different actors. Thus, specifically, the author synthesizes the findings from this chapter into conclusions and recommendations for the United States (i.e. President Obama and the US

Department of State), Canada (i.e. the federal government), and the railroad industry, before closing with some final thoughts.

United States: President Obama and US Department of State

As discussed in **Chapter 2**, President Obama must decide whether to approve the Keystone XL on the basis that it is in the United States' "national interest." This term is not defined, but, under Executive Order 13337, the president must consider a wide range of viewpoints by "[requesting] the views of, the Secretary of Defense, the Attorney General, the Secretary of the Interior, the Secretary of Commerce, the Secretary of Transportation, the Secretary of Energy, the Secretary of Homeland Security, [and] the Administrator of the Environmental Protection Agency." President Obama has indicated that he is particularly concerned with the climate change implications in his national interest determination (*The New York Times* 2013).

Denying the Keystone XL permit on the basis that it would constrain oil sands production and thus limit climate impacts is a difficult stance to justify. While bitumen production and refining does produce more GHG emissions than other sources of heavy crude oil imported into the US, railroads are capable of transporting significant volumes of this crude oil at a cost competitive with pipelines. Even if railroads could not transport all of the oil, if railroads produce even modestly more GHG emissions than pipelines on a per barrel basis (which cannot be firmly concluded based on the conflicting studies reviewed in this chapter), any GHG emissions decreases from constrained oil sands production could be offset by higher transportation emissions. In other words, the GHG emissions implications are within the margin of error of the available studies.

President Obama could potentially approve the Keystone XL on the basis of enhancing US energy security and economic development. Building the pipeline, as compared to railroads, will increase the reliability of the oil flow to the USGC, thus lowering total logistics cost of shipping the bitumen, and thus making the crude oil more affordable to US markets. Additionally, unlike with railroads, there is no uncertainty as to the capacity that could be provided by the Keystone XL for transporting bitumen. Therefore, oil sands bitumen would be more affordable to the US. However, the energy security benefits are predicated on oil sands being an environmental acceptable source of oil in the long-term; Chan et al. (2012) have found that oil sands production is more susceptible to production reductions in the event of an international climate policy were eventually put in place. More importantly, if one believes that the cost and capacity expansion capability of railroad transport of raw bitumen approaches that of pipeline transport and hence the volume of oil that is

transported to the US is similar regardless of the modality used, then these economic and energy security impacts are also modest.

On an economic basis, the choice of modality does not appear to significantly support or constrain oil sands expansion. Considering other societal impacts also does not offer strong support one way or the other. Direct climate change and economic impacts cannot be used to differentiate the two modes. Pipelines and railroads produce comparable emissions on a per barrel basis (within the range of uncertainty found by the studies looked at in this thesis). Additionally, both rail and pipeline transport would result in investments (and hence jobs) in the US from the manufacturing and construction that would need to take place to transport the expected volumes of crude oil by railroads (infrastructure and rolling stock) or pipelines (infrastructure). Therefore, using these two societal performance metrics to differentiate the two modes is difficult.

Land use and safety impacts are somewhat different between the two modes. Pipelines would have greater land use impacts: if the Keystone XL were not approved, less land would be disturbed than if railroads were used (Department of State 2014, Table 5.3-1). While terminal facilities are required for rail transport, existing rights-of-way would be used to transport the oil. However, railroad safety remains an area of concern particularly given the relatively novelty of the crude oil by unit train modality and the greater proximity to communities. As the Canadian Association of Petroleum Producers (CAPP) (2014b) points out "[pipelines] have long been recognized as one of the safest, most reliable and well-regulated ways to move crude oil and petroleum products," that is, pipelines have a longer history transporting crude oil safely. However, bitumen is not volatile in the same way as the light shale oil is (Canadian Standing Senate Committee on Energy, the Environment and Natural Resources 2013) (and there may be advantages to transporting raw bitumen over diluted bitumen that have not been fully explored), and railroads have stricter reporting requirement than pipelines. Collectively, these findings suggest that (1) neither mode is dominant in terms of all societal impacts, but that (2) regulatory oversight is particularly required for railroads because of the novelty of North American railroads transporting large volumes of crude oil.

Because of the ambiguity that exists in terms of the impacts of approving or denying the Keystone XL, President Obama may be able draw out his decision to achieve his climate objectives. Though the author cannot say whether President Obama has leverage in this situation, there may be factors that can affect it. For example, until (or if) Canada is able to expand pipeline capacity to its coasts,

they may be more interested in negotiations over the issue. While the Canadian federal government has the ability to approve the Enbridge Northern Gateway this summer, there is potential for litigation by pipeline opponents to delay the ultimate permitting process outcome until after the Canadian federal election in 2015. Additionally, as found in **Section 3.3**, railroads may not expand capacity until they are fairly certain pipelines will not be approved, potentially contributing to production constraints. (This analysis assumed that railroads are nearing their capacity limits.) If railroads were to be more hesitant to invest, because of the regulatory uncertainty over pipeline approvals, getting final pipeline permit approvals (or denials) would become increasingly important in Canada. Because Canada benefits economically from oil sands production expansion more than the US, the Canadian government may be more willing to negotiate with the US.

Thus, the path that President Obama takes to decide on approving or denying the Keystone XL may be more important than the ultimate decision that he makes regarding the project. Not only is the choice between pipeline and railroad likely to have a limited impact on oil sands production, it also is likely to have limited impact on the amount used in transportation end use (e.g. Knittel 2013). Other followers of the debate over the Keystone XL have suggested that an approval of the Keystone XL be used to advance other objectives (McNutt 2014, Friedman 2014). For example, Dr. Marsha McNutt (2014), Editor-in-Chief of *Science*, argues:

> *. . . allowing Keystone XL to move forward could advance both goals [of reducing GHG emissions and increasing investment in renewable energy] . For example, President Obama, who has yet to decide on the pipeline, could put conditions on approval that require Canadian authorities to reduce the carbon intensity of extracting the tar from the oil sands and processing it into a liquid petroleum product. As part of a compromise to allow the project to move forward, let's now insist on an income stream from Keystone XL revenues to support investment in renewable energy sources to secure our energy future.*

President Obama could potentially try to redirect the debate from a focus on the question of approval or denial of Keystone XL, to what complementary policies would be necessary if the Keystone XL were approved or denied.

Canada

As discussed in the recommendations for President Obama, because of the significant economic benefits to Canada of oil sands bitumen production expansion, the Canadian government's strategic imperative is to ensure sufficient transportation capacity supports this production growth. However, until pipelines are constructed, Canada is at a disadvantage in that (1) President Obama has less of an imperative to approve the Keystone XL given the domestic political ramifications, and (2) there is uncertainty over whether railroads can develop sufficient capacity to transport oil

sands bitumen, particularly as they may be cautious until they are certain that pipelines will not be constructed. This uncertainty is likely why Foreign Minister John Baird requested that the US provide an early answer on the Keystone XL, even if it meant that the Keystone XL permit were not approved (Koring 2014). In essence, this comment suggests that the uncertainty over the Keystone XL decision is more harmful to the Canadian government's goal of expanding oil sands production than President Obama denying the permit.

As a shaping strategy to reduce this uncertainty, Canada could implement a carbon-pricing scheme to reduce the GHG emissions emitted during oil sands production, and thus reduce US's concerns over the climate change implications of greater oil sands production growth. Though, as noted in **Section 3.1**, there are potential negative economic implications to this decision, ultimately Canada will need to address emissions from the oil sands if it were to attain even its current, modest, emission's targets shared with the US. Providing the economic incentives now will provide incentives to help ensure the necessary GHG reductions-technologies are in place as climate change becomes are more pressing issues in the future.

Canada could also take a hedging strategy and more carefully study the implications of greater crude oil by rail transport along safety and other dimensions. This strategy also has inherent value in that it makes it easier for the Canadian government to make a defensible decision vis-à-vis approving or denying pipeline permits to the east and west coasts if the tradeoffs between rail and pipeline transport are well-known and clearly communicated to the public. A Canadian Senate Committee (2013) study on the safety of hydrocarbon transport in Canada is a useful first step and could be expanded on to consider safety in more depth and other issues, such as climate change, more broadly.

Railroads

From the railroad industry's perspective, the findings in this chapter suggest caution in terms of approaching this market. First, given the uncertainty associated with pipeline permit approvals or denials by governments, it does not appear profitable to invest in capacity, unless that capacity expansion is relatively inexpensive. Of course, this finding is based on the assumption that railroads are nearing capacity, which may not be the case given the decline in domestic coal transport that has occurred in the US. Second, the historical risk data, though not truly comparable between modes, suggests to the casual reader that pipelines are safer. Furthermore, the use of unit trains to transport crude oil is still a relatively new approach in the context of the North American railroad industry. Therefore, arguing that railroads have more stringent reporting criteria alone does not

actually prove that railroads' are as safe as pipelines. Thus, instead of focusing on the historical data, the railroad industry could work to understand how it can transport crude oil safer, such as the potential benefits of transporting bitumen in its raw form, and communicate these results to the public.

As noted in both the discussion of the Canadian and American strategies, if governments were to decide or be forced to rely on railroads to transport greater quantities of crude oil, then scrutiny of railroad safety is only going to increase. The railroad industry should carefully consider what changes may be required to increase railroad safety and communicate these changes to policy makers and the government, instead of being reactive to government regulation.

Final Thoughts

Ultimately, the debate over the Keystone XL has become very symbolic and perhaps displaced attention from more constructive efforts. At the national and North American policy level, the tradeoffs between railroad and pipeline performance metrics considered were modest – often within a range of uncertainty – and certainly less than the symbolic debate over the Keystone XL. Furthermore, the debate over whether the Keystone XL should be approved – a debate focused on a technological solution – detracts from a debate over how to *improve* transportation safety and *mitigate* climate change using policies that specifically address these issues. In other words, greater emphasis should be on efforts to improve the overall system, such as implementing appropriate safety or climate policies, rather than debating the merits of a particular mode.

As a result, in **Chapter 4**, the author considers railroad safety using a novel approach system safety called STAMP. In keeping with the spirit of the above conclusion, the tools relying on STAMP emphasize identifying and controlling hazards, and rather than evaluating safety quantitatively.

4 UNDERSTANDING THE CRUDE OIL BY RAIL SAFETY CONTROL STRUCTURE

Success with the drill did not, however, guarantee financial success. It meant new problems. What were Drake and Uncle Billy to do with the flow of oil? They got hold of every whiskey barrel they could scrounge in the area, and when all the barrels were filled, they built and filled several wooden vats. Unfortunately, one night the flame from a lantern ignited the petroleum gases, causing the entire storage area to explode and go up in fierce flame . . .

Daniel Yergin, author of *The Prize: The Epic Quest for Oil, Money, and Power* (2009), discussing the striking of oil by "Colonel" Edwin L. Drake and William "Uncle Billy" Smith near Titusville, Pennsylvania in 1859 (p. 12).

On July 6, 2013, following a dramatic increase in oil production transported by railroads from just 9,500 carloads in 2008 to 234,000 in 2012 (AAR 2013b), an oil-laden unit train derailed and exploded in Lac-Mégantic, Quebec, levelling its downtown and tragically killing 47 people (Transportation Safety Board of Canada [TSB] 2014c, Cairns 2013b).[71,72] As in 1859, the recent dramatic increase in production, storage, and transport of a hazardous energy resource exposed new safety challenges for those individuals, companies, regulators, and governments involved in the commodity's supply chain.

The accident prompted the question posed in **Chapter 1**: *should* railroads transport crude oil? Responding directly to this question is challenging, however. The transport of crude oil appears to be a lucrative market for railroads and is helping the industry make up for declining domestic coal traffic. Even if railroads did *not* want to transport crude oil, under their common carrier requirements, provided the oil is properly documented and loaded into tank cars meeting government requirements, railroads are generally required to. As a result, this chapter assumes that railroads will continue transport crude oil. The challenge of this chapter is thus to reflect on recent events and consider opportunities to improve safety:

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[71] The Wikipedia page for the Lac-Mégantic Derailment (http://en.wikipedia.org/wiki/Lac-M%C3%A9gantic_derailment) also provides a thorough literature review on the accident.

[72] As a potentially helpful comparison, US railroads have also recently seen significant growth in ethanol transport, from about 70,000 carloads in 2005 to 325,000 carloads in 2010, the latter figures represents about 1.1% of all carloads. The Association of American Railroads (AAR, 2012) previously described "[ethanol] is a small but rapidly growing commodity for railroads." Since that document was published, however, the number of ethanol carloads originated has plateaued (Railroad Safety Advisory Committee 2013), whereas the rail crude oil traffic continues to grow.

> If railroads are to take a greater role in the transportation of crude oil, what considerations of safety at the railroad management and regulatory level should be addressed?

This question is initially addressed in **Chapter 3**, in which pipeline and railroad crude oil transport safety are compared using historical data. While the study provided some insights – rail generally has a lower spill rate than pipelines based on historical data, but that public safety of rail transport remains of concern – there are limitations on the conclusions that can be drawn from an approach relying on historical data. Such analysis, instead of improving safety, can lead to debate that focuses on the technicalities of data collection, for example, as the requirements differ between the pipeline and railroad industries. The analysis in this chapter attempts to avoid this pitfall by considering specific context of the crude oil by rail market, and identifies possible improvements to the management and regulation of crude oil transport by railroads and regulators. In other words, the goal is not to try to compare the safety of rail transport to pipelines, but to find ways to improve rail safety.

In the wake of the Lac-Mégantic accident, most would concur that rail safety warrants scrutiny. However, given railroads and governments have implemented precautions in response to the direct causal factors leading to the accident (as discussed in **Section 4.5.1**), some might question the need for further academic study. For example, some may argue that had the locomotive engineer ensured sufficient functional handbrakes had been applied, the accident would not have occurred. Similarly, had the railroad implemented modest changes to operational practices, such as ensuring the train was parked on the siding (instead of the mainline) would have, arguably, prevented the accident. Now that Transport Canada has put in place prescriptive safety measures requiring such operational practices, and that the Minister of Transport has proposed new tank car and emergency response plan requirements, it is unlikely that a similar accident could occur should the practices be followed (Transport Canada 2013, Mackrael 2014). Thus, some might believe that these actions are sufficient such that further study is not required.

The author agrees that many of the direct causes of the accident have been addressed, but hypothesizes that there are systemic indirect causes that also need to be considered. Specifically, this research is particularly concerned with the adequacy of the railroad industry's risk management structure and processes. Prior to the accident at Lac-Mégantic, as well as the other recent accidents involving crude oil discussed in **Chapter 3**, the rapid growth of the railroad's crude oil traffic allowed the system *to migrate to a higher state of risk*. Previously, railroads typically hauled carloads (not unit train loads) of crude oil. With the use of unit trains, railroads were now

transporting large volumes of flammable material in close proximity, increasing the likelihood of large fires and explosions (Frittelli et al. 2014).[73] Additionally, some crude oil, such as the oil from the Bakken formation, is now generally understood to be more volatile than previously thought (Pipeline and Hazardous Materials Safety Administration [PHMSA] 2014).[74] A Transport Canada committee struck following the accident notes "crude oil was not generally expected to be highly dangerous" (Emergency Response Assistance Plan [ERAP] Working Group 2014). Thus, the transportation of volatile crude oil using a modality not previously used to the transport the commodity help create the circumstances for the accident at Lac-Mégantic could occur.

However, it is unclear what steps the railroad industry and its regulators took to address these risks prior to the accident. Risk control measures are put in place during a risk management process, which Transport Canada (2012b) defines as ". . . the process of identifying risks, assessing their implications [typically the probability and severity of consequences], deciding on a course of action, and evaluating the results."[75] Some in the railroad industry readily admit that this market came upon the railroad quickly – like a "gold rush" – giving rise to the potential for hazards to go unaddressed (Canadian Pacific [CP] CEO E. Hunter Harrison cited in Robertson and McNish 2013). Additionally, two of the three initial recommendations by the TSB (2013a) suggest concern about the risk control measures taken by the railroads:

- *The Department of Transport [Transport Canada] set stringent criteria for the operation of trains carrying dangerous goods, and require railway companies to conduct route planning and analysis as well as perform periodic risk assessments to ensure that risk control measures work, [and]*
- *The Department of Transport [Transport Canada] require emergency response assistance plans for the transportation of large volumes of liquid hydrocarbons.*[76]

It can be inferred from these recommendations that the TSB is questioning the adequacy of the risk control measures taken prior to the accident. More directly, *The Globe and Mail* Editorial Board, a Canadian-based newspaper closely following the accident, opines: "[while] [the] [Canadian] government is to be commended for its actions in improving rail safety . . . they were asleep at the

[73] Manifest trains with multi-commodities also present risks due to the impact from the coupling and recoupling of the cars as the train moves between multiple rail sorting yards (Frittelli et al. 2014). Therefore, this point is not to suggest that unit train are inherently less safe as compared to manifest trains, but that they present new safety when transporting crude oil due to the proximity between the cars.

[74] In the case of oil sands diluted bitumen, there is concern over the environmental impact of a spill of diluted bitumen, particularly following pipeline releases (Crosby et al. 2013).

[75] Risk is often defined as some function of the severity (magnitude) of the consequences of an accident and the probability of the accident occurring (Transport Canada 2012b).

[76] The third recommendation relates to the design and construction of the DOT-111 tank cars used to transport crude oil.

switch before last summer's deadly accident" (*The Globe and Mail* 2013). This author does *not* agree that governments or railroads were "asleep at the switch," but he does share the concern that risks are not being adequately identified.

The issue that this chapter aims to address is why, following the rapid increase in crude oil traffic, appropriate safety control measures were not put into place by railroads and enforced by regulators. The lack or inadequacy of risk management related to the crude oil transportation market is potentially an important indirect causal factor to the incident. Indirect causality is meant in sense of the statement "smoking causes lung cancer."[77] Just as the author cannot say that if one smokes, therefore he or she will develop lung cancer, the author cannot argue, if a railroad risk assessment was not completed, therefore, a train accident will occur. There may be multiple other factors that could cause lung cancer as could cause an accident. However, smoking heightens the chance of getting lung cancer, just as the lack or inadequacy of a risk assessment may contribute to an accident. The latter can help explain why multiple possible physical control actions, such as leaving the train on the siding instead of the mainline, were not taken (instead of interpreting them as a series of independent random events) thus providing opportunity to prevent similar accidents following a major operational change with different direct causes.

One could question whether it is possible to consider such indirect causes. The selection of the "root" causal factor is, at best, a reasoned decision of the analyst, and at worst, an arbitrary selection. If an accident were to be viewed as a chain of events, a common accident-causation model in which event X causes event Y, which causes Z, and so on, the selection of the originating event X – the "root cause" – can be based on considerations such as: (1) the familiarity of that event, (2) the ability to correct something to avoid that event, (3) the lack information backwards in the chain beyond that event, or (4) the political acceptability of that event being the cause (Leveson 2011a). Given this arbitrariness, Leveson (2011a) argues that it is important to consider the entire *process*, not only "events underlying an accident," in order to provide the most insights into how to improve safety following an accident. In the case of this thesis, the author considers how risk management is undertaken in the railroad industry, because the author believes there are opportunities for new insights to improve the safety of the railroad industry.

In the context of crude oil by rail transport, this chapter investigates the safety control structure of the industry, with specific emphasis on the risk management process of the railroad industry. The

[77] Example adapted from Leveson (2011a).

safety control structure, which will be further discussed in **Sections 4.2 and 4.4**, is the mechanism by which institutional and technical constraints are put in place to ensure the system operates safely. The methodology used for this study is known as CAST (Causal Analysis based on STAMP) (Leveson 2011a).[78] CAST is an accident investigation tool based on STAMP, an accident causation model, which is discussed further in **Section 4.2**. The purpose of this study will be to develop an initial set of recommendations for where improvements could be made to the management and regulatory oversight of crude oil by rail transport, as well as to inform future studies on institutional *design* using a complementary methodology to CAST known as STPA (System-Theoretic Process Analysis), a hazard-analysis technique.

The Lac-Mégantic accident, which has been widely reported, is used as the starting point for this study. As a result, the emphasis is on the Canadian railway[79] industry and regulatory landscape. The Canadian landscape is chosen because: (1) much has been written in Canada following the accident at Lac-Mégantic, which will provide insights into the safety control structure of the railway industry; and (2) bitumen, which is the emphasis of the early part of this thesis, originates in Canada. However, because of the interconnectivity of the Canadian and American rail networks, approaches from both sides of the border must be considered to some degree.

Before discussing the analysis results in **Section 4.4**, in **Section 4.2**, the methodology used in this study is further discussed, and in **Section 4.3**, some of the key literature is presented. However, prior to getting into the substantive sections of this chapter, further motivation for this study is provided in **Section 4.1**.

4.1 Is Crude Oil by Rail Transport *Really* a Safety Concern?

Notwithstanding the concerns over crude oil by rail following the Lac-Mégantic accident, railroads are generally a safe mode of transport. As management historian Alfred D. Chandler, Jr. points out in *The Visible Hand: The Managerial Revolution in American Business,* the organizational structure of modern railroads was developed in the 1850s to ensure the safety of railroad operations, illustrating how railroads have had an emphasis on managing safety in their complex operations since nearly their inception. More recently, the Association of American Railroads (AAR) notes that 99.998% of all hazardous material shipments reach their intended destination without release (AAR 2013b). Furthermore, railroad safety has generally been improving, with the number of main-

[78] These methodologies are proposed by Professor Nancy Leveson (2011a) in *Engineering a Safer World: systems thinking applied to safety*, and have proven effective in other industries.

[79] Canadian nomenclature typically refers to railroads as railways. Both terms are used interchangeably throughout this chapter.

track derailments and reportable incidents decreasing involving a release of dangerous goods decreasing in Canada (Cairns 2013b). Overall, railroads can transport hazardous materials safely.

Railroad industry leaders would also point out that railroads transport far more hazardous materials that the railroads have been transporting safely for years, such as toxic-inhalation hazards (TIH, e.g. chlorine and ammonia), from which a release from a single car in a densely populated area could cause hundreds of deaths and injuries. Though not directly comparing crude oil to these chemicals, Norfolk Southern CEO Charles Moorman has previously publicly contemplated "every time we pick up a carload of chlorine, we're placing a bet on the company" (Kemp 2014).[80] One carload of crude oil does not present nearly the same hazard as a carload of a TIH chemical. Prior to the incident at Lac-Mégantic, Canadian railroad executives have previous argued that they have extensive experience hauling hazardous materials. Michael Farkouh, Vice-President, Safety and Sustainability, at CN, notes that railroads have been transporting diesel and aviation fuels for many years.[81] Similarly, Glen Wilson, Vice-President, Safety, Environment and Regulatory Affairs, Canadian Pacific (CP), explains that ". . . [CP has] been moving dangerous goods for well over 100 years . . . so crude oil just falls within that as another class of product that [CP has] to move."[82] While there have been accidents involving these commodities, railroads have developed the capability to transport hazardous materials safely in most situations.

If the railroads can safely transport materials that are more hazardous than crude oil, then why is there a need to consider the safety of crude oil by rail traffic? In particular, because (one could argue) many of the technical and organizational factors that contributed to the accident at Lac-Mégantic have been addressed through orders made by safety regulators in Canada and the US, why is there a need to study the issue further?

First, just because the railroads have had an impressive safety record in the past, does not mean that the public accepts the specific risks posed by the transport of crude oil by rail. Notably, Wendy Tadros, Chairwoman of the Transportation Safety Board of Canada, (2013) comments following the Lac-Mégantic accident:

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[80] In this quote, Mr. Moorman is referring to the financial implications of a TIH release for the railroad industry, but the author believes that the quote should be interpreted more broadly to suggest Mr. Moorman's overall concern with the environmental and public safety consequences of a TIH release.

[81] Michael Farkouh, Vice-President, Safety and Sustainability, and Sam Berrada, General Manager, Safety and Regulatory Affairs, Canadian National Railway Company, presenting to the Standing (Canadian) Senate Committee on Energy, the Environment and Natural Resources, May 23, 2013.

[82] Glen Wilson, Vice-President, Safety, Environment and Regulatory Affairs, Canadian Pacific, presenting to the Standing (Canadian) Senate Committee on Energy, the Environment and Natural Resources, June 4, 2013.

> *In this new environment, it is no longer enough for industry and government to cite previous safety records or a gradual, 20-year decline in the number of main-track derailments. There has been an erosion of public trust, and Canadians require reassurance that action is being taken, that risks are being properly identified and mitigated, and that future movements will be safe.*

Her statement emphasizes that just because rail safety is improving overall, does not mean that the public finds the level of risk associated with crude oil transport by rail acceptable. Leveson (2011a), when defining an accident, notes that "an accident need not involve loss of life, but it does result in some loss that is unacceptable to the *stakeholders*" [emphasis added]. Safety is thus defined to some degree by what the public considers is acceptable.

There are several reasons why the public may be less accepting of the risk posed by crude oil. Bray (2013) compiles several generic factors such as that can heighten the perception of risk, such as: the unfamiliarity of risk, the involuntariness of the risk, the lack of control over the risk, and the potential for catastrophe of the risk. Crude oil by rail touches on several of these factors. First, not only is it arguably relatively new risk (in the public's mind), but also one that has demonstrated that it can have catastrophic consequences, as demonstrated by the accident at Lac-Mégantic. (Even though bitumen is not as volatile as light crude oil, its transport also raises concerns about safety.) Second, the risk posed by crude oil by rail transport is involuntary for the public and there are limited mechanisms through which it can control the risk: other than indirect mechanisms through which individuals can influence regulations, the public does not have control over what or how the railroads transport crude oil. This messaging may have been reinforced by both pipeline proponents, and railroads, who have stated, for example:

- "If infrastructure was permitted for [loading crude oil onto ships] on the West Coast [of Canada] and a request was made to CN, we would respond and do what our business mandate and common carrier obligations call for – move these products as safely and efficiently as we can for the benefit of all Canadians" (CN president Claude Mongeau, cited in Pynn and Hoekstra 2013).
- "Whatever people bring to us, we're ready to haul . . . [if Keystone XL] doesn't happen, we're here to haul" (BNSF spokesperson Krista York-Wooley cited in Efstathiou 2012).

