A scan of the long-distance oil pipeline research literature: A focus on Canada

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Cover image

Trans Mountain Expansion site in the Coldwater Valley, south central BC. Photo: K. Hanna.

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Summary

This review, or scan, is a desk-based study that provides a synopsis and list of what has been done and where areas of research concentration exist – it offers an image of the state of existing work with a focus on those works that have relevance to the Canadian setting, which included works on a North American topic or case.

The scan included academic, peer-reviewed publications and relevant *grey literature* (e.g. technical reports, select industry manuals (for research references), conference proceedings, patent filings, best practice manuals, reporting systems) and covers both technical and non-technical material (e.g. social, economic, environmental, or non-technical regulatory topics).

Search terms were used in various combinations, accounting for variations. The initial searches with these keywords generated a total of 3,407 documents. These were then reviewed for relevance to the defined topics. The next step in the analysis involved a preliminary scan of the results to apply the exclusion criteria. The criteria excluded works having a focus on a geographic area outside of North America, works dealing exclusively or primarily with natural gas pipelines, results from popular or news media, and literature that dealt exclusively or predominantly with oil exploration, extraction or the oil industry more broadly. This initial analysis focused on searching the titles, keywords, and abstracts of works. This narrowed the number of relevant documents down to 947. Each abstract or summary was reviewed in order to confirm the relevancy to the scan topic (e.g. a discussion of oil pipeline research with relevance to Canada) and then assigned to one of eight. The final count of works included is 231.

The results show a relatively large body of work with direct relevance to the Canadian setting. Technical fields are well covered. For example, there has been a lot of fundamental academic research around corrosion: this includes internal and external pipe corrosion, pitting corrosion, stress corrosion cracking (particularly important in the Canadian context) and modeling of various corrosion phenomena, as well as coating performance. There is also a significant body of work on pipeline steels and welding from a physical metallurgy perspective. Similarly, a lot of work has been done on geotechnical issues in the Canadian context.

Non-technical topics were more widely covered than anticipated. However, there are specific areas of concentration such as in United States cases and northern Canada, and few on western Canada. Some earlier works may still have relevance to the contemporary setting. The scan suggests there is a need for more work on issues of perception of pipelines, and public trust in industry and regulators.

In Canada, controversies are relatively new, becoming more pronounced in the last 10 years as major projects such as Enbridge's Northern Gateway proposal and the Trans Mountain Pipeline Expansion Project entered the permitting and assessment processes. We expect to see more

work published in the next few years from social scientists as the future of key projects, especially in western Canada, are decided.

Indigenous considerations are an important part of the Canadian regulatory setting. There are few works specific to this area, but this will likely improve as researchers develop more work on the field and their results are gradually published.

The scan can provide the foundation for a more detailed knowledge synthesis, and enable a deeper look the literature, and bring in a range of expertise to identify specific research gaps and areas where knowledge concentrations exist. A knowledge synthesis would also benefit from focusing on specific topics, for example leak detection and provide a comprehensive review of research, and the knowledge developed to date.

Introduction

There are over 840,000 km of transmission, gathering and distribution pipelines across Canada. (Natural Resources Canada, 2016). Pipelines transport the great majority of Canada's oil and natural gas – for domestic use and for export.

Until recent years, Canada's pipeline industry had little public profile despite the long presence of pipelines in urban areas and across many rural and remote parts of the country. However, proposals for new or expanded oil and diluted bitumen pipelines have become a flashpoint for objection and inter-regional political conflict.

In Canada, significant pipeline events resulting in spills and injury or substantial environmental damage are rare. For Canada's federally regulated pipelines, the Transportation Safety Board of Canada (TSB, 2020) reports that in 2020 of the 48 occurrences (111 in 2018), 20 resulted in a release of product (15 were sweet natural gas, 1 was sour or acid gas, and 4 were low vapour pressure hydrocarbons). In 2018 report the TSB (2019) noted that taking an 8-year series of occurrence rate values by year from 2011 to 2018 there was a strong, negative correlation indicating a downward trend in occurrence rate per 1000 km over the period, for all types of pipeline. This trend continues. Moreover, 28 occurrences in 2019 did not result in a release of product, which is slightly below the average over the last decade (TSB, 2020). A similar trend is seen for events in Canada's provincially regulated lines.

Globally, advances in materials, construction techniques, regulations and oversight, and monitoring and operating practices have advanced safety and other aspects of operational performance. But incidents and accidents do happen, and when they are significant, such occurrences highlight the need for continuing development of best practices, operator and regulator vigilance, improvements to monitoring techniques and technologies, and continued support for research and innovation.

Canada's Pipeline System

In 2019, Canada's federally regulated pipeline system, 40 companies transported 240 million m^3 of oil through approximately 18 200 km of oil pipelines (including 19 companies that transported both oil and gas). Over 180 billion cubic metres of gas was transported through some 51 600 km of pipelines. A further 1115 km of pipelines carries other products. Overall this is about 18.8 EJ of energy (TSB, 2020).

Pipeline Occurrence Rate

For 2019, an occurrence rate of 0.7 per 1000 km of operating pipeline was calculated based on the 48 occurrences reported and the 70,860 km of federally regulated pipelines operational in Canada during the same year. This is down from 1.6 in 2018 and 1.8 in 2017, and below the average of 1.8 since 2011 (TSB, 2020)

Public debate about oil pipelines stems from a range of complex factors. These can include concerns about safety, marine oil spills from vessels loaded at pipeline terminuses, distrust of industry and regulators, regional and local political issues, a lack of knowledge about the industry, concern about climate change impacts, and a dislike by some of the oil and natural gas industry. Some of these issues might be best characterized as uncertainties, which indicates the need for further research and improvements to the technology and operating rules for the industry. Other issues are social and political and may be difficult to address even with more information and better knowledge of the industry.

There is also a tendency to see the hydrocarbon transportation industry as a whole rather than as distinct components with different operators, different products being transported, different jurisdictions with varying regulatory oversight, and unique regional challenges. This poses questions about how much Canada-relevant research has been done on the sector, where our concentrations of information and knowledge are situated, and where future research efforts may need to be focused.

This review, or scan, provides an outline of the current status of the literature and related technical reporting. While the focus is on pipeline operation and development in the Canadian context we have also included North American works relevant to Canada. The state of the research in this field is extensive and covers a range of topics. Some topics are more broadly covered than others. In this synthesis we categorize the state of knowledge into categories, which reflect the nature of the Canadian geographic, industry, and regulatory setting. The scan covers technical and scientific issues, as well as work from the social sciences.

The results of the scan are organized according to the main subject of the work (for example, if a paper was about advances in techniques for stream crossing it would be included under the construction techniques category). The scan provides the list of references in two formats; one is a standard list of all references cited in alphabetical order, and the other (shown in the Appendix) groups the references according to the themes used to categorize the works.

The outline of results provides an image of the types of research done with brief descriptions, and where specific concentrations of work exist, however it is not a synopsis of all works. The term works refers to papers, presentations, reports, and other documents. The conclusions provide a summary of strengths, and identifies those areas where further research is needed to build specific knowledge for the Canadian context.

The scan provides an indication of what has been done, where knowledge concentrations may lie, and where more research may need to be done. It is a list of what is out there. It does not assess the quality of the works or the gaps that may exist in the many specific sub-disciplines related to the sector.

Method and Approach

This scan is a desk-based study that provides a synopsis and list of what has been done and where areas of research concentration exist – it offers an image of the state of existing work with a focus on works that have relevance to the Canadian setting, including works on a North American topic or case. The scan also includes some works that have a United States or Mexico focus. Given the integrated nature of the distribution network, and some regulatory similarities, the continental focus was deemed appropriate.

