Final Report: Knowledge Synthesis Grant

Hydraulic Fracturing and Public Policy[*]

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Brief Summary and Key Messages

This knowledge synthesis explores policy pertaining to and regulation of hydraulic fracturing in the context of a continually evolving knowledge base. The technology itself has become quite contentious in Canada, with active development in western provinces, exploratory development in the north, and moratoria in the east. Our hope is that the research presented here will help improve public understanding of hydraulic fracturing, and lead to better public policy and regulation in Canada. We reviewed the academic literature, grey literature, and government and regulatory documents. Our findings reveal a number of key themes:

Theme 1: More Research is Needed

Our literature review revealed that there is an active academic community exploring the scientific aspects of hydraulic fracturing, including environmental and human health impacts. Knowledge gaps have been identified, and a significant amount of work is going towards closing the gaps. In some cases, the research is leading to the discovery of additional knowledge gaps and areas for further research. This speaks to the difficulty of forming policy and regulations aimed at mitigating the negative effects of hydraulic fracturing in the presence of uncertainty about the size, scope and impact of those effects. Compounding this difficulty is that research into the socioeconomic effects has not progressed. We were unable to find research quantifying costs or benefits, or evaluating net benefits. This places politicians, policy-makers and the public at a significant disadvantage in evaluating whether the benefits of hydraulic fracturing justify the costs.

Theme 2: Risk versus Reward

The different treatment of hydraulic fracturing across Canada has revealed differing perceptions of risk and different risk tolerances. Provinces with previous oil and gas development are more welcoming of hydraulic fracturing, in part due to already robust regulatory systems and experience with the tangible economic benefits of hydrocarbon development. Implicit in this decision is a choice that the benefits justify the costs. In contrast, provinces and territories less familiar with oil and gas development convened review panels or strategic assessments of hydraulic fracturing to identify risk, costs and benefits. In many cases, the question of whether the risk is worth the reward has not been settled.

Theme 3: Policy and Regulation: Limited Linkages to Science

In reviewing government and regulatory documents from across Canada, we discovered that there is limited or no reference to the relevant academic literature. The exception to this is the report produced by the Council of Canadian Academies evaluating shale gas in Canada, the government-initiated review panels of hydraulic fracturing in New Brunswick and Nova Scotia, and Quebec's strategic environmental assessment of shale gas. While regulation and government policy is undoubtedly based on scientific evidence, the lack of explicit link undermines the credibility of both.

Theme 4: Public Trust and Confidence

Public discussion of hydraulic fracturing often characterises the technology as "good" or "bad"; many groups are vehemently opposed to its use because of perceived environmental costs and the uncertainty around the risks. In part, this opposition stems from a lack of confidence in policy and regulation, and is not surprising, given that our understanding of the consequences (good and bad) of hydraulic fracturing is evolving. The review panels are an important step in gaining and maintaining public trust and confidence, but continued communication to affected groups is also key.

Executive Summary

Hydraulic fracturing is becoming an increasingly important component of both oil and gas extraction in Canada, used to produce natural gas and light oil from tight and shale reservoirs. Production from these reservoirs currently accounts for approximately half of Canada's natural gas and light oil production. The Canadian Association of Petroleum Producers has stated that in 2014, fracturing occurred in 60 per cent of wells drilled in Saskatchewan, 70 per cent of wells in Alberta and 90 per cent of wells in British Columbia. With little history of the widespread use of this technique, questions concerning the safety of hydraulic fracturing have been raised across the country. Common areas of concern include groundwater contamination, wastewater disposal, and induced seismicity. Regulatory approaches differ significantly across the country, and these differing approaches have been informed by multiple sources of information on hydraulic fracturing, including government review panels, environmental assessments and research from academia and non-government organizations.

The opposing regulatory approaches found across Canada arguably make it difficult for average Canadians to know what to think about the risks of hydraulic fracturing in their communities and provinces. One consequence is a public, often passionate, debate about the merits of hydraulic fracturing conducted in an arena with competing information, historical data and reference materials. Moreover, the continually evolving scientific literature on the risks, costs and benefits of hydraulic fracturing adds to the complexity of the issue. The opposing regulatory approaches also have a strong influence on investment and the distribution of economic activity and its associated benefits. It is becoming increasingly important to improve the knowledge and understanding the impact of widespread use of hydraulic fracturing on the range of public interest concerns from health and safety to market stability.

Our objective in this research is to synthesize the existing scientific information available and produce a synoptic overview of the issues and present these in the context of policy choices. We provide an objective summary of research to date, including academic literature, the grey literature, and regulatory and government documents. Based on this, we identify knowledge and policy gaps, and opine on why regulatory authorities and governments have been approving such a wide range of field practice and reporting, while reaching vastly different conclusions on the use of hydraulic fracturing.

The goal of this Knowledge Synthesis Grant report is to contribute insights to answering the question "What effects will the quest for energy and natural resources have on our society and our position on the world stage?" The research presented in this paper addresses the theme "What will be the cultural, environmental, economic, gender, political and social implications of the quest for and extraction, production and use of energy and natural resources in Canada?" and the subtheme "What could be the

cultural, social, economic and environmental impacts on different groups and communities of disruptive technologies for accessing and developing natural resources?"

What We Discovered

Despite numerous government-commissioned reports on the environmental and socio-economic effects of hydraulic fracturing, and the growth of academic research over the past decade, there are substantial knowledge gaps. Major reviews have been provided by the Council of Canadian Academies (CCA), the Canadian Water Network (CWN), and review panels in Nova Scotia and New Brunswick. The most significant knowledge gaps related to hydraulic fracturing identified by the CCA, CWN and the two provincial review panels include a lack of baseline data, insufficient information on long-term cumulative effects, and a lack of region-specific information overall. Although a significant amount of additional research in both the academic and grey literature has been completed since the CCA report was released, these gaps continue to be emphasized. To a large extent, the new research is also unearthing new information that raises more questions than answers. For example, in many cases the research is leading to conflicting results for which explanations are sought. Results for one region raise questions about whether similar impacts are observable in others, and observations of negative environment and health outcomes with an insufficient understanding as to the causality of these outcomes.

As the complete study of hydraulic fracturing has many missing pieces, it is only logical that there will be consequent missing pieces in policy and regulation. Indeed, policy-makers and regulators are in a catch-22 situation: better understanding of the risks and costs of development requires both improved measurement and allowing further development, but it is difficult to effectively formulate policy and regulation without a fulsome understanding of risks, benefits and costs.

Key Themes

Theme 1: More Research is Needed

Our literature review revealed that there is an active academic community exploring the scientific aspects of hydraulic fracturing, including environmental and human health impacts. Knowledge gaps have been identified, and a significant amount of work is going towards closing the gaps. In some cases, the research is leading to the discovery of additional knowledge gaps and areas for further research. This speaks to the difficulty of forming policy and regulations aimed at mitigating the negative effects of hydraulic fracturing in the presence of uncertainty about the size, scope and impact of those effects. Compounding this difficulty is that research into the socioeconomic effects has not progressed. We were unable to find research quantifying costs or benefits, or evaluating net benefits. This places politicians, policy-makers and the public at a significant disadvantage in evaluating whether the benefits of hydraulic fracturing justify the costs.

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The different treatment of hydraulic fracturing across Canada has revealed differing perceptions of risk and different risk tolerances. Provinces with previous oil and gas development are more welcoming of hydraulic fracturing, in part due to already robust regulatory systems and experience with the tangible economic benefits of hydrocarbon development. Implicit in this decision is a choice that the benefits justify the costs. In contrast, provinces and territories less familiar with oil and gas development convened review panels or strategic assessments of hydraulic fracturing to identify risk, costs and benefits. In many cases, the question of whether the risk is worth the reward has not been settled.

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In reviewing government and regulatory documents from across Canada, we discovered that there is limited or no reference to the relevant academic literature. The exception to this is the report produced by the Council of Canadian Academies evaluating shale gas in Canada, the government-initiated review panels of hydraulic fracturing in New Brunswick and Nova Scotia, and Quebec's strategic environmental assessment of shale gas. While regulation and government policy is undoubtedly based on scientific evidence, the lack of explicit link undermines the credibility of both.

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Public discussion of hydraulic fracturing often characterises the technology as "good" or "bad"; many groups are vehemently opposed to its use because of perceived environmental costs and the uncertainty around the risks. In part, this opposition stems from a lack of confidence in policy and regulation, and is not surprising, given that our understanding of the consequences (good and bad) of hydraulic fracturing is evolving. The review panels are an important step in gaining and maintaining public trust and confidence, but continued communication to affected groups is also key.

Context: Hydraulic Fracturing in Canada

Natural resource development is a significant economic mover in Canada and energy – particularly the extraction of oil and natural gas – forms a critical part. Canada has vast hydrocarbon resources that we can develop and export but there are many regulatory and social hurdles to overcome. Public opinion on hydrocarbon resource development in Canada is divided and the opposing voices are loud. Of particular concern is the development of oil and gas resources using hydraulic fracturing. Hydraulic fracturing, or fracking as it is more commonly known, is a complex process used to access oil and gas resources that were previously unattainable due to their location in tight rock formations.

While hydraulic fracturing provides potential access to new reserves of oil and gas resources across the country, questions have been raised regarding the safety of the process, the legitimacy of regulatory processes and the effectiveness of regulations governing the development of hydrocarbons, and the potential negative effects on air, water, land and human health. As a result of these questions, which largely remain unanswered, hydraulic fracturing has become a target of the movement against hydrocarbon development in Canada. Objective, science-based information exists on the topic, but is it effectively informing regulation and government policy? What key information is missing from the discussion of hydraulic fracturing, and how is that affecting the policy and regulatory landscape in Canada? These are the key questions that we will address in this paper.