Thus, not only do the public have limited actual mechanisms to control the risk, but the railroads have been reinforcing the notion that they have limited control over whether crude oil gets transported by railroad, perhaps further exacerbating this issue. Third, the debate over crude oil by rail safety is happening in the larger debate over whether oil sands and fracking should be expanded. With other TIH chemicals that railroads must transport, there is no question that at least some chemicals must be transported (Branscomb et al. 2010). In the case of crude oil, the public is

debating whether it is acceptable, from an environmental perspective, to produce and transport bitumen from the oil sands at all. Therefore, as compared to other hazardous materials that the railroads much haul, there is heightened scrutiny and risk perception in regard to crude oil by rail.

Second, there is the opportunity to study of crude oil by rail safety using more systemic methodologies. Following the accident in Lac-Mégantic, there scrutiny over safety concerns has focused on the tank cars used to transport the oil. It is an ongoing concern: the "TSB has been commenting on the vulnerability of Class 111 cars for about 20 years" and found that improved tank car construction would have helped prevent the extent of the consequences following the train derailment and explosion in Lac-Mégantic (TSB 2014a). Changing tank car design is also very difficult safety issue to address given the multiple actors involved in tank car design, construction, and use, including manufacturers, shippers, railroads and regulators. However, there were many other factors that led to the accident worthy of further study. While many of these factors are being considered, such as third-party liability coverage in Canada (CTA 2013a,b), each is often considered in its own respective silo. CAST provides a framework to consider the safety control structure more holistically.

Some research considers rail safety more systemically. Four papers provide a review of possible policy alternatives for improving the safety of hazardous material transport in Canada and the US. Following the Lac-Mégantic accident, Cairns (2013b), writing for the Canadian Transportation Research Forum (CTRF), helpfully describes some of policy alternatives for improving the rail safety in Canada and reviews the positions of the actors in regard to these policies. Around a similar timeframe, Campbell (2013), from the Canadian Centre for Policy Alternatives, a think-tank, describes some of the regulatory-level events leading up to and following the Lac-Mégantic accident. More recently, Frittelli et al. (2014) similarly describes, from the US perspective, some policy alternatives for improving rail safety for crude oil transport. Branscomb et al. (2010) thoroughly review the safety and security risks associated with transporting toxic-inhalation hazards (TIH) chemicals and summarize policies for risk reduction, with a particular emphasis on economic policies (e.g. approaches to deal with the safety and security externality created by the transport of these chemicals). However, as all three papers are primarily literature reviews, they do not propose an analytical framework for considering the interaction and coordination issues among the policies. For example, one of the conclusions of the Branscomb et al. (2010) report was the need to ensure that "[regulatory] authority must be clear and, if not focused in a single organization,

must be consistently coordinated" (p. 63). While these reviews were very thorough, there is still a need for a methodology to understand the relationship between actors and various policies.

At the physical system level, Liu et al. (2013) provide a quantitative framework to identify the optimal risk reduction strategy considering two alternative investments approaches – reduce broken rails and improve tank car design[83] – given a certain budget. The approach is very useful for identifying long-term investment strategies where historical data is well known, and also provides a quantitative framework with which to determine the value of risk reduction (in million dollars per one percent risk reduction). However, the approach does not identify new hazards in new situations (e.g. crude oil by rail) or operational changes that may not be able to be easily quantified. It also does not address the management or regulatory process with which the optimal level of investment is determined. There is thus the opportunity to develop a framework to study operational, management, and regulatory risks more holistically.

This research is complementary to those approaches. The CAST methodology, discussed in **Section 4.2**, provides a method with which to understand potential flaws in the safety control structure and consider policies for improvement, such as those considered in the above literature reviews. It also provides a method to not only consider technical factors, but also institutional factors in the safety control structure, thus complementing the work of Liu et al. (2013). The CAST methodology is now described.

4.2 METHODOLOGY

An accident investigation tool called CAST (Causal Analysis based on STAMP) is used to study the *safety control structure* (discussed below) in place during the Lac-Mégantic accident. CAST is a tool built on STAMP (Systems-Theoretic Accident Model and Processes), an accident causation model (Leveson 2011a). An accident causation model is a set of assumptions, whether formally learned or developed through experience, that exists in the mind of the analyst studying system safety (Thomas 2013). There are other models of accident causation, such as the chain of events model discussed in the introduction of this chapter.

Another well-known model is the "Swiss Cheese" model of accident causation, proposed by James Reason in 1990, which is cited in the literature on the Canadian rail regulatory framework (Thomas 2013, Lewis et al. 2007, Standing Senate Committee on Energy, the Environment and Natural

[83] There are possible improvements, but Liu et al.'s (2013) analysis reveals that broken rails are the most frequent cause of train derailments.

Resources 2013). As shown in **Figure 4-1,** the Reason model suggests an accident will occur when "absent or failed defense" (Thomas 2013) between "hazards and a potential losses", represented by holes in slices of Swiss cheese, temporarily align creating "a trajectory of accident opportunity" through which an accident can occur. Reason argues that these holes are created by both active failures (i.e. operator errors) and latent conditions (i.e. design errors) (Reason 1998), the latter of which "[arise] from the failure of designers, builders, managers and maintainers to anticipate all possible scenarios" and put in place the necessary safeguards and barriers mentioned above. Like the basic model discussed in the introduction, the Swiss Cheese model thus suggests a linear-chain-of-events, i.e. accidents will be prevented one can block or plug a hole with an additional defenses or reduce the size of the holes through improving safety cultures. The model also suggests an element of randomness of the holes and independence between the layers of defense (Thomas 2013), such that "[some] gaps will always escape attention and correction" (Reason 1998).

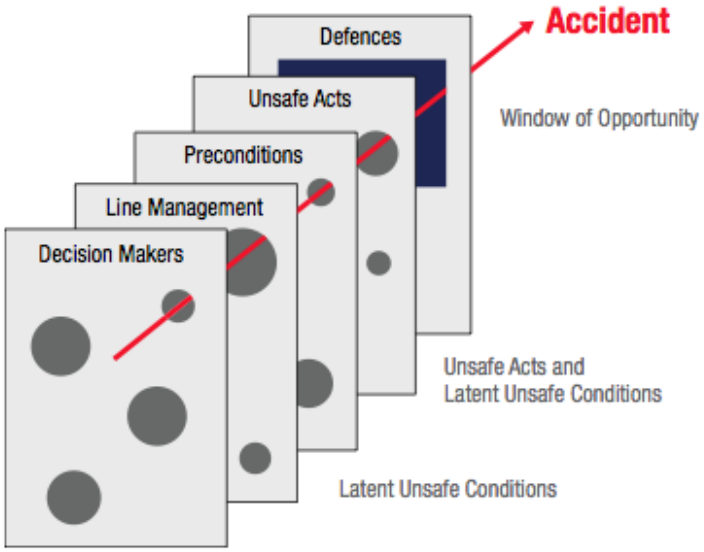

Figure 4-1: Reason's Swiss Cheese model of accident causation (Source: Lewis et al. 2007)

Instead of viewing accident causation as a linear chain-of-events, STAMP views safety as an active control problem in which multiple interacting causal factors – not necessarily failures – result in a hazards that lead to an accident. Specifically, STAMP is based on a hierarchical control structure in which upper-level controllers, based on their process model, provide control actions to lower-level processes or controllers (i.e. the downward arrow), and receive feedback in return (i.e. the upward arrow). Controllers can be automated systems, individuals, organizations, regulators and governments. The process model is the controller's understanding of the relationship between the observed state of the system and how the state could change, such that the controller can determine

what action to take (Leveson 2011a). These control loops, shown in **Figure 4-2**, allow upper-level controllers to impose constraints upon the degree of freedom of lower-level controllers and processes, which allow the safe behavior of the overall system to emerge.

Figure 4-2: Two example of a single control loop: on the left, a controller controls a process and on the right, a an upper-level controller controls a lower level controller (Source: Leveson 2011a [left] and author, adapted from Leveson 2011a [right])

In the case of the Lac-Mégantic accident,[84] the locomotive engineer (the controller) was responsible for applying train car handbrakes (a control action on the controlled process, i.e. the operation of the train) and for checking that they were functioning using a push-pull test, a mechanism to receive feedback from the physical system (Dummett et al. 2013). If the handbrakes were not functioning as intended, the push-pull test could provide the locomotive engineer some information about the current state of the controlled process with which to take further action. The locomotive engineer's process model would be that if the train moves (i.e. the observed state of the system) more handbrakes need to be applied. If this control loop functioned as intended, a constraint would have been imposed on the train preventing it from rolling down the hill (i.e. restricting its degrees of freedom).

As shown in as shown in **Figure 4-3**, such a control loop is situated within a larger hierarchical control structure: politicians pass legislation, which requires regulators to create regulation to constrain the behavior of company management, which is reflected in company rules affecting the behavior of individual employees, who then control the physical system. Simultaneously, there is a feedback structure among these multiple levels in the hierarchy. Following the above example, the locomotive engineer would have likely applied the handbrakes following some company policy, which is required by rules promulgated by Transport Canada. There are other control loops associated with ensuring the functioning of the handbrakes by maintenance and inspection. The key

[84] This example, while based on the accident at Lac-Mégantic, is only used to illustrate the idea of a control loop.

to this research is to understand the functioning of these control loops and their potential interactions.

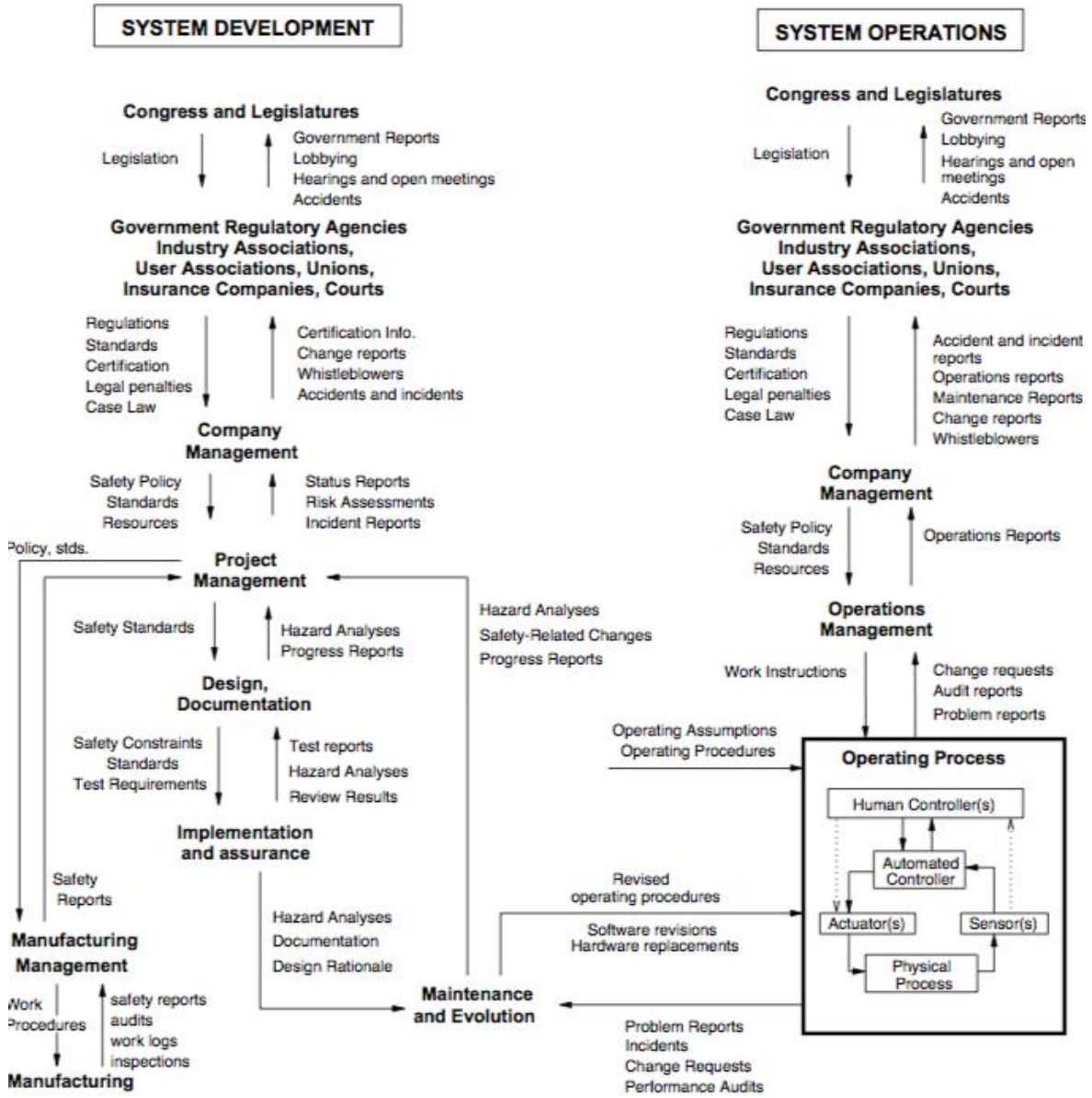

Figure 4-3: Hierarchical control structure assumed in STAMP (Source: Leveson 2011a)

CAST is a tool built on the STAMP mental model of a system. The emphasis of CAST is not on assigning blame or falling in a trap of hindsight bias, in which the analyst gets trapped into thinking about what the actors *should* have been done leading up to an accident; rather it is on understanding the behavior of the actors in the control structure given the context they were in at the time. Readers will see this emphasis as they read through the steps of CAST cross-referenced with their location in this chapter (Leveson 2011a):

1. *Identify the system(s) and hazard(s) involved in the loss.* ***(Section 4.4.1)***
2. *Identify the system safety constraints and system requirements associated with that hazard.* ***(Section 4.4.1)***
3. *Document the safety control structure in place to control the hazard and enforce the safety constraints. This structure includes the roles and responsibilities of each component in the structure as well as the controls provided or created to execute their responsibilities and the relevant feedback provided to them to help them do this. This structure may be completed in parallel with the later steps.* ***(Section 4.4.2)***
4. *Determine the proximate events leading to the loss.* ***(Section 4.5.1)***
5. *Analyze the loss at the physical system level. Identify the contribution of each of the following to the events: physical and operational controls, physical failures, dysfunctional interactions, communication and coordination flaws, and unhandled disturbances. Determine why the physical controls in place were ineffective in preventing the hazard.* ***(Section 4.5.2)***
6. *Moving up the levels of the safety control structure, determine how and why each successive higher level allowed or contributed to the inadequate control at the current level. For each system safety constraint, either the responsibility for enforcing it was never assigned to a component in the safety control structure or a component or components did not exercise adequate control to ensure their assigned responsibilities (safety constraints) were enforced in the components below them. Any human decisions or flawed control actions need to be understood in terms of (at least): the information available to the decision maker as well as any required information that was not available, the behavior-shaping mechanisms (the context and influences on the decision-making process), the value structures underlying the decision, and any flaws in the process models of those making the decisions and why those flaws existed.* ***(Section 4.5.2)***
7. *Examine overall coordination and communication contributors to the loss.* ***(Section 4.5.2)***
8. *Determine the dynamics and changes in the system and the safety control structure relating to the loss and any weakening of the safety control structure over time.* ***(Section 4.5.2)***
9. *Generate recommendations.* ***(Section 4.6)***

Because much is still be determined about the causes of the Lac-Mégantic accident, the application of CAST in this chapter is as an analytical framework to review the existing literature and information on the safety control structure for hazardous material transport by railroads. It should not be considered less a specific accident investigation, nor is the study specific to the Montreal, Maine & Atlantic (MM&A) involved in the accident. The analysis results are discussed in **Section 4.4**. Before providing the analysis results, a description of some of the key literature reviewed is provided next in **Section 4.3**.

4.3 LITERATURE REVIEWED

In addition to the brief methodological review in **Section 4.2**, in conducting this analysis, the author reviewed Canadian rail safety legislation and regulation as well as several important reports on rail safety in Canada.

Canada's Railway Safety Act (RSA), Transportation of Dangerous Goods Act (TGDA), and Canada Transportation Act were also reviewed, along with relevant associated regulation, for this analysis.

The former two acts pertain to railway safety specifically and dangerous goods (hazardous materials) transportation by any mode, respectively. The Canada Transportation Act primarily pertains to economic regulation of railroads; however, one section gives the Canadian Transportation Agency to issue or revoke a Certificate of Fitness to railroads, which is required to operate in Canada.

In 2006, the Railway Safety Act Review Panel was initiated following a string of accidents across Canada between 2002 and 2005, (Lewis et al. 2007). In 2007, the Panel issued a report detailing the overall rail safety regulatory framework in Canada. The emphasis of the Panel's work was to review the "efficiency", "effectiveness" and "operations" of the overall regulatory framework and specific sections of the RSA, as well as to address concerns pertaining to the environmental impacts of rail accidents. The report contained 57 recommendations (Lewis et al. 2007), which were later supplemented by 14 recommendations from a parliamentary committee in 2008. This report is almost certainly the most comprehensive review of Canada's rail safety regulatory framework considered, and was supplemented by several, more detailed, consultant reports (such as SMS Aviation Inc. [2007]).

The RSA includes provisions for railroads to implement safety management systems (SMS) in additional to the other rules and regulations required under the RSA. In 2010, Transport Canada issued "A Guide for Developing, Implementing and Enhancing Railway Safety Management Systems," which explains, in more detail, Transport Canada's expectations for the implementation of the SMS at each railroad (Transport Canada 2010a). Included in this guide are two annexes, which contain generic examples of content for each section of the railways' SMS. Because each railroad's SMS documentation is not publicly available, this documentation will be used in this research as indicative of what each railroads' SMS may look like.

Other more recent reviews of the railway safety in Canada have been conducted. Starting in 2012 and reporting in 2013, the Standing Senate Committee on Energy, the Environment and Natural Resources studied the safety of crude oil transportation in Canada by pipeline, rail, and marine modes. While it was not intended to focus on rail, the accident at Lac-Mégantic raised further issues with the safe transportation of crude oil by rail that are addressed in the report. The report notes that "earning a social license" – i.e the "broad approval by society (at the local, regional and/or national level) for a given activity or projects" – is a critical component of being able to transport hazardous energy resources to market (Standing Senate Committee on Energy, the Environment

and Natural Resources 2013). This concept is based on the notion that "every company needs tacit or explicit permission from governments, communities, and numerous other stakeholders to do business" (Porter and Kramer 2006). Beyond citing the specific report, evidence given by regulators, railroad companies, and The Pembina Institute, an environmental think-tank, at hearings was also considered in the analysis in this chapter.

In 2013, the Auditor General of Canada (2013) completed an audit of Transport Canada, which heavily emphasizes a review of Transport Canada's policies and procedures for overseeing each railroads' SMS. The report notes that it "was not designed to conclude on whether individual federal railways or the rail industry in Canada are safe," though it did find several issues, such as concerns with Transport Canada's ability to audit each railroads' SMS, which raises safety concerns. It also follows up on some of the recommendations made by the 2007 Railway Safety Review panel to see whether they had been implemented.

In the fall of 2013, following the accident at Lac-Mégantic, The Canadian Transportation Agency (CTA), Canada's economic regulator, initiated a Review of Railway Third Party Insurance Coverage Regulations. At the start of the review, the CTA (2013b) issued a discussion paper outlining the current regulations and posing 14 questions for stakeholder consideration. Information in this discussion paper was considered and some responses provided by railway stakeholders on January 21, 2014, were also reviewed.

In order to seek more information about the each railroads' SMS, on January 22, 2014, the author filed an Access to Information Request with Transport Canada, which, broadly stated, requested information pertaining to CN and CP's SMS.[85] Transport Canada responded on February 20, 2014, that "no records were found that contain the information that you are seeking," but that "Transport Canada Inspectors have access to the records on site of inspection, however the documents are not

[85] The request asked for " . . . Safety Management System (SMS) documentation of the Canadian National Railway Company (CN) and the Canadian Pacific Railway (CP) submitted to Transport Canada (TC). Although the request is for the complete document, the request is particularly interested in SMS documentation on the following subjects: (1) CN and CP's policies and procedures for handling hazardous commodities (NB: This request is cognizant that there are security concerns around this subject. This request is not interested in particular operating procedures [e.g. specific routings], but rather, CN and CP's description within its SMS of its broader roles and responsibilities for dealing with hazardous commodities). (2) CN and CP'S policies and procedures for updating the SMS in response to or in anticipation of new hazards (3) CN and CP's policies and procedures for assessing risks in response to or in anticipation of major operational changes (including, but not limited to, the transport of new commodities) In addition, this ATIP requests any correspondence between CN and CP's and TC (since 2011) pertaining to the transport of crude oil (including bitumen), including but not limited to, any proposed or discussed modifications to the SMS of both railroads to transport this commodity."

collected by our Department." It was confirmed with Transport Canada that while inspectors may view documents when they complete the inspection, no copies of these documents are kept.[86]

On March 17, the author emailed a request to Transport Canada for information pertaining to the Advisory Council on Railway Safety (ACRS),[87] a council to advise the Minister of Transport on issues of railway safety, but was directed to file another access to information request because "the none [sic] published information is not of public domain as it involves a third party." These two requests and their responses have been included in **Appendix B**.

Along with regulatory review documents, documentation available from railroad companies was also considered. Though CN was not involved in the Lac-Mégantic, some information regard CN's SMS was located in the public domain. CN issued a "Leadership in Safety 2013" document highlighting its safety efforts in 2012. The document notes that CN undertakes risk assessments prior to operational changes and currently maintains a database of over 140 risk assessments on the company's intranet. It indicates that unionized employees are involved in these risk assessments, and that they also have a separate process for local, field level risk assessments. The documentation does not contain any information on the specific methodology or approach used, or when undertaking a risk assessment becomes necessary. CN also maintains safety guidelines for customers on its web site.

Less documentation pertaining to CP's SMS were located in the public domain. However, on CP's website, it also maintains a customer safety handbook. However, it does not have any specific information regarding its SMS that is readily available.

Finally, recent information published and directives issued by the Transportation Safety Board of Canada (TSB), Transport Canada, the Federal Railroad Administration (FRA), and Pipeline and Hazardous Material Administration (PHMSA) following the Lac-Mégantic accident has also been reviewed.

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[86] Telephone call with Celine Paquette, Transport Canada, March 20, 2014.

[87] The email was a "request information on the work of the Advisory Council on Railway Safety (ACRS). . . Besides some specific press releases (e.g. http://tc.gc.ca/eng/mediaroom/releases-2013-h140e-7389.html) and the original terms of reference of the ACRS (http://www.tc.gc.ca/eng/railsafety/rsar-299.htm), I have been unable to locate on the Transport Canada any updated and specific information regarding the council's current structure, membership, contact information, and ongoing work (e.g. meeting minutes). . . .Would you kindly let me know if this information is posted, and if so, where it can be located? If it is not available online, would you direct me to the person who is best positioned to respond to my request, please?. . . "

Collectively, this literature was used to apply the CAST methodology. Now that the key literature used in the analysis has been outlined, **Section 4.4** provides the results of the analysis.

4.4 SAFETY CONTROL STRUCTURE

4.4.1 High-level Accidents, Hazards, and Safety Constraints

The first and second steps of CAST are to identify the accidents, hazards, and safety constraints that can lead to the loss of concern, which can include the "[include] loss of human life or human injury, property damage, environmental pollution, mission loss, etc." (Leveson 2011a). In keeping with the intent of the RSA, in which the overarching objective is to "promote and provide for the safety and security of the public and personnel, and the protection of property and the environment, in railway operations" (Section 3[a]), the concern in this research is the loss of human life, property damage, or environmental degradation that can result from a crude oil spill.

An *accident* is defined as "an undesired or unplanned event that results in a loss." (Leveson 2011a). In the case of the Lac-Mégantic event, the accident of concern a release of crude oil resulting in human injury or death, property damage, and/or environmental degradation.

A *hazard* is defined as "a system state or set of conditions that, together with a particular set of worst-case environmental conditions, will lead to an accident (loss)" (Leveson 2011a). In regard to the transport of crude oil by rail, the upper-level hazards of interest are exposure of the public or the environment (i.e. vegetation, wildlife, soil, water, and air) to crude oil.

While this definition is similar to the definition of an accident, the existence of a hazard does not necessarily imply that an accident has or will occur. For example, if a limited amount crude oil is released while filling tank cars at a terminal but does not reach outside the terminal area and is cleaned up quickly, a hazardous situation existed, but because it did not lead to environmental degradation, an accident did not occur. This definition provides more flexibility to consider alternative constraints to manage the hazard.

These hazards must be enforced by *constraint*s in the safety control structure. In the context of this research, the railroad safety control structure for transporting crude oil must:

1. Ensure that crude oil remains contained in the tank cars; and
2. Ensure, if a release were to occur, that additional exposure of the public and the environment to crude oil is mitigated;

The first constraint is phrased broadly to include ensuring that the crude oil remains in the tanks cars by, for example, (1) preventing derailments and (2) if a derailment were to occur, ensuring that that the tank cars do not allow the crude oil to be released.

The next step of CAST is to document the safety control structure used to enforce those two high-level constraints.

4.4.2 Safety Control Structure

The third step of CAST is to document the safety control structure used to enforce the previously identified safety constraints. As discussed in **Section 4.4.1**, in this analysis, the safety control structure of the railroad industry must prevent the public and the environment from being exposed to crude oil, and should it be exposed, mitigate its impacts.

The railroad control structure is graphically represented in **Figure 4-4** and further described in this section. The system boundary is extended from the railroads both horizontally along the value chain to include shippers, and vertically in the control hierarchy to include the physical-system level and the regulatory levels.