The scan included academic, peer-reviewed publications and relevant *grey literature* (e.g. technical reports, select industry manuals (for research references), conference proceedings, patent filings, best practice manuals, reporting systems) and covers both technical and non-technical material (e.g. social, economic, environmental, or non-technical regulatory topics). The standards that guide or instruct industry activities were not included. The focus is on works that report a research or investigative outcome, with an emphasis (not exclusively) on peer-reviewed works.

The review excluded works that did not have a focus on oil pipelines. This eliminated those that focused exclusively or mostly on fossil fuel exploration, extraction and other development activities, as well as much of the literature on spills. Those with a primarily non-North American focus were also not included. Generic works, for example on a new technology for detecting leaks, which could have value to Canadian operators may not have been captured. This means that the list developed has a bias toward case-based work, which is common in this field. However, many technical works review specific case examples, or draw on tests or data from specific locales. The method relies on the judgment of the researchers. Not all works relevant to the scan will have been captured.

The systematic approach, based on initial filtering criteria and then a more detailed review of abstracts, has been used in similar studies and gap analyses (e.g. Noble and Hanna, 2015 and Hanna et all, 2018). There were four stages in the scan.

First, search terms were used in various combinations, accounting for variations in spelling or conjugation, in Internet and academic search engines (e.g. Google Scholar and Web of Science). The initial searches with these keywords generated a total of 3,407 documents. These were then reviewed for relevance to the defined topics. Examples of the keyword combinations are noted below.

Examples of Search Combinations

Oil pipeline + one or more of the following

- Acceptance
- Axial (cracking/stress)
- Biodiversity
- Bitumen/dilbit
- Canada (or Canadian), North America United States, American, Alaska(n), Mexico
- Coating, Epoxy coating
- Compression/buckling
- Construction (techniques)
- Corrosion
- Deposition
- Economic/economy
- Ecosystem
- Environment (al)
- Failure
- Geologic(al)/geology/geotechnical
- Indigenous / First Nations / Aboriginal, Native America (n)
- Induction/current
- Inspection
- Leak(s) (detection)
- Long distance/Trans boundary
- Mackenzie Valley
- Media (coverage)/report (s) / reporting
- Oil sands/tar sands
- Perception
- Permafrost
- Policy/Law/Legal
- Prediction
- Refinery
- Regulatory / regulation / regulator
- Remediation
- Right of way Media/press coverage
- Safety
- Social issues
- Steel
- Stress
- Stress corrosion cracking (SCC)
- Training
- Transportation
- XL/Keystone

<u>Second.</u> The next step in the analysis involved a preliminary scan of the results to apply the exclusion criteria. The criteria excluded works with a focus on a geographic area outside of North America, works dealing exclusively or primarily with natural gas pipelines, results from popular or news media, and literature that dealt exclusively or predominantly with oil exploration, extraction or the oil industry more broadly. This initial analysis focused on searching the titles, keywords, *and* abstracts of works. This process narrowed the number of relevant documents from 3,407 down to 947.

<u>Third.</u> Each abstract or summary was reviewed in order to confirm the relevancy to the scan topic (e.g. a discussion of oil pipeline research with relevance to Canada) and then assigned to one of eight categories (see below). This reduced the potential for excluding relevant works. At this stage the bibliographies or reference lists for each work was reviewed to identify any additional relevant sources that the keyword searches might not have identified. This final analysis allowed for further elimination of works not relevant to the scan and the identification and removal of duplicates. This step narrowed the number down further. The final count of works included here is 231.

Throughout the process works were grouped/classified according to one of the eight categories. The classification is based on which category best describes the main theme or subject of the piece, but of course some works touch on more than one subject or may overlap categories. Works on *construction techniques* were initially included with *materials, operational issues, and other practice issues*, but these were separated out at the last stage to provide a more detailed illustration of topics covered. The distribution of works is summarised in Table 1.

<u>Fourth.</u> During the last stage, a short description of the works was developed. These brief descriptions note the topic of the work.

Eight categories used to classify works

1. Materials, operational issues, and other practice issues
2. Construction techniques
3. Incidents and accidents
4. Indigenous considerations
5. Public perception and social acceptance
6. Economics and economic development potential
7. Political, public policy, legal, and regulatory issues
8. Ecological issues

Table 1: Summary of search results by category.

Categories	Coarse search results	Initial filtering	Sources added by PII reviewers	Final results
Materials, operational issues and practices	987	382		80
Design, construction and operations			12	38
Incidents and accidents	817	222		22
Indigenous considerations	283	40		15
Public perception and social acceptance	355	78		22
Economics	326	66		12
Political, public policy, legal and regulatory issues	494	134		21
Ecological issues	145	25		21
Totals	3,407	947		231

A first draft of the scan was circulated to expert reviewers within the Pipeline Integrity Institute who for suggestions of any additional sources (12 in all).

Results

Materials and related issues and practices

Steel alloys, engineering, and testing of novel materials

Pipeline design is dependent on materials and their unique properties. Work in this field supports the development and testing of novel materials, construction techniques, and maintenance and operation practices.

Some works combined both economic and technical dimensions via descriptions of the impact of physical metallurgy on pipeline material cost. Sanderson et al. (1999) for example, described the impact of material strength on a cost assessment for high strength X-100 grade pipeline steel. Glover et al. (2004) showed that higher pressures and thus oil throughput might be obtained with stronger pipeline materials such as X100 steel. They also described elements of the design, the construction, and the installation processes, as well as the applicable construction codes and regulatory bodies.

An industry report produced by Stalheim (2005) examined the development and application of high temperature processing steel (HTP) for use in high-pressure oil and gas transmission pipelines. Guo et al. (2008) also explored a way of strengthening steel for use in pipelines to better withstand physical impacts, in this case by adding zirconium to the alloy.

Zhang et al. (2002) examined various techniques for reducing drag effects in pipelines due to paraffin deposition, largely through the application of different internal pipeline coatings. Niu and Cheng (2008) further examined the use of coating technology in pipelines, particularly those operating in areas of permafrost. Ramezanzadeh and Rostami (2017) examined the effect of Cerium (Ce) surface treatment and acid washing on the composition and surface morphology of steels used in pipeline construction.

There are also works that focus on equipment developments for pipeline operations in Canada. Dewinter and Kedrosky (1989) published on the application of a 3500 HP variable frequency induction motor drive (VFD), the first of its kind described in Canada which resulted in an extended capacity of bitumen blend flow from the Cold Lake pipeline. There is also a body of work that describe innovative technologies and patents for both production techniques and transportation of product (e.g. separation of sand from bitumen and the subsequent transport of bitumen or slurry in pipelines) (e.g. Kane, 1967; Cymerman et al., 1989; Frankiewicz and Handon, 1989; Allcock et al., 1997; Maciejewski et al., 1997; Maciejewiski and Cymerman, 1998).

Materials failures-corrosion and cracking

Corrosion in oil pipelines is a major cause of pipeline failure, and can result in significant impacts. There is an extensive body of literature on the identification, analysis, understanding, prevention, and management of pipeline cracks. For instance, Bryner (2006) reported on the shutdown of output from the Prudhoe Bay oil field due to the discovery of a corroded and leaking transit pipe.

Stress corrosion cracking (SCC) is a particularly extensive area of study. The Canadian government launched a national inquiry into the problem in an attempt to determine the causes, conditions, and management practices of SCC that were occurring in the country (NEB 1996; Paviglianiti et al., 2008).

In 2008 Batte et al. proposed a method of ranking the severity cracking to assist management plans and help prioritize responses. The Canadian Energy Pipeline Association regularly produces recommended practices guides to help operators manage SCC (see CEPA 1997, 2007, 2015a, 2015b). In the United States, the National Association of Corrosion Engineers (NACE) develops a similar best practices guide (NACE, 2008).