The primary objective of this paper is to understand how existing science-based, academic and grey literature about hydraulic fracturing, and how the knowledge gaps identified by this literature, are influencing and informing government policy about hydraulic fracturing and the regulatory process.

We begin the discussion of hydraulic fracturing with an overview of hydraulic fracturing, explaining the process and where hydraulic fracturing is taking place in Canada. We then discuss the implications of hydraulic fracturing for Canada, and describe the methodology used to explore how policy and regulation are informed by the scientific literature. We detail the regulation of hydraulic fracturing in Canada for each province and territory. Next we explore previously identified knowledge gaps by considering four major reports that have been released over the last two years. These four reports are from the CCA, the Nova Scotia Review Panel on Hydraulic Fracturing, the New Brunswick Review Panel on Hydraulic Fracturing and the Canadian Water Network. All four reports provided comprehensive overviews of existing literature and identified key knowledge gaps related to hydraulic fracturing. We will then provide an overview of the literature that has advanced since the first report, from the CCA, was published. We will demonstrate which, if any, knowledge gaps have been filled and how the conversation has progressed. The literature will be summarized and organized into three categories that synthesize the knowledge gaps, the categories include: environment, economy and community, and regulation and governance. To conclude, we will describe how existing knowledge gaps on the topic of hydraulic fracturing have resulted in policy and regulatory gaps.

Overview of Hydraulic Fracturing

Hydraulic fracturing is a method of extracting oil and gas from low-permeability rock formations. The process involves drilling and completing a well (typically with a horizontal component) and then pumping fluid or gas into the wellbore to create pressure in the formation. This pressure results in the fracturing or cracking of rock. After the initial fractures are created the fracturing fluid is mixed with proppant (typically sand or ceramics of a specific size). The fracturing fluid and proppant is pumped down the wellbore and into the fractures in the rock, allowing the fractures to remain open after the

fracture fluid is removed. The "propped open" fractures release the oil or gas contained within the pores of the rock and create pathways through which oil or gas travels into the well, and from there to the surface to be marketed and sold.

Production of hydrocarbons via hydraulic fracturing has potential benefits and risks. Potential benefits include the extraction of oil and gas from unconventional resource plays characterized by low-permeability rock. These resources were previously unrecoverable using conventional vertical production wells, as the natural pathways in the rock are too tight to allow for movement of oil and gas without induced fractures. Hydraulic fracturing is also conducive to the use of multi-well drilling techniques, in which multiple horizontal wells are drilled from a single well-pad. This can greatly reduce the surface disturbance and the land impact of oil and gas production, particularly relative to production from vertical wells, which, for a similar production area, have to be spaced out and built on separate well pads. Natural gas is also perceived by some as a more environmentally friendly source of energy, particularly for electricity generation and heat, as it has a lower emissions-intensity than coal and fuel oil. For example, natural gas used across Canada emits an average of 52 kilograms of CO_2 per GJ of energy produced, while coal and heavy fuel oil produce averages of 88 and 76 kilograms per GJ respectively.[1] The lower emissions intensity of natural gas makes it more attractive as an energy source, and hence makes production of natural gas via hydraulic fracturing more appealing.

A number of potential risks are associated with hydraulic fracturing, including induced seismicity, groundwater contamination, the impact of water usage on local water supplies, greenhouse gas emissions, and waste disposal. In addition to the direct environmental impacts, there is concern that deterioration in local air and water quality may impact human health. The cumulative effects of all potential risks of hydraulic fracturing are also not well known, which creates uncertainty around the relative benefits and costs of the production technique.

Where is Hydraulic Fracturing Occurring in Canada?

Hydraulically fracturing is primarily used to produce natural gas and light oil from tight and shale reservoirs. Production from these reservoirs currently accounts for approximately half of Canada's natural gas and light oil production. Specifically, Canada's total natural gas production averaged 14.7 billion cubic feet (bcf) per day in 2014, of which 7.6 bcf per day was from shale and tight gas reservoirs in the Western Canadian Sedimentary Basin [82]. Alberta is the largest producer of shale and tight gas (4.4 bcf per day), followed by British Columbia (3.1 bcf per day) and a small amount of production in Saskatchewan (0.1 bcf per day). Tight light oil production in the Western Canadian Sedimentary basin was approximately 375,000 barrels per day in 2014 [81]. The majority of this production is occurring in Alberta and Saskatchewan with small amounts also coming from British Columbia and Manitoba. Total Canadian light crude oil production in 2014 was approximately 890,000 barrels per day [82].

In addition to the commercial hydraulic fracturing operations found in the western provinces, a small amount of exploratory hydraulic fracturing is occurring in the Northwest Territories [83]. Exploratory hydraulic fracturing has also been approved in the Yukon, although only in the Liard Basin and any drilling requires the consent of affected First Nations [38]. Exploratory hydraulic fracturing has occurred in Quebec, Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland and Labrador [83].

[1] Author calculations using emissions intensity data from Environment and Climate Change Canada's 2016 National Inventory Report and energy conversion tables from the National Energy Board.

Quebec, Nova Scotia and New Brunswick have since conducted thorough reviews of hydraulic fracturing and, as of spring 2016, have ongoing moratoriums in place. A similar review is under way in Newfoundland and Labrador, and a temporary moratorium is in place until the review process is complete.

While there have been calls for a ban on hydraulic fracturing in Ontario, no shale gas or shale oil is being extracted in the province and there are no requests to conduct exploratory activities [65]. As a result, the government has declined to introduce a moratorium and has stated that it will continue to monitor research in other jurisdictions and if any applications come forward, then it will ensure that adequate consultations are completed and appropriate environmental measures are put in place [37]. A private members bill to ban hydraulic fracturing was introduced in 2015, and has since been passed to the Committee on General Government.

Implications

The slow nature of policy development, and the political connotations policy issues often have, is particularly detrimental when considering evolving technologies such as hydraulic fracturing. In Canada, policy-makers and regulators are facing immense knowledge gaps on the risks, costs and benefits of hydraulic fracturing. In Western Canada, already robust regulatory systems have eased this burden, and an implicit choice has been made to "learn-by-doing". In Central and Eastern Canada, uncertainty about both the economic benefits, and environmental and other costs has led to provincial evaluations of hydraulic fracturing, and in many cases, moratoriums. The consequence of a moratorium, however, is that more knowledge is unlikely to be gathered, except from other regions, and this knowledge is not always transferrable.

There is a clear need for more research into the impacts of hydraulic fracturing. The assessment of shale gas in Canada by the Council of Canadian Academies (CCA) identified many knowledge gaps that have yet to be filled. The most significant knowledge gaps related to hydraulic fracturing identified by the Council of Canadian Academies, Canadian Water Network and the Nova Scotia and New Brunswick review panels include a lack of baseline data, insufficient information on long-term cumulative effects, and a lack of region-specific information overall. Although a significant amount of additional research in both the academic and grey literature has been completed since the CCA report was released, these gaps continue to be emphasized. To a large extent, the new research is also unearthing new information that raises more questions than answers.

Looking ahead, perhaps most challenging for resolving the environmental and health uncertainties around hydraulic fracturing is that the appropriate baseline data was never collected. While there is now a clear awareness that baseline data is needed, the collection of this data is hindered by the significant development and production that has already occurred.

The potential negative environmental and health impacts of hydraulic fracturing have grown to dominate headlines in recent years, and as a result, they also dominate current research and the discussion around knowledge gaps. In doing so, however, they arguably draw away from developing a full understanding of the risks and opportunities, and costs and benefits of hydraulic fracturing. In particular, the economic and community impacts of hydraulic fracturing appear to be largely understudied. This may be driven in part by what appears to be limited public interest in hearing about the positive impacts that could be accompanied by development, or on the flip side, the negative impacts that could result from not

proceeding with development. As there are a full suite of environmental, health, social and economic costs and benefits associated with hydraulic fracturing development this research goes well beyond the niche areas of most individual academics. Rather it is most likely best addressed by government through, for example, a comprehensive cost-benefit analysis which uses monetary values as a metric to evaluate changes in wellbeing associated with policy changes. The development of a balanced analysis has not been done to date and is necessary to inform and improve the quality of public policy decisions in relation to hydraulic fracturing.

Methodology

The primary objective of this paper is to understand how existing science-based, academic and grey literature about hydraulic fracturing, and the knowledge gaps identified by this literature, are influencing and informing government policy about hydraulic fracturing and the regulatory process. To accomplish this objective we divided our review of the literature into three areas. The first area is a review of government legislation and research related to hydraulic fracturing in each of Canada's provinces and territories. A key aspect of this review was determining the extent to which provincial policies and directives around hydraulic fracturing are drawing on science-based literature, and how – and if – policy is addressing issues around which there are significant knowledge gaps.

The second area of literature that we reviewed is articles published in peer-reviewed academic journals. This literature has grown rapidly in recent years. As noted in a recent report published by the Canadian Water Network, a *Web of Science* index search for "hydraulic fracturing" finds 98 articles published in 2010, 169 in 2012 and 437 in 2014 [12]. To help narrow our review we focused on articles that were published after November 2013. This was the cutoff date for publications included in the CCA report, *Environmental Impact of Shale Gas Extraction in Canada*, which provides a comprehensive overview of existing literature and identified key knowledge gaps. We further used the knowledge gaps identified in the CCA report as an additional filter for our review. Specifically, we focused on identifying and reviewing articles with research questions and results that were directly related to these gaps.

The last area of literature that we reviewed was the grey literature, consisting primarily of reports from government appointed review panels and non-governmental organizations including policy think tanks and environmental groups. We employed a similar approach to our review of the academic literature. That is, we focused on reports that had been published since November 2013, and paid particular attention to those that could provide further information related to knowledge gaps identified in the CCA report.