One of the limitations of this representation is that is that it does not include a temporal dimension. The physical-system-level control loops operate on the order of minutes whereas the regulatory-level control loops operate on the order of days, months, and years. For example, the locomotive engineer perhaps takes an hour to apply and test handbrakes and to ensure that they are functioning, whereas for the government to create and implement new regulations may take months, if not years. This time dimension is not represented in **Figure 4-4**.

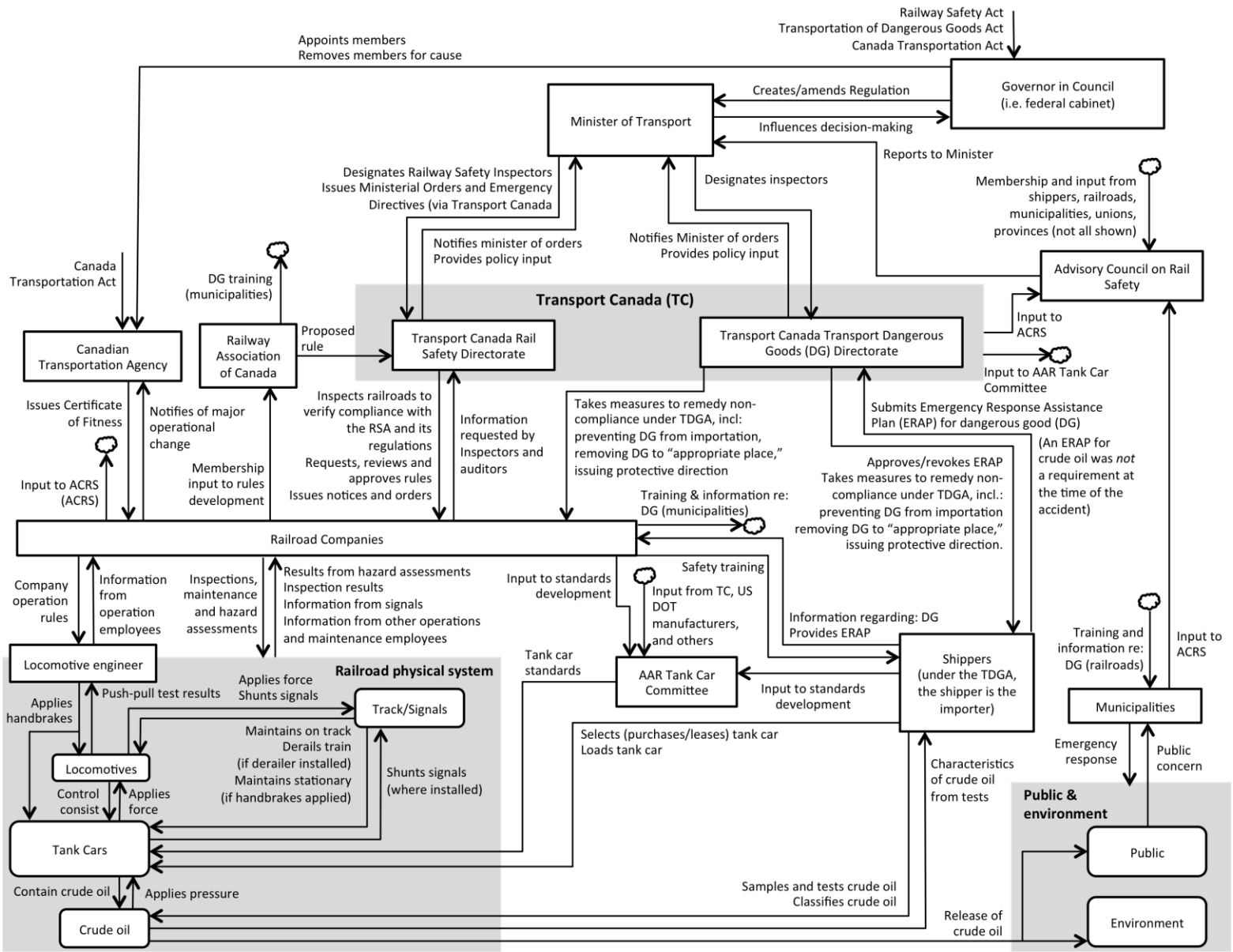

Figure 4-4: Safety control structure for crude oil transportation in Canada (Source: author)

All of the controllers, and the relationships between them, are now discussed in more detail.

Physical Railroad System

Starting at the physical system level, the tank cars are used to contain the crude oil. Newer tank cars have enhanced capabilities to resist punctures along with other design features. An operating locomotive controls the tank car consist by applying air pressure to the braking system.

Track infrastructure ensures that the tank cars remain under control by the locomotive. If the track is equipped with a signaling system, the infrastructure can also provide feedback to the railroad company. For example, if the track is in centralized traffic control (CTC) territory, the presence of a tank car (train) will shunt the signals and provide an indication for dispatchers as to the location of the train (feedback). The track near Lac-Mégantic was not equipped with a signaling system (TSB 2014c).

Railroad Companies

In order to ensure that the physical system operates as intended, railroad companies inspect and maintain the physical system (track and rolling stock) to ensure that they function as intended. Railroads have engineering standards for track and rolling stock, including inspection frequency, which must meet Transport Canada minimum requirements. In regard to physical infrastructure, "Rules Respecting Track Safety" (TC-E-54) dictate inspection and maintenance requirements depending on the track class. These rules also dictate the maximum operable speed of a train, depending on the track class. In regard to rolling stock, railroads must inspect and maintain rolling stock according to "Railway Locomotive Inspection and Safety Rules" (TC O-112) and "Railway Freight Car Inspection and Safety Rules" (TC O-159). Railroads would ensure their own internal standards that meet or exceed these requirements.

Railroads also develop and apply prescriptive operational rules to which operating employees must conform. Specifically, railroad employees involved with rail operations must be qualified using the Canadian Rail Operating Rules (CROR), which have been developed by the Railway Association of Canada and approved by Transport Canada (TC-O-167). The CROR applies to all railways across Canada. Under these rules, the railroad company is responsible under CROR Rule 112 to develop operating procedures for the number of handbrakes required when a train is left unattended. Locomotive engineers are then required to follow these procedures and perform a push-pull test to ensure that the number of handbrakes applied is sufficient.

In addition to these prescriptive operational policies that must meet minimum Transport Canada requirements, under the RSA, Railway Safety Management System Regulations (SOR/2001-37), each railroad is required to implement SMS to control risks. Railroads must identify annual safety targets and carry out a plan to meet these targets, which must be reported to the Minister of Transport. The SMS also require processes for identifying, assessing, and evaluating the risks of new hazards. The SMS is a key component of the Canadian performance-based regulatory scheme, a term which is discussed in more detail at the end of this section.

Shippers

Shippers under the Transportation of Dangerous Goods Act are persons[88] offering the crude oil to the railroads for transport, or persons responsible for importing the crude oil into Canada. In practice, the shipper could therefore be the oil producer, another midstream company, or the customer in Canada who is responsible for importing the crude oil. Shippers are responsible for testing and classifying the crude oil, and selecting and loading the tank car as appropriate according to Transportation of Dangerous Goods Regulation. In the case of the accident at Lac-Mégantic, the shipper would have been the refinery in Saint John, New Brunswick, that was importing the oil (Deveau 2013b).

At the time of the accident, shippers of petroleum crude oil (UN1267, a Class 3 flammable liquid under the TDGA) were *not* required to have an Emergency Response Assistance Plan (ERAP). ERAPs, where required, would detail the response required should be done if a dangerous good is released is released, and would need to be approved by Transport Canada prior to transport. However, under the prescriptive Transportation of Dangerous Goods Regulations (Part 5, Subsection [2] and [8], and Schedule 1), these plans were not required for crude oil at the time.

Transport Canada

Transport Canada is the rail safety regulator in Canada, and the equivalent of the Federal Railroad Administration (FRA) in the US. It also regulates the transport of dangerous goods across all modes, a responsibility of the Pipeline and Hazardous Materials Administration (PHMSA) in the US. Transport Canada is responsible for enforcing the RSA, the TDGA, as well as other regulations pertaining to railroad safety.

Transport Canada's Rail Safety Directorate, which includes Rail Safety Inspectors, is responsible for inspecting the railroad's operations and auditing the railroad's safety management system. Under

[88] A "person" is an individual or an organization.

the RSA, inspectors receive their authority directly from the Minister of Transport (Section 27). Inspectors are given access on the railroad's premises to view documentation pertaining to the railroads' SMS; however railroad documentation remains on site. Inspectors are also required to monitor railway company safety performance using the safety metrics developed under the SMS regulations; however, as of April 2014, these metrics are continue to be developed (Auditor General of Canada 2013).

If inspectors perceive there to be a safety deficiency, they have several tools available as a result of the power delegated to them by the Minister of Transport. Under Section 31, inspectors may issue notices to railroads if railway construction, infrastructure, vehicle, or operation "poses a threat to safe railway operations." If the threat is immediate, they can order a railroad to discontinue the use of the infrastructure, vehicle, or the specific operation creating that threat. Under Section 32 of the RSA, if the Minister perceives there to be a deficiency in railway infrastructure (subsection [1]) or the railroads SMS (subsection [3.1]) that could risk railway safety, the Minister can order the railroad company to correct the deficiency using a Ministerial Order. If there is an immediate threat to railway safety, the Minister can issue an emergency directive that orders the railway company to discontinue a certain operational practice or specifically follow a certain practice as set out in the directive (RSA Section 33[1]).

Transport Canada regulates the transport of hazardous materials through its Transport Dangerous Goods Directorate. It derives its authority from the TDGA, which states that "[no] person [individual or organization] shall import, offer for transport, handle, or transport any dangerous goods unless" that person complies with all application regulations (Section 5). The Transport Dangerous Goods Directorate's Compliance and Response Branch "ensures that [all shippers and railroads] are complying with the regulations through a national inspection, investigation and enforcement program and coordinates the activities of all dangerous goods inspection agencies." Its Remedial Measures Specialists also review and investigate all emergency response plans that shippers of dangerous goods are required to submit. The directorate also has other branches for risk-management research, informing new legislation and regulation, and also provides input to the AAR's tank car committee (Transport Canada 2012a).

The Transport Dangerous Goods Director also enforces some sections of the Transportation of Dangerous Goods Regulations specifically dealing with rail transport. For example, it specifies information pertaining to the location of a dangerous goods in the train consist; notably, a tank car

cannot be located directly adjacent to an operating or occupied locomotive "unless all the railway vehicles in the train, other than engines, tenders and cabooses, have placards displayed on them (Part 10, Section 10.6[1]). There are no restrictions on the use of unit trains to transport crude oil.

There are other control actions that the Directorate is responsible for. First, it reviews and approves/revokes Emergency Response Assistance Plans (ERAPs, a requirement under Section 7 of the TDGA). However, these plans were not required for crude oil at the time of the accident. The directorate, in an emergency, can issue protective directions to persons to "cease [an] activity [that poses a risk to public safety] or to conduct other activities to reduce any danger to public safety," if no other response exists under the TDGA (Section 32).

Canadian Transportation Agency

The Canadian Transportation Agency is the economic regulator for rail transport in Canada and equivalent to the Surface Transportation Board (STB) in the US. In terms of safety, the Canadian Transportation Agency (CTA) regulates the provision of Certificates of Fitness and third-party liability insurance for railroad companies operating in Canada (an authority that the STB does *not* have [CTA 2013b]). The CTA makes the determination on whether the third party liability insurance is adequate (and thus that CTA can issue a Certificate of Fitness) partly on the basis of the "risk associated with the . . . operation of a railway", which includes considering the "class and volume of dangerous goods transported." The CTA has the authority to make regulations as to the adequacy of third party liability insurance.

Under current regulations, the onus is on the railroads to disclose to the CTA whether its insurance coverage has changed or that "a change in construction or operations may mean that its coverage is no longer adequate." However, there is no specific guidance on when a change is significant enough for the railways to inform the agency (CTA 2013b).

Ministerial Level: Federal Cabinet

The Minister of Transport is referred to in the RSA, the TDGA, and the Canada Transportation Act. The Minister has several powers. In Section 19 of the RSA, the Minister can order a railroad company to create rules that they must follow regarding operation or maintenance processes and procedures. Transport Canada (2011) describes the rulemaking process in more detail. Additionally, as discussed, under the RSA and the TDGA, the Minister of Transport can designate inspectors who can take action to ensure that railways are operating in compliance with the appropriate act.

The Governor-in-Council, which, in essence, is the federal cabinet, has the authority to make regulations under the RSA and TDGA. Notably, under the RSA, Section 18 and 47.1, the Governor-in-Council may make regulations pertaining to railroad construction, maintenance, operations and the implementation of each railway's SMS. Under the TDGA, Section 27, the Governor-in-Council has authority to make regulations that specific how dangerous goods are classified, whether they can be transported and under what circumstances, and require safety management systems for transporting certain goods.

Parliament

Parliament, the legislative branch of the Canadian government, passes amendments to the RSA, TDGA, and the Canada Transportation Act. In particular, the RSA includes a provision requiring the legislation to undergo a review five years after the legislation comes into force (Section 51).

Other Institutional Actors in the Safety Control Structure

There are several other actors in the safety control structure that, while important, do not necessarily play a formal role, in the regulatory sense, in the safety control structure:

- Municipalities have an important role in the safety control structure. Their fire department, for example, would likely be the first responders in the event of a release. They are thus concerned about issues of railway safety. At the national level, municipalities are organized into the Federation of Canadian Municipalities, which has a National Municipal Rail Safety Working Group studying rail safety.
- The AAR Tank Car committee, which comprises railroads, shippers, US DOT, Transport Canada, and tank car manufacturers and owners, creates standards for tank cars. Though they not required to, these standards can go over and above government regulations (AAR 2013e).
- In Canada, the Railway Association of Canada can develop rules on behalf of its member railways for approval by Transport Canada.
- An Advisory Council on Railway Safety (ACRS), comprised of members from Transport Canada, railway companies, the Railway Association of Canada, shippers, suppliers, labour unions, provinces, municipalities, and the public, provides input into strategic railway safety issues, including: (1) "*identifying railway safety issues that need to be addressed through new or amended regulations, rules, policies, standards or procedures; (2) "recommending/advising on regulatory priorities;" (3) "ensuring all affected stakeholder views are directly involved in, or consulted on, the development of new or amended regulations, rules, policies, standards or procedures; and" (4) "dialoguing on railway safety issues and possible courses of action.*" (Transport Canada 2008).

Summary

The most important characteristic of the safety control structure is that Canadian railway safety regulatory framework contains a mix of prescriptive and performance-based regulations. Prescriptive regulation includes "[standards,] [rules,] or guidelines for [physical system

characteristics] or . . . processes . . . that are used to determine whether a system should be certified." Railways are required to follow such regulations pertaining to both physical system characteristics *and* process requirements: track must meet certain design standards *and* must be inspected and maintained at specified intervals. Performance-based regulations "focus on desired, measurable outcomes, rather than required product features or prescriptive processes, techniques, or procedures" (Leveson 2011b). For example, in the RSA, each railway is required to have SMS in which railways provide Transport Canada with safety performance measure information, who then would take appropriate regulatory action based on this information.

Prescriptive and performance-based regulations exist along a spectrum in the sense that "performance standards can be either loosely or tightly specified" (Coglianese et al. 2003). For example, Railway Safety Management System Regulations specify that railways must have a process for risk management. In looser performance-based regulatory environment, such a regulation would not necessarily exist: the regulator might only specify that the railway must not have more than X number of accidents per ton-mile per year. By contrast, in a tighter specification, the railway might be required to perform its risk management process according a very specific procedure.

Both prescriptive and performance-based regulations are included in the analysis in **Section 4.5**.

4.5 Analytical Steps of CAST

4.5.1 Relevant Situational Data, Proximate Events, Regulatory History and Regulatory Response to Lac-Mégantic

The fourth step of CAST is to identify the relevant situational data and proximate events leading to the accident.

On July 6, 2013, a Montreal, Maine, and Atlantic Railway (MM&A) crude oil unit-train derailed and exploded, resulting in the loss of 47 people and destruction of the downtown of Lac Mégantic, Quebec, Canada. The approximate location of the accident is shown in **Figure 4-5**. The Transportation Safety Board of Canada (TSB) provides a succinct description of the relevant situational data and the events leading up to the runaway:

> *At about 22:45 Eastern Daylight Time (EDT) on 05 July 2013, Montreal Maine & Atlantic [MM&A] freight train MMA 2 (the train) was proceeding eastward on the [MM&A] Sherbrooke Subdivision, en route from Montréal, Québec, towards Saint John, New Brunswick. . . It was comprised of 5 head-end locomotives, a VB car (a special-purpose caboose), and 1 loaded box car followed by 72 Class 111 non-pressure tank cars loaded with petroleum crude oil. The*

> *waybill information described the product in each tank car as Petroleum Crude Oil, UN 1267, Class 3, Packing Group (PG) III . . .*
>
> *The petroleum crude oil had originated from New Town, North Dakota and was destined to an oil refinery in Saint John, New Brunswick. The tank cars were picked up at New Town by Canadian Pacific Railway (CP) and transported to Montréal. The train, with the same waybill information, was then interchanged to [MM&A].* (Johnson 2013c)

According the TSB, at about 22:50, the train was stopped on the mainline track at Nantes, Quebec, a designated crew change location for the MM&A. After securing the train, the single operator of the train, the locomotive engineer, left for the night. The track had a grade of approximately 1.2% descending into Lac-Mégantic. At 23:50, a nearby resident reported a fire on the lead locomotive to a 911 operator, who dispatched the local fire department. A second MM&A employee attended the scene of the fire. Following fire department procedures, the fire department shut down the locomotive and extinguished the fire (Johnson 2013a), and both the fire department and MM&A employee left the scene. Just before 01:00, the train began rolling down the grade towards Lac-Mégantic, and at 01:15, the 63 of the tank cars derailed. According to the findings of the TSB, the crude oil ignited nearly immediately.

Leading up to the accident, there were other events at the company management and regulatory level raising potential systemic issues. The parent company of MM&A, Rail World Inc., had purchased the former CP mainline in 2003. According to media reports, partly due to the shut down of a major forest products customer, the MM&A was under financial pressures leading to wage reductions (Turcotte 2003) as well as maintenance concerns (Mackrael 2013). In 2012, the MM&A also began using single-person train operations (Deveau 2013a).

Additionally, railway safety regulation in Canada had undergone notable changes in the years leading up to the accident, as shown in **Table 4-1**. Most importantly in the context of this research was the introduction of the SMS requirements in 2001. While these requirements are nearly 15 years old, they are relatively new in the context of the 175-year-long history of railroading in Canada.[89]

Following the accident at Lac-Mégantic, the TSB sent several letters to safety regulators in Canada and the US (Johnson 2013a,b,c,d). Several of these letters pertained more specifically to rail safety. On July 18, the TSB sent two letters to Transport Canada (Rail Safety Directorate) advising it to

[89] Coincidentally, the terminus of the first railway in Canada, the Champlain and Saint Lawrence Railroad, and of the MM&A, are in approximately the same location (Marsh 2014).

consider changes to CROR Rule 112, which pertains to ensuring sufficient hand brakes are applied when equipment is left on tracks, as well as to consider rules for ensuring that equipment carrying dangerous goods are "are not left unattended on the main track" (Johnson 2013a,b).

Table 4-1: Regulatory events leading up to the accident at Lac-Mégantic (Source: compiled by author).

1989	The Railway Safety Act (RSA) comes into force, which was one component of a shift separating the economic and safety legislation overseeing the railway industry (Lewis et al. 2007).
1995	Canadian National Railways, a government-owned Crown corporation, is privatized.
1999	Parliament adds requirements in the RSA for railways to establish a safety management system (SMS)
	Transport Canada's Rail Safety Directorate establishes a "Railway Safety Consultative Committee (RSCC), but as of 2007, had not met since 2001. Lewis et al. (2007) found that the committee grew to 130 members, making action by the RSCC difficult. The executive of the committee had met irregularly up until at 2006, and is inactive. (In the US, the Railroad Safety Advisory Committee is tasked to develop recommendations on specific safety tasks, notably studying FRA rulemaking).
2001	The Railway Safety Management System Regulations come into effect.
2007	The Railway Safety Act Review Panels (Lewis et al. 2008) provided 57 recommendations following a string of high-profile accidents, which were later supplemented by 14 recommendations from a parliamentary committee in 2008 (Auditor General of Canada 2013).
2008	Following the conclusion of the Railway Safety Act Review Panel, the terms of reference for a Advisory Council on Rail Safety are published (Transport Canada 2008).
2009	The Canadian government provided $43 million to improve railway safety management regulation and Transport Canada's oversight (Auditor General of Canada 2013).
2011	The Association of American Railroads (AAR) adopted higher standards for new tank cars transporting crude oil ordered after October 1, 2011 (AAR 2013e).
2012	The RSA is amended following the review in 2007 (Cairn 2013b).

Partly in response to this advisory, on July 23, Transport Canada issued an emergency directive that ordered rail operators to:

- *Ensure that no locomotive attached to one or more loaded tank cars transporting dangerous goods is operated with fewer than two qualified persons on a main track or sidings;*
- *Ensure that no locomotive attached to one or more loaded tank cars transporting dangerous goods is left unattended on a main track;*
- *Ensure, within five days of the issuance of the directive, that all unattended controlling locomotives on a main track and sidings are protected from unauthorized entry into the cab;*
- *Ensure the directional controls, commonly known as reversers, are removed from any unattended locomotives, preventing them from moving forward or backward, on a main track or sidings;*
- *Ensure that their company's special instructions on hand brakes are applied to any locomotive attached to one or more cars that is left unattended for more than one hour on a main track or sidings;*
- *Ensure that, in addition to complying with their company's special instructions on hand brakes referred to in the item immediately above, the automatic brake is set in full service position and the independent brake is fully applied for any locomotive attached to one or more cars that are left unattended for one hour or less on a main track or sidings.* (Transport Canada 2013)

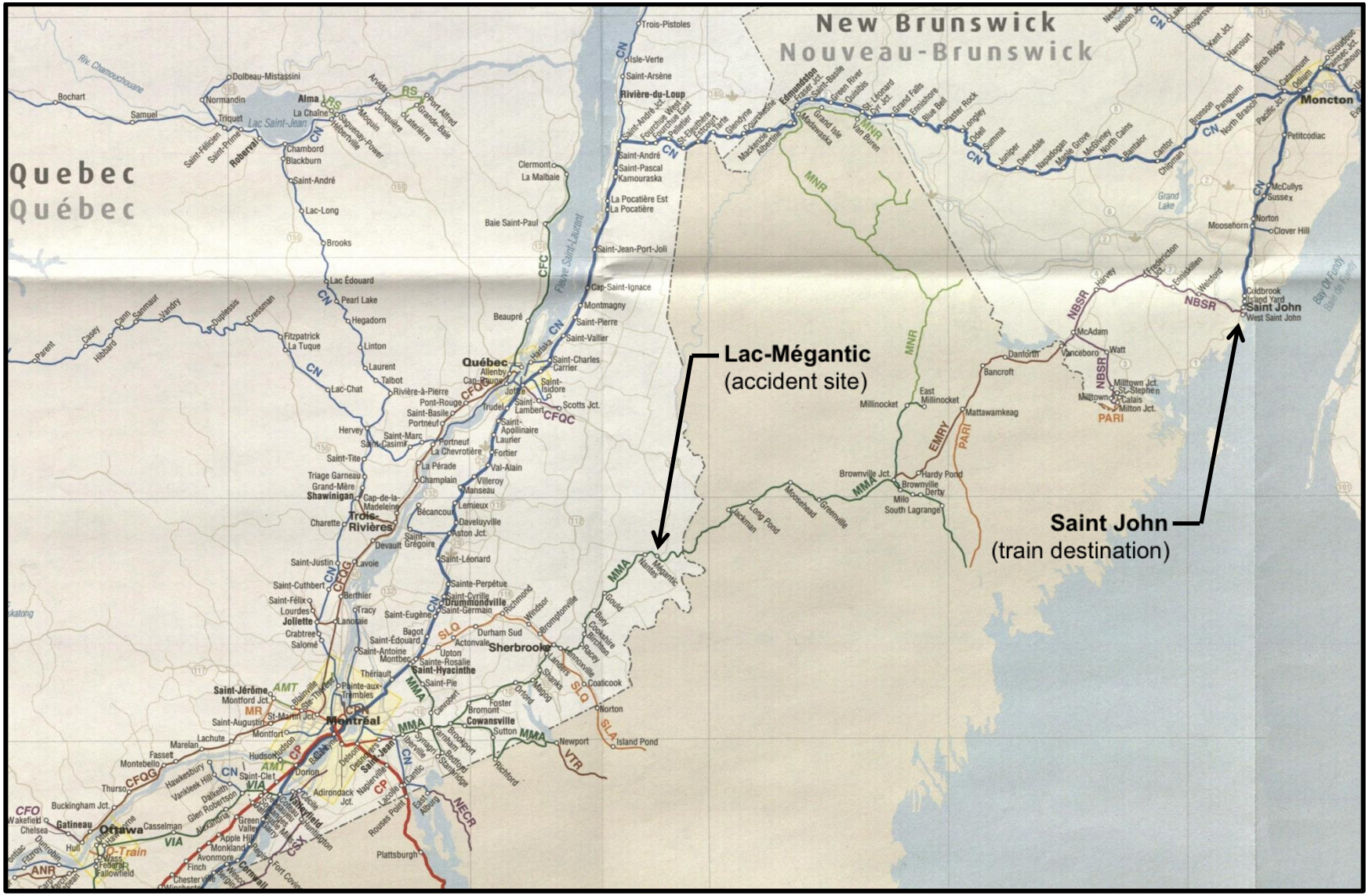

Figure 4-5: Map of the MM&A and CN routes from Montreal to Saint John (Adapted from: Railway Association of Canada 2012)

In regard to the issue of trains left unattended, on November 20, the Railway Association of Canada (RAC) submitted revised Canadian Rail Operating Rules (CROR) on behalf of its member companies, which were approved by Transport Canada rules on December 26 (Transport Canada 2014b).