The role of depositions and sedimentation in corrosion is well recognized and is a topic of important study. For instance, the effects of inert solid deposits on corrosion rates in pipelines have been examined (Huang et al., 2010; Been at al., 2010). Been et al. (2011) developed a means of testing the corrosivity characteristics of sludge deposition, and offered recommendations to support mitigation practices. Been (2011) reported on the differences between the corrosivity of conventional crude oils, and diluted bitumen (dilbit).

Works on bitumen transport are particularly relevant given the importance of this petroleum product to the Canadian fossil fuel industry, and the role that pipeline expansion in Canada will play in accessing new markets for bitumen. In a series of papers on the topic, Papavinasam et al. developed and tested a model to predict internal pitting corrosion in pipelines (2005; 2007; 2010). In 2009, they presented on the effects of surface pitting on internal corrosion. In 2012, they traced the corrosion conditions as bitumen travelled through existing infrastructure, from initial extraction to consumer markets.

Detection methods and prediction models

The causes, effects, and consequences of stress corrosion cracking have been extensively studied (Fessler and Rapp, 2006; Kariyawasam et al., 2007; Klein et al., 2008; Tomar et al., 2008; Hrncir et al., 2010; Marr et al., 2010; Rehman et al., 2010; Conrad et al., 2012; Jäger et al. 2012; Chen et al., 2012). For instance, Beavers (2015) presented a method for the detection and control of pipeline stress corrosion cracking on underground pipes under high pH and near-neutral pH soil conditions. Hornsby and Place (2012), and Fessler and Batte (2013), presented on different aspects of crude corrosivity testing in transmission pipelines.

Duncan et al. (2009) studied corrosion-causing microorganisms in oilfield pipelines to better understand the conditions that lead to their presence in, and damage to, oil pipelines. Jacobson (2007) studied corrosion along the Trans-Alaska Pipeline, using ultrasonic testing to determine thickness and conduct corrosion tests along the pipeline. Velázquez et al. (2009) proposed a predictive model to determine the pitting corrosion of buried oil and gas pipelines, using a case study to illustrate the model.

At the 2012 Northern Area Eastern Conference, Friesen et al. and Collier et al. presented on relative corrosivities of crude oils as it relates to oil transmission pipelines, examining various factors that affect corrosion in these materials. Place et al. (2008) presented a progress report on the process made in mitigating under-deposit corrosion in crude oil pipelines, particularly by evaluating the characteristics of sludge deposition. Lepková and Gubner (2010) developed a test model investigating the under-deposit corrosion in the oil and gas industry.

Studies of the causes of stress corrosion cracking are an important theme in the field (e.g. Linton et al. 2007, Brongers et al. 2009, and Fessler and Sen,2014). Parkins (1987) and Parkins and Singh (1990) studied the mechanics of crack development and growth, to better understand how to manage a detected crack. Allan et al. (2008) and Bates et al. (2010) studied the formation and causes of biaxial stresses in pipelines.

Concern about the potential for cracking is a common and important issue in public discussions on pipeline safety. Research that addresses such issues can contribute to better understanding of risks and support best practices in operation and maintenance. Fessler et al. (2008), Gao et al. (2008), CEPA (1997; 2007; 2015) describe best practice procedures for managing pipeline cracks.

Alamilla et al. (2013) presented an approach for failure analysis of underground oil pipelines. They tested their approach on a pipeline that had failed due to corrosion and found that the corrosion had been accelerated due to two corrosion mechanisms: iron oxides and iron sulfides.

Campbell (1978) examined the auroral and induction currents created by the Alaska pipeline in an effort to determine predictable patterns of temporal and spatial changes of field pulsation. Campbell (1980) measured currents induced from the ionosphere auroral electrojet at three different sites in Alaska. Campbell and Zimmerman (1980) used superconducting quantum interference device (SQUID) magnetometer and a gradient fluxgate to measure the currents induced in an Alaskan oil pipeline during a period of geomagnetic disturbance. Gummow and Eng (2002) examined the impact of telluric current activity on the corrosion control systems found in northern region pipelines.

Pipeline coatings

The application of internal or external coatings is an important method of protecting the integrity of pipelines, as well as a way of reducing the effects of corrosion. Coatings are a first line of protection. The use of internal coating for oil pipelines is not as common as for gas lines.

Usually, internal coatings are intended for gas phase drag reduction, while the effect on oil is much smaller.

The field has evolved considerably since the development of early long-distance pipelines in North America. The importance of coatings is highlighted through the comprehensive and substantial treatment it has received in the research literature.

Guidetti et al. (1996) explored the potential for various epoxy resin, coal tar enamel, and polyethylene coatings on pipelines, which, despite representing only 5% of the total cost, are one of the best options for protecting and increasing the longevity of the pipelines. Bayram et al. (2015) studied fluoropolymer and hybrid epoxy/fluoropolymer resins for their potential to reduce corrosion on oil and gas pipelines. More broadly, Melot et al. (2009) summarized their experiences with different pipeline coatings, highlighting positive experiences and failures as well as problems identified with new technologies.

Varughese (1993) addressed the increasing need for in-situ rehabilitation strategies as aging pipeline infrastructure enters a period where failure may become more likely, or indeed actually begin to fail. The problems caused by corrosion in particular were addressed, and various coatings were proposed as a means of dealing with infrastructure stress. Similarly, Howell and Cheng (2007) explored the possibility of using high performance composite coating (HPCC) to facilitate maintenance and improve the integrity and performance of pipelines in northern areas. While Harris and Lorenz (1993) explored two potential coatings for steel structures used in corrosion-prone environments, such as areas of elevated temperatures, and areas with high levels of exposure to marine or tidal splash zones.

A paper by Been et al. (2005) presents research on the factors that affect the long-term adhesion, or disbondment of external fusion bond epoxy (FBE) coatings, as a response to field observations that reported peeling, blistering, and loss of effectiveness. Papavinasam et al. (2012) looked at potential improvements against external corrosion in underground oil and gas pipelines. They proposed three layers of defense; a metallic under-layer coating, a polymeric top-layer coating, and an applied cathodic protection to protect the external surface of the pipeline.

Not unexpectedly, most of the literature on coatings covers external coatings. Papavinasam et al. (2009; 2012) examined internal pitting corrosion in hydrocarbon pipelines, the effects of surface layers and various coatings on corrosion.

Failure prediction models

Advancing methods for failure prediction is an area that illustrates the breadth and integrative nature of much of the research in pipelines. Predictive works often cover a range of factors. Azevedo (2007) analysed the failure of a crude oil pipeline due to transversal cracking, determining that it was caused by stress-oriented hydrogen induced cracking. Shipilov and Le

May (2006) explored the structural integrity over time of coated buried pipelines with cathodic protection. They highlighted the role of hydrogen embrittlement (H-induced cracking) caused by products resulting from cathodic protection in the carbon steels of the pipelines.

Dey et al. (2004) presented a model for multi-criteria risk-based decision making for maintenance of offshore pipelines. While the risk of pipeline failure due to natural disturbances may be minimal in many North American locales, the potential exists. Porter et al. (2004; 2016) presented a framework for estimating the influence of natural hazards on potential pipeline failure. Porter et al. (2012) presented work on estimating the influence that natural hazards play in pipeline risks.

Spalding and Hirsh (2012) examined a risk assessment procedure for routing pipelines, with a particular emphasis on the risks to groundwater and ways of reducing risks and consequences from failure.

In 2013 the Transportation Research Board and National Research Council published a report analysing whether there was an increased risk of bitumen release from pipelines relative to risks associated with the transportation of other crude oils. Crosby and colleagues (2013) produced a similar report assessing the risks and issues surrounding the transportation of products from Alberta's oil sands, and they dedicate a section to assessing pipeline infrastructure.