As a final step we cross referenced the results of our review of the academic and grey literature with our review of government reports and regulations. This step allowed us to determine whether government policies are accurately reflecting and addressing the literature on hydraulic fracturing, how the government is adapting to knowledge gaps, and the extent to which there are policy gaps in current regulations.

Regulation of Hydraulic Fracturing in Canada

This section very briefly covers the regulation of oil and gas in Canada, and outlines any regulations specific to hydraulic fracturing. We also note if the regulations or regulatory documents reference the extant scientific literature. A summary of regulations is provided in Table 1.

Table 1: Regulation of Oil and Gas Exploration and Production in Canada

Jurisdiction	Regulations specific to Hydraulic Fracturing?	Do regulations reference science-based material?	Play-based or Area-based Regulations?	Moratorium in Place?	Is FracFocus used?*	Government Review of Hydraulic Fracturing?
Federal Government	No	No	N/A	No	Yes	No
British Columbia	Yes	Yes	Yes	No	Yes	Yes**
Alberta	Yes	No	Yes	No	Yes	No
Saskatchewan	Yes	No	No	No	No	No
Manitoba	No	No	No	No	No	No
Ontario	No	No	No	No	No	Yes
Quebec	No	No	No	Yes	No	Yes
New Brunswick	Yes	No	No	Yes	No	Yes
Nova Scotia	No	No	No	Yes	No	Yes
Prince Edward Island	No	No	No	No	No	No
Newfoundland and Labrador	No	No	No	Temporary	No	Ongoing
Nunavut	See Federal Government	See Federal Government	See Federal Government	No	See Federal Government	No
Northwest Territories	No	No	Yes	No	No	Yes
Yukon	No	No	No	No	Yes	Yes

*Note: FracFocus is a national hydraulic fracturing chemical registry.
**Note: The B.C. Oil and Gas Commission initiated studies related to seismic events in the province and a detailed review of BC's hydraulic fracturing regulatory framework which was completed in 2015. The B.C. Ministry of Health commissioned a three-phase human health risk assessment which began in 2012 and was completed in 2015.

Federal Government and Nunavut

Shale gas and oil extraction falls under provincial jurisdiction unless it takes place on federal lands or offshore, or falls within the federal mandate due to specific provisions under the *Canada Water Act*, the *Species at Risk Act*, the *Fisheries Act, the Migratory Birds Convention Act* or federal regulations pertaining to chemical substances. Oil and gas activities under federal jurisdiction are regulated by the National Energy Board (NEB), Environment Canada, and Health Canada under the *Canada Oil and Gas Operations Act*, the *Canada Petroleum Resources Act*, the *Canadian Environmental Protection Act*, and the *Indian Oil and Gas Act*. Regulations that pertain to oil and gas activities include the Indian Oil and Gas Regulation and the Canada Oil and Gas Drilling and Production Regulations. Although, the acts and regulations include detailed requirements, it is unclear what they are based on as they include very limited reference to scientific materials and source documents. None of the acts or regulations contain requirements that are specific to hydraulic fracturing.

British Columbia

The B.C. Oil and Gas Commission (BCOGC) is the provincial regulatory agency responsible for overseeing oil and gas operations in B.C. Acts, rules and regulations that apply to hydraulic fracturing include the *Oil and Gas Activities Act*, the *Petroleum and Natural Gas Act*, the *Environmental Management Act*, the Drilling and Production Regulation, the Environmental Protection and Management Regulation, the Consultation and Notification Regulation, the Oil and Gas Activities Act General Regulation, and the upcoming *Water Sustainability Act*. A detailed review of B.C.'s hydraulic fracturing regulatory framework was completed in 2015, as well as a three-phase human health risk assessment which began in 2012 and was completed in 2015.

Alberta

Acts, rules and regulations that relate to hydraulic fracturing include the *Water Act*, the *Environmental Protection and Enhancement Act*, the *Oil and Gas Conservation Rules*, as well as Alberta Energy Regulator directives pertaining to casing requirements, waste management, storage requirements, as well as flaring, incinerating and venting. Directive 083 specifically addresses hydraulic fracturing subsurface integrity. Although the directives and acts include detailed requirements, it is unclear what they are based on as they include very limited reference to scientific materials and source documents.

Saskatchewan

Oil and gas activities in Saskatchewan are regulated by the *Oil and Gas Conservation Act*, the *Water Security Agency Act*, the Oil and Gas Conservation Regulations, as well as Directive PNG015 – Well Abandonment Requirements, Directive S-10: Saskatchewan Upstream Petroleum Industry Associated Gas Conservation, and Directive S-20: Saskatchewan Upstream Flaring and Incineration Requirements. The following guidelines also apply: Saskatchewan Hydraulic Fracturing Fluids and Propping Agents Containment and Disposal Guidelines and Guideline PNG026 – Gas Migration. None of the Acts or regulations include specific requirements related to hydraulic fracturing. Although they include detailed requirements related to oil and gas activities, it is unclear what they are based on as they include very limited reference to scientific materials and source documents.

Manitoba

All activities related to oil and gas production in Manitoba are regulated by the Petroleum Branch of Manitoba Mineral Resources under the *Oil and Gas Act*, the *Water Rights Act*, and the Drilling and Production Regulation. The regulation specifies the requirements for the issuance of a well license, including wellbore design, material utilization, offset requirements, setback requirements and performance security. Under the *Water Rights Act*, proponents must obtain a license for the use or diversion of water. None of the Acts or the regulation include references to scientific materials, and there are no specific regulatory requirements related to hydraulic fracturing in Manitoba.

Ontario

Acts, regulations and standards that pertain to oil and gas activities include the *Environmental Protection Act*, the *Ontario Water Resources Act*, the *Oil, Gas and Salt Resources Act*, Regulation 387/04 – Water Taking and Transfer, Regulation 245/97 – Exploration, Drilling and Production, and the Oil, Gas and Salt Resources of Ontario Provincial Operating Standards. Although the acts, regulations and standards

include detailed requirements, it is unclear what they are based on as they include very limited reference to scientific materials and source documents. None are specific to hydraulic fracturing.

Quebec

Oil and gas exploration and production are regulated by the Ministry of Energy and Natural Resources and the Ministry of Sustainable Development, the Environment and Climate Change (MDDELCC), under the *Mining Act*, the *Environmental Quality Act*, the Regulation respecting petroleum, natural gas and underground reservoirs, the Regulation respecting the application of the Environmental Quality Act, and the Water Withdrawal and Protection Regulation. None of the acts or regulations contain requirements that are specific to hydraulic fracturing, or references to scientific materials or other source documents.

In May 2011, the MDDELCC established a Strategic Environmental Assessment (SEA) Committee on Shale Gas. The Committee initiated over 75 studies, including from academic sources, on the regulatory framework in Quebec, environmental impacts, induced seismicity, social acceptability, health risks, as well as the socio-economic relevance of shale gas development. Findings and recommendations are summarized in a 246-page report which was published in January 2014. On January 30, 2014, as a follow-up to the Strategic Environmental Assessment (SEA) Committee on Shale Gas's report, the Bureau d'audiences publiques sur l'environnement (BAPE) was tasked by the Minister of Development, Environment, Wildlife and Park to hold an inquiry and public hearings specific to shale gas exploration and exploitation in the St. Lawrence Lowlands Utica shale field. The report was issued in December 2014, and includes references to a large number of scientific articles. In 2015, a 250-page Consultation Document on the Strategic Environmental Assessments of hydrocarbon in general and specifically on Ile d'Anticosti was released summarizing results of 43 studies, as well as findings and issues raised related to environment, society, the economy, transportation, and technical matters.

New Brunswick

Oil and gas activities in New Brunswick are regulated by the Department of Energy and Mines and the Department of Environment and Local Government. Acts, rules and regulations that relate to oil and gas activities include the *Oil and Natural Gas Act*, the *Underground Storage Act*, the *Bituminous Shale Act*, the *Clean Environment Act*, the *Clean Water Act*, the *Clean Air Act*, the Air Quality Regulation, the Environmental Impact Assessment Regulation, the License to Search and Lease Regulation and the Responsible Environmental Management of Oil and Natural Gas Activities in New Brunswick – Rules for Industry. In June 2015, the *Oil and Natural Gas Act* was amended to allow the government to create regulations that prohibit or regulate and restrict the hydraulic fracturing of a well, as well as the use of certain fluids and chemicals, additives or proppants in the fluids used for hydraulic fracturing. It is unclear from the regulatory documents and acts whether they are based on scientific materials.

In December 2014, the Government of New Brunswick introduced a moratorium on hydraulic fracturing in the province stating it would not be lifted until there was (i) a social license in place, (ii) clear and credible information about the impacts of hydraulic fracturing on human health, the environment and water, (iii) a plan that mitigates the impacts on public infrastructure and that addresses issues such as waste water disposal, (iv) a process in place to respect the provinces obligations under the duty to consult with First Nations and (v) a mechanism in place to ensure that benefits are maximized for New Brunswickers, including the development of a proper royalty structure [34]. In March 2015, the New Brunswick Commission on Hydraulic Fracturing was appointed to determine whether the five conditions

required to lift the moratorium could be met. In February 2016, the Commission submitted their three-volume final report to Premier Brian Gallant.

Nova Scotia

Oil and gas activities in Nova Scotia are regulated by the Department of Energy and are legislated by the *Petroleum Resources Act*, the Petroleum Resources Regulations, the Onshore Petroleum Geophysical Exploration Regulations, the Onshore Petroleum Drilling Regulations, the Offshore Petroleum Drilling and Production Regulations, and the *Underground Hydrocarbons Storage Act*. In September 2014 the provincial government introduced amendments to the *Petroleum Resources Act* which placed a moratorium on high-volume hydraulic fracturing for onshore oil and gas shale development. None of the acts or regulations include specific requirements related to hydraulic fracturing, or references to scientific materials or source documents.