Some of the issues raised in the letters sent by the TSB pertained more directly to the crude oil being transported and its containers. On September 11, the TSB sent a letter to the PHMSA and Transport Canada (Transport of Dangerous Goods Directorate) advising them that the crude oil in the Lac-Mégantic accident was not properly labelled (Johnson 2013c,d). This concern was later confirmed through testing (TSB 2014b). The crude oil involved in the accident had a lower flash point (i.e. was more volatile) than the packaging group it was assigned by many of the shippers.

In response, on October 18, Marie-France Dagenais (2013a), Director General of the Transport of Dangerous Goods Directorate of Transport Canada, issued Protective Direction No. 31, requiring railways and shippers to perform classification testing for any crude oil being transported in Canada, and provide the results of these tests to Transport Canada upon request. If the crude oil is not tested, it must be classified under the most stringent category, i.e. as a Class 3 Packing Group I material. On November 20, she issued Protective Direction No. 32, requiring railways and shippers to disclose to municipalities aggregate information on the "nature and volume of the dangerous goods the company transports by railway vehicle through the municipality" on a quarterly basis (for Class I railway companies) and a yearly basis or anytime a major change occurs (for non-class I companies) (Dagenais 2013b).

On January 23, 2014, the TSB issued three recommendations to federal ministers that:

- *The Department of Transport and the Pipeline and Hazardous Materials Safety Administration require that all Class 111 tank cars used to transport flammable liquids meet enhanced protection standards that significantly reduce the risk of product loss when these cars are involved in accidents.*
- *The Department of Transport set stringent criteria for the operation of trains carrying dangerous goods, and require railway companies to conduct route planning and analysis as well as perform periodic risk assessments to ensure that risk control measures work.*
- *The Department of Transport require emergency response assistance plans for the transportation of large volumes of liquid hydrocarbons.*

Two of these recommendations were noted earlier in this chapter. Shortly before these recommendations were issued, on January 11, 2014, Transport Canada issued a proposed amendment to the Transportation of Dangerous Goods Regulations updating the tank car design standards (Transport Canada 2014a), addressing the first recommendation.

Canada's transport economic regulator, the Canadian Transportation Agency also took action following the accident. On August 13, 2013 the Canadian Transportation Agency suspended MM&A's Certificate of Fitness, effective August 20 (CTA 2013a). The same month, the Canadian Transportation Agency also launches a consultation process over the regulations for third-party liability insurance requirements for railways (CTA 2013b).

Following the accident, other stakeholders, notably municipalities, have also issued recommendations. On August 23, 2013 the Federation of Canadian Municipalities (2013) "[called] on the federal government to:

- *Equip and support municipal first responders to rail emergencies;*
- *Ensure federal and industry policies and regulations address the rail safety concerns of municipalities;*
- *Prevent downloading of rail safety and emergency response costs to local taxpayers.*

In response to some, but not all, of the recommendations and concerns discussed above, Minister of Transport Lisa Raitt announced several actions that the federal government would take to improve rail safety:

- The least crash resistant tank cars with "no continuous reinforcement of their bottom shells" will be phased out within 30 days by ministerial order;
- Remaining tank cars that do not meet AAR standards promulgated in 2011 will be phased out over three years;
- Emergency response assistance plans will now be required for all crude oil shipments, regardless of the number of cars involved; and
- Trains carrying dangerous goods will now be limited to 80 kilometers per hour and further risk assessments will be conducted in several areas of the country. (CBC News 2014b).

Collectively, these changes respond to most of the recommendations made so far by TSB, except for the recommendation that route planning recommendation be required.

4.5.2 Study of Inadequate Control

This section proceeds through steps five through eight of CAST, inclusive, introduced in **Section 4.2**. The emphasis of CAST is to understand "how and why each successive higher level allowed or contributed to the inadequate control", as well as how coordination among the actors may have contributed to the loss. The emphasis of this analysis is not on assigning blame, but on understanding *why* an actor did not provide sufficient control. Thus, it is important that this analysis be done with an understanding of the context of the decision-maker, i.e. "the information available to the decision-maker as well as any required information that was *not* available, the behavior-shaping mechanisms (the context and influences on the decision-making process), the

value structures underlying the decision, and any flaws in the process models of those making the decisions and why those flaws existed" (Leveson 2011a). This step of the analysis will start first at the physical and operational level, and move upwards in the hierarchy to the company management and regulatory levels.

Physical and Operational Systems

It is almost certain that an insufficient number of car handbrakes[90] were applied to prevent the train from rolling down the relatively steep grade in railway terms of 1.2%. The handbrakes became necessary to hold the train on the grade when the lead locomotive was shutoff following a fire.[91] Shutting down the locomotive engine allowed the air brakes to lose pressure,[92] which were the other set of brakes holding the train stationary.

However, regardless of the fire, CROR Rule 112(a) requires that "[when] equipment is left at any point a sufficient number of hand brakes must be applied to prevent it from moving. Special instructions will indicate the minimum hand brake requirements for all locations where equipment is left." These special instructions are company-specific (McDiarmid 2013). If the number of handbrakes specified in the instructions was insufficient and/or handbrakes did not function as intended, the operator, under CROR Rule 112(c), is required to test the brake effectiveness using the push-pull test.

To date, the TSB has not released their interpretation of the events from the night of the accident. Assuming the operator (the locomotive engineer) did not apply sufficient handbrakes and/or did not perform the push-pull test, there may have been several interrelated contextual factors why the operator took this course of action. The procedure for applying the necessary handbrakes would have been time consuming for both the engineer on duty before the accident and the engineer who

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[90] In a conceptually similar fashion to an automobiles emergency brake, operating personnel apply car handbrakes manually by turning a wheel at one end of the car. Each car is equipped with a handbrake, and railroad operating procedures specify how many handbrakes are required.

[91] The local fire department was called to extinguish a fire of the locomotive (TSB 2014a).

[92] Train airbrakes are failsafe: air pressure from air tanks on each car is constantly being applied to the brakes. For the brakes to come off, the locomotive must be applying air pressure through hoses to each car's brakes. Thus, if cars become disconnected from the locomotive, pressurized air tanks in each car reapply the brakes, because air pressure from the locomotive is no longer being applied. However, when the locomotive is turned off for extended periods of time, the tanks in each car gradually lose pressure as well. The failsafe mechanism is intended for a situation in which cars become disconnected from an operating locomotive, not for situations in which the locomotive is deliberately turned off. A fuller discussion of the functioning of air brakes can be found here: http://www.popularmechanics.com/technology/engineering/understanding-a-runaway-train-how-do-air-brakes-work-15678938.

would have been on duty following the accident. If approximately 16-handbrakes were required[93] and each tank car were approximately 60-feet long,[94] the locomotive engineer would have had to walk 960 feet from the lead locomotive – approximately three football fields long – and back to complete the push-pull test to ensure that the number of brakes were sufficient. Though this type of work is expected as a train operator, because it was a designated crew-change location, the operator may have expected the next operator to arrive shortly. Additionally, the operator had left the locomotive running, which, in the absence of the later shutdown by the fire department, would have ensured that the airbrakes maintained the train stationary on the grade. ICI - Radio Canada (2014) reports that the MM&A had been repeatedly cited by Transport Canada for failing to apply adequate handbrakes at Nantes over a period of several years, as well as an additional time at another location following the accident at Lac-Mégantic. Therefore, whether sanctioned by the company or not, the evidence publicly-available thus far suggests that not applying the required handbrakes become the conventional operating procedure at Nantes.

A related contextual issue is the single-person train operation. Though in general, there is not evidence to suggest that two-person crews are safer overall (Wilner 2014), in these particularly circumstances, the presence of a second operator could have allowed one crew member to get off the train early, while the other train pulled into its final position, saving one one-way of the walk along the locomotive. The locomotive engineer may have also felt safer walking along a train at night with another crew member nearby, and had any medical condition come upon one of the crew members, the other would have been available to respond. Even if the track were equipped with a signalling system, or positive-train control system been installed (which has the ability to brake the train *if* the locomotive is running), neither would have been able to stop the train before Lac-Mégantic, thus making the crew a critical component in the safety control structure. Currently, there is debate over the safety benefits of two person crews, and there is not enough evidence released thus far to suggest the one-person crew contributed to the accident.

Some other operational practices created the conditions for the incident. Because the train was parked on the mainline instead of the siding (which was filled with other cars), there was no track infrastructure that could have derailed the train to prevent it from rolling into Lac-Mégantic.

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[93] The MM&A requirements under CROR Section 112 would require the handbrakes on 16 piece of rolling stock (Jang 2013). McDiarmid (2013) finds a wide range of different standards across Canada for handbrake requirements. They can vary depending on the length of the train and grade. McDiarmid (2013) found instances in which the TSB has determined that more handbrakes were required than the minimum standards set by the railroad required.

[94] http://www.gbrx.com/files/files/NAR/Tank_Cars/Tank30000.pdf

Additionally, no derailer, a device clamped on the track to derail a train if it begins moving unintended, was used. Because the track was not equipped with any signalling system, there was also no way that dispatchers would have known of the runaway. Though installing the latter safety control represents a large expenditure, the former, i.e. parking the train on the siding, likely only represents a modest operational change.

Two factors may have contributed to the magnitude of the accident: the design of the DOT-111 tank cars and the lack of an ERAP. While, given the speed at which the train was moving, it is not clear that improved tank car design would have prevented the accident, the TSB concludes that it would have mitigated its consequences (TSB 2014a). The lack of an emergency response assistance plan requirement meant that it was largely by chance that specialized firefighting equipment was available in Lac-Mégantic following the accident:

> *In this accident, the relative proximity of the [St-Lévis Ultramar] refinery, the availability of the required type and quantity of foam concentrate and the capability to deliver it to Lac-Mégantic in a timely manner provided the firefighters with one of the critical materials to successfully fight the large hydrocarbon fire. However, if this accident had occurred in a community in Canada where supplies and other specialized resources were not available in a timely manner, the emergency response efforts would have been jeopardized (TSB 2014a).*

Fortunately in the case this accident, the firefighting equipment was nearby.

Railroad Companies

The above discussion raises questions about MM&A operations and maintenance oversight. Based on media reports thus far, it is plausible that the MM&A was not ensuring that its employees were applying sufficient handbrakes to the cars and not performing the push-pull verification test (CROR Rule 112). Additionally, because the locomotive caught fire, it appears that the maintenance of the MM&A's rolling stock was poor, although, as the investigation is still ongoing, there is no evidence that MM&A's locomotive maintenance procedures did not meet minimum requirements. Poor maintenance represents an indirect cause to the accident worthy of further investigation.

The above discussion also raises questions about the MM&A's risk management processes. One of the objectives of the RSA is that companies must "demonstrate, by using safety management systems and other means at their disposal, that they continuously manage risks related to safety matters" (Section 3[c])." Specifically, under the SMS Regulations, railways must have a process for identifying, assessing, and controlling risks, updating maintenance, operations and response policies and procedures as necessary. As discussed, there were additional precautions that MM&A could have taken that would have helped prevent and mitigate the accident, including increasing

maintenance frequency, stopping the train on the siding, installing a derailer, and enhancing its emergency response for crude oil. A risk management process may have identified these concerns.

There is the related question about how dangerous goods routing decisions are made by the Canadian railroad industry. As discussed in the introduction, the TSB has recommended that railroads perform route level risk assessments before transporting crude oil (TSB 2014a). A recent media report notes that there are no rules for hazardous material routing guidance in Canada (McDiarmid 2014). As noted in **Section 4.5.1**, CP handed the shipment to MM&A in Montreal. CN has an alternative route to Saint John from Montreal. While routing decisions involve complicated tradeoffs, the financial pressures that MM&A were under financial pressure leading up to the accident, raises questions about the decision to route the traffic over the MM&A at all.

Based on the discussion so far, it is unclear whether risk assessments were not performed by the railroads involved, or whether risk assessments were performed and the risks posed by current operations were deemed tolerable. As much remains to be learned about the Lac-Mégantic accident, for the remaining analysis, the railway industry will be considered generically, i.e. the conclusions will not be specific to any particular railroad. Again, this analysis is not intended to find the specific causes of the accident or assign blame, but seek opportunities for possible rail safety improvements following further research.

Railroads did take some measures to control risks posed by increasing crude oil traffic. For example, the CP, the railroad on which the Bakken crude originated, indicated that it was placing firefighting equipment at strategic locations around its network to deal specifically deal with a crude oil fire. In response to a question at a Canadian Senate hearing on crude oil (bitumen) transport safety, CP provided the following information:

> ***Senator Wallace:*** *When you are transporting bitumen and you are positioning your spill response equipment and resources in the event an incident occurred, are there any special steps you take if bitumen is being carried? Is there special equipment and special expertise you would require from the people who would be directing the response? Does bitumen bring up anything out of the ordinary versus conventional petroleum?*
>
> ***Mr. Wilson [Vice-President, Safety, Environment and Regulatory Affairs, CP]:*** *Yes. In fact, what it does is some of the firefighting equipment needs to be specialized. It takes what is called AFFF foam. Regular water does not work to suppress a fire. We have acquired, I think it is three or four just in the last year of these foam trailers that we have positioned across our*

network and we can deploy them, mix them with local firefighting and basically they pump the water through the trailer to create the fire suppressant necessary.[95]

However, based on other questions, it does not appear that this action was in response to a formal risk assessment of the transport of crude oil or bitumen:

> ***Senator Seidman:*** *. . . Have you participated in studies related to the safe transport of bitumen?*
>
> ***Mr. Wilson:*** *We have not studied it as an isolated commodity per se. We certainly do risk assessments at any new facility to ensure that a facility that comes online is up to standards. We look at marshalling of trains and all kinds of other things. However, as I said at the outset, we have been moving dangerous goods for well over 100 years at Canadian Pacific, so crude oil just falls within that as another class of product that we have to move.*[96]

There are several reasons why railroads formal risk assessment may not have been undertaken specific to the transport of crude oil, and thus why the risk control measures, as perceived with the benefit of hindsight, were not adequate.

First, one of the challenges that the railroad industry faces in performing a commodity-specific risk assessment is that railways are required to ship a variety of hazardous materials offered to them by shippers under the railroads common carrier requirements, including more hazardous TIH chemicals and hydrocarbons such as gasoline and diesel, provided that they are adequately contained in tank cars meeting regulatory standards. As articulated by the quotes in **Section 4.2** and the previous quotation, railroads viewed the transport of this commodity to some degree as "just another" commodity it has to move, which was compounded by the general perception that crude oil was, relatively speaking, not very hazardous (ERAP Working Group 2014). Additionally, in the TDGA, the shipper is generally responsible for preparing Emergency Response Assistance Plans (ERAP), and thus, though railroads are the first responders to an incident, do not consider themselves experts in regard to every hazardous commodity:

> ***Senator Wallace:*** *. . . If there is a derailment, who has the obligation to respond to the spill, recover the product and minimize environmental damage? Is it CP's obligation? Who has the legal obligation to put a spill response plan in place if an incident occurs, such as I just described?*
>
> ***Mr. Wilson:*** *Simply, senator, we do. Canadian Pacific has the obligation to respond, and we do not shy away from that obligation. We take on a lead role in response to a train accident.*

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[95] Glen Wilson, op. cit.

[96] Glen Wilson, op. cit.

> *Because of the nature of the commodities and the vast number of commodities, we rely on shippers for information relating to those products. If it is a product that is subject to an emergency response assistance plan, then that shipper shares some legal obligation as well. It is not necessarily in the sense of being a first responder so much as participating in the safe handling of the commodity. . . .*
>
> ***Senator Mitchell:*** *With the question of the response plan, is it not the case that the shipper has to have a response plan? Do you have to have one as well? How are those two things coordinated?*
>
> ***Mr. Wilson:*** *We do. Ours is very much about train accident response. We cannot have a specific plan to contemplate the unique properties of the hundreds of different commodities that we move. We have a thorough response set to international standards, audited and exercised. Our plan is very thorough, but you cannot contemplate all the various potential consequences of all the various potential commodities that could be on any given train, and there can be multiple commodities on any given train.*

Prior to the accident, an ERAP was not required for crude oil transport, so the railroads may have had limited knowledge of the risks posed by crude oil. Furthermore, the railroads' knowledge of the hazardous material was further eroded by the mislabeling of the commodity type by shippers, who are responsible for testing and classifying the crude oil, based on the hazard it poses (Johnson 2013d). Therefore, unless the railroads had taken specific steps to test the crude oil themselves and/or prepared a response plan, they may not have been aware of the risks posed by crude oil transportation by unit trains.

Additionally, there is the question about whether the volume of crude oil traffic the railroads were transporting would have been sufficient to trigger a commodity-specific risk assessment. Whereas the volume crude oil transported by the MM&A likely represented a large fraction of their traffic, and thus a higher risk to their business, the traffic volumes on the Class I's still only represents a small fraction of their overall business. CN, in a recent letter to the Canadian Transportation Agency, comments in regard to the regulatory obligation to inform the Agency in response increased risks:

> *. . . an increase of X to Y carloads of dangerous goods handled on a shortline may constitute a major change, whereas it may constitute a fraction of a percentage point on a Class (Patenaude 2014).*

In 2012, across all Class I railroads in the US, less than 1% of railroad traffic (by carloads) was made up by crude oil on average. As a result, while the individual shipments increase risks to the communities they pass by, at the railroad executive level, the increased traffic may not have been perceived as an increase in risk. Having said that, this argument is perhaps difficult to justify in the

face of the significant year-over-year growth of crude oil traffic (by carload) of 355% between 2011 and 2012 for the US railroad industry.

Second, in terms of the railroads' risk assessments have tended to focus on specific technical changes in railroad operations being contemplated, not when broader organizational or other strategic changes occur as a result of ongoing operations. This focus was one of findings from the 2007 review panel on railway safety in Canada, who stated:

> *. . . From the Panel's experience, there are not many examples of risk assessments conducted on ongoing operations. Rather, risk assessments tend to be event-based and focus on technical aspects of operations. The identification and assessment of hazards and risks relating to human and organizational factors may be forgotten. As a result, mitigation strategies will not take into account the overall context within which problems occur (Lewis et al. 2007, p. 80).*

Given this comment, that railroads employed unit trains previously to transport other commodities, and that railroads did not view crude oil as a particularly hazardous commodity, it is understandable why railroads did not perform a full risk assessment of increasing crude oil by rail. Transporting crude oil by rail did not require, in the railroads' view, a significant change in their technological operations. Nonetheless, increased risks emerged as a result of both deliberate marketing efforts and shifts in the marketplace, which may not have be subject to the traditional risk management processes employed by the railroads.

In the context in which the railroad industry has previously operated – i.e. as a common carrier – transporting increasing amounts of crude oil by rail may not have triggered a formal risk assessment. This response by the railroads is likely at odds with the public, who are concerned with the risks posed by crude oil transportation. Thus, the issue turns to the regulatory control existed for railroads to implement a risk assessment. First, however, the shipper's responsibilities in the safety control structure are discussed.

Shippers

In the case of the Lac-Mégantic accident, the shipper of the oil would have been the importer of the oil, the Irving Oil refinery in Saint John, New Brunswick (Mackrael et al. 2013). Though they did not require an ERAP, the crude oil in many of the tank cars was mis-classified as less-volatile crude oil than it actually contained (Johnson 2013d). This could have lead to the incorrect selection of tank cars as well as an improper emergency response (Johnson 2013d). Campbell (2013) notes, citing the TSB, that in the case of the Lac-Mégantic accident, "even if the oil *had* been properly classified, it would still have been allowed to be transported in the DOT-111 tank cars [involved in the

accident]." Thus, properly labeling the crude oil would not likely have prevented the accident itself, but may have mitigated the consequences.

One of the practical challenges that Irving Oil may have faced is that they were not the company loading the oil. In fact, there were multiple suppliers of crude oil in North Dakota. The TSB notes that the suppliers provided 10 different material safety data sheets (MSDS) with information that "varied widely and was contradictory in some areas" (Johnson 2013d). Though Irving Oil, as the importer, was responsible for this information, unless they had a testing facility at the loading terminal or the Canadian border, would have likely not been able to verify the accuracy of the information provided. The police have currently seized documents from Irving Oil's headquarters to probe this issue further (Mackrael et al. 2013).

Transport Canada

This section first discusses Transport Canada's oversight role in regard ensuring that railway companies follow prescriptive rules (such as CROR Rule 112) and then discusses its oversight of the performance-based regulations involving each railway's SMS.

Transport Canada had inspected the MM&A several times leading up to the accident, and had previously issued several inspection reports to the MM&A noting that employees had repeatedly not followed CROR Rule 112 (ICI – Radio Canada 2014). Transport Canada noted this repeated non-compliance in a report to the MM&A:

> *Concerning the corrective measures which you propose in your response to the May 22, 2009 notice, consisting of revision of the* ***CROR Rules 112*** *and 104.5 by the employees, where continuous non-compliance were noted. We would like to remind you that these same measures were already put forward on several occasions since 2005 without having obtained the expected results; These corrective measures were previously identified as follows: "We informed our employee to be extremely watchful", May 25, 2005; "Re-training has been conducted we these rules", January 12, 2006; "Safety meetings will be conducted one the following", July 17, 2006; "We informed all our employees to be extremely watchful", May 4, 2007 (ICI – Radio Canada 2014, summary of reports by Transport Canada).*

However, unless a "threat is immediate"[97] under Section 31(3)(b) under the RSA, Transport Canada Railway Safety Inspectors cannot order the railway company to correct a deficiency, but only "inform [the company] of [the Inspectors'] opinion" (Section 31[3][a]). The day following the accident at Lac-Mégantic, following the inspection of another train on the MM&A property, a

[97] Under Section 4(4.1) of the RSA, "a threat is a hazard or condition that could reasonably be expected to develop into a situation in which a person could be injured or made to be ill or damage could be caused to the environment or property, and **a threat is immediate if such a situation already exists**" [emphasis added].

Transport Canada Railway Safety Inspector issued an order under Section 31(3) of the Railway Safety Act requiring the MM&A to ensure that any train left unattended is secured with a sufficient number of handbrakes and confirmed with a rail traffic controller.[98] In this instance, the Inspector argued that the threat was immediate. Though the RSA does have monetary penalties under Section 41.1, Section 31 does not have a mechanism for the Railway Safety Inspector to issue an order based on repeated rule violations.[99] Therefore, in dealing with MM&A's CROR Rule 112 violation, Transport Canada Inspectors do not have a targeted mechanism to correct rule violation unless the threat is imminent.

The analysis now turns to considering Transport Canada's oversight of the performance-based SMS regulations. As discussed in the section of this analysis regarding the railways' control loop, the fact that there were further opportunities to manage the risks of a crude oil unit train (e.g. by stopping the train on the siding and ensuring it is clear for trains to stop) raises questions about the effectiveness of the railway's risk management process. By extension, this finding raises questions about the effectiveness of the regulatory schemes overseeing the plans. Transport Canada verifies railroads' compliance with the RSA through audits and inspections by Railway Safety Inspectors, including reviewing each railway's SMS (Section 47.1[1] of the RSA). This regulation requires railroads to "implement and maintain a safety management system that includes . . . a process for identifying safety issues and concerns, including those associated with human factors, third parties and significant changes to railroad operations" (SOR/2001-37 Section 2[e][i]).

One possible inadequate control action is the limited number of audits conducted by Transport Canada on the railroads' SMS. In three fiscal years ending in 2012, Transport Canada completed 14 audits, which did include the two Class 1 freight railroads (CN and CP), but did not include Canada's national passenger rail operator, VIA Rail Canada. Furthermore, the audits only focus on specific aspects of the SMS, not the entire document (Auditor General of Canada 2013). Therefore, Transport Canada did not appear to be auditing each of the railway's SMS plans sufficiently prior to the accident. The Auditor General of Canada also found that Transport Canada does not have a systematic audit approach to ensure that the railroads are "complying with safety requirements"

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[98] Letter (in French) to MM&A President Robert Grinrod, dated July 10, 2013, from a Transport Canada Railway Safety Inspector (cited on ICI – Radio Canada 2014, with the Railway Safety Inspector's name redacted).

[99] There are two other control mechanisms in the Railway Safety Act that Transport Canada can use. Transport Canada issues Ministerial Orders (on the behalf of the minister) for railway companies to remove an unsafe railway work or for railways to correct deficiencies in their SMS (RSA Section 32). Transport Canada issues emergency directives (on the behalf of the minster) requiring the company to cease using an operating practice that poses an "immediate threat" to "safe railway operations" (RSA Section 33).

and does not provide sufficient guidance to inspectors to plan, conduct, conclude, and follow-up on audits (Auditor General of Canada 2013). Transport Canada does not maintain information on the railways' risk assessments following the audit for learning purposes (Auditor General 2013, p. 20). Collectively, the Auditor General's audit raises concerns about Transport Canada's ability to oversee the railways' SMS.

Of course, the limited number of audits may be the result of insufficient funding; funding for Transport Canada is subject to the will of elected officials in Parliament. In 2011-2012, Transport Canada spent "$33 million and employed 173 staff in its Rail Safety Directorate, including 101 inspectors responsible for conducting inspections and audits to oversee rail safety in Canada" (Auditor General of Canada 2013), including an influx of $72 million in 2009 over five years to increase staff to over 200 full-time employees. It is beyond the scope of the analysis to determine whether this number is sufficient, but in the review of available documents, the author found some evidence that there is the perception within the policy community that the SMS regulatory approach would be less costly than a traditional approach involving prescriptive regulation. The Auditor General of Canada (2013) notes "[in] the mid-1990s, the government determined that the [traditional prescriptive] oversight approach to railway safety was increasingly difficult to sustain because of the expected increase in traffic volume [not just crude oil] and projected shortages of technical personnel in the rail industry," which implicitly suggests that performance-based regulations would be less costly to oversee. First, this belief seems counterintuitive as the SMS regulations were layered *on top* of existing regulations, thus presumably increasing oversight requirements. Second, the author has not found any evidence that suggests that the SMS approach is less costly or more effective.[100] This is a perception that Transport Canada may need to address in its discussions with political decision-makers responsible for their funding levels.