The state of knowledge for pipeline construction materials, techniques, and technologies has advanced in recent years and draws principally from industry sources and engineering science. The literature on operational issues focuses on failure rates, causes, detection, and prevention, and is generally generated by industry entities. However, aside from certain best-practice guidelines, there is comparatively less literature on the human dimensions of pipeline operation, such as workplace safety, health impacts, or other related social and economic issues.

Design, construction, and operations

There is substantial research literature on construction techniques, best practice procedures, and the regulations surrounding pipeline development found largely in industry publications, reports, and manuals.

Martinez-Palou et al. (2011) published a review of the existing and emerging transportation techniques to move heavy and extra-heavy crude oils through pipelines, focusing in particular on the novel technologies emerging to deal with the unique challenges of heavier oils. They propose a greater emphasis should be placed on hybrid technologies.

Technological advancements in exploration and oil extraction support the expansion of energy development into previously inaccessible areas. Alquist and Guénette (2014) explore this idea in the context of the United States' oil market, and highlight how increasingly efficient pipeline technology leads to more effective transportation of the product from more costly production locales. Some works also focus on improving cost estimation. Rui et al. (2011), for example, developed five regression models to estimate pipeline construction costs and help optimize effectiveness and reduce costs.

Zhou et al (2009) suggested that the current CSA standards for pipeline design (CSA Standard Z662), while historically valuable, do not reflect observed failure mechanisms. Rather than an allowable stress-based standard, they proposed a reliability-based design and assessment approach that addresses all mechanisms of failure in the design phase.

Flow dynamics

Work on flow dynamics extend back for several decades. Charles et al. (1961) examined the flow patterns of various equal-density oil-water mixtures in a one-inch diameter laboratory pipeline. Wu et al. (2006) presented on flow characteristics of heavy crude pipelines. In more recent research, Bbosa et al. (2016) produced a simulation to assist in the selection of flowline sizes and carrier fluid rheology for various solid particle types in response to the problem of slurry deposition impeding the efficient transportation of oils. Wang et al. (2016) examined flow dynamics in a multiphase flow pipeline system, looking specifically at fully developed turbulent three-phase flow.

Lab studies were conducted to examine yield behaviour and strength of gelled crude oil in the Trans Alaska pipeline (Perkins et al. 1971). Burger et al. (1980) examined the effects of solvent viscosity and pipe diameter on drag reduction, while assessing the feasibility of applying polymer drag reducing additives in the Trans-Alaska Pipeline to increase flow rates. Burger et al. (1981) studied the mechanisms and mechanics of wax deposition in the Trans Alaska Pipeline system. Burger et al. (1982) reported on the first commercial use of a polymeric drag-reducing additive to increase flow rates within a crude oil pipeline. This began in 1979 with the Trans-Alaska Pipeline System and eventually led to full-scale additive use.

Anand (2011) studied the operations and potential expansions at Enbridge, in addition to lending insight into the line rates and various flow patterns of their existing and projected pipeline infrastructure. Aspenes et al. (2009) examined the influence of petroleum acids on the wettability of solid surface energy in pipeline development, examining various metal compositions and surfaces, as well as glass and epoxy coatings. Rensing et al. (2008) outlined how rheological measurement can be used to study the clathrate hydrate formation and accumulation – which can reduce flow.

Geohazards

The guidelines developed by Honegger (2009) for the Pipeline Research Council International, Inc. offer recommendations for the assessment of new hydrocarbon pipelines in places with potential for ground displacements resulting from landslides and subsidence. The guidelines provide a mechanism for advancing understanding of the types and quality of hazard information and practical measures available to reduce or manage the risk pipeline operation in areas susceptible to landslide and subsidence hazards.

A report from ASCE (1984) summarizing the Pipeline Research Council International, Inc. (PRCI) guidelines provides recommendations for the assessment of new and existing hydrocarbon pipelines subjected to potential ground displacements that result from landslides and ground subsidence. One of the most significant benefits of the guidelines is the systematic approach developed for managing pipeline risks from landslide and ground subsidence hazards. Sweeney (2017) also investigated historical risk from pipeline rupture data due to landslides and outlined the modern safety and environmental standards required for pipelines in remote areas subject to geohazards.

The lifecycle of a pipeline typically involves several phases, from conception, including route selection, environmental assessment and engineering design, through construction, and into integrity management during operation. Each phase benefits extensively from the characterization of the terrain and existing or potential geohazards along the pipeline corridor. Porter et al. (2014) outlined a vision for integrating terrain and geohazards knowledge into the pipeline lifecycle.

The US Geological Survey published a report (Baum et al., 2008) outlining the reliability of landslide hazard maps for pipeline routes. They list the data sources (geologist, technician, or engineer) that provide the qualitative or quantitative background data to create hazard maps. These maps display hazard probability and the authors discuss the issues around the considerable variability in data uncertainty, and the minimum data requirements to make accurate assessments.

Seismic activity is a considerable concern for pipelines located on or near fault lines. Such as the Trans-Alaska Pipeline that intersects the Denali Fault. Significant engineering considerations were made to compensate for potential ground movement in this area, particularly after the fault ruptured (Sorensen & Meyer, 2003). O'Rourke (2008) studied earthquake-ground induced ruptures and pipeline induced performance after earthquakes through the application of large-scale testing.

Buried pipeline, while safer from the risk of damages due to hazards such as third-party interference, are subject to the impacts of ground movement. The performance of buried steel pipelines subjected to relative soil movements in the axial direction was investigated (Wijewickreme & Honeggar, 2008) using full-scale pullout testing in a soil chamber. Measured axial soil loads from pullout testing of pipes buried in loose dry sand were comparable to those predicted using guidelines commonly used in practice. Paulin et al. (1998) also worked to remediate a lack of large-scale pipeline-specific data regarding pipeline-soil interaction. They worked with a full-scale pipeline/soil interaction test facility that had been established in St. John's Newfoundland. The paper presented a description of the test facility, details on experimental procedures, and comparative results from lateral and axial testing in sand and clay. Other work done on soil-pipe interactions analyzed the effect of groundwater for various loading conditions, assuming either drained or undrained conditions (C-CORE, 2003).

Groundwater influenced soil-pipeline interactions are particularly hazardous where pipelines cross or interact with rivers. O'Neil et al. (1996) studied the challenge of maintaining pipeline integrity at river crossings where landslide terrain dominates the approach slopes. Findings based on rainfall and slope instrumentation data showed that soil exhibited small rates of movement independent of the rainfall and increased rates over a short period of time following heavy amounts of rainfall. The study also found there was an approximately 1 month lag between rainfall and ground movement.

This hazard has been demonstrated in recent years in Canada. A geotechnical report (Stantec, 2016) was done after the 16Tan Pipeline spill into the Northern Saskatchewan River. The cause of the spill was determined to be deformation of the pipeline due to the unequal slope movement which led to increased stress at a bend join in the line. The report suggests mitigation measures that could be taken to reduce the likelihood of reoccurrence here or in geomorphologically similar locations.

Permafrost and cold climate issues

For some Canadian locations, studying the changing aspects and impacts of unstable permafrost; a factor that will become more important within the climate change context. Such changes will have significant impacts on pipeline infrastructure in many Canadian regions. But permafrost thaw and other direct climate change effects are not the only geotechnical risks. Any natural cause of ground movement or potential for erosion could be a geotechnical risk: water inundations leading to soil shift, earthquakes, erosion, or soils with a high liquefaction potential are all examples of challenges operators can face.