Following the release of the report of the Nova Scotia Independent Review Panel on Hydraulic Fracturing, Energy Minister Andrew Younger announced that the government would introduce legislation to prohibit high volume hydraulic fracturing for onshore shale gas [36]. On September 30, 2014, the Government of Nova Scotia announced it introduced amendments to the *Petroleum Resources Act* which place a moratorium on high-volume hydraulic fracturing for onshore oil and gas shale development [35]. The amendments include (i) prohibiting high-volume hydraulic fracturing to develop shale formations, (ii) authority to make regulations to define the technique and to allow testing or research, and (ii) defining the process government will follow before reconsidering the moratorium. In the press release, the Government of Nova Scotia states that to reconsider the moratorium and determine if there is a net benefit to Nova Scotians, the Energy Minister must consider social, economic, health, environmental, regulatory effectiveness and scientific and technical considerations. The bill with the amendments to the Petroleum Resources Act is awaiting proclamation before it becomes effective.

Prince Edward Island

Oil and gas activities on Prince Edward Island are regulated by the Department of Transportation, Infrastructure and Energy, as well as the Department of Communities, Land and Environment. Acts and regulations that pertain to oil and gas activities include the *Environmental Protection Act*, the Air Quality Regulations, the Watercourse and Wetland Protection Regulations, the *Oil and Natural Gas Act*, the Oil and Gas Conservation Regulations, and the Permit, Lease and Survey System Regulations. None of the acts or regulations contain requirements that are specific to hydraulic fracturing, or references to scientific materials or other source documents.

Newfoundland and Labrador

Onshore oil and gas activities in Newfoundland and Labrador are regulated by the Department of Natural Resources and the Department of Environment and Conservation under the *Environmental Protection Act*, the *Water Resources Act*, the *Petroleum and Natural Gas Act*, and the *Petroleum Drilling Regulations*. Offshore oil and gas activities are regulated by the Newfoundland and Labrador Offshore Petroleum Board under the *Canada – Newfoundland and Labrador Atlantic Accord Implementation Newfoundland and Labrador Act*. The Acts and regulations do not include any requirements specific to hydraulic fracturing. It is also unclear what information they are based on as they do not include references to scientific materials or source documents.

Northwest Territories

The Department of Industry, Tourism and Investment of the Government of Northwest Territories is responsible for the administration of onshore oil and gas interests in the Northwest Territories, while offshore interests fall under Indigenous and Northern Affairs Canadas's responsibility. The National Energy Board (NEB) is the regulator of oil and gas activities in the Inuvialuit Settlement Region [39]. Neither the Act nor the regulations include references to scientific materials, or specific requirements related to Hydraulic Fracturing. However, the government is considering improvements to the regulatory regime relating to future hydraulic fracturing developments. The regulations are currently being reviewed by Cabinet for approval.

Yukon

Oil and gas activities in the Yukon are legislated by the *Oil and Gas Act*, the Oil and Gas Drilling and Production Regulation, the *Environment Act* and the *Waters Act*. The *Waters Act* establishes the Yukon Water Board which is responsible for providing for the conservation, development and utilization of water in the Yukon. None of the acts or regulations include requirements that are specific to hydraulic fracturing, or references to scientific materials or other source documents. In 2013, a committee was established to report its recommendations and findings to the Legislative Assembly regarding the development of a hydraulic fracturing policy in the Yukon. The report was published in 2015 and includes 21 recommendations. The government of the Yukon has yet to make any changes to regulation or policy.

Previously Identified Knowledge Gaps

The first major Canadian report to consider knowledge gaps related to hydraulic fracturing was the CCA report on the environmental impacts of shale gas extraction in Canada [18], which was made public in May 2014. The report was commissioned by Environment Canada with the goal of answering the following question, "*What is the state of knowledge of potential environmental impacts from the exploration, extraction and development of Canada's shale gas resources, and what is the state of knowledge of associated mitigation options?*" The report draws on research on hydraulic fracturing that was published prior to November 2013.

The CCA report considers the environmental impacts of hydraulic fracturing for shale gas and the subsequent knowledge gaps across four subareas: shale gas technology and well integrity, water, greenhouse gas and other air emissions, and land and seismic impacts. Most knowledge gaps relate to a lack of baseline information, and insufficient monitoring of the geological and environmental conditions where shale gas extraction takes place. In the absence of critical baseline information, which allows researchers to evaluate changes over time in water quality, air quality and susceptibility of a region to seismic activity, it is difficult to evaluate the effect the process is having on the environment. Other knowledge gaps identified by the CCA report include the cumulative effects of hydraulic fracturing activities, the measurement of well integrity and fracture propagation and how these factors may contribute to groundwater contamination and fugitive emissions from fracked wells, the nature and risks associated with the chemicals that are used in fracturing fluids, and the contaminants that are present in flowback water and produced water from hydraulic fracturing.[2]

[2] Flowback water is the mixture of fracturing fluid and proppant that is extracted from a well after the hydraulic fracturing process is complete and before production of natural gas or oil begins. Produced water is water that is

In addition to reviewing the direct environmental impacts of hydraulic fracturing, the CCA report considers how the environmental effects translate into human health impacts, and the challenges for effective regulation and governance of the process. The knowledge gaps relating to health are similar to the knowledge gaps present within the environmental discussion, particularly a lack of baseline information and transparency of chemicals used in the process of hydraulic fracturing and associated risks. Deficiencies in baseline information make it difficult to evaluate the overall impacts like incremental pollution.

As stated in the CCA report, "The design of an adequate regulatory framework is hampered by limited information." Due to the extensive knowledge gaps present within research on environmental and health effects of hydraulic fracturing, the CCA found that many of the regulations for hydraulic fracturing in Canada are not based in strong and conclusive science. The CCA report argues that a lack of baseline information and consistent monitoring in areas where hydraulic fracturing is occurring is generating further knowledge gaps around the effectiveness of current regulation.

From a governance perspective, the CCA identified knowledge gaps around existing technology and best practices that could minimize or obviate many of the potential environmental and health impacts of hydraulic fracturing. Specifically, the economic feasibility of many of these potential solutions is unknown and it is also unclear whether all of the potential risks of hydraulic fracturing can be addressed with current knowledge.

Since the release of the CCA report there have been a number of other reports produced in Canada that synthesize existing literature on hydraulic fracturing and identify knowledge gaps and challenges for governance. The report of the Nova Scotia Independent Review Panel on Hydraulic Fracturing was released in August 2014 [118]; the Canadian Water Network released a summary report, *Water and Hydraulic Fracturing: Where knowledge can best support decisions in Canada* in October 2015 [12]; and the New Brunswick Commission on hydraulic fracturing released its final report in February 2016 [64].

The Nova Scotia independent review panel report identified many of the same environmental- and health-related knowledge gaps raised in the CCA report. In particular, the report notes that further research is required on wastewater treatment, water protection, remediation, and site-specific geology and hydrologic systems. The report also emphasizes the deficiency of data and research on the long-term impacts of hydraulic fracturing, particularly as they relate to cumulative effects on the environment and public health. The authors conclude that in the absence of sound information it is impossible to be conclusive about the frequency or scale of the risks associated with hydraulic fracturing.

In addition to stressing many of the knowledge gaps from the CCA report, like deficiencies in baseline data, the Nova Scotia report draws attention to further knowledge gaps around the potential mental health and climate change effects of hydraulic fracturing. Specifically, the report notes that noise and light pollution from hydraulic fracturing operations can lead to psychological impacts that impinge on mental health. Regarding climate change, the report finds there is conflicting evidence on the scale of fugitive methane emissions from hydraulic fracturing and as a result, the emissions footprint of natural gas produced via hydraulic fracturing cannot be definitively calculated. The potential for fugitive emissions

produced from the well along with the natural gas or oil. It is often a mixture of fracturing fluid and water from the formation that may contain both hydraulic fracturing chemicals and naturally occurring contaminants found underground [112].

calls into question the claim that natural gas has lower lifecycle emissions than coal or oil and its role as a "bridge fuel" in meeting climate change commitments.

With a mandate that extended beyond environmental impacts, the Nova Scotia report also pays significant attention to economic and community impacts of hydraulic fracturing, both of which are not often investigated, leading to gaps in understanding. The report stresses that there are significant unmeasured economic costs and benefits associated with hydraulic fracturing, including effects on employment patterns, income, property value, physical infrastructure and government revenue. The report identifies a similar pattern of potential positive and negative community effects in areas such as social infrastructure and cultural and social diversity, and notes that there needs to be a better understanding of how hydraulic fracturing may differentially impact community members, particularly across socioeconomic groups.

The Canadian Water Network (CWN) report, released in October 2015, summarized the results of five in-depth research projects funded by the CWN and completed between 2014 and 2015. The CWN research projects involved 70 researchers from 18 universities across Canada and examined issues surrounding water governance, watershed and water demand management, unconventional wastewater management, subsurface impacts of hydraulic fracturing, and landscape impacts. Across potential community, economic, environment and health impacts, the summary report identifies what is currently known, where additional research is needed most urgently, what are reasonable expectations regarding the advancement of knowledge, and where the opportunities for knowledge advancement are.

Similar to the CCA report and the Nova Scotia review panel, the CWN report highlights the need for greater baseline data, ongoing monitoring and data collection, more refined information on the chemicals used in fracking fluids and how these fluids interact with groundwater and the environment, A need for a more thorough understanding of the long-term cumulative effects of hydraulic fracturing, including social and economic costs and benefits, was also identified. The report notes that more research is required on what kinds of baseline data would be most effective in monitoring ongoing changes in groundwater quality, waste disposal and what kinds of governance models are most effective for cumulative effects monitoring. It also identifies an insufficient understanding with respect to where a lack of data disclosure is most hindering decisions around water use and wastewater management, and knowledge around the toxicity of flowback fluids and hydraulic fracturing chemicals.