In addition to not necessarily having sufficient inspection capability, it also appears that Transport Canada has a limited process model with which to enforce the existing regulations. Performance-based regulations require railways to demonstrate to Transport Canada that their operations are safe by providing safety performance measure reports, and implementing and documenting processes, such as risk management procedures, for controlling risks. Transport Canada monitors and audits these performance measures and processes, respectively, to ensure that the railways are operating safely. However, currently within the regulations, there are (1) few performance

[100] Coglianese et al. (2002) finds: "Despite growing interest in the performance of government regulation, researchers have yet to subject performance-based standards to close empirical scrutiny."

indicators of safety, (2) no definition of "major operational change" that could trigger a risk assessment, and (3) no standardized definition of acceptable (tolerable) risk and/or how to achieve it. The absence such mechanisms and associated quantitative and qualitative targets makes Transport Canada's oversight role difficult because it has no mechanism (i.e. a process model) with which to tie the railways' safety performance to an oversight action.

More specifically, first, currently the Railway Safety Management System Regulations only require that railroads report accident rates per 200,000 hours worked by employees, and train and grade crossing accident rates, per million train miles (Section 3[1][b]). Transport Canada is working on developing additional metrics as required under Section 3[2] (Auditor General of Canada 2013). Second, although Transport Canada (2010a) SMS guidelines do include some examples of major operation changes, the list does not include transporting increasing amount of new commodity. Third, there is not any definition of "acceptable" risk or the process by which the railroads would achieve that acceptable risk. The Railway Safety Act Review Panel recommended that the Railway Safety Act be amended to require railroads "to demonstrate, through their safety management systems, that they continuously manage their safety risks to a level **as low as reasonably practicable**" (Lewis et al. 2007, p. 46), a commonly used approach in the United Kingdom (Leveson 2011b). However, even this definition, fraught with definitional issues (i.e. what does "demonstrate", "reasonable" and "practicable" suggest concretely?) was not instituted in the 2013 amendments of the Railway Safety Act, which currently states "companies [are responsible] to demonstrate, by using safety management systems and other means at their disposal, that they continuously manage risks related to safety matters" (Section 3[c]). In other words, Transport Canada has not received any target from the political decision-makers as to what is considered an acceptable risk, thus making it difficult for them to determine whether the industry is taking on acceptable risks.

Transport Canada (2010a) SMS guidelines do not offer much additional information. The Transport Canada (2010a) guidelines for risk evaluation indicate that once railroads identify hazards identified and calculate their risks (as a function of probability and severity), railroads have to "evaluate and determine whether the associated risk is *tolerable*, *tolerable with mitigation* or *unacceptable*, using a predetermined company risk classification methodology." Transport Canada provides several example frameworks in which risks are classified based on their probability and severity, one of which is shown in **Figure 4-6**. However, because Transport Canada does not have a

mandate within the existing act or regulation, the definitions of "tolerable" versus "unacceptable" is in essence left up to the railroad companies.

Thus, in the context of the Lac-Mégantic accident, even if Transport Canada had been aware of the risk posed by the transport of the volatile Bakken crude, Transport Canada would not have had a good basis with which to determine whether the use of unit trains presented an acceptable risk or whether additional operational precautions should have been taken. For example, as discussed, these precautions could have included making sure the train was left on the siding (as discussed above) or other precautions such as installing buffer cars containing inert material between tank cars. Even if the necessary engineering evidence were developed suggesting this approach would lower risks of a spill, Transport Canada has no basis with which to negotiate with the railroads to argue for a potentially higher level of safety.[101] Additionally, in the risk management flow chart that Transport Canada (2010a) provides in its guidelines (and shown in **Figure 4-7**), the directionality of the arrows suggest that any contemplated change, with the right controls, would be acceptable to proceed with. In other words, it does not suggest that there may be circumstances in which a proposed change would need to be abandoned due to having too high of a risk.

Frequency	**Frequent 5**	low 5	medium 10	high 15	very high 20	very high 25
	Probable 4	low 4	medium 8	high 12	high 16	very high 20
	Occasional 3	very low 3	low 6	medium 9	high 12	high 15
	Remote 2	very low 2	low 4	low 6	medium 8	medium 10
	Improbable 1	very low 1	very low 2	very low 3	low 4	low 5
		Minimal 1	**Marginal 2**	**Serious 3**	**Critical 4**	**Catastrophic 5**
		Severity / Consequence				
Legend:						
(f)x(s)		01 - 03	04 – 06	07 – 11	12 – 18	19 - 25
RISK		Very Low	Low	Medium	High	Very High

Figure 4-6: Example risk assessment matrix (Source: Transport Canada 2010a)

Additionally, the author raises the question whether the emphasis should be on probabilistic risk assessment, particularly in situations when new risks were present. Coglianese et al. (2002),

[101] In Transport Canada's (2011) rulemaking guidelines, it notes that Transport Canada "will . . . make decisions based on evidence and the best available knowledge and science in Canada and worldwide, while recognizing that the application of precaution may be necessary when there is an absence of full scientific certainty and a risk of serious or irreversible harm . . ." However, additional guidance on what level of precaution that is necessary is not provided in this document.

speaking more generally about performance-based regulations, note "measuring performance presents distinct challenges, something that is especially the case when the standards are based on predictions rather than actual measurable events." In the case of the Lac-Mégantic accident, it would have been difficult to model the events leading up to the accident probabilistically. If one were to take a chain-of-events causation view of the accident at Lac-Mégantic (described in **Chapter 4**), there were several unusual events combined with environmental factors that led up to the accident: the fire on the locomotive, the locomotive being shut down by the fire department, the train parked on the mainline instead of the siding, the steep grade leading into Lac-Mégantic, the fact that sufficient handbrakes were not set or that they did not function properly (a potential rules violation), the use of unit trains to transport crude oil, and the fact that the oil was more volatile than first thought. Identifying *and* assigning probabilities or severities to any of these events would have been very difficult. Even if this probabilistic information were developed, it would be tempting to use the analysis to justify that the risk posed by a certain operational acceptable on the basis of probabilities, rather than use the information to improve safety practices.[102] Therefore, it is unclear whether a probabilistic risk assessment would have been helpful in addressing the circumstances leading up to the Lac-Mégantic accident.

A related finding to the lack of risk acceptability definition in the legislation or regulation is that the Railway Safety Inspectors are often former railway employees (Auditor General of Canada 2013), meaning that they are likely to have the same perception of risks as the railroads they are to oversee. Thus, there is potential for risk acceptability to be viewed through the lens of the railroad, rather than that of the public: the railroads operate in an inherently high-risk business, and a risk that is acceptable to them may not be acceptable to the public. Relatedly, the Auditor General (2013) notes concerns with ensuring "independence and objectivity" of inspectors. Recently, one Transport Canada inspector was found to have faked inspection reports, though it was not revealed what transportation mode he or she inspected (The Canadian Press 2013b). Given that the public

[102] Probabilistic risk assessments can lead to incorrect conclusions because of the many assumptions they have to build in. For example, in late 2012, Boeing launched their new 787 Dreamliner, which uses innovative materials such as a carbon body and lithium-ion batteries. On January 7, 2013, a Japan Airlines 787 parked at Boston Logan Airport had a battery fire occur. In a press release a month later, the National Transportation Safety Board (NTSB) (2013) reports: ". . . that as part of the risk assessment Boeing conducted during the certification process, [the NTSB] determined that the likelihood of a smoke emission event from a 787 battery would occur less than once in every 10 million flight hours. Noting that there have been two critical battery events on the 787 fleet with fewer than 100,000 flight hours, Hersman [the NTSB Chairman] said that "the failure rate was higher than predicted as part of the certification process and the possibility that a short circuit in a single cell could propagate to adjacent cells and result in smoke and fire must be reconsidered." In other words, the actual occurrence of the battery fire event is 200 times higher than the calculated prediction, because the underpinning assumptions used in the analysis did not match the physical workings of the system. Leveson (2011a) argues that this type of incorrect analysis is common when conducting probabilistic risk assessment (PRA) in safety cases.

cannot request the railway SMS documents themselves, even in partially redacted form, it is difficult for the public to provide oversight of the inspections or provide input into the acceptability of risks taken by the railroad industry. Furthermore, the workings of the Advisory Council on Railway Safety, though including members from Transport Canada and the public, does not publicly disclose its work in the absence of an access to information request. Though there is no evidence of any systematic impropriety by Railway Safety Inspectors, given their railroad industry background, their mental model of risk would be shaped by their industry experience, rather than driven by the public interest.[103]

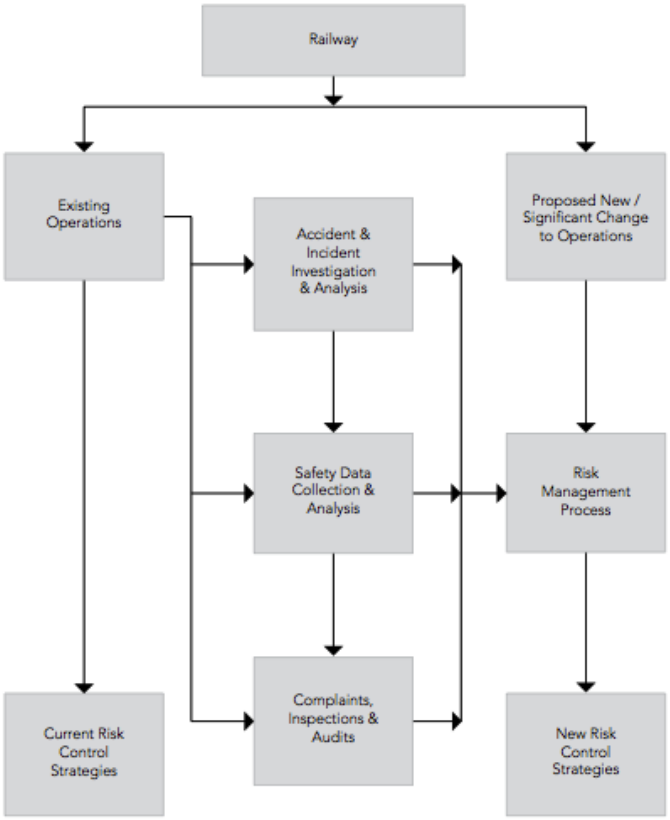

Figure 4-7: Process for managing risks for "existing and new/significantly changed operations" (Source: Transport Canada 2010a).

Finally, there are instances in which the prescriptive aspects of the RSA may undermine the performance-based goal of the legislation. For example, under Section 31(4) of the RSA, "a railway safety inspector shall not determine that the standard of construction or maintenance poses a threat to safe railway operations if that standard conforms to all applicable regulations, rules and

[103] On the railroad industry's side, they are concerned that providing such "will be 'misused against' them." Furthermore, as of 2007, there was a culture of mistrust "within individual companies, between rail companies, between Transport Canada and the rail industry, and within Transport Canada (amongst some functions, and between some regions and Headquarters)" (SMS Aviation Safety Inc. 2007).

emergency directives [for the purposes of subsection (1) and (2).]"[104] This subsection potentially undermines the railway safety inspector's ability to justify that a higher standard is required to manage a particular risk. This section is also not consistent with the overall objective of the RSA to put the responsibility on railway companies to demonstrate the safety of their operations.

In summary, while the limited number of audits performed by Transport Canada on the railroads' SMS is one aspect of inadequate control, a potentially more insidious issue with the current control structure is the lack of goals related to acceptable risk levels defined in the legislation or regulation, making it difficult for Transport Canada to oversee the safety of the railroad industry. As noted at the start of this section, it is already difficult for Transport Canada to order a railroad to take action when it is not following a prescriptive regulation, and the ambiguity in the current performance-based regulations increases this challenge when overseeing the latter regulations. Ultimately, following the Lac-Mégantic accident, Transport Canada had to revert to a more prescriptive approach and provided railways specific requirements for transporting crude oil through the use of an emergency order, which was not the intent of the SMS approach.

Canadian Transport Agency

The Canadian Transport Agency's process for issuing and revoking Certificates of Fitness, which railroads require to operate, has some definitional issues. In the case of the Lac-Mégantic accident, the Canadian Transportation Agency (2013a) only revoked the MM&A's Certificate of Fitness following the accident, even though the MM&A's $25 million insurance policy will not cover the $200 million in clean-up costs expected (Kemp 2014).

One of the practical challenges that lead to this inadequate control is that railroads can only afford so much coverage if they are to operate, which is an issue for shortline railroads. In the case of large railroads, insurers can only provide so much insurance; Class I railroads that already typically have over $1 billion in coverage (Kemp 2014). However, another concern is that while railroads are required to notify the Canadian Transportation Agency if the ". . .operation [of the railroad] has changed so that the liability insurance coverage may no longer be adequate" (Canada

[104] Section 31(1) of the RSA reads as follows: "31. (1) If a railway safety inspector is of the opinion that the standard of construction or maintenance of a line work or railway equipment of a company poses a threat to safe railway operations, the inspector (*a*) shall, by notice sent to the company, inform the company of that opinion and of the reasons for it; and (*b*) may, in the notice, if the inspector is satisfied that the threat is immediate, order the company to ensure that the line work or railway equipment not be used, or not be used otherwise than under terms and conditions specified in the notice, until the threat is removed to the inspector's satisfaction." Subsection (2) reads similarly but pertains to at-grade crossings of railways.

Transportation Act Section 94[1][b]), in practice, CN and CP both note that is no practical definition of when this might occur (Guthrie 2014, Patenaude 2014).

The Canadian Transportation Agency is also fundamentally an economic regulator, concerned with ensuring the transportation system operates effectively and balancing the needs of railroads and shippers. Therefore, even if the railroads contacted them to indicate that they suspect their coverage may no longer be adequate, it is unclear whether the Canadian Transportation Agency would be in the best position to address this concern. Typically, they rely on fairly high-level metrics of the risk posed by railroad operations, as defined by Railway Third Party Liability Insurance Coverage Regulations Section (4).

In response to the concern that the Canadian Transportation Agency does not need to verify that the railways it certifies to operate have a minimum level of safety, the Railway Safety Act Review Panel proposed that Transport Canada require railroads to obtain a Rail Operating Certificate (ROC) before they can apply for the Certificate of Fitness (Lewis et al 2007). The ROC would require railroads to demonstrate a minimum level of safe operations before they could receive the ROC. Transport Canada (2014c) has issued a Regulatory Impact Statement containing the draft of the regulations to implement the ROC. Even though ensuring that railroads have a system for risk management is a key part of the performance-based regulatory framework in Canada, having such a process is not required as a minimum standard to receive an ROC. In fact, most of the requirements of the proposed ROC regulations focus on prescriptive standards. Therefore, the author is unsure about the value of the proposed change.

4.6 Conclusions, Recommendations, and Further Research

Using CAST, an accident investigation tool based on STAMP, the goal of this research was to investigate some of the inadequate control mechanisms that may have lead to the accident at Lac-Mégantic, Quebec, Canada. Specifically, it is concerned with investigating the control structure involved in ensuring that railroads perform risk assessments on their operations, a concern identified by the Transportation Safety Board of Canada following the accident. The goal of this research was not to provide specific conclusions related to the Lac-Mégantic – or to assign blame – but rather to look at the railroad industry more generically to see where there were opportunities to pursue safety improvements.

One of the key findings of the research is that the railway industry in Canada operates under a hybrid of prescriptive and performance-based regulatory approaches. The prescriptive approach is

the traditional approach, in which railroads follow specific requirements in terms of how they operate. In the performance-based approach, the regulators specify certain outcomes, and the railroads are given the flexibility to meet those outcomes through the use of risk management tools within a Safety Management System. The latter approach was introduced in 2001 and is layered on top of the existing prescriptive regulations.

Railroad Industry

This research found that the railroads did perform some risk assessment prior to the Lac-Mégantic accident and implement some additional controls, but did not conduct a formal risk study the transportation of crude oil according to the presentation of Glen Wilson, Vice-President, Safety, Environment and Regulatory Affairs, Canadian Pacific before the Canadian Senate. The railroads, as common carriers, appeared to view the transportation of crude oil as another hazardous commodity that they are required to transport. The research also found that while railroads are required to have a process for identifying and assessing risks and taking actions based on that assessment, railroads have also tended to focus on contemplated technical changes within their existing risk assessments, instead of broader issues of operations, organizational and technical factors.

In response to the concern that railroads focus mainly on technical issues in their risk assessments, executives and senior management should be required to perform strategic level risk assessments of their operations on an ongoing basis. Furthermore, requirements for audits of senior level management should be included in Transport Canada Safety Management System guidelines. These could be performed by a committee composed of railroad employees, with their associated expertise in railroad engineering and operations, as well as consultants with expertise in management oversight.

If railroads are seeking to expand their crude oil transportation business, they should seek to be experts at the transport of this commodity. Unlike the transport of other hazardous commodities, such as TIH chemicals, which railroads transport but would prefer not to,[105] the transport of crude oil is generally one that has been welcomed by railroads – particularly in light of declining coal revenues – and appears lucrative to them. Thus, transporting crude oil by rail is less of a service to society driven by regulations than a lucrative market for the railroads, which could affect the public's perception of the "voluntariness" of the risk. This perception that the public has limited

[105] In Chapter 1 of this thesis, the author discussed a case in which UP tried to avoid transporting chlorine through a declaratory order by the Surface Transportation Board.

control over the risks posed by crude oil by rail transportation may be further reinforced by some of the railroads' messaging that suggests that railroads are simply responding as common carriers. Additionally, as discussed in **Chapter 3** the public is more critical of the acceptability of producing bitumen for environmental reasons, and thus, by extension, whether it should be transported. Thus, railroads should be able to clearly justify their safety procedures for transporting crude oil to the public.

Canadian Government

At the legislative and regulatory levels, this chapter identified areas of concern. First, while the Railway Safety Act (RSA) contains administrative monetary penalties for railway companies that do not follow the RSA, or the regulations, rules, and standards that it contains, Transport Canada Railway Safety Inspectors do not appear to have a mechanism to order a railway company to take action in response to a safety concern, unless there is an immediate threat to railway safety. The Transport Canada inspections reveal that the MM&A employees repeatedly did not follow CROR Rule 112 requiring the use of handbrakes when a train is left unintended; yet it was not until July 8, 2013 – the day after the accident when it became clear the risks posed by the behavior could be serious – that a Transport Canada Railway Safety Inspector issued an order to the MM&A. Therefore, the author recommends that Railway Safety Inspectors be provided with an additional mechanism within the RSA, such that a repeated rule violation constitutes sufficient grounds for an inspector to issue an order to a railway company.

There is also no definition of what is an acceptable risk or how an acceptable level of risk could be demonstrated in the RSA, its regulations, or Transport Canada guidelines, and few mechanisms for the public to understand the risks posed by railroads and provide input to monitoring the ongoing risks posed by railroad operations. Additionally, Transport Canada continues to develop performance measures to oversee railroad safety management performance. As a result, as currently implemented, the SMS appear to provide limited control in regard to how railroads perform risk management over their operations.

A definition of acceptable risk and a process for achieving that level of risk needs to be clearly stated in the RSA. Negotiating this goal is not an easy task but is fundamental to the overall performance-based regulatory approach being pursued in Canada (and now in the US with the passage of the Railroads Safety Improvement Act of 2008). The public should be involved in this consultation. Additionally, approaches other than probabilistic risk assessment, should be considered as appropriate tools within the railways' risk management approach. CAST/STPA have

proven to be powerful tools for qualitative accident investigation and hazard identification, and thus should be considered. In general, further research is needed to determine whether Transport Canada should mandate specific risk management approaches by regulation.

Transport Canada should strive to communicate more information regarding railroad safety to the public. First, information pertaining to the Advisory Council on Railway Safety should be posted for public viewing in a similar fashion to the Railroad Safety Advisory Committee (RSAC) (https://rsac.fra.dot.gov/home.php). Second, in keeping with a recommendation by SMS Aviation Safety Inc. (2007), Transport Canada and the railroads should provide more information on the state of railroad safety in an annual, concise format available to the public. CN did take a good first step in this regard by producing its "Leadership in Safety 2013." While the railways are obviously concerned that the public communication of their information might be used against them (SMS Aviation Safety Inc. 2007), the fundamental premise of the performance-based regulations requires the regulator, and by extension the public (under Section 3[a] of the RSA), to be confident that the railways' are managing safety appropriately.

Finally, the author found one instance in which the prescriptive nature of the RSA potentially undermines the performance-based regulations. Under Section 31(4), a Railway Safety Inspector explicitly may *not* order a railway to increase its construction and maintenance standard in response to a safety threat. Thus, more broadly, the author hypothesizes that prescriptive regulations, in which railroads must follow a specific construction, inspection, maintenance, and operational practice, undermine the performance-based regulatory regime by shifting the onus away from the railways to demonstrate that they operate safely. For example, in a new or specific situation that a railway may encounter, an existing rule or regulation may not provide the necessary safety control, yet there is no requirement for a railway to justify the use of that rule (instead of a more stringent one) as providing an acceptable level of control in the situation. Under the current Railway Safety Management System Regulations, railways are only required to ". . . list . . . applicable railway safety regulations, rules, standards, orders and exemptions" within their SMS documents (Section 4[1][f]). Therefore, Transport Canada should investigate the interaction between the existing prescriptive regulations and the new performance-based standards and identify any potential conflicting requirements.

Final Thoughts

The author believes that CAST proved to be an effective way to study the control structure that existed prior to the Lac-Mégantic accident, summarize existing concerns that pertain to the

accident, and identify new areas of concern. The recommendations and further questions raised by this discussion will hopefully help improve the safety of an already very safe industry.

In the next chapter, **Chapter 5**, potential areas of future research are articulated following a discussion of the broader implications of the research contained in this thesis.

5 Conclusions, Recommendations, and Further Research Questions

EXCLUSIVE | Confidence falls in safe transport of oil, polls suggest

Pipelines have most support, but confidence in Ottawa's ability to protect environment slipping

By Margo McDiarmid, Environment Unit, CBC News Posted: May 06, 2014 5:00 AM ET | Last Updated: May 06, 2014 5:50 AM ET

Screenshot of the online headline of McDiarmid (2014), a CBC News article discussing low public confidence in the safe transport of crude oil

ENVIRONMENT 1761 COMMENTS

U.S. Climate Has Already Changed, Study Finds, Citing Heat and Floods

By JUSTIN GILLIS MAY 6, 2014

Screenshot of the online headline of Gillis (2014), a The New York Times article discussing the findings from the recently released "National Climate Assessment," a report issued by the US Global Change Research Program

The motivations for this thesis – railway safety and the Keystone XL permitting decision – remain pressing public policy debates. First, as the author began drafting this chapter in late-April 2014, a train carrying crude oil from the Bakken formation exploded in Lynchburg, Virginia (Dave 2014). Though its proximity to nearby buildings meant that there was the potential for tragic results, fortunately no one was injured. Second, the Transportation Safety Board of Canada (TSB) continues to investigate the accident at Lac-Mégantic, Quebec, and much remains to be learned from its final report as well as from the regulatory response that will follow in both Canada and the United States (US). Finally, recent media reports suggest relatively few Canadians feel that the government is adequately managing crude oil safety concerns. For example, only 28% percent of Canadians polled believe that governments can adequately respond to an on-land oil spill (McDiarmid 2014).[106] Safety concerns related to crude oil transported by rail remain on the political agenda in Canada and the US.

[106] This poll was conducted by Natural Resources Canada in October and November 2013. The author would speculate that the figures may have risen since then due to government regulatory action, but the low figures nonetheless indicate concern.

Simultaneously, the ongoing debate over the Keystone XL continues. In February 2014, a Nebraska judge struck down a state law giving the state governor the ultimate decision on pipeline siting (Bernstein 2014). As discussed in **Chapter 2**, though the US federal government has ultimate decision-making authority over whether a pipeline is approved, state governments are allowed to enact laws regarding local matters, such as pipeline location. Ostensibly in response to this decision, President Obama's administration indicated on April 18, 2014 that it would reserve its decision until Nebraskan courts rule on who can dictate the pipeline route (McCarthy 2014). One Republican senator called President Obama's latest decision "a stunning act of political cowardice" whereas environmental advocates have indicated that Obama lacks "courage" for not seizing the moment and rejecting the pipeline permit (cited in McCarthy 2014). The rhetoric on both sides remains heated.

Underlying this rhetoric is intense debate about the imperative of addressing the critical contemporary issues of climate change, energy security, economic development, and safety. In addition to being concerned about the risks of an oil spill, environmentalists and individuals critical of pipeline construction are concerned that building pipelines such as the Keystone XL would enable increased production of bitumen from the oil sands in Alberta, Canada, which are energy-, and thus carbon-intensive to produce. As found in **Chapter 3**, crude oil from the oil sands produces 2% to 19% more well-to-wheel (WTW) greenhouse gas (GHG) emissions than comparable heavy oils imported in the US (Lattanzio 2013). Though climate change is a politically challenging issue to address, scientific agencies such as the Intergovernmental Panel on Climate Change [IPCC] and US Global Change Research Program are increasingly reporting that climate change is not just a distant concern, but rather is a phenomenon that is already having significant effects (IPCC Working Group II 2014, US Global Change Research Program 2014).