Nixon and Burgess (1999) studied the effects of thaw strain and the associated pipeline movement in the Norman Wells oil pipeline in order to assess the axial stress caused by frost heave. In an earlier study, Nixon and MacInnes (1996) had assessed a geothermal model developed to predict the temperature profiles in the ground surrounding a buried pipeline using data collected from the Norman Wells pipeline. The model was shown to not only accurately predict the oil temperatures at various places in the pipeline, but also to accurately describe heat loss, freezing, and thawing around the pipeline.

Hwang (1976) compared predictions to measurements and observations of the effects of a warm gas pipeline on permafrost, in particular the geothermal regime and the heat exchange. Burgess and Harry (1990) undertook a long-term permafrost and terrain-monitoring project along the buried pipeline running between Norman Wells and Zama, in Alberta, with the goal of quantifying the changes in the geothermal regime and collecting general observations of the changes observed along the pipeline's 869 km route. Notably, they observed warming trends along both the mean annual pipe temperatures and the mean annual right-of-way ground temperatures. Similarly, Smith and Riseborough (2010) used field observations from the thermal monitoring network along the Norman Wells pipeline corridor in conjunction with thermal modelling to gain insight into the effects of climate change, vegetation clearing, and environmental disturbance. The ground thermal regime in the vicinity of the pipeline and the right-of-way clearing was assessed as a way of looking at the effects of disturbance over time.

Changes in permafrost distributions along the Norman Wells pipelines were studied by Nixon, Saunders, and Smith (1991) who catalogued areas of continuous and discontinuous permafrost. This also acts as a benchmark for future studies examining the effects of the oil pipeline on the surrounding permafrost.

Ground penetrating radar (GPR) surveys were used by Jol and Smith (1995) to determine the ideal placement for buried oil pipelines in peat deposits by determining the thickness of the peat. They proposed the novel use of GPR technology to determine the ideal placement of oil, gas, or water pipelines as a more cost-effective method compared to traditional peat coring.

Burgess and Lawrence (1997) presented data on 12 years of observation on thaw strains and thaw settlements around the Norman Wells pipeline. Doblanko et al. (2002) provided an outline and review of monitoring data from an Enbridge oil pipeline, which is located in discontinuous permafrost.

Research on construction techniques and oil pipeline infrastructure is comprehensive. Research ranges from the properties and capabilities of the materials used, to the restrictions, changes, and effects of the environments where pipelines are located.

Incidents

The literature regarding pipeline incidents and accidents focuses on the description and analysis of past incidents and on the development of predictive models in order to prevent future incidents. Typically, predictive modelling relies on identification, understanding, and management of pipeline cracks, leaks, and failures (see the "Materials-Failure Prediction Models" section).

Predictive models

Literature on predictive models tended to fall into one of two fields: work that presents or validates a model being developed, or works that use an established model to predict and analyse an outcome or case example.

Risks associated with geohazards, such as landslides, shifting and compression due to land compaction, or earthquakes are the subject of many predictive models, programs, and guides. Jeglic (2004) presented an analysis of trends and ruptures in Canadian pipeline systems. But work in this field has largely focused on understanding, predicting, and mitigating pipeline failures due to geohazards or land movements (Leir, 2004; 2009; Rizkalla, 2008; Johnston et al., 2016; Ferris et al., 2016; Porter et al., 2016). Further research has examined means of assessing the impacts of pipeline failure. For instance, Ripley et al. (2012) outlined a system based on Geographical Information Systems (GIS) technology to assess the environmental impacts that can occur if pipeline ruptures occur at watercourse crossings.

Beyer and Painter (1977) described various techniques, which can be used to prevent future spills, though they cautioned that few predicative models are able to accurately account for differences caused by technological advancements. Aljaroudi et al. (2015) applied a quantitative approach to pipeline leak risk assessment and proposed a novel method of assessing system integrity and detecting leaks through a risk-based assessment scheme. The model predicted both the failure rates and the potential consequences of the failures of offshore pipelines, with a particular focus on the economic consequences. Brito & de Almeida (2009) used multi attribute utility theory (MAUT) to aggregate a range of risk factors and consequently rank pipeline segments according to greatest risk and greatest impact of a spill.

The use of fuzzy logic as an analytical tool is seen in several cases. The use of the fuzzy fault tree analysis (FFTA) technique is explored by Cheliyan & Bhattacharyya (2018), and Yuhua & Datao (2005). Likewise, Shahirar et al. (2012) used a fuzzy-based bow-tie analysis to conduct a risk analysis for oil and gas pipelines, with an emphasis on the integrity and sustainability of the developments. A fuzzy artificial neural network (ANN) was used by Sinha and Pandey (2002) to conduct a reliability assessment of oil and gas pipelines.

Iturbe et al. (2007) examined remediation techniques and their suitability to various soil contamination levels. They analysed the chemical composition and contamination level of various sampled soils, characterised by the presence of total petroleum hydrocarbons and polycyclic aromatic hydrocarbons.

A 2014 report prepared by the Canadian Energy Pipeline Association (CEPA, 2014) outlines the measures currently in place to deal with large-scale land spills, drawing on the experiences and perspectives of liquid hydrocarbon transporters.

Pipeline integrity

Pradley (1998) estimated pipeline reliability using a probabilistic analysis framework. The approach was designed to determine optimal inspection times, and included in-line inspection data, which incorporated the impacts of pipeline inspections, repair initiatives and activities.

A review of the literature on pipeline integrity management practices was presented by Kishawy and Gabbar (2010) in which they analysed aspects of pipeline integrity, explained and classified various aspects of the threats and failures, as well as design practices. They outlined inspection techniques and presented a design for pipeline integrity management. The design was developed from activity models, process models, and 'knowledge structures'.

Sandberg et al. (1989) provided an overview of classic leak detection systems before proposing a novel system comprising of a flexible hydrocarbon-sensing cable capable of detecting and locating leaks. And more recently, Frings and Walk (2011) characterized pipeline failure as a result of real-time monitoring, and as such applied fibre optic sensing technology to develop a model capable of detecting physical parameters such as temperature, vibrations, sound, or strain to localize problem areas and improve the over-all safety of the pipeline.

The state of existing work on pipeline incidents, failures, and accidents is comprehensive. Extensive work has been conducted to identify the various potential causes of previous failures in an effort to identify potential weaknesses or dangers moving forward. Building upon such work, many predictive models and sensing systems have been developed that allow for better management of pipeline integrity and reduction of incidents.

While there is significant research on the lingering effects of oil spills on the environment, a relatively small proportion focuses on the effects of catastrophic failure, and there is little work on the social or economic effects of such events.

Indigenous considerations

A significant part of the research on the social acceptance and perceptions of oil pipelines focuses on Indigenous communities. Indigenous and environmental interests can be interwoven, especially when opposition to specific projects is discussed. But the linkages between environmentalism and Indigenous issues and interests are complex, often event or project specific, and continuously evolving. As some Indigenous communities develop links to the industry and gain economic benefits, such relationships will also change.

Indigenous interests are multifaceted and progressing in the Canadian legal and regulatory context, but recent legal decisions have strengthened the role of Indigenous communities and their governments in the review and approval of natural resource development projects, and decision-making about land use. Indigenous communities are not all the same. Concerns and interests will vary depending on location, history, economy, and experiences with the resource industries. The diversity of views and experiences is important for understanding the issues that communities may bring up in considering pipeline developments, and the opportunities and challenges they can entail.

Sabin's 1995 review of the Mackenzie Valley Pipeline Inquiry focused on the perspectives of and impacts on the Indigenous communities that were affected by oil development on distant frontiers. In a similar vein, Simon (2009) explored the need for greater inclusion of Inuit perspectives and traditions in decision making in the North broadly, though with some mention of the development of oil pipelines in the Arctic as an ongoing issue relating to wealth inequality, poorly distributed resources, and a misplaced sense of sovereignty.