Similar to the CCA report, the CWN report also considers how knowledge gaps related to hydraulic fracturing operations are generating additional knowledge gaps around governance of the process. The three key gaps in understanding governance identified by the CWN focus on how to most effectively address regulatory challenges like transparency and trust, public opinion and how it is informed, and the best way to honor the rights of Indigenous communities. The CWN report notes additional challenges relating to how to resolve the gaps in understanding from the perspective of public engagement strategies.

Unsurprisingly, the New Brunswick Review panel report repeats many of the knowledge gaps identified by the CCA, the Nova Scotia review panel and the CWN. The knowledge gaps are found to be driven by the short timeframe and limited scale over which hydraulic fracturing has occurred in New Brunswick, the lack of ongoing monitoring of environmental and health impacts, and the absence of comprehensive cumulative effects assessments.

In identifying these knowledge gaps, the New Brunswick report places emphasis on the community impacts of hydraulic fracturing. In particular, the report highlights the need for site-specific research,

noting it is not always possible to transfer research results from other jurisdictions to the unique geology of New Brunswick. In addition to geological differences, other important considerations are variation in construction standards, oil and gas regulations, and operating practices. The need for research to be completed by an "independent and trusted entity" that can provide communities with "timely, transparent, and objective information" about the impacts of hydraulic fracturing is strongly urged. Lastly, and similar to previous reports, the New Brunswick report considers knowledge gaps related to the mental health of community members, noting that the start-up of hydraulic fracturing operations in a community can lead to stress and anxiety with regards to its potential impacts. Conversely, the report also notes that there are potential mental health impacts associated with the stress of being without work, and being unable to support one's family in the place where they wish to live. Unlike the other reports, the New Brunswick report provides a deeper discussion of mental health implications associated with the process.

The reports from the CCA, the CWN and the two review panels demonstrate many knowledge gaps on the subject of hydraulic fracturing. The significance of a lack of baseline data against which to measure all implications of unconventional oil and gas development is identified as a critical missing piece by all four reports. An expanded understanding of long-term cumulative effects is identified by the reports as critical. Public trust and difficulties with public engagement in the process of consultation, regulation, management and monitoring of hydraulic fracturing was identified. A lack of sufficient information on broad environmental concerns ranging from GHG emissions to well-integrity and water issues was common among the reports. Regional considerations were identified as crucial to safe and effective development. Economic assessments that consider costs, benefits, and implications for new technology and industry best practices were noted by the reports as critical in determining the feasibility of the process of hydraulic fracturing.

As the benefits and costs of hydraulic fracturing are investigated, it appears researchers have found more questions than answers. In an effort to advance the discussion of hydraulic fracturing, the literature that has been put forward since the release of the CCA report will be analyzed, to determine if and how the knowledge gaps have begun to narrow.

Recent Advances in Knowledge

Though little time has passed since the four reports discussed above were published, there is a substantial body of research that has evolved and is attempting to resolve and close the knowledge gaps identified above. This section explores how subsequent research is addressing the knowledge gaps and advancing the discussion of hydraulic fracturing. Summaries of the publications released since the CCA report will be provided in accordance with the following categories: environment, health, and economy and community. The literature continues to emphasize that a lack of baseline data is hindering identification of the environmental and health effects of hydraulic fracturing. Cumulative effects analysis pertaining to both these areas is similarly lacking. From an economic perspective, more credible and broad social and economic analysis of the costs and benefits of hydraulic fracturing is required.

From the community standpoint, overall public engagement practices and means of engaging indigenous groups are undetermined. The public has become more engaged in the process of energy development now than ever before. Concerns related to the potential risks of the process are significant, and the potential negative impacts on the environment relating to water, air quality and seismicity are important issues for the public. It is the responsibility of government to ensure that public safety and public interest

are sustained, if the public is left out of the discussion and is not sufficiently informed of the potential risks and benefits of hydraulic fracturing, government is not doing its job. If the public is not engaged in the approval and regulation processes of hydraulic fracturing, there is likely to be continued opposition, which in some cases has effectively halted development.[3]

Environmental Effects

The potential environmental effects of hydraulic fracturing can be organized into the following subsections: risks to water quality and water supply, greenhouse gas emissions, risks to air quality, waste management, land and resource use, and the problem of induced seismicity. Noteworthy research in each of these subsections is summarized below.

Water Use, Contamination, Disposal and Alternatives

The potential for ground and surface water contamination is the most significant water-related concern associated with hydraulic fracturing activities. Previous research in this area has identified knowledge gaps with respect to understanding the pathways through which contamination may occur, and the properties and behaviors of chemicals and other contaminants that may be included in fracturing fluids and waste water. There is a severe lack of baseline data that has made it difficult to measure the degree of impact that current hydraulic fracturing activities may be having on nearby groundwater sources. The impacts of high volumes of water usage and consequent processing of waste water are also both critical issues associated with hydraulic fracturing and are not well understood.

A lack of regional baseline data continues to be identified by numerous studies as a significant barrier to demonstrating a causal link between ground- or surface-water contamination and hydraulic fracturing operations. A recent study of U.S. hydraulic fracturing operations showed that shallower wells pose more significant risks to water quality than deeper wells [52]. This indicates that the geologic and hydrologic characteristics of the shale play are an important consideration, and that wells drilled in shallower plays may merit additional monitoring and regulatory requirements.

Recent models developed for the U.S. and Europe have identified groundwater contamination pathways that pose serious risks under certain conditions such as poor well construction, faulty well casings and a high density of wells in a particular area [12, 30]. Contamination pathways are also influenced by the geology of the rock formations in and near the fracturing zone, natural faults and the location of potable water aquifers relative to this zone [7, 99]. This further emphasizes the need for regionally-specific research. Progress is being made, however, in both the development of early contamination indicators for groundwater [58, 68, 101] and in the characterization of contaminants contained in flowback waters [28]. A few studies also suggest that hydraulic fracturing fluids and drill cuttings can be "fingerprinted" to identify potential sources of contamination [54, 116]. By providing more accurate information on contamination sources this research should also contribute to improving early detection.

Water research in Canada has tended to focus on identifying methane levels in groundwater. Humez et al conducted a baseline study for background methane in monitoring wells in Alberta [51]. Although methane was found to be ubiquitous, it was identified at levels not harmful to human health. Similar

[3] For example, opposition to hydraulic fracturing in Nova Scotia by the Mi'Kmaq and the general public was a major contributing factor to the eventual moratorium in the province.

studies in Ontario and Quebec have identified baseline methane and natural gas concentrations in wells and aquifers located in areas where hydraulic fracturing could occur the future [70,79].

Although water contamination is frequently cited as a significant concern around hydraulic fracturing, there is opposing research that suggests the concern may be overstated. Specifically, some studies dispute the risks of contamination and its severity [22], while others conclude there is insufficient evidence to link the contamination in question to hydraulic fracturing activities [113]. Another study states the risks of hydraulic fracturing to surface water are not unique, and likens them to those of agriculture, silviculture, mining, and urban development [12]. The fact that groundwater contamination from conventional and unconventional oil and gas operations is often indistinguishable muddies the issue further [113].

The quantity of water required to conduct the process of hydraulic fracturing is also frequently cited in the discussion of environmental impacts. Historically, freshwater has been used in large volumes, presenting concerns around impacting the availability of regional water supplies for human consumption or other uses such as agriculture. Unsurprisingly, however, the literature is divided over the degree of this concern. One frequently cited study from the U.S. argues that concerns around water usage are unfounded as usage is lower than in other energy extraction methods and represents only a fraction of total industrial usage [59]. A second study finds that, on average, the water intensity of hydraulic fracturing is not significantly different from conventional oil and gas production [60]. The authors acknowledge that the additional competition for water may strain regional resources, but still conclude that water quantity concerns are secondary to water quality.

The magnitude of concerns around water demand will also vary regionally, as consumption has been found to vary widely across resource plays. Studies that quantify water usage across the U.S. have produced water consumption estimates of 1,000 to 30,000 m^3 per well per year [16] and 1.0 to 10.2 litres per gigajoule of produced natural gas [59]. Technological improvements over the past decade have also proven to be a double-edged sword with regard to water demand. A study in the Barnett shale play in the U.S. found that water intensity (measured in water requirements per unit length of horizontal drilling) has improved, but that horizontal drilling lengths have doubled [85]. As a result, total water consumption in the play has significantly increased.

Although the risks of high water-usage still apply in a Canadian context, Canada-based studies on water usage are lacking. The most comprehensive Canadian study provides an overview of various programs that have been introduced in Northeastern B.C. to ensure water security is minimally impacted by expanding hydraulic fracturing operations [48]. A second report focused on water sustainability in NE B.C. identifies areas where further research is needed; key priorities include research on water balance, aquifer identification and characterization, the development of methods for defining environmental flow needs, and quantifying the cumulative effects of resource development and land use change on water quantity and quality [62].

Concerns around water usage has motivated further research that considers methods for reducing freshwater demand. Some scholars discuss alternative technologies, including waterless techniques [19] and supercritical carbon dioxide [73]. The former technology is already in wide use in Canada while the latter remains in the experimental stages. Other research has considered the viability of transitioning to brackish water, flowback water, or wastewater from municipal and industrial sources as an alternative to freshwater sources [47, 56].

The final water-related concern associated with hydraulic fracturing activities is how to safely and effectively treat and dispose of wastewater. Both flowback water and produced water may contain water, proppant, chemicals and hydrocarbons. The exact characteristics of the wastewater are often uncertain as they depend on regional geology, engineering methods, rate of flowback and company specific fracturing fluid and proppant blends [23, 25, 32, 66]. Given that proppant and fracturing fluid "recipes" are considered trade secrets, companies are not required to disclose the exact quantities of chemicals used. One recent study posits that issues related to waste management, along with the confidentiality – and subsequent lack of disclosure – of hydraulic fracturing proppant blends breeds public mistrust [108].