Pipeline proponents counter that not building the Keystone XL would result in bitumen being transported by rail, which would be less cost-effective, less safe, and less environmentally-friendly, and ultimately lead to the same volume of GHG emissions from the production and refining of oil sands bitumen (e.g. Krugel 2013). Supporting this argument is that railroads, unlike pipelines, are not subject to extensive environmental reviews for modest capacity expansion (e.g. sidings and side tracks), an issue discussed in **Chapter 2**. Additionally, the proponents counter, the pipeline would enhance US and Canadian economic development and US energy security, which has been an issue

that US presidents have focused on for decades. Energy security has also become a higher-profile issue recently following geopolitical events in the Ukraine.[107]

The railroad industry injects another argument into the debate by suggesting that they are a safe and cost-effective way to transport crude oil. For example, the Canadian National Railway (CN) released a marketing brochure for crude oil by rail transport from the Bakken formation suggesting that it had a lower GHG emissions intensity per tonne-mile than pipelines (CN 2012). Additionally, as discussed in **Chapter 4**, there is particular disagreement between the railroad industry and other actors over the issue of railway safety. The railway industry questions whether a comparison of pipeline and railway safety data can be made given the differences in data collection requirements between the two modes. Chapter 5 of the Final Supplemental Impact Statement (FSEIS) of the Keystone XL suggests that railways are less safe than pipelines, but the AAR (2013b), using its own data analysis concludes that " . . . both railroads and pipelines are safe, reliable ways to transport crude oil."

The above discussion suggests that there are two matters of debate. First, there is the question of what issue actors should focus on addressing. While all of the actors – governments, pipeline and railroad companies, and the public – are finding themselves in the crosshairs of conflicting and interacting critical contemporary issues – e.g. economic development, energy security, climate change, and safety – actors do not agree on what concern is paramount. Second, there is the matter of what railroads could and would do, and more importantly what they *should* do in response to the increasing production of crude oil in North America. Addressing this question is the aim of this thesis, as well as the aim of the future research proposed in this conclusion.

Thus far, much effort has been spent understanding whether railroads could and would transport crude oil. Comparably less effort has been spent determining whether they *should* transport it. The author reviewed two documents that considered potential transportation capacity expansion from the oil sands. Cairns (2013a) discusses the volume of crude oil from the oil sands that the two Canadian railroads, CN and CP, could potentially transport given their infrastructure. In Section 1.4 of the US Department of State's (2014) Keystone XL FSEIS of the Keystone XL, the State Department extensively reviews the cost of transporting bitumen by rail, the potential ability of railroads to expand their capacity, and the implications of pipeline constraints on oil sands production. By contrast, while the Keystone XL FSEIS does review in great detail some of the environmental

[107] For example, earlier in 2014, Russia has threatened to prevent gas supplies from running through the Ukraine (Rayman 2008). Russia is a major oil and gas producer for Europe.

impacts of rail alternatives for transporting crude oil, some of the assumptions used are open to debate (such as the safety data discussed above). Additionally, because the FSEIS is focused on the Keystone XL, it does not discuss the broader ramifications on the railroad industry if large volumes of crude oil were to be transported by rail. There are thus still opportunities to further understand the role of crude oil by rail transport.

However, as this thesis was written, the emphasis is changing to focus more on understanding whether railroads *should* transport crude oil. Fritelli et al. (2014) of the Congressional Research Service issued a relatively comprehensive study of "US Rail Transportation of Crude Oil: Background and Issues for Congress," which discusses some of the economic, environmental, and safety ramification of this mode. The purpose of this thesis is to further such endeavors by reviewing whether railroads could and would transport crude oil, and more importantly, considering some of the broader economic, energy security, climate change, and safety ramifications.

This conclusion chapter synthesizes what the author has learned so far about the role of the railroad industry in transporting crude oil. Because the role of railroads in transporting crude oil remains on the political agenda in Canada and the US, new information is continually being released that shape the author's view. Based on the research thus far, the author proposes the conclusions and recommendations outlined in **Section 5.2**. Then, before closing in **Section 5.4**, potential future research is proposed in **Section 5.3**.

First, however, in **Section 5.1**, the problem formulation and methodological approach used in this thesis are reviewed, and the key contributions of this thesis posited.

5.1 Problem Formulation and Methodological Approach

The organizing conceptual framework for this thesis is the *CLIOS Process*, an approach for studying complex, large-scale, interconnected, open, sociotechnical (CLIOS) systems and the critical contemporary issues (CCIs) associated with these systems. In this thesis, the CLIOS system under study is the oil sands production system, its associated pipeline and railroad transportation system, and economic and environmental subsystems of interest to society. Strategic alternatives – pipeline and rail capacity – have been proposed to expand the capacity of the oil sands transportation system and allow bitumen production to increase. This thesis is concerned with the impact of the strategic alternatives on economic development, climate change, energy security, and safety (i.e. the

CCIs of interest) which would result from the increasing volumes of bitumen production and transportation.

The CLIOS Process views the system as a physical domain, consisting of multiple subsystems, encapsulated in a system of actors referred to as the institutional sphere. The subsystems discussed in the paragraph above – e.g. oil sands production and transportation – are influenced and/or controlled by institutional actors: the public (individuals and non-governmental organizations), companies (pipeline and railroad), and governments (Canada and the US). The explicit consideration of the institutional sphere in the system results in (what Sussman et al. [2014] term) nested complexity and evaluative complexity, both of which make it difficult for the researcher to understand CLIOS system behavior. (This complexity is explained in Chapter 1.) However, this view of the overall system has proven useful in the past, because the researcher can consider both physical and institutional strategic alternatives to improve CLIOS system performance.

To address the overarching question of this thesis – should railroads transport crude oil – three additional questions are posed that align with the three **stages** of the CLIOS Process: (1) *Representation;* (2) *Design*, *Evaluation and Selection*; and (3) *Implementation*. The first stage is descriptive and responds to the question: *what is the system.* To begin understanding the behavior of the system, important characteristics of the system are reviewed, and physical components and institutional actors are identified. The second stage is evaluative and responds to the questions: *what are the criteria of good performance* and *how do the strategic alternatives perform.* To see how the strategic alternatives could affect the performance of the system, relevant performance metrics are identified and the strategic alternatives are evaluated against them. Sussman et al. (2014) recognize that multiple strategic alternatives may be necessary to achieve desired performance criteria, and therefore suggest that they be implemented as *bundles*. Finally, the third stage is practical, and responds to the question: *how to implement the selected bundle of strategic alternatives.*

Using the three stages of the CLIOS Process, the author posed three questions – descriptive, evaluative, and practical – that address the role of railroad transport in the crude oil transportation market. For each question, the research approach and relevant literature considered are briefly summarized, along with any particular methodologies used to respond to the question. The contribution of the theses response to each question is then posited.

(1) What is driving the demand for greater transportation capacity of crude oil in North America, what are the strategic alternatives for providing that transportation capacity, which institutional actors have influence over the implementation of these strategic alternatives, and what influence do these actors have?

Chapter 2 uses information from government (notably the Alberta Government, National Energy Board of Canada [NEB], the US Energy Information Administration [EIA], and US Department of State), industry sources (notably the Canadian Association of Petroleum Producers [CAPP]), other researchers and consultants (notably the Canadian Energy Research Institute [CERI], as well as, Cairns, Dunbar, Forrest, Gordon, Choquette-Levy, Chen et al.), and media reports to describe the existing oil sands production system, its transportation system, and the trends motivating the desire for greater transportation capacity. It then identifies information regarding the strategic alternatives using information from the US Department of State as well as pipeline and railroad industry sources. Using information from government agency websites, relevant statutes, the Congressional Research Service (CRS), and trade reports, the particular contribution of this chapter is that it identifies and describes the role of governmental actors in overseeing the implementation of both rail and pipeline strategic alternatives in both Canada and the US. By the end of **Chapter 2**, it is clear why there is such debate over the potential response by railroads to pipeline permitting decisions, because, unlike with pipelines, few regulatory mechanisms exist to limit railroads' ability to transport crude oil.

Chapter 2 provides the necessary background with which to compare the performance of pipelines and railroads by responding to **Question 2**.

(2) In the context of the strategies of the Canadian and US governments related to broader issues of public policy, how does the performance of rail transport compare to pipelines?

a. Furthermore, how does uncertainty affect the strategies of the actors?

Chapter 3 evaluates the tradeoffs of railroads versus pipelines using the Keystone XL (i.e. Alberta to the US Gulf Coast) as its case study. Specifically, the chapter considers not only the direct impacts of the transportation system itself along economic, environmental, and safety dimensions, but also how it interacts with the oil sands production system to impact economic development, energy security, and climate change. It relies heavily on the information researched in the US Department of State Final Environmental Impact Statement (2014), but also critiques the findings in this document using information from academic, government, industry, environmental and other researchers (such as CERI, CRS, the Manhattan Institute, The Pembina Institute, Council on Foreign

Relations, Cairns, Knittel, Tarnoczi, Shelton-Davis, etc.). The chapter also incorporates other information from media and trade publication reports as appropriate.

The chapter also considers the impact of regulatory uncertainty – the uncertainty created by governments as they contemplate whether to approve pipeline permits or not – on railroad industry investment in bitumen transportation capacity. It provides the results of a dynamic program – a modeling technique used to consider situations in which a decision-maker can take action at multiple periods in the future – to suggest how railroads would invest in transportation capacity (infrastructure and rolling stock) before and after they know the results of the pipeline permitting decisions.

The contribution of this chapter is that it provides an evenhanded discussion of the performance of railroads and pipelines, as well as the tradeoffs associated with expanding oil sands production. It makes this contribution by compiling literature from several trade and academic sources, and by discussing the merits of each. Additionally, using the results from a dynamic program, the chapter also makes a contribution by explaining the regulatory uncertainty facing the railroad industry mentioned in other sources (Auffhammer 2014, Forrest and Brady 2013). While the dynamic programming model cannot explain railroad action precisely given the lack of exact cost and capacity data, it provides insight into the railroad response (or lack thereof) to the growing production of bitumen from the oil sands.

One of the issues raised in **Chapter 3** is whether rail and pipeline safety data can be compared due to differences in data collection. This issue provides further motivation to consider railroad safety in **Question 3**.

(3) If railroads are to take a greater role in the transportation of crude oil, what considerations of safety at the railroad management and regulatory should be addressed?

Chapter 4 addresses railway safety of crude oil transport assuming the railroads were going to continue to transport crude oil. Using the Lac-Mégantic accident and the Canadian railway regulatory environment as context, the chapter uses the accident investigation tool CAST (Causal Analysis based on STAMP) to describe the hierarchical safety control system for transporting crude oil by rail. CAST is premised on an accident causation model known as STAMP (Systems-Theoretic Accident Model and Processes), which views accident causation as resulting from inadequate control provided by or coordination issues within a safety control structure. A safety control

structure is a mechanism in which hierarchically arranged controllers apply constraints to lower-level controllers and a process to ensure safe behavior of the overall system emerges (Leveson 2011a).

The use of CAST was motivated by the ambiguity in using historical safety data to compare the safety of pipelines and railroads for transporting petroleum products: differences in data collection between the modes and the fact that railroads in North America had not transported large volumes of crude oil until 2008 using unit trains means that even if conclusions could be drawn, they would still be subject to debate by pipeline proponents and opponents. Nonetheless, in the wake of rail accidents involving crude oil, rail safety is of concern. CAST provides a tool for identifying safety concerns, rather than a tool for evaluating safety quantitatively. In other words, the results from CAST can help refocus the debate on the safety issues that may need to be addressed, rather than focusing on whether railroads are more or less safe than pipelines.

The CAST analysis in **Chapter 4** uses government reports and hearings prior to the Lac-Mégantic accident, governmental responses to the accident, statutes and regulations (notably the Railway Safety Act, the Transportation of Dangerous Goods Act, and the Canada Transportation Act), and railroad industry documentation, to construct the safety control structure of the industry and comment on possible inadequate control that may have existed. Specifically, a lot of the information comes from Transport Canada (Canada's railway and hazardous goods safety regulator), the Transportation Safety Board of Canada (Canada's transportation accident investigator), and the Canadian Transportation Board (Canada's transportation economic regulatory). Additionally, a important source of information was a 2007 Railway Safety Act Review Panel (Lewis et al. 2007), which extensively reviewed the Canadian regulatory framework and offered 57 recommendations for improvement. These sources are described in **Chapter 4, Section 4.3**.

This chapter makes a contribution to improving railway safety by positing the causal relationship between the adequate control actions at the physical system level to the regulatory level. Others, such as Campbell (2013) and Cairns (2013b) have reviewed Canadian rail safety concerns at the regulatory level following the Lac-Mégantic, and this chapter contributes to the discussion by adding some underpinings using system theory. Additionally, to the author's knowledge, this was the first time that CAST was applied to the safety of the North American freight railroad industry. (As this thesis is written, Kawakami [2014] applied STAMP to study high-speed passenger rail in North America.)

When considering the thesis overall, the author found the CLIOS Process a useful mechanism for organizing the research and for integrating the findings from multiple approaches. The process also allowed the author to start with a broad view of the CLIOS system considering oil sands production, pipelines and railroads, before focusing on the railroad industry. Using the CLIOS Process, the author was able to understand how the transport of crude oil is intertwined with critical contemporary issues of economic development, energy security, and climate change, and, based on this understanding, proposes the following conclusions.

5.2 Conclusions, Recommendations, and Further Questions

The goal of this thesis is not to recommend to decision-makers that either railroads or pipelines are the preferred alternative. As highlighted in **Chapter 3**, the question – "should railroads transport crude oil?" – is value-laden. The analysis results that inform this decision are often also ambiguous and can lead to multiple interpretations. This ambiguity is further compounded by the uncertainty about each actor's decision, as well as questions regarding how issues such as climate change play out in the political realm (and its potential impact on oil sands production, for example). Therefore, interpreting the body of research that this thesis has assembled in a fair and evenhanded manner is a challenging undertaking subject to the values of the author.

Consequently, because the role of an academic thesis is not to suggest a final decision to a question requiring significant societal debate, the conclusions and recommendations presented in this chapter are generally framed either as tradeoffs that decision-makers must consider or as questions for further study. Though the author attempts to provide balanced conclusions taking the perspective of the goals of the different actors, he takes the public's view when developing the conclusions. In other words, he views the consideration of societal issues explicitly as greater concern than the profits of companies or the political ramifications of a government decision. Obviously, these interests do not always diverge and ideally should align as much as possible, but where there is ambiguity, the author takes the societal viewpoint.

Keeping these limits in mind, the author invites readers to consider the following conclusions. They are organized by the two motivations that led to this thesis. **Section 5.3.1** considers conclusions that pertain to the ongoing evaluation of the Keystone XL, and **Section 5.3.2** pertain to the role of the railroad industry in transporting crude oil. Each conclusion is first stated in **bolded text** and labeled with a Roman numeral. Then, the findings associated with the conclusion are discussed.

5.2.1 The Keystone XL and Other Pipelines

I. There are not only tradeoffs but also longer-term interdependencies between the issues of economic development, energy security, and climate change as these issues relate to the oil sands and its transportation system.

The oil sands is a huge natural resource, containing 170 billion barrels of economically extractable oil, the third largest in the world behind Saudi Arabia and Venezuela. *Assuming adequate transportation capacity,* current forecasts have production increasing from about 2.0 MMbbl/d to about 5.0 MMbbl/d in 2030, and, as compared to shale oil production predictions, there is less uncertainty about future oil sands bitumen production levels provided sufficient transportation capacity is provided and in the absence of climate change policies. This resource represents enormous economic potential for Canada, with some estimates suggesting Alberta and Canada could receive $455 billion (in tax revenue and royalties) and $311 billion (in tax revenue) over the next 25 years (Honarvar et al. 2011). The resource also has the potential to increase US energy security because of the physical availability of the resource (i.e. the large reserves) and the geopolitical accessibility (i.e. the US's close trade relationship with and proximity to Canada).

However, because of the energy intensive processes required to extract the bitumen (i.e. surface mining and in situ steam-injection techniques) and refine it (e.g. coking), each barrel of bitumen produced has higher GHG emissions than other heavy crude oils refined in the US. Because of the energy intensive production processes, by 2020, Canada is poised to *increase* its GHG emissions from 2005, instead of decrease them as planned.

In the short term, attempts to rein in carbon emissions are plausibly going to have an effect on oil production, and hence reduce the economic and energy security benefits from oil production. Partington et al. (2013) from The Pembina Institute, an environmental think-tank, suggest that the effective cost for a $150 per tonne of carbon dioxide carbon tax (as compared the current Alberta program charging $15 per tonne) would only amount to $2.87 per barrel, which is comparable to the incremental cost of transporting raw bitumen by unit trains compared to pipelines. By contrast, the high cost of oil sands production (as compared to other sources of crude oil), the availability of alternative investments (e.g. shale oil), and the general reluctance or challenge that the Canadian government has had putting in place a federal oil and gas carbon constraint strategy suggest that oil producers would be sensitive to a carbon tax and thus reduce further capacity investments. The impact is likely affected by how any tax or program is structured, which is a consideration beyond the scope of this research. Ultimately, in the short term given current technology, addressing

climate change will likely reduce economic development and energy security benefits from possible oil sands production expansion.

However, in the long term, addressing all three issues simultaneously is important because achieving energy security is predicated on the acceptability of the energy source. The additional GHG emissions from the oil sands are coming under societal scrutiny and thus reduce the acceptability of bitumen as an energy source. If a worldwide climate policy were ultimately put into place, bitumen production would be particularly affected under current technology due to its higher emissions intensity per barrel (Chan et al. 2012). The higher emissions intensity of the oil sands lowers the acceptability of the resource and potentially undermines its long-term economic and energy security benefits to Canada and the US. Of course, in the long run, burning oil for transportation use – where most of the emissions would be released – still remains incompatible with climate change, but the impact of the energy-intensive processes would be reduced if appropriate climate policies were put into place.

The tensions and interdependencies discussed above were elaborated on in **Chapter 3**. Ultimately, because of the massive size of the oil sands and because of the benefits and costs associated with increasing production, the debate over the oil sands' role in feeding society's need for energy – transportation energy – will likely continue long after any decision is made on the Keystone XL, or any other pipeline for that matter.

II. The symbolism that has been attached to the Keystone XL permitting decision appears to exceed its substantive implications, including as the decision relates to climate change.

There is symbolic value to President Obama approving or denying the Keystone XL permit. An approval of the Keystone XL would affirm the president's commitment to ensuring the US's economic development and energy security, as well as its relationship to Canada and other countries. Denial of the Keystone XL permit would affirm the president's commitment to addressing climate change. This thesis, given the competitiveness of rail, finds that the substantive implications of either an approval or denial are less than the symbolism suggests. **Conclusion II** discusses this finding as it relates to the issue of climate change.

If the goal were to transport oil sands bitumen as efficiently as possible over a long period of time, pipelines are arguably the preferred approach. As discussed in **Chapter 3**, pipelines are generally most cost-effective for large shippers, the necessary feeder infrastructure is already in place, and they have a long history of operating relatively safely. Nonetheless, railroads are now offering a

service competitive with pipelines, particularly if raw bitumen is transported (i.e. within $3 per barrel according to US Department of State [2014]) estimates). Furthermore, considering broader societal criteria, neither pipelines nor railroads are dominant alternatives to transport crude oil. As a result, though symbolism is an important consideration that will be discussed in **Conclusion III**, the substantive implications of a Keystone XL permit approval or denial are not as significant as the symbolism suggests.

In regard to the issue of climate change, given the range of uncertainty that exists in predicting GHG emissions from oil sands bitumen production and transportation, GHG emissions could potentially increase or decrease if the Keystone XL is denied. This conclusion is based on several findings. First, the US Department of State (2014) finds that in 2035, oil sands production would be constrained by 0.2 MMbbl/d if all pipeline capacity were constrained. Second, bitumen has a higher (well-to-wheel) WTW GHG emissions intensity than other heavy oils refined in the US (i.e. 4,391 to 90,444 gCO_2e per barrel more). Thus, if 0.2 MMbbl/d of oil sands bitumen were not produced due to binding transportation capacity constraints, 4,391 to 90,444 gCO_2e per barrel of GHG would not be emitted on these 0.2 MMbbl/d. Third, it is unclear whether railroads emit more or less GHG emissions per barrel of crude oil transported (an assumption discussed in the next paragraph). Assuming that: (1) 47,368 gCO_2e per barrel of oil sands bitumen produced is emitted over and above other heavy crude oils imported into the US, (2) railroads emit 3,400 gCO_2e per barrel transported more than pipelines from Alberta to the USGC, and (3) all additional oil sands production (2.8 MMbbl/d) is transported by railroads, then there would be no net gain or reduction of GHG emissions annually.

The highest incremental emissions that railroads could emit over and above pipelines for the net GHG emissions from oil sands production and transportation to breakeven was found to be approximately 3,400 gCO_2e per barrel – a value within the range of those found by the US Department of State (2014) and Tarnoczi (2013). The US Department of State (2014) calculates that railroads emit 4,308 gCO_2e per barrel more emissions than pipelines (which emit 10,311 gCO_2e per barrel) when transporting bitumen from Alberta to the USGC. Tarnoczi (2013) finds *pipelines* produce more GHG emissions than railroads on a per barrel basis because electricity from coal plants are used to power pipeline pump stations, but additional research is needed to confirm this result given that it is inconsistent with his other findings. Even though the GHG emissions from transportation part of the crude oil lifecycle are an order of magnitude less per barrel than the total incremental WTW GHG emissions from oil sands bitumen as compared to other heavy oils, this

component of total WTW emissions could be significant because the incremental transportation emissions would be accrued on every barrel transported (not only the barrels of oil not produced due to transportation constraints). In other words, if railroads produced even slightly more GHG emissions than pipelines on a per barrel basis, then any benefit from the constraining oil sands production is reduced if not reversed. Further research into the emissions from crude oil transport is needed to more firmly suggest a less ambiguous conclusion.

Because it is not possible to determine whether denying the Keystone XL permit would increase or decrease GHG emissions, justifying a denial of the permit on the basis that it would "significantly contribute to carbon in our atmosphere," (*The New York Times* 2013) is a difficult argument for President Obama to make, unless he had further research suggesting that railroads produced fewer emissions than pipelines that confirms the findings of Tarnoczi (2013).

III. Ultimately, the symbolism associated with the Keystone XL permitting decision matters as it relates to long-term political will to address climate change, but the decision still has to be carefully justified based on the technical evidence.

Because of the symbolic value that has now been attached to the Keystone XL decision, President Obama must consider how this decision will affect the longer-term political will to address climate change. Denying the Keystone XL would represent a major shift in US presidential policy away from its historical prioritization of energy security (see e.g. discussion in Freudenburg and Gramling 2012).[108] Would a pipeline permit denial enhance the political support for addressing climate change more than it would create opposition from those who support the Keystone XL, oppose, and/or are ambivalent towards addressing climate change? Would it reduce the likelihood of Canada taking action to address climate change (because the Canadian government would believe that there would be no chance of expanding their crude oil exports to the US), or would it simply lead to a short cooling of Canada-US relationship? Would President Obama's decision encourage climate change activists internationally to press their cases politically? Addressing these questions is outside of the scope of this thesis, but the author recognizes that they are important factors in the evaluation.

Nonetheless, careful technical justification of President Obama's decision on a national interest basis – the test he must use according to Executive Order 13337 – is still required. As discussed in

[108] Jon Stewart, on his satirical *The Daily Show with Jon Stewart*, provides history of US presidents' statements on their plans to achieve energy independence in his June 16, 2010 show, highlighting the ongoing attention given to this issue. Stewart, Jon. 2010. *An Energy-Independent Future*. http://thedailyshow.cc.com/videos/n5dnf3/an-energy-independent-future.

Conclusion II, arguing that denying the Keystone XL would constrain oil sands production and prevent climate impacts is a difficult argument to use. However, because railroads perform competitively with pipelines, one could also question whether the pipeline is really necessary. Because President Obama must still find the pipeline to be in the national interest, he also needs to consider his justification carefully.

If President Obama were to approve the pipeline, it could be on the basis of enhancing economic development and energy security. Though jobs are created if railroads were used to transport crude oil, the upfront construction jobs from the Keystone XL could act as a modest stimulus when the economy is not operating at its full output, resulting in longer term effects (Knittel 2013). Additionally, supporting increased production of the oil sands could enhance energy security and economic development. The oil sands is an available and geopolitically-accessible resource to the US. Approving the pipeline would also make the oil slightly more affordable because transport by pipeline is slightly less costly than by rail. However, as discussed in **Chapter 3**, the effects associated with the Keystone XL approval would be modest, not only because railroads would be able to transport significant volumes of oil if the pipeline were not approved, but also because increasing oil production from Canada is (1) unlikely to have a significant impact on world oil prices and (2) the US would still likely require a strong presence in geopolitically sensitive oil production areas, notably the Strait of Hormuz and the Middle East in general. Therefore, energy security will remain a concern. Overall though, US energy security would be enhanced along three of the four dimensions considered in this thesis: availability, accessibility, and affordability.

If President Obama were to deny the pipeline, his justification could perhaps be based on a lifecycle perspective of oil transportation infrastructure, as well as because of the concern over the long-term acceptability of the oil sands. Pipelines, given that they require more new infrastructure than rail lines, would initially have a higher construction environmental impact (more land is disturbed initially) but arguably have lower ongoing operational impact. If oil production were to continue to grow as forecasted until 2030 or so, then, on balance, approving the pipeline would likely make sense. However, as Chan et al. (2012) have shown, due to its higher GHG emissions intensity, oil sands bitumen production might be constrained if a worldwide climate policy were implemented. In other words, if the political will to address climate change were to become strong enough to implement climate policies, oil sands bitumen would no longer be seen as acceptable. If such a policy were put in place soon, then the need for a pipeline is questionable. If President Obama were to deny the pipeline on this argument, he would likely require additional research to understand

when a "breakeven" point would be appropriate, i.e. how soon would climate policies need to be implemented for the pipeline to no longer make sense. This research could also include enhanced documentation of the WTW GHG emissions of all crude oils imported into the US.