Preston (2013) explored the socio-economic and socio-political atmosphere in which the Northern Gateway project was developed with a particular emphasis on the criticisms brought forward by Indigenous and environmental groups. It casts the development of the energy industry in the Arctic as a form of 'modern colonialism', and cautions that this dynamic must be studied and addressed if development is to continue and conflicts are to be anticipated and acknowledged.

There are illustrations of research with a specific focus on pipelines and related developments. Bond (2015) for example studied the effects of oil pipelines from an anthropological perspective, examining the ways that oil pipelines shape the perceptions of the environment held by those whose lives are affected by them. Ironside (2000) explored the shift away from a top-down governance structure to increasingly decentralized governance structures, and used oil and gas pipeline development as an example of how Indigenous communities participate in the economy.

Schnoor (2013) wrote a short opinion piece in which he objected to the Keystone XL development project and suggested that the final decision power should ultimately rest with

Canadians, First Nations, and Indigenous communities. This presents an image of stakeholders as not only diverse, but consisting of distinct communities with different interests and evolving power. Sherval (2015) also framed the ongoing resource exploitation going on in the Arctic as a question of Arctic sovereignty, and questions the wisdom of future development projects in the Arctic, and introduces the notion (and the phrase) that “liquid modernity” has become a reality in North American energy production.

McCreary and Milligan’s assessment (2013) of the Carrier Sekani Tribal Council’s protest of the Enbridge Corporation’s plans to build a pipeline through un-ceded tribal lands explored the politics of this kind of economic development as it interacts with Indigenous rights and the legal obligations surrounding construction through Indigenous lands. Huseman and Short (2012) explored the impacts of the development of the oil sands on the Indigenous communities of the Treaty 8 region in Northern Alberta, which some described as a “cultural genocide”.

Veltmeyer and Bowles (2014) looked at the case of the Enbridge Oil Pipeline project in northern British Columbia, using a theoretical framework to examine the project as an illustration of ‘extractivism’. The paper also explores resistance to the project originating from Indigenous communities.

Wright and White (2012) explored the potential risks and benefits to Indigenous communities when the development and exploitation of energy reserves on and near Indigenous territories and lands occurs. The authors note the potential for economic diversification and wealth redistribution. But they also warn of potential risks to communities from increased social inequity, social upheaval, displacement, and environmental degradation.

An earlier work, by Bone and Green (1983), explored the effect of energy development projects in Canada’s Arctic on the wage economies in various Indigenous communities in Northern Saskatchewan with various levels of previous exposure to these economies. Bone and Mahnic (1984) also published a descriptive historic study of the development surrounding the Normal Wells oil fields and pipeline areas in the Northwest Territories. Later, Bone and Stewart (1987) studied the socio-economic effects of the Norman Wells Oilfield Expansion and Pipeline Project on four remote communities in Northern Canada (Norman Wells, Fort Norman, Wrigley, and Fort Simpson). Bone (1989) also considered the effects of the Norman Wells Project on the consumption of country food by Indigenous community members.

Public perception and social acceptance

Social acceptance

The importance of pipeline development projects achieving and sustaining social acceptance is increasingly key to the success of future projects. Social acceptance is reflected in public trust in the industry and regulators, which arguably flows from transparency, understanding and knowledge of the industry, and good communication.

Stern (2007) examined Indigenous representation in media pieces reporting on the Mackenzie Valley Gas Pipeline specifically, as well as pieces on the oil and gas industries more generally. Brusso (2018) and Alexander and Van Cleve (1983) describe the history of the Alaska Pipeline. Scott (2013) examined the networked infrastructures of the coast-to-coast pipeline proposed in Canada, suggesting that is was likely to increase inequity. Gravelle and Lachapelle (2015) drew on surveys from the Pew Research Centre to map the different levels of support for the Keystone XL pipeline project among the United States public relative to their geographic proximity to the proposed sites. They used a spatial analysis of public opinion to determine not only how the proximity to the pipeline influenced perceptions, but also how underlying economic and environmental values/attitudes affected support.

Axsen (2014) conducted a similar study, using values theory to determine citizen acceptance of the Keystone XL pipeline based on their geographic proximity to the proposed pipeline and the role of community values on the wiliness of communities to accept projects. Rogers (1974) described the North Slope segment of the Alaska project and presented some of the initial mapping work on the conflicts and impacts caused by the project.

Terry (2012-2013) presented an analysis suggesting that the economic advantages that the Keystone XL pipeline would offer Americans should outweigh the fears of increasing a dependence on foreign oil.

Public discourse on the Keystone XL pipeline was so ubiquitous that certain authors used the project as a case study or proxy for a range of topics –sometimes much broader than the specific project discussed. For example, Smythe (2014) used brief discussion of attitudes surrounding the Keystone XL to introduce a larger discussion about the role of humans in relation to the environment “as we move firmly into an era of the Anthropocene”. Beckrich (2012) provides a teacher’s perspective on different ways to approach teaching children about the development of the Keystone XL but linking it to larger issues in fossil fuel use, and developing the “tar sands”.

Earlier work by Gamble (1978) presented a summary of the inquiry that surrounded the Mackenzie Valley Pipeline development conducted by Justice Berger. Gamble examined the interplays of technical, social, cultural, and environmental issues that resulted from the proposed project.

Studies of media and social media coverage

Several studies focus on the role of media representation and language in public perceptions of the decisions, protests, and potential impacts of pipeline projects. Way (2011) examined the role of language use in Canadian news media representation of the oil sands development subsequent to the then Conservative government's *branding* of Canada as an 'emerging energy superpower'. Comparably, Hodges (2016) explored the use of language in social media, in particular the use of Twitter by environmental activists in response to the Keystone XL pipeline. Deschamps (2014) used a content analysis to analyse the way that groups and individuals engaged and interacted with various policy topics, and used comments on *YouTube* about the Keystone XL pipeline to help frame arguments and discussions.

Raso and Neubauer (2016) used a similar approach, exploring the journalistic practices that surrounded the political controversy of the Keystone XL pipeline and the Northern Gateway project. The article argues that over-reliance on official sources for information and the importance of industry-backed organizations, and related influence media coverage "all conspire to structure the public discourse on Northern Gateway in favour of elite preferences and rationalities".

Using the Keystone XL pipeline as a case study, Kojola (2017) examined the role of media portrayal in the public dialogue about environmental costs versus economic benefits of a pipeline project. Rogers and Ethridge (2014) also used the Keystone XL project as a case to examine the role of the media and how increased public interest is affecting how the project progresses, and how controversy can create broad public awareness and shape perception of a project.

Gasser (2012) noted the extensive media coverage of Keystone XL and the impacts on public perception. Gasser attempts to reconcile to debates and identify the quality of different arguments. Brown (2012) examined the rights to accessing information and public participation in the discussions of Keystone XL Oil Sands pipeline under the National Environmental Policy Act. Parker (2013) assessed the permitting process, relevant case law, and the president's authority in decision-making as it pertained to Keystone XL.

At the 2011 Canadian Crude Quality Technical Association (CCQTA) General Meeting, Ha (2011) presented on the expansion of the Keystone XL pipeline, focusing largely on the economic value arguments associated with the project, as well as using the opportunity to update the industry professionals present on the developments in the project.

In many respects, analyses of media coverage of pipeline development issues are emerging. This is not unexpected as many of the issues and projects that have garnered the most attention are themselves recent. There is a need for research that examines how events are presented in the media, and how the science of pipeline construction and operation and incident responses are understood and communicated to the public. Social science research can also help industry plan projects to better maximize benefits and better mitigate social and economic impacts. Some may see such work as activist. The results and knowledge this research produces can help industry and regulators to anticipate and understand impacts, and assess best options for mitigation and communication.