The transportation of waste to appropriate disposal sites is another issue, as poor disposal practices have resulted in significant environmental damages in some jurisdictions [113]. Information regarding exposure pathways for chemicals used in the fracturing process is limited, but wastewater handling and treatment is described as the highest risk pathway [4, 102]. On-site treatment is instead recommended by recent research as it can mitigate or even eliminate certain contamination pathways (for example, the risk of contamination via transport) [31, 56]. Finally, a lack of consistent, quality data and monitoring techniques continues to be a serious obstacle for industry and government, as does a lack of treatment options for water that is not recaptured following stimulation.

Greenhouse Gas Emissions

The scientific literature is conflicted over the extent and intensity of greenhouse gas (GHG) emissions from hydraulic fracturing. The dueling evidence was outlined in the CCA report, which cited several studies that disagreed in their emissions estimates by over "two orders of magnitude." This discrepancy has not been settled in the interim. However, the literature suggests that the range of findings can largely be attributed to the variability in well design, operator practices and the regions in which the research is conducted. The literature on hydraulic fracturing and GHGs focuses on a number of key concerns including continuous monitoring of emissions, fugitive and lifecycle emissions, the extent to which hydraulically fractured hydrocarbons are displacing high-emission energy sources and whether the increased hydrocarbon production enabled by hydraulic fracturing poses a threat to the development and adoption of near-zero-carbon technologies.

Emissions estimates for hydraulic fracturing operations vary considerably within the literature. A paper by Caulton et al found the drilling phase for shale gas in Pennsylvania emitted methane at a rate that is two to three orders of magnitude greater than the official estimates reported in the U.S. Environmental Protection Agency's greenhouse gas inventories [14]. Howarth, who published the first peer-reviewed paper on the greenhouse gas footprint of shale gas in 2011 [49], is cited numerous times in the CCA report as a high-end estimate for industry emissions. A subsequent paper by Howarth, published after the CCA report, uses updated data to reaffirm that emissions from shale gas have a larger greenhouse gas footprint than coal or oil, particularly when used for residential and commercial heating [50]. While another study has supported this result [105], others have questioned this finding [46]. A study from Shahriar et al, for example, finds the greenhouse gas footprint of shale gas is generally lower than coal, and also notes that greenhouse gas emissions estimates vary widely and are influenced by characteristics of the reservoir, as well as local regulation (most notably in relation to flaring) [100].

One area where there is consensus within the literature is that stronger and more consistent monitoring standards and practices are needed for emissions. A recent paper on hydraulic fracturing in the United Kingdom goes so far as recommending continuous monitoring of hydraulic fracturing wells so as not to

miss any "emission events" [107]. In addition to the direct emissions from hydraulic fractured wells, there needs to be a better understanding of the emissions associated with support activities for hydraulic fracturing. For example, emissions related to road construction and water delivery [118].

Fugitive emission rates – particularly from upstream leakage - are also a concern. Bouman et al. investigate the impacts of fugitive emissions from coal, natural gas and shale gas in the Marcellus formation using a multi-regional lifecycle assessment model [**Error! Reference source not found.**]. heir analysis suggests that fugitive emissions can vary by orders of magnitude depending on the region and operational practices, and that overall more regionally-focused research on fugitive emissions is still required. In addition to upstream leakage, the potential for fugitive emissions from abandoned wells is an area of concern [8].

The literature also indicates that without controls on fugitive emissions, the potential benefits of natural gas as a lower carbon intensity fuel are minimal [119]. For example, one study found that methane leakage rates of 2 and 4.8 per cent over 20 and 100-year time horizons, respectively, may eliminate half of the emissions benefits of electricity generation from natural gas over coal [96]. Absent a standard framework for detecting leaks and measuring industry-wide emissions, a knowledge gap on the emissions-reduction benefits of unconventional gas is likely to remain. This knowledge gap is further complicated by the question of whether unconventional gas is displacing or delaying the transition to near-zero emission-intensity energy sources. Recent research finds the potential for this delay undercuts the argument of unconventional gas serving as a "bridge fuel" to a lower carbon future [21, 45, 69].

Land and Resource Use

The literature on land use impacts covers a wide range of subject matter, as each stage of hydraulic fracturing operations poses unique environmental risks. The most studied issues in the literature are habitat fragmentation and risks to wildlife. A smaller amount of research is available for traffic-related effects including increased road wear, noise and air emissions. Many of the knowledge gaps presented in the CCA report cannot be addressed without large-scale longitudinal studies or action from regulatory bodies. The need for cumulative-effects research is stressed throughout the literature and play-based research is also required in order to provide meaningful data in a Canadian and regional context.

Several trends emerge from the papers on habitat fragmentation. First and foremost, the lack of coordination amongst operators, specifically with respect to the construction of gathering lines, access roads and wells pads, exacerbates the problem [1, 57]. The destruction of core habitat and forest cover is also cited as a serious issue [74, 89]. Recent research into these challenges have found that impacts can be minimized with relatively simple regulatory mechanisms. Solutions proposed include reducing well pad density [1, 57], requiring gathering lines to follow pre-existing roads [1], and incorporating ecological constraints into project planning [89]. Another study proposes using conservation-oriented planning guidelines to optimally space and distribute well pads to minimize land impacts [74]. With one exception [89], the models here are not Canadian, but the results – particularly the regulatory recommendations – are largely transferable.

The risks to wildlife and aquatic resources are similar to those of conventional oil and gas resources, with some exceptions. Wastewater spills in particular present a significant risk to land, wildlife and water due to their variable and uncertain compositions [3, 10]. A recent paper that presents a comprehensive literature review of the impacts of hydraulic fracturing on plants and wildlife identifies the impact of wastewater escape on freshwater contamination as a key research priority [103]. Other research priorities

relate to the impact on freshwater of equipment failure, illegal discharge, accidents and chemical migration, as well as the cumulative ecological impacts of development. Toxicity and the cumulative impact of chemical contaminants may also present significant ecological risks. However, the lack of aerial and aquatic monitoring data means that predicted eco-toxic effects cannot be confirmed

Seismicity

The literature on seismic events related to oil and gas operations stretches back decades, and studies linking hydraulic fracturing to seismic events were published long before hydraulic fracturing became a widespread commercial practice. Recent research on the issue is conflicted; consensus exists that hydraulic fracturing can cause seismic events, but estimates of the severity of these impacts vary. A lack of baseline data of pre-existing faults and inadequate regional modeling are the most critical knowledge gaps preventing a complete understanding of the risks of seismicity and hydraulic fracturing.

Several studies on seismicity have been conducted in Canada since the release of the CCA report. A study in B.C.'s Horn River Basin suggests that hydraulic fracturing is increasing both the frequency and severity of seismic events [26]. An Alberta-based study found a correlation between hydraulic fracturing and seismicity [98]. These field studies pointed towards more severe seismic events than research relying on simulations and models [94].

Regional baseline data is crucial to understanding the natural seismicity of a region, and the extent to which hydraulic fracturing is exacerbating natural seismicity cannot be determined otherwise. Models are available for this process but their application to date has been limited [61, 94]. Another area of concern is the risk of seismic events opening up new communication pathways between the fracture zone and underground aquifers [94]. Again, regional variability in geology, hydrology and seismicity, as well as the scope, nature and depth of hydraulic fracturing operations are all important considerations [27, 115].

The CCA report states that seismic events from wastewater injection are more likely than seismic events from well stimulation. Research since then, however, has produced mixed conclusions on this topic. One study supports this assertion, finding that both wastewater and CO_2 injection is capable of causing more severe seismic events than fracturing [63]. A metastudy from the U.S. also supports this claim and further notes that wastewater injection is used by conventional oil and gas operations [93]. The authors go so far as to argue that recent observed increases in seismicity are not specific to hydraulic fracturing but rather are a result of an overall increase in oil and gas extraction.

More recently, however, research specific to the Western Canadian Sedimentary Basin (WCSB) challenges the consensus that wastewater injection poses a greater risk of inducing seismicity than hydraulic fracturing [5]. The authors' observations in the WCSB suggest that fracturing activities, not wastewater injection, were associated with a greater proportion of high-magnitude seismic events. A second paper that focuses on seismic events related to fracturing finds the probability of a high-magnitude event consistently increases with the amount of fluid injected but also that the probability of a seismic event differs across plays [43]. These results again point to the importance of regional considerations. As the robustness and sensitivity of monitoring networks have been improving in recent years, including in Alberta and B.C., this may begin to narrow the regional specific knowledge gaps in the long term.

Health

The two most prominent knowledge gaps related to human health and hydraulic fracturing are cumulative impacts and environmental exposure pathways via air and water. Long-term studies have not been

conducted, as the technology is (generally) not mature enough to allow for the collection of data over meaningful timeframes.[4] Retrospective studies, which look for a relationship between current health outcomes and exposure or events that occurred in the past, are the best available option at present.

A lack of baseline data and the need for better ongoing data collection of both water and air quality indicators and associated human health impacts is a common theme in the literature [2, 67, 76, 80, 117]. Also highlighted is the need to move on from the current research emphasis on identifying toxicological causality and to instead focus on developing predictive models of toxicological impacts [33].

With respect to water contamination, a number of studies examine the health risks posed by known fracturing fluid components, as well as naturally occurring contaminants that may surface with produced water [23, 24, 55, 80]. Many of these chemicals and contaminants are carcinogens and have also been found to pose risks to reproductive and development health [23, 71, 80, 117]. Contributing to additional concern – and even more significant knowledge gaps – is that the majority of fracturing fluid ingredients are not known publically due to the proprietary nature of company-specific blends. This makes it virtually impossible to assess the full suite of risks, and the risk pathways, through which human exposure may occur [33, 106].