Supporting the above justification, President Obama could potentially argue that Canada's limited action on climate policy in the oil and gas sector restricts the economic security benefits of the pipeline by not addressing the environmental acceptability of bitumen production. The US already imports 1.3 MMbbl/d of oil sands bitumen (included upgraded synthetic crude oil) and has previously justified pipeline approvals on the basis that Canada would address climate change using its own policies. For example, when a previous pipeline permit was issued in 2009, a US Department of State (2009) press release argued that "[the Obama] administration believes the reduction of greenhouse gas emissions are best addressed through each country's robust domestic policies and a strong international agreement." As found by Demerse and Partington (2013), Canada is on-track to increase its GHG emissions from 2005 levels instead of decrease them 17% by 2020, a shared goal with the US. (Though the US is not on track either, they could still decrease emissions from 2005 levels). Because Canada's oil and gas sector represented 23% of its total GHG emissions in 2011, climate policies are likely required in this sector to achieve Canada's overall goals. However, as this thesis conclusion is drafted in May 2014, there is no climate policy addressing the oil and gas sector. In 2013, President Obama has stated that ". . .there is no doubt that Canada at the source in those tar sands could potentially be doing more to mitigate carbon release" (*The New York Times* 2013). In other words, he could argue that the previous basis on which he found cross-border pipelines to be in the national interest is not being met.

There is also the question of the larger economic role of pipelines and railroads. Railroads support the US economy by transporting a wide variety of goods and generally rely on their own capital to invest in their infrastructure. If President Obama were to deny the Keystone XL, would it enhance the railroad industry's ability to continue to make investments in its own infrastructure, and thus support the economic transport of a wider variety of goods? As discussed in **Chapter 1**, railroads are already concerned with declining US domestic coal revenues due to increasing environmental restrictions on coal-fired power plants (Stagl 2013). Furthermore, the increasing market share by railroads could potentially discipline the pricing of both pipelines and railroads. Alternatively, would the increasing transport of crude oil by rail displace other rail traffic as railroads allocate their capacity and lead to higher rail rates? Though 2013 was a bumper-grain-crop year in Canada and its winter was particularly harsh (reducing rail capacity), grain farmers on both sides of the

border have argued that their traffic is not being sufficiently prioritized due to the growth of crude oil by rail (MacPherson 2014, The Canadian Press 2014, CBC News 2014c). Additionally, railroads could potentially increase their rates as they gain greater market share in the crude oil by rail market. Oil producers, who would have made large capital investments in transportation infrastructure, would now be captive to the railroad industry, unless both parties sign sufficiently long-term contracts. These economic questions have not been explored in the US Department of State's report on the Keystone XL and should be explored by the President before he makes his decision.

Ultimately, President Obama needs to carefully justify his decision, particularly if he were to deny the pipeline permit. Not only is there going to be domestic political repercussions, as the author drafts this conclusion, there have been reports that Canada and TransCanada could pursue arbitration under the North American Free Trade Agreement (NAFTA), broadly arguing that the US's treatment of the Keystone XL permitting process is discriminatory as compared to previous permitting decisions (Cattaneo 2014). Though President Obama cannot state that denying the Keystone XL would constrain GHG emissions, there may be other climate change-related and economic justifications he could consider in his decision of whether or not to find the Keystone XL in the national interest.

In the meantime, the time he takes to contemplate his decision has implications for the actions of railroads.

IV. President Obama's postponement of his decision increases the regulatory uncertainty for the railroads, and by extension, oil producers. Does the delay itself represent more policy significance than President Obama's ultimate decision?

One of the findings from the dynamic program results presented in **Chapter 3** is that railroad's may be hesitant to invest due to the uncertainty faced by pipeline approvals in both Canada in the US. Additionally, starting with the feeder pipelines that run from oil sands mines to rail loading facilities, because the existing oil sands transportation system is largely configured to run using diluted bitumen, oil producers making serious use of rail transport would likely need to invest in diluent recovery units to make use of lower cost rail transport of raw bitumen. Forrest and Brady (2013) note that a five-year payback period on raw bitumen rail infrastructure is required to make such investment economic for oil producers and that "the rationale, so far, for not investing in the pure bitumen transport option is that most oil sands producers are assuming that sufficient pipeline capacity will become available in a few years." Auffhammer (2014) also suggests that

regulatory uncertainty is likely slowing oil sands production expansion. Regulatory uncertainty is plausibly discouraging rail capacity investments by railroads and oil producers.

Do these findings suggest that the implications of President Obama's delay are more significant than the actual decision by President Obama itself? If such were the case, how might these findings affect his strategy? Canadian Foreign Minister John Baird previously suggested in early 2014 "[the] time for a decision on Keystone is now, even if it's not the right one" (Koring 2014). In essence, this comment suggests that the uncertainty over the Keystone XL decision is more harmful to the Canadian government's goal of expanding oil sands production than President Obama denying the permit.

While the author cannot conclude that the regulatory uncertainty provides leverage for President Obama to push for climate policies in Canada, there are factors that likely affect his leverage. If, for example, railroad capacity does not expand as much as needed and/or pipelines to the Canadian West Coast are not able to start construction before the next Canadian federal election in 2015 (due to political opposition that could play out in the courts), the Canadian government will increasingly be seeking the construction of Keystone XL. Given the US domestic political polarization (i.e. lose-lose) on the Keystone XL issue, delay may also be one of the more effective strategies that President Obama may have to push for climate policies.

5.2.2 The Railroads' Role in the Crude Oil Transportation Market

V. Crude oil by rail is a potentially significant market for the railroads, but the traffic growth will not help the railroads lower their dependence on fossil fuel traffic.

As discussed in **Conclusion I**, the oil sands represent a massive crude oil resource. If all additional oil sands production between 2014 and 2030 were to go by rail transport (approximately 3.0 MMbbl/d), on the order of 50 trains per day would be required. The Canadian Pacific Railway (CP) currently handles 30 to 35 trains per day on its east-west mainline (Cairns 2013a), and the Canadian Nation Railway (CN) would likely handle a similar volume. Though the traffic would likely be spread out over a variety of routes, Cairns (2013a) suggests that this growth may be a "stretch to far" for the railroads to handle.

Along with shale oil production increases, a rise in bitumen production would also have important implications for all North American railroads because some of the crude oil would be transported to US refineries. If all of the crude oil production growth projected between now and 2014 were to be transported by railroads, approximately 3.5 million carloads per year would originate on Canadian

and American railroads.[109] To put this figure into context, oil production growth could represent about 12% of the about 28 million carloads in 2008 (AAR 2013a).

Nonetheless, coal traffic is, and would remain, the railroad's largest traffic and revenue source, but crude oil by rail offers a potential new revenue source for the railroads to make up for the decline in their domestic coal traffic. In 2012, railroad revenues from coal transport, both for domestic and international coal markets, totaled $14.7 billion, or about 22% of US Class I railroad revenues (AAR 2013a). However, in 2012, coal traffic was down by 1.51 million carloads from its peak of 7.71 million carloads annually in 2008 (AAR 2013a). BNSF CEO Matthew Rose, in an October 2012 presentation at MIT, notes that they will almost replace their coal traffic with growth in oil traffic from the Bakken-formation crude.[110]

Of course, there is uncertainty for the railroads as to whether additional crude oil traffic from the oil sands will materialize. In the short term, regulatory uncertainty exists as to whether governments will approve pipelines. In this research, the dynamic program presented in **Chapter 3** suggested a cautious posture is warranted in regard to capacity expansion investments needed to transport crude oil because pipelines remain the mode preferred by many oil producers. However, this study assumed that railroads were at their capacity limit. Additionally, this analysis assumed that shippers would always prefer pipelines.

There may be markets in which railroads are always competitive with pipelines. As suggested by the US Department of State (2014) findings, railroads transporting raw bitumen for small shippers may always remain competitive with pipelines because small shippers cannot receive the long-term contracted rates from pipeline companies. Railroad rates are lower than non-long-term contract rates from pipelines. Additionally, some have suggested that transporting raw bitumen may be a safer alternative than transporting diluted bitumen (e.g. Fielden 2013a), but this claim that would have to be confirmed or refuted through further research. Thus, railroads could potentially further enhance the competitiveness of the raw bitumen market by supporting the research on the implications of raw bitumen transport (as compared to diluted bitumen transport).

In the longer term, while crude oil by rail would provide railroads with a boost in revenue, it does not necessarily help the railroads' wean off its dependence on fossil fuel related traffic. As noted in

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[109] This calculation assumed an unweighted average tank car capacity of 588 barrels per tank car.

[110] Rose, Matthew. 2012. *Strengthening the US Supply Chain*. Presentation at the Massachusetts Institute of Technology Center for Transportation and Logistics, October 3. http://www.youtube.com/watch?v=SiOQ9Qp8XXM

the introduction to this chapter, the scientific evidence is increasingly suggesting that human-induced climate change is happening now. Though climate change is a particularly challenging issue to address politically, it is still a concern among the public, with 42% of respondents to a recent survey indicated that "global warming should be a . . .[high or very high] priority for the president and Congress" as compared 28% a low priority (Leiserowitz 2013). Stanford University recently became the most prominent university to divest from direct investments in coal (Mufson 2014). Following the implementation of worldwide climate change policies, Chan et al. (2012) have provided scenarios in which oil sands production would decrease. The railroad industry, by transporting more crude oil, would be maintaining its exposure to a market that would be impacted by climate policies.

However, the author could foresee a scenario in which railroads could leverage their ability to haul multiple commodities and use their capacity they have developed for crude oil traffic to transport biofuel production if this market were to further develop. Chan et al. (2012) (in the same study cited above) caution that one of the open questions is whether biofuels with low WTW emissions will develop to replace petroleum products:

> *Much of the demand for petroleum products is driven by transportation needs, and so the fate of the oil sands industry depends on the availability of transportation alternatives to petroleum (or oil sands)-based diesel and gasoline. If there are alternatives such as biofuels that can be economically competitive and produced with low life cycle CO2 emissions, then petroleum product demand is depressed leaving less demand for oil sands products. If such options are not available, are too costly, or are themselves CO2 intensive because of land use change emissions, then we find that the roles for Canadian oil sands may remain crucial.*

In other words, there is likely to be some level of investment in crude oil transportation that could be leveraged into other markets, and hence making it more sustainable (in the business sense of the word) in the longer term. If the railroads are not doing so already, they should study how energy system transitions would affect their investment decisions in the crude oil market.

VI. What should the railroads' role be in influencing the debate over the environmental and safety issues related to the commodities that they ship? In some of their statements, railroads have suggested their social responsibility does not include questioning the commodities that they transport.

In both Canada and the US, railroads are common carriers and are required to transport goods and commodities offered to them by shippers upon a reasonable request. The Canadian Transportation Agency and the US Surface Transportation Board regulate this requirement in each country. In regard to the crude oil market, railroads have previously used this fact to suggest that they would

have to transport crude oil regardless of whether or not they felt that was in their economic interest to do so:

- "If [ship-loading] infrastructure was permitted for this purpose on the West Coast [of Canada] and a request was made to CN, we would respond and do what our business mandate and common carrier obligations call for – move these products as safely and efficiently as we can for the benefit of all Canadians" (CN president Claude Mongeau, cited in Pynn and Hoekstra 2013).
- "Whatever people bring to us, we're ready to haul . . . [if Keystone XL] doesn't happen, we're here to haul" (BNSF spokesperson Krista York-Wooley cited in Efstathiou 2012).

As discussed in **Chapter 1**, there is no question that railroads are constrained by common carrier requirements. Regulators give shippers – the individuals and organizations requesting transport – deference in interpreting these requirements. For example, in 2009, the Union Pacific Railroad (UP) argued that it should not be required to transport certain chlorine shipments, because there were other sources of chlorine near the destination and the shipment would transit through heavily populated areas (Quinlan 2009). Even though chlorine is very hazardous to transport, the UP was not able to defend its argument to the Surface Transportation Board, which ordered the railroad to transport the chlorine if requested by the shipper.

However, unlike such toxic-inhalation hazard (TIH) shipments that railroads would like to avoid as "bet on the company" risks (see discussion **Chapter 4**), crude oil transport are generally being welcomed by the industry. As discussed in **Conclusion V**, there is significant traffic potential for the railroads in transporting crude oil. While it may be true that railroads transport crude oil because they have to, this argument may seem unconvincing to a skeptical public given the legitimate business reasons that exist for railroads to transport crude oil. Additionally, unlike with the modal split between trucks and railroads as it relates to TIH shipments in which railroads are generally thought to be the safer mode (and more environmentally-friendly mode as well) (e.g. US Department of Transportation [DOT] 2008), railroads are not generally assumed to be as safe (or environmentally-friendly) as pipelines. Railroads are thus entering a market in which society believes that railroads are not as efficient as pipelines.

Given this situation, what should their corporate social responsibility stance be towards this crude oil market (and fossil fuels more generally)? Specifically, how do they reconcile their efforts at promoting their GHG efficiency (see e.g. "Freight Railroads Help Reduce Greenhouse Gas Emissions" [AAR 2013c]) with the fact that their industry enables the use of fossil fuels?

The railroad industry could develop an industry-wide stance led by the AAR towards climate change and carbon policies. BNSF CEO Matthew Rose, at a 2012 presentation at MIT, mused in response to a question from the audience ". . . what are some of the downsides to carbon pricing?" that "[net]-net we [BNSF] think [that carbon pricing] is a real positive force [because it will increase rail intermodal traffic more than it will decrease coal traffic]." (31:54)[111]. However, while individual railroads have likely considered the issue internally, the strategy at the industry-level (i.e. AAR) appears less coherent as presented publicly. The AAR divides its discussion of what railroads haul into commodity groups[112] but does discuss more holistically how policies such as carbon pricing could affect the overall mix. Given the efforts that railroads have made to reduce their own energy and emissions footprint, considering what they ship and how it affects climate change could become part of their corporate responsibility strategies. They may wish to develop an industry-wide policy on their stance on climate change and whether lobbying for a climate change policy would be beneficial to the industry's long-term sustainability.

VII. Do the necessary railway safety regulatory tools exist to allow railroads to establish a social license? Within railway safety legislation and regulation, there is no clear strategic definition of acceptable risk, who determines it, and how it is determined

Following the accident at Lac-Mégantic, there has been policy discussion in Canada about whether railroads (and other modes of transportation) have the necessary "social license" to operate in Canada. A Canadian Senate Committee report defined social license as the "broad approval by society (at the local, regional and/or national level) for a given activity or project" (Standing Senate Committee on Energy, the Environment and Natural Resources 2013, p. 6). In this thesis, this issue of social license has implicitly (until this point) come up in two issues. First, it has come up in the issue of whether producing bitumen is *acceptable* to the public because of its impacts on climate change and the environment. Second, it has come up when considering safety in terms of what are *acceptable* risks from the public's perspective. In **Chapter 4**, the author considered this issue of acceptable risk – risk being defined as some function of the likelihood and severity of an undesired event – in the context of the Lac-Mégantic accident.

Even though the concept of risk *acceptability* is fundamental to the issue of earning a social license, the explicit discussion of the issue is not featured prominently within legislation or regulation subject to societal scrutiny, but in fact discussed within Transport Canada's (2010a) ". . . Guide for developing and enhancing railway safety management systems," which is a document explaining

[111] Rose, Matthew. 2012. Op cit.
[112] https://www.aar.org/economy/Pages/What-Railroads-Haul.aspx#.U2-1vS_lEWE

Transport Canada's expectations for each railways' safety management systems. The RSA, the centerpiece of Canadian railway safety legislation, enables *prescriptive* rules, regulations, and standards, **and** *performance-based* regulations. As part of these latter regulations, each railway is required to have a process, within its SMS, for "(i) identifying safety issues and concerns, including those associated with human factors, third-parties and significant changes to railway operations, and (ii) evaluating and classifying risks by means of a risk assessment" (SOR/2001-37 Section 2[e]), which includes "[determining] . . . whether the associated risk [of a safety issue or concern] is tolerable, tolerable with mitigation or unacceptable, using a predetermined company risk classification methodology" (Transport Canada 2010a). Though Transport Canada proposes some frameworks in the associated annex to its guidelines, the specific risk classification framework used to classify risks into tolerable or unacceptable is determined by the company, which is only viewed by the Railway Safety Inspector on site. In other words, risk acceptability appears to be defined at the railroad and regulatory inspection level.

The fact that this definition is not more prominently featured is an issue in the case of crude oil by rail transport, because the systemic issues created by the growth in this traffic is of concern to multiple actors in the safety control structure. As discussed in **Conclusion VI**, railroads, as common carriers, are required to transport a wide variety of hazardous goods, and are thus not necessarily experts in the handling and spill response of every commodity that they transport. The prescriptive requirements for transport of hazardous materials are defined in the TDGA and its associated regulations, and the requirements for safe transport are shared among Transport Canada, the shippers, and the railroads themselves, and also involve tank car manufacturers and lessors, and industry associations for example. In the case of the Lac-Mégantic accident, it is unclear how a quantitative risk assessment process defined by Transport Canada (2010a) would have been able to quantify the risk from the interaction of systemic factors that led to the accident (e.g. the increasing traffic of volatile crude oil from the Bakken formation and the use of unit trains), and thus to lead to appropriate actions in response.

A political-, regulatory-, and company-management-level system safety issues exist, but there is no associated definition to guide how it is to be resolved. The closest reference at the legislative level occurs in the objectives of the RSA, one of which states that "companies [are responsible] to demonstrate, by using safety management systems and other means at their disposal, that they continuously manage risks related to safety matters" (Section 3[c]). However, this reference does

not provide much guidance in terms of what is an acceptable risk. The author conjectures that not debating this issue and having it stated explicitly has the following implications:

a. Railway Safety Inspectors do not have any guidance with which they can argue that railroads need to take action over and above the prescriptive requirements in the rules and regulations unless there is a clear, immediate threat to railway safety. The Senate Committee cited notes that "earning a social license" involves having ". . . a robust safety system, with a clear focus on the environment, transparency, early consultation and continued community engagement. . ." and ". . . *can sometimes mean going beyond regulated requirements to address community concerns*" (emphasis added, p. 6). However, the RSA generally limits these inspectors from issuing a direct order unless there is an immediate threat to railway safety. There may also be instances in which the inspectors are prohibited from making an order over and above the existing standards. For example, under Section 31(4) of the RSA, "a railway safety inspector shall not determine that the standard of construction or maintenance poses a threat to safe railway operations if that standard conforms to all applicable regulations, rules and emergency directives [for the purposes of subsection (1) and (2).]" Therefore, it is unclear how an inspector might justify action that goes above and beyond existing prescriptive regulations. If the intent of the RSA is to have railroads demonstrate that they manage safety risks, is following existing rules and regulations sufficient?

b. Public skepticism towards railway safety and the belief that railroads are "de-regulated" or "self-regulated." In Transport Canada (2010a) argues that the inclusion of SMS "does not mean. . ." ". . . de-regulation . . . " or ". . . self-regulation . . ."; "existing [prescriptive] regulatory requirements [still exist]" and ". . . Transport Canada [still] . . . oversees compliance with regulations" (p. 6). The author's findings also support these statements; regardless of the existence of the SMS regulation, railways are still highly regulated. However, the lack of clear definition of acceptable risk within the legislation or regulation themself could contribute to the skepticism that railroads have excessive influence over this definition. Additionally, the author found it difficult to understand how the public could contribute in a meaningful way to the oversight of rail safety. For example, the Advisory Council on Railway Safety (ACRS), a council made up of railway stakeholders (including a member of the

public) does not publish its membership or deliberations in a conspicuous place (e.g. online) (Transport Canada 2008). When the author requested information from Transport Canada regarding the council's composition, he was directed to file an Access to Information Request (refer to the correspondence in **Appendix B**). Unless the member of the public knew exactly what he or she was looking for, this process would prove cumbersome.

c. Concern by the railway industry and shippers that there will be "knee-jerk" reactions by regulators to accidents. Following the accident at Lac-Mégantic, both shippers and railroads expressed concerns that governments would be too heavy-handed in regulating railway safety. CP CEO E. Hunter Harrison made the above comment regarding "knee-jerk" reaction, and goes on to suggest ". . . I think you could have a dialogue and think about it and maybe have a public discourse about it before there's some snap reactions" (CBC News 2014d). A shippers' trade magazine made a similar comment: "I urge legislators not to take this [the accident] as free license to impose unnecessary legislation" (Smyrlis 2013). Because the accident provided evidence that railroads were not necessarily managing some risks appropriately, the government was able to respond with appropriate regulation backed up by political will among its constituents. If a more proactive risk assessment process was put in place that prevented the accident, there would have been less need to be concerned about an overreaction in government regulation.

The findings of this thesis suggest that more work is needed to understand what is considered an acceptable risk, and whether it is incumbent upon the railroad industry to justify that the risk is acceptable, or whether Transport Canada must justify that the risk is unacceptable. A greater understanding of how this tension is developed and resolved is thus an issue warranting further study.

VIII. Are there other approaches to addressing safety and communicating analysis results to the public other than probabilistic risk assessments? Using quantitative methods may not always be the most effective approach to addressing safety.

A related question to the issue of acceptable risk is question how risk is qualified or quantified. The railroad industry emphasizes the use of probabilistic risk assessment along with benefit-cost analysis in its risk assessment. For example, in the case of Transport Canada guidelines (2010a), while they state that risk estimation can either be done "qualitatively or quantitatively," the

remainder of the subsequent discussion focuses on quantitative or semi-quantitative methods. (By semi-quantitative, the author means that probability and severity are classified using terms such as "Improbable," "Remote," "Occasional," "Probable", and "Frequent" and "Negligible," "Marginal," "Critical," or "Catastrophic," respectively, each with associated text definitions [Annex I, p. 29]). The guide further suggests, "[where] no relevant historical data are available, other methods such as fault-tree or event-tree analysis may be used to generate estimates [of risk]." While the author does discount the need for a quantitative framework to assess tradeoffs in the capital-intensive railroad industry, perhaps there is a need to emphasize how qualitative frameworks can be used to identify and address hazards as well.

For example, it is difficult to understand how a quantitative risk assessment would have been effective in guiding action prior to the Lac-Mégantic accident, considering its circumstances. If one were to take a chain-of-events causation view of the accident (described in **Chapter 4**), there were several unusual events combined with environmental factors that led up to the accident: the fire on the locomotive, the locomotive being shut down by the fire department, the train parked on the mainline instead of the siding, the steep grade leading into Lac-Mégantic, the fact that sufficient handbrakes were not set or that they did not function properly, the use of unit trains to transport crude oil, and the fact that the oil was more volatile than first thought. Identifying *and* assigning probabilities or severities to any of these events would have been near impossible. If, before the accident, an analyst were to take a fault-tree analysis approach to figuring out the probability of a crude oil train derailing in Lac-Mégantic and exploding, the author suspects that some a very low probability of the accident occurring would be developed (possibly because some of the events may have been excluded *and* because it would have neglected systemic issues such as MM&A's financial pressures) or that efforts would be abandoned. A qualitative hazard identification framework, such as STPA (also built on STAMP), would have refocused the emphasis not on quantification, but on identifying the hazards that might lead to an accident.

To be clear, the author is not suggesting that a qualitative framework would have prevented the accident at Lac-Mégantic. This conclusion and further question comes from the simultaneous observation of the difficult-to-assign-quantitative-probability hazards leading up to the Lac-Mégantic accident and the emphasis in the railroad industry on the use of probabilistic risk assessment. As a result, it may be worthwhile to understand how other qualitative methodologies could be used as part of the risk assessment process, and question: when is it necessary to quantify?

There is the related question as to whether quantitative risk assessment and associated benefit-cost analysis is the most effective way to communicate safety tradeoffs to the public. Leveson (1995) argues:

> *The prevailing position in our society is the utilitarian view that the only reasonable way to make technology and risk decisions is to use risk-benefit analysis. This belief is so widespread that we often accept risk-benefit analysis as the* ***only*** *way to make technology and risk decisions, without realizing that there are alternatives. (emphasis in original, p. 14)*

The question regarding the use of quantitative risk assessment and communication with the public is particularly relevant as it relates to the relatively recent (2008) mandate by the US Congress to have US railroads install positive train control (PTC) on rail lines with passenger rail or certain hazardous material traffic.[113] The US Railroad Safety Improvement Act of 2008 requiring PTC was spurred by two accidents:

> *[a] 2008 crash in Chatsworth, Calif., in which a Metrolink commuter train ploughed into a freight train because its contract operator engineer ignored[114] a red signal while text messaging, resulting in the unnecessary loss of 25 lives and injury to 135 others. Another catalyst of the Act was the 2005 collision at Graniteville, SC, that resulted in the release of poisonous gas and nine deaths.* (Banks 2014)

Much of the literature in reference to PTC, including by the Association of American Railroads (AAR), emphasize the excessive costs as compared to benefits of the technology (e.g. Banks 2014, AAR 2013d, Cairns 2013b, Peters and Frittelli 2012); however, it is unclear whether these arguments resonate with the public outraged over potentially preventable accidents. Bray (2004) finds that there are factors related to risk tolerability that may provide arguments for "higher levels of expenditure on rail safety" and Leveson (1995) argues "[making] decisions such as how safe is safe enough involves addressing moral, ethical, philosophical, and political questions that cannot be answered fully by algebraic equations or probabilistic evaluations" (p. 17). A more qualitative approach to addressing the hazards that led to the accident (i.e. operator distraction) may have led to a more productive policy conversation about what steps could be taken to *improve* safety rather than providing a benefit-cost justification for *not* taking a certain action. Following the PTC mandate and the accident at Lac-Mégantic, the author suggests there is the occasion to reflect on whether other qualitative approaches may be more effective at communicating their rail safety actions to the public.

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[113] PTC ensures that a train brakes when required by the signaling system.

[114] The author has not read the original accident investigation and thus does not necessarily support the use of the value-laden term "ignore" to describe the operator's actions.

5.3 FURTHER METHODOLOGICAL RESEARCH

The author raised several questions in the above conclusions – particularly in **Conclusion VIII**. As such, another way to view this thesis is as a scoping document for further research. The two particular issues that were raised in the above discussion relate to institutional safety issues as well as the role of corporate social responsibility as it relates to *what* the railroads transport. Based on these issues raised, the author proposes the following methodological research that could follow related to Safety-Guided Institutional Design (**Section 5.3.1**) and the Integration of Societal Issues and Strategy (**Section 5.3.1**).