Economics

A key argument for oil pipeline development centres on the potential direct and indirect economic outcomes of projects, and the importance of the sector to the national and regional economies. As such, there is a substantial literature that examines benefits and opportunities.

Page (1981) explored the economic implications of the expansion of the Norman Wells oilfield due largely to the Interprovincial Pipeline. Rees (1989) examined the socio-economic and administrative factors that determined the development of the Norman-Wells project. Rees compared and critiqued the estimated and demonstrated outcomes. He concluded that the while funding for inclusive assessment may 'soften' the face of the project, but without structured plans in place to help ensure participation affects actual outcomes, such funding is ultimately not too useful.

Hughes (2010) explored the distribution of energy resources throughout Canada, and argued that the absence of oil pipelines in Eastern Canada results in an over reliance on crude oil from exporting countries. Swart and Weaver (2012) wrote a short commentary paper emphasising the need to compare and weigh the economic benefits of the Alberta oil sands against the larger ecological concern regarding oil exploitation, as well as the global need for a reduction in carbon emissions.

Major pipelines can provide good examples of case studies of economic and social impacts of resource development. Carrington (1996) looked at the impacts of oil pipeline construction on temporary economic growth and the effects on remote Arctic communities. Carrington (1996) studied economic impacts of building of the Trans-Atlantic pipeline on the Alaskan labour market in the mid-1970s, with an emphasis on the impacts on remote communities. Similarly, James (2016) analyzed the rapid peak and subsequent gradual decline of Alaskan oil production following the 1977 completion of the Trans-Alaska Pipeline system. James presents the project as a case study of a 'resource boom'.

In the American setting, there is interest in the economic advantages of reducing dependence on foreign oil markets. Bridges (2013) explored the impacts of Keystone XL Pipeline on trade relations between Canada and the United States, suggesting there are both negative and positive outcomes. Lesser (2012) assessed the potential economic impacts if the Keystone XL Pipeline were not to be developed. Gasser (2012) (also mentioned above) examined the contradictory arguments on the economic impacts of the Keystone XL project, the paper notes and the selective use of information to frame debates and shape opinion. Gasser also highlighted the issue of United States dependence on foreign oil as a domestic political issue when considering a pipeline originating in Canada, noting that some commentators point to the dependence issue as one that should more accurately be focused on dependence on "hostile" sources.

Organizations such as the Canadian Association of Petroleum Producers issue annual reports summarising forecasts in the oil markets, as well as annual supply and production data. The Energy Resources Conservation Board and the National Board of Energy also produce publications summarising the current state of the energy reserves industry. This includes the existing transportation infrastructure, as well summarizing projections and proposals for expansion (see Energy Resources Conservation Board, 2013; National Board of Energy, 2009)

In 2016 a report produced by Veracity Plus Consulting prepared for the Canadian Energy Pipeline Association examined the advantages of expanding Canada's existing pipeline infrastructure. Angevine Economic Consulting (2016) produced a similar report on the economic impacts of Canada's transmission pipelines, and the specific regional and other benefits (direct and indirect economic impacts) that come from the sector.

Political, policy, legal and regulatory issues

Pipelines can traverse long distances, and can also cross interprovincial and international boundaries. Cross-boundary lines require operators to address the policies, laws, and political/social realities of multiple jurisdictions. The jurisdictional complexity of a project can result in issues that emerge in one locale becoming a factor in the deliberations and approval processes of others.

Gattinger (2012) studied the ways in which energy policy-making has become increasingly complicated in the last three decades. The author notes that policy makers now have to address ecological and economic concerns, both of which must be done in a way that is acceptable to *a public* that will often hold conflicting and contradictory views.

Zoldan (2015-2016) used the Keystone XL project to illustrate the *inner workings of Congress* and the impacts of public opinion on the legislative process in the United States. The Congressional Research Service (CRS) prepared a report outlining issues that may influence government decision-making, summarising the key arguments both for and against the project, and outlining the US regulatory setting for the project (Parfomak et al., 2013). The CRS also provided *update reports* on the Keystone XL project.

Thomas and Thomas (1982) examined how the development of the petroleum industry, and pipelines, in Alaska were directly related to public policy issues, such as reliance on foreign oil. The work illustrates how concern about environmental issues can be overcome by building awareness and support for domestic energy production.

Stabler and Olfert (1980) presented a paper on the political economy environment that led to the development of an energy pipeline through the Western Arctic despite significant opposition from environmentalists and Indigenous communities. The authors examined the bases for the conflicting concerns and ultimately examined and commented on the process that allowed the government to move forward with the Northern Gas Pipeline.

In an earlier work, Kirkey (1997) examined the political strategies used by Canada to convince American regulators and business that an overland pipeline transporting Alaskan oil through the Mackenzie Valley was preferable to the use of oil tankers. The Canadian position was that in the event of a tanker spill the potential risks to coastal waters and ecosystems were too great, thus a pipeline overland was preferable.

There are works that take a legal studies approach, such as Cherry (2011) and Harrigan (2012). They summarise applicable case laws and statutes while providing a unique interpretation and perspective on the applicability of these laws, as well as the necessity for changes or revisions to existing laws. Grenier (2004) focused on the legal infrastructure that helped support the Alaska Gas Pipeline project. Blake (2014) examined the issue of *eminent domain* in energy transportation, focusing on the Nebraskan portion of the pipeline proposed by TransCanada Corporation in 2008.

Hobert et al. (2012) presented a paper on the energy-environment policy and governance in Canada and the United States through case studies of two pipelines: the Keystone XL Crude oil pipeline and the Northern Gateway Pipeline. They focused on the procedural requirements in each country, determining that the courts played a major role in Canada, while the state and local governments were responsible for the most significant procedural activities in the United States.

There are studies that focus on the intersection of public perception and political issues surrounding pipeline development. Shum (2013), for instance, applied international relations theory to explore the policy interpretations and to explain the persistence of the Keystone pipeline controversy in both the political and public spheres. Hoberg's 2013 study described the political risks associated with development of Canada's oil sands.

The conflicting interests of the oil industry and political realities are also discussed in the literature. Berry (1974), for instance, explores the confrontation that the oil crisis of the 1970s created between the oil lobbyists and the Canadian federal government. Similarly, Gramling and Freudenburg (1992) explored the impacts of a major event on the relationship between oil industry representatives and the federal government. They offered a case study of the Exxon Valdez oil spill, and explored the associated impacts on the social and cultural context of oil extraction in the United States.

The Exxon Valdez accident also led to an increase in work on environmental disclosure (e.g. shown by Pattern's 1992 study of the legitimacy theory in the case of environmental disaster). Such work shows the potential for a major accident to have implications for many parts of an industry and the different parts of the supply chain. Kurtz (2010-11) also examined the relationships between the organizational culture and regulatory regime that contributed to extensive corrosion going unaddressed until the 2006 British Petroleum oil spill was reported.

Etkin (1999) provided an overview of oil spill statistics between 1960 and 1998 and showed that while oil tanker spills often receive the most media attention, their total volume loss of oil is often less than that seen in spills resulting from failure of pipelines, storage tanks, and other related facilities.

Cochran (2013) used the Keystone XL as an example of how focusing on the wrong subset of a project, in this case carbon emissions directly related to the construction and operations of the pipeline, can lead to an omission of the larger and more important issues; specifically, the overall connection of the project to national and global carbon outputs.