Hydraulic fracturing operations have been found to have numerous negative impacts on air quality. Elevated airborne volatile organic compound levels are consistently found downwind of well operations [67, 120], silica and ambient polycyclic hydrocarbons have been identified near drilling operations at levels hazardous to human health [86, 91], and a possible link to elevated ozone levels has also been established [3]. Although individual gas wells are unlikely to impact air quality more than 100 metres downwind [120], the economies of scale brought about by multi-pad drilling means that individual wells are uncommon and most hydraulic fracturing operations will therefore result in wider-reaching air quality concerns. Recommendations for addressing knowledge gaps related to air quality concerns include measuring baseline air quality prior to hydraulic fracturing development, completing a full chemical classification of life cycle emissions, collecting independent scientific data on the scope of methane leaks from wells, creating an inventory of abandoned wells, measurements on emission variations between different natural gas and oil plays, and establishing greater collaboration between scientists, regulators and operators.

Hydraulic fracturing for natural gas can also have positive impacts on air quality (and hence human health) through the use of natural gas as a substitute for coal in electricity generation. Specifically, natural gas fired electricity is generally associated with lower emission levels of particulate matter, mercury and sulphur dioxide [52]. While it is recommended this outcome be taken into account as part of a comprehensive assessment of the health impacts of unconventional natural gas development, it is only one of numerous impacts that include the negative air and water impacts identified above, as well as potential social effects such as the impact of development on the demand for local health care services [87]. For example, although failing to identify an exact cause, recent research has found correlations

[4] Hydraulic fracturing was first used in the Cardium play in Alberta in 1953 [78]. However, it was not until the mid-2000s that the technology started to be adopted and used on a wider scale. As the technique was minimally used prior to the mid-2000s data collection from this period appears to have been minimal. In addition, any data that does exist does not capture the cumulative impacts that accompany more extensive development. This is significant as many of the environmental and health impacts of hydraulic fracturing are thought to be related to well density.

between proximity to unconventional natural gas wells and hospital visits, low birth rates and birth defects [53, 71, 104].

The failure of regulators to sufficiently address the public and environmental health risks of hydraulic fracturing has also been identified in the literature as an area of concern, particularly as it has resulted in companies not being held accountable for the damages associated with their operations [15]. Recommendations to address this include the adoption of regulations that require industry to reduce the negative effects of their operations, and government to undertake more comprehensive oversight.

Economic, Community and Social Effects

The potential for hydraulic fracturing to have positive and negative economic, community and social effects was identified by the CCA and CWN reports, as well as the reports from the provincial hydraulic fracturing review panels. Economic effects identified include: industry revenues, government revenues (royalties and other taxation), jobs, and economic growth, among others. Community and social effects identified include: water quality, air quality, community well-being due to rapid growth of an extraction industry, health and safety issues due to increased traffic and the influx of a new workforce, increased land and water use, noise and other nuisances, population growth, etc.

As mentioned above, the review panel reports along with the CWN and CCA reports identified greater knowledge of social and economic costs and benefits as a necessary condition for accurately evaluating the positive and negative effects of hydraulic fracturing. Unfortunately, the short time period since the CCA report was published means there is very little new research on socioeconomic costs and benefits associated with hydraulic fracturing. What does exist is fairly general, or very specific to the region examined (with unique socioeconomic features), limiting our ability to draw conclusions about the advancement of knowledge. However, as the CCA mandate did not explicitly include economic or social impacts, research that preceded it will also be covered in this section. Analysis of socioeconomic impacts mainly comes from think tanks as opposed to peer-reviewed scientific literature. Due to the localized nature of hydraulic fracturing, existing studies of socioeconomic effects are typically province- or region-specific. The majority of studies only cover economic benefits; those that quantify environmental impacts are for the United States.

For Quebec, the Canadian Energy Research Institute completed two studies (in 2013 [72] and 2015 [92]) of the potential for shale oil and gas development, specifically the Utica and the Macasty basins. Both studies quantify the expected economic effects of shale resource development in terms of GDP, employment, and provincial and federal taxes. Other effects, such as health or environmental, were not included in the analysis. In both reports, positive economic impacts were identified; however, the 2015 report concluded that because of the expected high costs of production in Quebec, the resource is unlikely to be developed. In a 2014 report from the Bureau d'audiences publiques sur l'environnement on shale gas development in the St. Lawrence Lowlands, potential negative impacts of shale and oil and gas development were identified, including air quality, noise, increased traffic, and decreased tourism [11]. The report concluded that there is an absence of evidence that shale gas production via hydraulic fracturing would be beneficial for Quebec. Further, it concluded that the net social value would be negative because of the costs and negative externalities being in excess of the economic benefits. However, specific details on the dollar value of the costs and benefits were not provided.

A report by the Atlantica Centre for Energy examines supply and demand for natural gas in New Brunswick and Nova Scotia, and the implications for the regional economy [6]. The report notes that natural gas production has historically resulted in substantial economic benefits, and the current ban on hydraulic fracturing places continued local production in jeopardy. The consequences include higher prices for natural gas, with a consequent drag on the economy, and removes the economic benefits associated with production. The report does not explicitly discuss potential environmental or health effects, although it does reference the CCA report.

A report by the Atlantic Institute for Market Studies reviews the energy mix in Atlantic Canada, discusses the impacts of restricting new natural gas developments, and proposes policy recommendations that allow markets to satisfy energy demand [88]. The discussion of hydraulic fracturing is around the lost economic benefits associated with a continued moratorium; the author relies on the Wheeler report to quantify economic benefits, and does not discuss environmental or health impacts.

Future New Brunswick commissioned Deloitte to examine the effect of shale gas development on New Brunswick [20]. The study assessed the opportunities available for New Brunswick companies that could potentially benefit from shale gas development. Economic impacts for gross revenue, GDP and jobs were calculated; no other impacts were considered.

A Canadian Water Network report on the subsurface impacts of hydraulic fracturing also examines the "true costs" of hydraulic fracturing, providing a review of some of the extant literature relating to water [95]. Ryan et al note that most studies examining the effects of hydraulic fracturing address narrow research questions, and so an estimate of the net effects of hydraulic fracturing, and whether it is welfare-improving, is not yet available.

The Fraser Institute has produced two reports examining costs and benefits of hydraulic fracturing in Canada more generally. Green (2014) [40] argues that there are substantial economic benefits, and because the literature on the risks is "not terribly conclusive and is sometimes contradictory", continued development should be allowed. Green notes that the various reports have advocated for proceeding with caution rather than outright bans, and improving knowledge of the risks can only occur with continued monitoring and development. In an update to the 2014 report, Green and Jackson (2015) [41] argue that the risks associated with hydraulic fracturing are similar to other industrial activities, and can be managed by or mitigated with existing technology and best practices. Both reports discuss the economic benefits in a limited way, and do not provide dollar values in the discussion of potential risks. This makes the reports of limited value in assessing overall costs and benefits, and whether the benefits of hydraulic fracturing are sufficient to justify the costs.

An older study from the Manhattan Institute examines and quantifies the economic and environmental effects of shale gas development in New York State, using data from the Marcellus formation in Pennsylvania [17]. The authors find a typical Marcellus shale gas well generates $4 million (USD) in economic benefits, and the economic damage from environmental effects is $14,000 (USD). The authors explain the environmental costs are so low because the probability of an environmental event is small, and the events are minor and local in their effects. The environmental costs considered include air pollution from typical natural gas production, air pollution from diesel use during hydraulic fracturing, water pollution, and forest disruption. It is important to note that this cost-benefit analysis does not include a dollar value for all of the risks and environmental or health consequences identified in the CCA,

CWN and review panel reports. Moreover, the many differences between the U.S. and Canadian provinces limit the applicability of this research to an evaluation of the costs and benefits of hydraulic fracturing in Canada, though it is informative.

Regulation and Governance

A report from the Canadian Water Network (Moore et al) identifies the key water governance challenges specific to hydraulic fracturing across Canada, and the knowledge gaps that need to be addressed to resolve such challenges [75]. They identified lack of trust in decision-making processes, concern about government capacity, and a perceived lack of accountability and limited transparency water allocation industry operations as major issues to be addressed in governance. They also note the need to improve community engagement processes, and address both "the lack of knowledge transfer among the different decision-making bodies and affected parties, and lack of knowledge about those same bodies and parties."

Resources for the Future (RFF) studied regulatory practices across a number of different states and found a wide range of regulations employed often differing from state to state [90]. The authors identified a tension between government regulations and voluntary actions taken on by industry to counter some of the negative impacts of fracking. Some difficulties identified by RFF in setting regulations are the quick adoption of new technologies and lack of transparency of what is expected by industry in the regulatory requirements. RFF found that there are opportunities in the U.S. for various nodes of government to work jointly on regulations by clarifying decision-making powers. The CCA also found that because of frequent technological changes, policies required a certain flexibility to be able to respond effectively.

Hydraulic Fracturing and Public Policy

Knowledge Gaps and Regulation

The most significant knowledge gaps related to hydraulic fracturing identified by the CCA, CWN and the two provincial review panels include a lack of baseline data, insufficient information on long-term cumulative effects, and a lack of region-specific information overall. Although a significant amount of additional research in both the academic and grey literature has been completed since the CCA report was released, these gaps continue to be emphasized. To a large extent, the new research is also unearthing new information that raises more questions than answers. For example, in many cases the research is leading to conflicting results for which explanations are sought, results for one region that raise questions about whether similar impacts are observable in others, and observations of negative environment and health outcomes but an insufficient understanding as to the causality of these outcomes.