5.3.1 Safety-Guided Institutional Design

In **Chapter 4**, CAST was used to understand the causal relationships between different levels of the system and built an initial representation of the railroad industry control structure. However, the analysis by itself is not sufficient to suggest concrete institutional design changes. Thus, the author proposes the idea of safety-guided institutional design. This process would be used to evaluate proposed changes to the railway system regulatory framework by identifying and addressing hazards associated within the legislative-, regulatory- and management-levels in the safety control structure. As this thesis is being written, Kawakami (2014) has used this concept to this concept to evaluate potential institutional structures for implementing high-speed rail projects in the US.

Safety-guided institutional design would be an extension of safety-guided design process proposed by Leveson (2011a). In this process, STPA, the hazard-analysis tool built on STAMP, is integrated with design decisions in an integrated process as shown in **Figure 5-1**. The safety-guided institutional design would be an extension of this process incorporating concepts from the fields of strategic management, governance, and public policy. At the 2014 STAMP Conference held at MIT, Neils Smit of the Dutch Safety Board (2014) incorporated these concepts into the study of the Dutch offshore petrochemical industry, Leveson (2013) has also investigated the development of leading indicators in petrochemical industry, another issue associated with regulatory and management oversight. The author believes that there is merit to developing such a methodology in the context of the railroad regulatory landscape

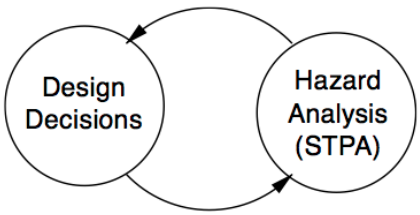

Figure 5-1: Iterations in the safety-guided design process (Source: Leveson 2011a)

While previous rail safety review panels, such as the 2007 effort in Canada (Lewis et al. 2007), and rail safety reports, such as Cairns (2013b) and Campbell (2013), are thorough, they do not offer theoretical underpinnings for their recommendations nor provide guidance as to the tradeoffs associated with their recommendation in terms of the hazards they are addressing. The safety-guided institutional design process could be used to evaluate proposed changes to the railway safety control structure using system safety theory as its underpinnings. For example, it could be used to investigate whether more prescriptive regulatory approaches are needed to specific how railroads carry out their risk assessments. Alternatively, it could be used to investigate the development of goals, objectives and performance measures for railroads and safety regulators to implement to oversee their SMS. The author envisions that such a tool could be useful to organize the debate over these issues.

5.3.2 Integration of Societal Issues and Strategy

The other set of questions raised by this conclusion chapter relate to corporate social responsibility role of railroads related to the commodities that they ship. Management professor Michael Porter has proposed the concept of "creating shared value" as a vision for how companies should operate. Porter and Kramer (2011) define shared value as, "policies and operating practices that enhance the competitiveness of a company while simultaneously advancing the economic and social conditions in the communities in which it operates." Porter and Kramer (2006) find that there are usually four categories of arguments for corporate social responsibility: "moral obligation, sustainability, [social] license to operate, and [company] reputation." The argument that railroads need a social license to transport crude oil has been raised in this thesis, but aligning societal values and railroad company efforts is a challenging endeavor when dealing with hazardous material transport because there are conflicting goals that must be addressed. Porter and Kramer's (2011) framework could potentially provide some insights into these issues.

There are also possible methodological extensions. One of the critiques of the framework proposed is that "Porter and Kramer are seeking to solve a system-level problem . . . with merely organizational-level changes" (Crane et al. 2014). Railways are similarly challenged trying to address the issues of safety and climate change: what they ship has a profound impact on their business and society (perhaps more so than how they ship it), but they have limited control over what they ship. To address these issues, they will require the involvement of other actors – notably regulators and shippers – that are external to their (railroads') organizations.

Therefore, there is potentially the opportunity to make a methodological contribution in the management literature in addressing the question – *how do companies "[create] shared value" by taking approaches outside of their organization* – in addressing the domain related question – *how should railroads attempt to influence the commodities that they transport*. Railroads already do this to some extent, for example, by training first responders for railway safety accidents. Are there other opportunities for the railroad to do so related to climate change or safety? This line of research could work towards developing a process for the railroads to identify shared value opportunities considering opportunities external to the railroads themselves.

5.4 FINAL THOUGHTS

Before closing, the author would like to remind readers (and himself) that this thesis emphasized supply side of the oil market. As individuals, we need not forget our own roles in addressing the critical contemporary issues – climate change, energy security, economic development and safety – raised in this thesis. As noted in **Chapter 2**, on the demand side, most oil is used for transportation purposes, which is when most GHG emissions from crude oil are released. While societal concern over the oil sands and Keystone XL is understandable given their environmental impacts, we all share responsibility in this debate in regard to our direct actions – where we live and work, whether we drive, what we drive – and not just those actions that relate to what we think *they* – governments, oil producers, railroad and pipeline companies – should do. Joy Williams, in the persuasive literary essay, "Save the Whales, Screw the Shrimp,"[115] argues: "[the] ecological crisis cannot be resolved by politics. It cannot be solved by science or technology. It is a crisis caused by culture and character, and a deep change in personal consciousness is needed. . ." We are all, as individuals, part of the CLIOS system described in this thesis, and as such, need to continually reflect on our own role in addressing the critical contemporary issues raised as we debate alternative policy mechanisms – strategic alternatives – to address these issues.

Motivated by the ongoing debate over whether the Keystone XL should be approved and the concern over rail safety following the Lac-Mégantic accident, the goal of this thesis was to address the question: should railroads transport crude oil? This question is value-laden with ambiguous and uncertain results, and the role of this master's thesis is not to answer this question with a "yes" or "no" answer, but raise questions about how the debate should be framed. In particular, the thesis raised questions about the long-term environmental acceptability of bitumen due to its impact on climate change, and described how environmental acceptability is implicit in advancing energy

[115] The essay appeared in the February 1989 issue of *Esquire*.

security and economic development. This thesis also raised questions about the acceptability of safety risks in the rail transport of crude oil and recommended that this issue be debated at the railway management, regulatory, and political levels. Both railroads and pipelines are environmentally efficient and safe modes, and the emphasis of the conclusions is that *improving* environmental performance and *improving* safety should be focused on whenever possible, not only by looking inwardly at one organization in isolation, but also by coordinating broader system-level changes.

Methodologically, the CLIOS Process, along with the CAST tool built on STAMP, were useful approaches for studying railroad and pipeline transport of crude oil. They allowed the author to study not only how these modes perform within the oil transportation system, but also how the transportation system interacts with the oil sands production system, environmental and economic systems of societal concern, and the institutional sphere governing these systems. The author was able to do so by compiling information from sources across disciplines to understand the interactions between the transportation system and the critical contemporary issues of economic development, energy security, climate change and safety. Ultimately, because there are practical tradeoffs between the breadth and depth of any study, the author emphasized the issue of railroad safety, but was initially able to undertake a broader discussion of the issues.

More importantly, the author, using the CLIOS Process and CAST, was able to look beyond the beliefs of any one actor in considering the critical contemporary issues discussed in this thesis. Doing so has important ethical implications. Baillie and Levine (2013), in a paper on engineering ethics, argue that "[professionals are responsible] to see beyond what ethics means within the boundaries of contemporary pressures and measures of success [that they face]." As a professional, they argue, considering any problem in isolation is not sufficient ethical justification to act. In this thesis, for example, railroads are under pressure to transport any product offered to them, and thus are challenged in looking beyond the boundaries of their industry. The author, while recognizing these pressures, attempted to look beyond them and consider other opportunities for actions. While readers may not agree with the conclusions and recommendations provided in this thesis, the author would also encourage them to broaden their understanding of the system using similar tools for studying complex sociotechnical systems.

The author would also like to thank readers for considering the questions raised by this thesis. Because this thesis represents the author's first attempt to consider the complex questions raised by the increasing production of crude oil in North America, he would welcome further discussion.

APPENDIX A:
UNCERTAINTY ANALYSIS METHODOLOGY

A dynamic program is used to determine if and when railroads would invest in capacity to transport crude oil from Alberta to the USGC, the route of the Keystone XL. Dynamic programming models a situation in which a decision-maker can take actions at various points in time in the future in order to maximize their objective function. Of interest in this thesis is how the railroad industry reacts to the growing supply of crude oil from the oil sands. Given their objective function to maximize profit, if and when should railroads invest in capacity to transport crude oil from the oil sands?

The problem horizon is 20 years starting in 2014. In total, there are five two-year periods and a final 10-year period. At each decision period, the railroad industry can decide whether to invest in capacity (infrastructure and rolling stock) to transport crude oil. Between the first and second, and second and third decision period, governments in the US and Canada will make decisions regarding whether to approve or deny pipeline capacity for exports from the Canadian oil sands. Railroads can invest now before pipeline permitting decisions are made, or defer their decision until it is certain that pipelines will not be approved. If the former decisions are made, railroads can make more profits in the short term, but may not be able to recover their investments if pipelines are approved. If the latter decision is made, railroads forgo short term revenue, but do not run the risk of not being able to recover their investment.

The goal of this research is not to suggest a specific strategy for the railroad industry; it is an aggregate model with all railroads using reasonable assumptions about costs and benefits (the specific numeric values are not publicly available from the railroad industry. Rather, the goal of the model is twofold. First, in conjunction with the other information in this chapter, its purpose is to understand whether the railroad industry, faced with uncertainty over pipeline approvals, should adopt a more cautious posture in this industry or aggressively pursue market opportunities. Second, the results of the model also provide some insights for governments as to the plausible actions of the railroad industry, assuming that the railroads follow the resulting implications from the model. The model thus provides a useful way to study how the uncertainty that governments create over pipeline approvals interacts with the behavior of the railroad industry.

The specific problem formulation is given below in **Section A.1** and all values assumed in the analysis are given in **Table A-6**. The reader concerned with the analysis results is referred to **Chapter 3**.

5.5 DYNAMIC PROGRAM FORMULATION

The objective of railroads is to maximize profit, π, (in $ million) over all periods. As provided in **equation A-1**, profit in a given time period t is defined as the transportation rate per million barrels (R) minus the variable transportation cost per million barrels (VC) multiplied by the amount of crude oil shipped by rail in million barrels (FD_t) over the time period (i.e. (365×2) in the case of the first five time periods), minus the capital cost incurred ($CapCost_t$).

$$\pi = \sum_{t \in T} \pi_t = \sum_t (R - VC)(365 \times 2) FD_t - \mathrm{CapCost_t} \tag{A-1}$$

If such pipeline capacity were available to a destination, it is assumed that oil shippers would rather ship by pipeline. Therefore, as given in **equation A-2**, fulfilled daily demand by rail (FD_t) is the minimum of the rail capacity (RC_t) that exists at the beginning of a given state, and the oil sands supply (OSS_t) that exceeds pipeline capacity (PLC_t). Oil sands supply and pipeline capacity are stochastic. All units are in millions of barrels per day (MMbbl/d).

$$FD_t = \min[\max[(OSS_t - PLC_t), 0], RC_t] \tag{A-2}$$

The capital cost (in $ million), given in **equation A-3**, is the sum the infrastructure investment cost ($LCost_t$) and the locomotive purchase costs ($ICCost_t$). The factors used to convert rail capacity investment actions (dRC_t, in million barrels per day) into these respective costs are given in **Table A-10**. This analysis assumes that the railroad companies are currently operating at their infrastructure and locomotive capacity limit, and thus transporting oil would require an immediate investment.

$$\mathrm{CapCost_t} = \mathrm{LCost_t} + \mathrm{ICCost_t} \tag{A-3}$$

The dynamic programming problem value function (in $ million) used in time periods 1 through 5 is given by **equation A-4**. The value function represents the best possible present value of expected profits that the railroads could achieve, given current railroad capacity at time t and optimal capacity investments in all future periods. The expected value (i.e. $E[\ldots]$) accounts for the future variability of pipeline capacity and oil sands supply. In essence, the value function at time period t

(V_t) is expressed as a trade-off between immediate and discounted future rewards. The value function is calculated recursively starting with the last time period and working backwards.

$$V_t(RC_t, PLC_t, OSS_t) = \max_{dRC_t}\{(R - VC)FD_t - CapCost_t + (1 + dr)^{-2}(E[V_{t+1}(RC_{t+1}, PLC_{t+1}, OSS_{t+1})])\}, \forall t = 1, 2, 3, 4, 5 \quad \text{(A-4)}$$

Equation A-4 is used for the first five time periods; the value function for the last 10-year time period ($t = 6$) is provided by **equation A-5**. This equation assumes that the annual profit the railroads receive is an annuity throughout the time period and dependent on the railroad capacity, pipeline capacity, and the oil sand supply at the beginning of the period. The annuity is converted to a present value at the start of the period using a present value factor.

$$g(RC_t, PLC_t, OSS_t) = (R - VC)(FD_6)(365)\left(\frac{1-(1+dr)^{-10}}{dr}\right), t = 6 \quad \text{(A-5)}$$

The maximum possible railroad capacity (including infrastructure and locomotives) expansion (dRC_t) in one period was assumed to be 0.6 MMbbl/d in 0.2 MMbbl/d increments. This value was selected to correspond with the maximum possible oil sands expansion, but is also plausible based on experience from the Bakken-formation region, where rail traffic increased by about 0.4 MMbbl/d between 2012 and 2013 (AAR 2013). Assuming that this trend could continue, the capacity expansion would be 0.8 MMbbl/d over a two-year period.

Table A-1 presents the oil sand supply probability mass function (PMF) used for all periods (i.e. the probability [P_t^{OSS}] of a possible growth in oil sands supply [ω_t^{OSS}] in any period), an approximation of the low, reference, and high oil sand production forecasts from the National Energy Board [NEB] (2013). It is assumed that oil sands supply in the subsequent time period cannot exceed the crude oil transportation capacity, as given by **equation A-6**.

$$OSS_{t+1} = \min(OSS_t + \omega_t^{OSS},\ PLC_t + \omega_t^{PL} + RC_t + dRC_t) \quad \text{(A-6)}$$

Table A-1: Probability mass function for oil sands supply.

ω_t^{OSS}	0.0	0.2	0.4	0.6	(MMbbl/d)
P_t^{OSS}	0.0	0.1	0.8	0.1	$\forall t \in T$

Possible pipeline expansion projects are listed in **Table A-2**. The probabilities that these pipelines are approved or not approved are assigned using judgment based on the understanding of the

decision-making authority of Canadian and US governments regarding pipelines, as described in **Chapter 2**. The selection of probabilities is also guided by a framework proposed by Hoberg (2013).

Hoberg (2013) is a paper from the field of public policy on the political risks of pipeline development from Canada, i.e. what are the political risks that a pipeline will not go ahead. It uses an analytical framework based on institutional veto points – "location[s] of authoritative decisions that can block the approval of a policy or project" – to consider whether a project will or will not go ahead. If more veto points exist, it suggests that the project is less likely to go ahead. The paper also provides a thorough discussion of the responses by actors in the US and Canada to proposed pipeline construction thus far. Hoberg finds that there is a medium to high political risk associated with the Keystone XL, a high political risk associated with the two pipelines to the West Coast of Canada (the Northern Gateway and the Trans Mountain Expansion), and a medium political risk with the Energy East project. These findings, along with the accompanying discussion, are used to assign a probability that each pipeline is ultimately approved.

Additionally, considerations were made recognizing that there is interdependency between the probability of approval of each pipeline. For example, if the Northern Gateway were approved, the probability that the Trans Mountain is approved likely also increases. Ultimately, creating the PMF relies on judgment, and as a result, three scenarios, "low", "base" and "high" were considered to capture a range of possible beliefs about the possible probability distributions. The probabilities that each pipeline is approved under these three scenarios are provided in **Table A-3** (for pipelines entirely within Canada) and **Table A-4** (for pipelines between Canada and the US).

Table A-2: Possible pipeline capacity expansion in time periods 1 and 2.

Pipelines	**Capacity (bbl/d)**
Require US approval; decision expected in period 1	*1,180,000*
Enbridge Alberta Clipper (AC) (Phase 1)	120,000
Enbridge Alberta Clipper (AC) (Phase 2)	230,000
TransCanada Keystone XL (KXL)	830,000
Require Canadian approval; decision expected in period 2	*2,215,000*
Enbridge Northern Gateway (NG)	525,000
Kinder Morgan Trans Mountain Expansion (TMX)	590,000
TransCanada Energy East (EE)	1,100,000

Table A-3: Probabilities assigned to Canadian pipeline expansion.

	Approval probability			Comments
	Low	**Base**	**High**	
NG	0.3	0.5	0.7	This pipeline involves construction of a new right-of-way (ROW) through rugged terrain, and there is local and First Nations opposition to it.
TMX	Given NG approved:			This pipeline uses existing ROW and the permitting decision will follow the NG; therefore, there is likely correlation between the two decisions.
	0.5	0.7	0.9	
	Given NG denied:			
	0.1	0.3	0.5	
EE	0.4	0.6	0.8	This pipeline will use an existing natural gas pipeline for much of the route, and there appears to be fairly broad support for this proposal. However, the proposal is the least well scrutinized to date.

The decision in period 1 is subject to the uncertainty of whether President Obama will approve approximately total 1.2 MMbbl/d of capacity from Canada to the US. Possible increments of pipeline capacity (ω_1^{PLC}) in period 1 and their associated probability (P_1^{PLC}) are given in **Table A-4** for "low", "base", and "high" scenarios.

Table A-4: PMF of pipeline capacity expansion, period 1.

$\boldsymbol{\omega_1^{PLC}}$	**0.0**	**1.2**	**(MMbbl/d)**
P_1^{PLC}	0.6	0.4	(low)
P_1^{PLC}	0.4	0.6	(base)
P_1^{PLC}	0.2	0.8	(high)

In time period 2, it is uncertain whether the Canadian government will approve up to 2.4 MMbbl/d of capacity. Possible increments of pipeline capacity in period 2 (ω_2^{PLC}) and their associated probability (P_2^{PLC}) are given in **Table A-5** for "low", "base", and "high" scenarios. Another step was required to generate the probability distributions in **Table A-5**. The probability distributions in **Table A-5** were determined by assuming a probability of approval of each of the Canadian pipelines, which listed in **Table A-4**, and using a probability tree to determine the probability of each increment of capacity expansion being approved from zero to 2.4 MMbbl/d.

A priori, the "base" scenario PMF seems reasonable given current knowledge. While the current Conservative party government is supportive of pipeline projects, because the next Canadian federal election is upcoming in 2015, the results of the next election will ultimately impact the approval of specific pipelines proposed entirely within Canada. Therefore, it is plausible that no pipeline capacity is developed or that all the proposed capacity develops, with assigned probabilities of 0.14 and 0.21, respectively. It also seems reasonable that the most likely eventuality is that 1.2 MMbbl/d of pipeline per day develops, which this corresponds to the capacity of the EE pipeline *or* the sum of the NG and TMX pipelines. The "low" and "high" scenario PMFs also seem like reasonable bookends of possible distributions. Therefore, even though the PMFs rely on judgment, the range provided reflects currently available information.

Table A-5: PMF of pipeline capacity expansion, period 2.

ω_2^{PLC}	**0.0**	**0.6**	**1.2**	**1.8**	**2.4**	**(MMbbl/d)**
P_2^{PLC}	0.378	0.132	0.342	0.088	0.060	(low)
P_2^{PLC}	0.140	0.120	0.350	0.180	0.210	(base)
P_2^{PLC}	0.030	0.044	0.246	0.176	0.504	(high)

Table A-6: Parameter values used in the dynamic programming model.

Parameter	**Value**
Car cycle time, CCT	21 days[a]
Rate, R	$ 10.88/barrels [b]
Variable Cost, VC	1/1.8 of rate [c]
Cars per train, CPT	100 cars
Car capacity, CC	525 barrels/car [d]
Tank car gross weight, TCGW	286,000 lb/car
Horsepower per locomotive, HPPL	4400 hp
Horsepower per trailing ton, HPT	0.6 hp/ton
Average length of haul, ALoH	2485 miles [e]
Infrastructure capacity unit cost, CI	$1.8 million/ train/day/100 miles[f]
Locomotive unit cost, CL	$2 million/ locomotive [g]
Trains per unit of capacity, NT	$1/(CC \times CPT)$
Locomotives per train, LPT	$\lceil (CPT)(TCGW)(HPT)/HPPL \rceil$
Total locomotive costs, $LCost_t$	$(CL)(CCT)(NT)(LPT)(dRC_t)$
Total infrastructure capacity cost, $ICCost_t$	$(CI)(ALoH/100)(NT)(dRC_t)(2)$
Discount rate, dr	11% [h]

[a]The travel time from Alberta to the USGC is 8-10 days by rail (Carey 2013); [b]US Department of State (2014), p. 2.2-30; [c]The maximum rate that a railroad can charge without review by the Surface Transportation Board (STB); [d]Cairns (2013a); [d]The rail distance from Lloydminster, SK to Port Arthur, TX (US Department of State 2014); [f]Lai and Barkan (2009) calculate the approximate cost of capacity using sidings for a typical 100-mile long subdivision; [g]Hagerty and Linebaugh (2012); [h]STB's cost of capital for railroads in 2012 (Progressive Railroading 2013).

APPENDIX B:
CORRESPONDENCE WITH TRANSPORT CANADA

This appendix contains:

1. Letter from Transport Canada, dated February 20, 2014
2. Email from Transport Canada, Rail Safety, dated March 25, 2014

The address, telephone number, and email address of the author have been redacted.

Transport Canada Transports Canada

Access to Information and Privacy Division
Division de l'accès à l'information et de la protection des renseignements personnels

Place de Ville, Tower C
330 Sparks Street
Ottawa (ON) K1A 0N5

Fax: 613-991-6594

Our File Notre référence
A-2013-00915 / CP

FEB 20 2014

Mr. Stephen Joel Carlson
[redacted]

Dear Mr. Carlson:

This letter is in response to your request made under the *Access to Information Act* (ATIA) for documentation pertaining to:

> **"This ATIP requests Safety Management System (SMS) documentation of the Canadian National Railway Company (CN) and the Canadian Pacific Railway (CP) submitted to Transport Canada (TC). Although the request is for the complete document, the request is particularly interested in SMS documentation on the following subjects: (1) CN and CP's policies and procedures for handling hazardous commodities (NB: This request is cognizant that there are security concerns around this subject. This request is not interested in particular operating procedures [e.g. specific routings], but rather, CN and CP's description within its SMS of its broader roles and responsibilities for dealing with hazardous commodities). (2) CN and CP'S policies and procedures for updating the SMS in response to or in anticipation of new hazards (3) CN and CP's policies and procedures for assessing risks in response to or in anticipation of major operational changes (including, but not limited to, the transport of new commodities) In addition, this ATIP requests any correspondence between CN and CP's and TC (since 2011) pertaining to the transport of crude oil (including bitumen), including but not limited to, any proposed or discussed modifications to the SMS of both railroads to transport this commodity."**

I wish to inform you that no records were found that contain the information that you are seeking. Please note that Transport Canada Inspectors have access to the records on site of inspection, however the documents are not collected by our Department.

.../2

You are entitled to file a complaint within 60 days of receipt of this notice by writing to: Office of the Information Commissioner of Canada, 30 Victoria Street, Gatineau (QC) K1A 1H3.

Should you have any questions, you may contact Celine Paquette at 613-993-5050 or via e-mail at celine.paquette@tc.gc.ca. Please quote the file number listed above in all correspondence pertaining to this request.

Yours sincerely,

Joanne Benoit
Chief,
Access to Information and Privacy

[redacted]

RE: Advisory Council on Railway Safety Information

RailSafety <RailSafety@tc.gc.ca> Tue, Mar 25, 2014 at 10:00 AM

[redacted]

Good morning Mr. Carson,

In response of your correspondence from March 17, we recommend that you contact the Transportation of Dangerous Goods, CANUTEC's Office for information on the transportation of crude oil by rail at 613-992-4624

For the Advisory Council on Railway Safety (ACRS) all the public information can be found at http://www.tc.gc.ca/eng/railsafety/rsar-299.htm, the none published information is not of public domain as it involves a third party. To access such information you must send your request via our Access to Information and Privacy Division office at ATIP/AIPRP@tc.gc.ca.

For further details on the Access to Information and Privacy Division office, please see contact information below.

Telephone: 613-993-6161
Fax: 613-991-6594
Mailing address: Access to Information and Privacy (ATIP) Division
Place de Ville, Tower C, XMSP, 330 Sparks Street
Ottawa, Ontario K1A 0N5

We thank you for your interest in rail safety.

Rail Safety | Sécurité ferroviaire
Transport Canada | Transports Canada
email: railsafety@tc.gc.ca | courriel : securiteferroviaire@tc.gc.ca
Telephone / Téléphone 613-998-2985 | Facsimile / Télécopieur 613-990-7767
Government of Canada | Gouvernement du Canada

From: [redacted]
Sent: March 17, 2014 11:41 AM
To: WEB Feedback
Subject: Advisory Council on Railway Safety Information

Dear Transport Canada,

I am a graduate researcher at the Massachusetts Institute of Technology originally from Canada and am studying the transportation of crude oil by rail. I am writing to request information on the work of the Advisory Council on Railway Safety (ACRS).

Besides some specific press releases (e.g. http://tc.gc.ca/eng/mediaroom/releases-2013-h140e-7389.html) and the original terms of reference of the ACRS (http://www.tc.gc.ca/eng/railsafety/rsar-299.htm), I have been unable to locate on the Transport Canada any updated and specific information regarding the council's current structure, membership, contact information, and ongoing work (e.g. meeting minutes).

Would you kindly let me know if this information is posted, and if so, where it can be located? If it is not available online, would you direct me to the person who is best positioned to respond to my request, please? If you have any questions regarding this request, please feel free to contact me by email at [redacted] or phone at [redacted]

Sincerely,

S. Joel Carlson

SM Candidate, Transportation and Engineering Systems

Massachusetts Institute of Technology

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