Jones (2013) also explored the American desire to reduce their dependence on oil from the Middle East, and how that desire created an atmosphere ready for the Keystone XL project to become a major political issue. Kalen (2012-2013) noted that the Keystone XL pipeline development became an influential political issue, and proxy for a range of environmental and other issues, during the United States election cycle and, a major talking point for the President at the time. Busenberg (2011) applied a punctuated equilibrium approach to exploring policy dynamics of the Trans-Alaska pipeline system and the long-term consequences and influence that the project has had on national policy and related regulatory dynamics. Such work shows that major projects can reshape policy discourse with lasting impacts on a range of policy areas such as energy strategies, protected areas policies, and the diversification and sustainability of regional economies.

This field is broad and the issues and disciplines are intertwined. There may be a tendency in policy studies to view projects critically, and potentially from an adversarial perspective. The legal realm warrants particular attention, and this area is rapidly evolving.

Current court cases will help decide how and if projects may proceed and may also result in a realignment of jurisdictional powers and authority, but also have the potential to provide clarity with respect to consultation and permitting requirements. But it will take some time to provide analyses of the implications and impacts of legal decisions and then see these in the research literature.

Ecological issues

Discussions of ecological issues and impacts form pipeline development, including impacts from the construction period, and from incidents during operation. These in landscape disturbance, effects on wildlife, and long-term impacts from incidents are topic covered.

Erickson and Lazarus (2014) used a lifecycle analysis to evaluate how energy transportation infrastructure can shape energy systems and the ecological consequences from different types of development. Murphy (2012) provides an overview of the key issues arising from the proposed expansion of the Keystone XL pipeline, including the ecological disturbances and the environmental degradation that would occur as a result.

Ramseur et al. (2014) produced a Congressional Research Service (CRS) report on selected environmental issues surrounding the Keystone XL pipeline and the oil it would transport. The CRS report looked at greenhouse gas emission implications, spills and other environmental impacts. Palen et al. (2014) wrote a comment opining that the debates surrounding pipeline development projects tend to have too domestic or localised a focus, without enough focus on broader environmental and climate effects.

Wildlife impacts and human dimensions of wildlife management

Some work in this field transcends looks at policy options. For example, Snyder (2014) outlined a conservation policy-funding framework related to Keystone Xl. The concept is based on a trade-off – if conservationists agreed to withdraw their opposition to the project, a tariff levied on the oil transported through the pipeline would be used to fund conservation projects.

Work in this field is often broad and can address a range of environmental qualities. For example, Swift et Al. (2011a & b) presented on the risks and environmental impacts of transportation of materials from the Alberta oil sands. Most work, however, focuses on particular impacts, and often from specific incidents and their outcomes. Work done includes both predictive and case-based research. Earlier work by Seburn et al. (1996) created an experimental point-spill in a simulated pipeline corridor to study the recovery of plant species. Kershaw (1990) created an experimental spill in a simulated right-of-way trench to study the absorptive qualities of the soil and the effects of the crude oil spill from a buried pipeline on the surface vegetation. Kershaw and Kershaw (1986) studied the effects of decades-old crude oil spills on plant compositions of tundra communities in the Yukon. Walker et al. (1978) had earlier conducted a similar study on six major plant communities affected by the Prudhoe Bay crude oil spill in Alaska.

Leopold (1994) examined the potential threats to wildlife should the United States government pass legislation that would allow drilling for oil in the Arctic National Wildlife Refuge. Jewell and Jewell (2007) examined the political issue of the Congressional debate regarding drilling for oil in the Arctic National Wildlife Refuge and argue that if development is approved, adequate transportation for the oil produced must first be developed, positing that a long-distance pipeline (potentially joining the Trans-Alaska Pipeline network) would be the safest option.

In the absence of major events/incidents, the most direct impactful period of pipeline development may be during the construction phase. Follmann and Hechtel (1990) reported on the human-bear interactions and conflicts encountered during the construction phase of the Trans-Alaska pipeline. Love and York (2005) compared the fish assemblage associated with an oil/gas pipeline and the adjacent seafloor in the Santa Barbara Channel and found observable differences in the way the different habitats were being used. Young and Mackie (1991) studied the effects of winter oil pipeline construction on the benthic invertebrates of Hodgson Creek, as well as the relative concentrations of suspended sediments found downstream of the right-of-way construction sites. Cameron et al. (1995) studied the functional loss of habitat for caribou living in and adjacent to an oilfield complex near Prudhoe Bay in Alaska.

Johnston (2015) studied the effects of energy extraction projects, including pipeline expansion, on colonizing and invasive downy brome (*bromus tectorum*) populations. This study specially looked at the effects of soil-density manipulation and herbicide application in six Wyoming big sage ecosystem sites, which were manipulated to simulate the impacts of a pipeline development.

Soil properties

And early study by Hunt et al (1973) examined the impacts of oil spills from the Fairbanks military pipeline on terrestrial ecosystems. They also examined the effects of microbial degradation, to determine if degradation rates could be improved with the addition of fertilizer.

An Ontario case study by Culley et al. (1982) examined the recovery of soils that had been disturbed by the installation of the Sarnia-Montreal oil pipeline. They measured soil properties and in some places field-crop yields were examined. The study observed soil compaction, porosity, and hydraulic conductivity, as well as chemical composition and availability of crop/plant nutrients.

Similarly, De Jong (1980) explored the effects of, and recovery from, an oil spill caused by a mid-winter break in a buried oil pipeline. The research examined the contamination of the soil caused by the oil travelling upwards roughly 850 m through cracks in the frozen soil. Likewise, Wang et al. (1998) provided a chemical analysis of soil composition 25 years following the Nipisi oil spills to help determine the effective restoration methods.

Conclusions and Recommendations

The scan shows that there is a relatively large body of work with direct relevance to the Canadian setting. Technical fields are well covered. For example, there has been a lot of fundamental academic research around corrosion: this includes internal and external pipe corrosion, pitting corrosion, stress corrosion cracking (particularly important in the Canadian context) and modeling of various corrosion phenomena, as well as coating performance. There is also a significant body of work on pipeline steels and welding from a physical metallurgy perspective. Similarly, substantial work has been done on geotechnical issues in the Canadian context.

Non-technical topics were more widely covered than anticipated. However, there are specific areas of concentration such as on United States cases and northern projects, and few on western Canada where arguably the issues are most poignant. Some earlier works may still have relevance to the contemporary setting. The scan suggests there is a need for more work on issues of perception of pipelines, and public trust in industry and regulators. It could emerge that much of the work in this field may be critical of the industry.

In Canada, controversies are relatively new and have become more pronounced in the last 10 years as major projects such as Enbridge's Northern Gateway proposal and the Trans Mountain Pipeline Expansion Project entered assessment and permitting processes. We expect to see more work published in the next few years from social scientists as the future of key projects, especially in western Canada, are decided. However, there were a notable number of works examining the Keystone Xl project.

Indigenous considerations are an important part of the Canadian regulatory setting. There are few works specific to this area, but this will likely improve as researchers develop more work on the field and their results are gradually published. Experiences and issues in engagement, consultation and consent will also likely receive increasing attention by researchers. We can also expect more case study work. For example, as the Trans Mountain pipeline Expansion advances we would anticipate analyses on the regulatory and conflict dynamics of the project.

The scan can provide the foundation for a more detailed knowledge synthesis. This would look more deeply at the literature, and bring in a range of expertise to identify specific research gaps and areas where knowledge concentrations exist. A knowledge synthesis would also benefit from focusing on specific topics, for example leak detection and provide a comprehensive review of research and the knowledge developed to date.

To build a more detailed understanding of gaps and strengths a more comprehensive long-term survey of the literature can be done which would delve more deeply into the content of papers. This knowledge synthesis approach should be coupled with a survey of industry and research experts in specific fields could be done to identify areas where information and knowledge is needed, and to understand where practitioners see specific requirements to best support their work and to advance best practices.

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Appendix

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Materials and related issues and practices

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