As the complete study of hydraulic fracturing has many missing pieces, it is only logical that there will be consequent missing pieces in policy and regulation. Given the potential risks and implications of a process like hydraulic fracturing, effective regulations are critical to the protection of people and land. In this section we will consider in more detail why these knowledge gaps continue to exist and how they are impacting public policy as well as the public's perception towards hydraulic fracturing.

The first commercial application of hydraulic fracturing occurred in the United States in the late 1940s [29] and in Canada in 1953 [78]. For the vast majority of the next half century, however, it was employed in only a small minority of oil and gas extraction operations and was not well-studied. Prior to 1990, for example, the number of published academic articles only once exceeded 20 per year and were generally in the single digits [13]. The topic drew slightly more research interest in the 1990s and early 2000s but,

perhaps unsurprisingly, research did not take off until application of the technology took off in the mid-2000s.

The rapid increase in the use of hydraulic fracturing in the last decade has been unprecedented. In the Western Canadian Sedimentary Basin (WCSB), for example, tight oil extraction has increased from virtually zero in 2005 to over 375,000 barrels per day in 2014 [81]. Tight and shale gas production in the WCSB over this same period has more than doubled [82]. Increases in the United States have been even more dramatic with tight oil production rising from 375,000 to 4.5 million barrels per day over this period [110] and shale gas production increasing from 1.0 trillion cubic feet (tcf) in 2006 [111] to 13.4 tcf in 2014 [109].

The knowledge gaps related to hydraulic fracturing are arguably driven in large part by the rapid pace at which the technology has become widespread. The pace of adoption does not appear to have been anticipated by the literature and the current focus on causal versus predictive analysis suggests that it has largely been playing catch-up ever since. Looking ahead, perhaps most challenging for resolving the environmental and health uncertainties around hydraulic fracturing is that the appropriate baseline data was never collected. While there is now a clear awareness that baseline data is needed, the collection of this data is hindered by the significant development and production that has already occurred. Specifically, the majority of new wells are drilled in resource plays with previous development and it is unclear how this may impact the baseline data for new wells. The ideal location for baseline data is in a resource play that does not have extensive development. The challenge, however, is that given the uncertainty and concerns over hydraulic fracturing that have arisen in recent years, these are also the plays that are most likely to be subject to moratoriums on development.

Knowledge gaps around cumulative effects are also significant and are largely a concern because hydraulic fracturing, on the current scale of use, has never been done before. In this case the challenge in resolving the knowledge gaps is that the current scale of development has been occurring for only a relatively short period of time. Long-term data collection, observation and research will contribute to resolving it but it is a process that is likely to take decades as opposed to months or years.

The potential negative environmental and health impacts of hydraulic fracturing have grown to dominate headlines in recent years, and as a result, they also dominate current research and the discussion around knowledge gaps. In doing so, however, they arguably draw away from developing a full understanding of the risks and opportunities, and costs and benefits of hydraulic fracturing. In particular, the economic and community impacts of hydraulic fracturing appear to be largely understudied. This may be driven in part by what appears to be limited public interest in hearing about the positive impacts that could be accompanied by development, or on the flip side, the negative impacts that could result from not proceeding with development. It is informative, for example, that the New Brunswick review panel report was the only major summary report in recent years that highlighted the negative mental health impacts from individuals being unable to find work and support their families while remaining in their communities.

As there are a full suite of environmental, health, social and economic costs and benefits associated with hydraulic fracturing development this research goes well beyond the niche areas of most individual academics. Rather it is most likely best addressed by government through, for example, a comprehensive cost-benefit analysis which uses monetary values as a metric to evaluate changes in wellbeing associated

with policy changes. The development of a balanced analysis has not been done to date and is necessary to inform and improve the quality of public policy decisions in relation to hydraulic fracturing.

Public Knowledge and Public Trust

When it comes to gaining pubic acceptance and support for large-scale energy development projects, it is often assumed that the public is misinformed and acting from a place of emotion. If the public was more informed of the particular process, the regulations and the risks and benefits that ensued, arguably the public would be more open to supporting said development. The literature review has demonstrated that many of the knowledge gaps on hydraulic fracturing identified by the review panels and the reports by the CCA and the CWN remain question marks. The most significant knowledge gaps, a lack of baseline data, insufficient data on cumulative effects, and scarce regional data, all drive home the fact that more information is needed to determine the lasting effects of hydraulic fracturing. In many ways, the public is justified in maintaining its skepticism of the ability of current policy and regulation on hydraulic fracturing to protect public interest.

Knowledge Gaps, Policy Implications and Science-based Regulation

Government is responsible for crafting laws and regulations that protect the public and the environment. It becomes difficult to safeguard the people and natural resources if we are unaware of the magnitude of potential risks associated with development via hydraulic fracturing. The burden falls on government to put forth more research that will address persistent knowledge gaps. Ultimate approval for hydraulic fracturing projects rests with government, and if the scientific literature demonstrates that significant pieces of information are missing from the discussion, it is irresponsible to move forward with development, as we are unable to mitigate unknown risks. The report by the Nova Scotia Review panel demonstrated that more research was needed into a number of critical areas, along with improved public engagement and consultation in the process, those recommendations should be considered carefully and strategically, however the response from governments has largely been political and impulsive.

Based on a thorough investigation of government laws and regulations on oil and gas development and hydraulic fracturing across Canada, there is scant reference to scientific literature. British Columbia is the only province that references scientific documents, and it does not occur within the regulations pertaining to hydraulic fracturing, but in other related government documentation. The question remains, is it government's responsibility to reference and cite scientific resources? In a time of significant mistrust of the energy industry, regulators and governments, demonstrating references to objective, credible scientific resources may be one step in the quest towards gaining public trust of energy projects.

The knowledge gaps related to hydraulic fracturing in Canada are widespread across regions, suggesting that it is not better knowledge about the risks and benefits of hydraulic fracturing that is driving the different regulatory approaches. Rather, the differences can more likely be explained by variation in risk tolerance. This variation likely stems primarily from the different historical roles of oil and gas extraction in the provinces.

Western Canada, and Alberta in particular, is the dominant producer of oil and gas in Canada. In turn, oil and gas has historically been a significant contributor to the economies of the western provinces. Many small communities rely on the oil and gas industry for the majority of their jobs and the public is largely accustomed to, and accepting of extraction operations. The growth of hydraulic fracturing in the late 2000s also came at a time when conventional natural gas and oil production was largely declining.

Concerns around hydraulic fracturing were not as widely known or researched at the time, and rather than being viewed as a danger to communities, it presented as a way to reinvigorate the oil and gas industry and to ensure continued strong economic growth and community livelihood. With a lack of widespread public opposition to hydraulic fracturing when it was first introduced, the technology was able to gain a strong foothold in the western provinces. Although significant knowledge gaps related to the impacts of hydraulic fracturing have since been identified – and concrete negative impacts have been observed in some communities – a widespread moratorium would almost certainly be met with extensive opposition. Instead, the western provinces are depending on well-established regulatory systems to minimize the negative impacts of hydraulic fracturing and to maintain public acceptance of ongoing hydraulic fracturing operations.

In contrast, long-term moratoriums on hydraulic fracturing are in place in Quebec, Nova Scotia and New Brunswick. Onshore oil and gas extraction in these provinces has historically been limited or non-existent. Forests cover about 85% of New Brunswick and 75% of Nova Scotia's land masses. Both have larger rural populations, less existing infrastructure for unconventional energy sources, and potentially significant geographic overlap with other industries (agriculture, fishing, forestry, and mining), important factors to consider in a discussion of public acceptance of energy development. Communities have not grown up accustomed to oil and gas operations in their backyard, nor have they relied on the industry for their livelihood. Concerns around the environmental and health impacts of hydraulic fracturing have also started to appear while the industry remained only in the exploration stage. At this time the provinces had virtually no reliance on hydraulic fracturing for jobs and tax revenues, less established regulatory systems for oil and gas development, and were facing significant public concern in relation to the risks of hydraulic fracturing. Establishing the review panels in each province therefore made ample political sense and as the impact of the ongoing moratoriums have been limited, they have in turn been met with limited public opposition.

Knowledge Mobilization

This paper will be useful to the academic community, as it informs academic researchers as to how their findings are being used by government, regulators and industry. In addition, the synthesis we have provided outlines gaps in knowledge from the consumers of the scientific literature, and future research areas for academics to inform policy choices.

Given the importance of this research agenda for shaping critical policy reforms now underway, communicating results outside the academic community will be crucial. In particular, assessing how policy, regulation and other (non-peer-reviewed) literature has been informed by the existing scientific knowledge and the gaps in that knowledge and the transfer of that knowledge will enable better policy-making and more efficient and effective regulation.

We propose several components[5] to the knowledge mobilization plan. The first is a press release and presentation to the media in Ottawa. We propose Ottawa as that ensures national media coverage, ensuring the research findings reach a broad audience across Canada. The second component is a public presentation in Atlantic Canada, as this is the region that appears to be struggling the most with whether the costs and environmental impacts of hydraulic fracturing are greater or less than the benefits of

[5] We note that the proposed activities will cost more than the amount allocated in the proposed budget. However, The School of Public Policy has a budget for various outreach activities, which will be used to offset the additional costs associated with the knowledge mobilization plan.

increased economic activity. We also propose a public presentation in Calgary, as the location of the majority of head offices for oil and gas producers in Canada. Members of the research team will also make ourselves available for briefings with various governments, particularly in Ottawa and Atlantic Canada.

As the research paper resulting from the grant is likely to be quite long and detailed, we will also develop a five- to ten-page extended executive summary outlining the key research findings. This will be more useful and accessible to senior policy-makers and executives, who may not have the time to read the full research report. Finally, Dr. Winter plans to write at least one op-ed based on the research findings, which will be used to inform the public.

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