The Merits & Demerits of Hydraulic Fracturing in Nova Scotia

In Partnership with the Cumberland Energy Authority

December 7, 2018

MGMT 5000: Group #22

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1.0 Executive Summary

In partnership with the Cumberland Energy Authority, an evidence-based assessment of the merits and demerits of hydraulic fracturing in Nova Scotia has been conducted. More specifically, this report focuses on the potential implications of hydraulic fracturing in Cumberland County where a large portion of the provinces onshore natural gas reserves exist. Before instituting a moratorium in 2014, the Nova Scotia government commissioned an intensive study regarding the impacts of fracturing operations. This project was led by Dr. David Wheeler who published the "Wheeler Report" in 2014.

Using the Wheeler Report as a basis and starting point for the research process, a systematic literature review has been conducted, designed to capture research focusing on hydraulic fracturing from 2014 onward. This involved the development of a comprehensive search strategy which aimed to inform areas of key integration points including the environmental, economic and societal implications of hydraulic fracturing. This report discusses several key findings in terms of technological developments, environmental implications as well as the economic and societal impacts of hydraulic fracturing.

There have been very few technological advancements since 2014. The main developments involve increased drilling lengths and the development of multi-lateral and stacked wells. These new methods decrease the overall impact on the surface of the drill site as they only require one well pad to sustain the entire frack. Aside from these more technical advancements there have also been developments in the safety and efficiency of hydraulic fracturing technologies.

Considering the current state of hydraulic fracturing technology, there is limited environmental risk associated with the hydraulic fracturing process. However, there are significant risks associated with the storage, treatment and management of chemicals, chemical waste and wastewater which can result in chemical contamination through either airborne pollution or drinking water contamination. These environmental risks also impact biodiversity, water quality and quantity, air quality and also increase both the risk of induced seismicity and global warming.

In terms of the economic factors associated with hydraulic fracturing, there will likely be benefits to Cumberland County as a result of job creation and royalty revenues that may be distributed by the province. However, these benefits must be weighed against other concerns and risks including the societal implications. For example, there is evidence that hydraulic fracturing has negative societal and health implications on local communities both through direct pathways (chemical contamination) and indirect pathways (things like light and noise pollution that are associated with the hydraulic fracturing process).

A strong case can be made both for and against hydraulic fracturing which is why it is such a contentious topic. As such, it is critical to inform and educate both the local government and decision makers as well as the public in order to come to a well-reasoned decision about how to proceed should the moratorium on hydraulic fracturing in Nova Scotia be lifted in the future.

2.0 Acknowledgements

We would like to thank Cumberland Energy Authority for choosing to work with our Dalhousie Management Without Borders Project Team. We would also like to thank Dr. David Wheeler for producing such an in-depth review of issues related to hydraulic fracturing as they were prior to 2014. We would also like to thank Lisette Muaror and Dr. Sandra Toze for their continued feedback and support throughout the semester. Lastly, we would like to thank the rest of the Management Without Borders faculty and staff.

3.0 Introduction

The Cumberland Energy Authority ("CEA") has partnered with Dalhousie University to participate in a Management Without Borders project. The mission of the CEA is to set the standard of leadership in local government for the development of renewable energy, support of the progressive energy industry and the encouragement of a sustainable future for Cumberland's communities. The CEA recognizes that hydraulic fracturing in NS is a contentious topic, that tends to elicit polarizing and passionate opinions. A large portion of onshore natural gas reserves in the province are located in Cumberland County. Currently, the CEA has no position on hydraulic fracturing, however, as discussion about the potential development of Nova Scotia's onshore natural gas reserves escalates, the CEA believes it is crucial for the organization to be well-informed on this topic. In partnership with Dalhousie, the CEA has tasked this project team with conducting an evidence-based assessment of the merits and demerits of unconventional shale gas development ("USGD") in Nova Scotia, with a specific focus on Cumberland County.

In 2013 the Nova Scotia government commissioned an independent review of the socio-economic impacts of onshore hydraulic fracturing, the common technical process associated with USGD. This review was led by Dr. David Wheeler, President of Cape Breton University. The results of this review were published in 2014 as the Wheeler Report which found that Nova Scotians were not yet ready to embrace high volume hydraulic fracturing. In response, the government of Nova Scotia introduced a provincial moratorium on hydraulic fracturing. The moratorium persists today, although a recent report from the Nova Scotia Department of Energy discussing Nova Scotia's onshore hydrocarbon resources, and the revenue that could be generated from their development, has resulted in renewed debate regarding the merits and demerits of lifting the moratorium. The report predicted that approximately 30% of the total provincial onshore oil and natural gas volumes fell within the Cumberland and Windsor study areas (Figure 3.1; Keppie, 2017).

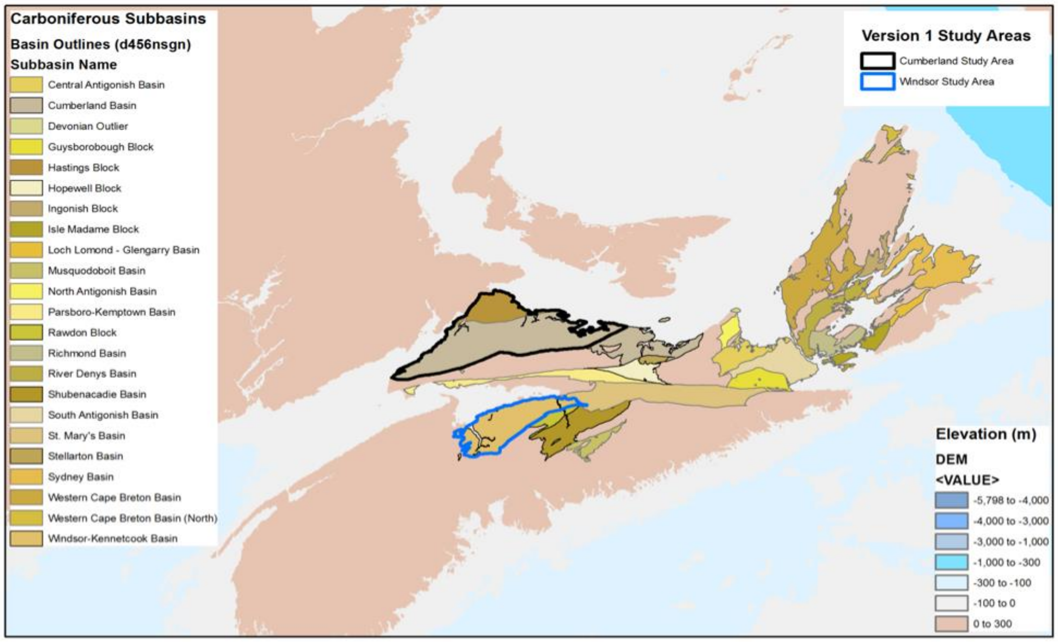

Figure 3.1: A classification of sub-basins in onshore Nova Scotia with inferred oil and gas potential. Targeted study areas from this atlas are indicated: (1) Cumberland Study Area (black outline) and (2) Windsor Study Area (blue outline) (Keppie, 2017).

Results from the study suggest that the Cumberland and Windsor areas have 36 trillion cubic feet (tcf) of Gas In Place potential, with recoverable gas volumes inferred to be approximately 6.5 tcf (Figure 3.2; Keppie, 2017). Estimates suggest that the 6.5 tcf of natural gas in the study area is valued between \$20 – 60 billion USD (Keppie, 2017). Further studies will be required to estimate the total recoverable potential, and value of the remaining 70% of onshore reserves in the province.

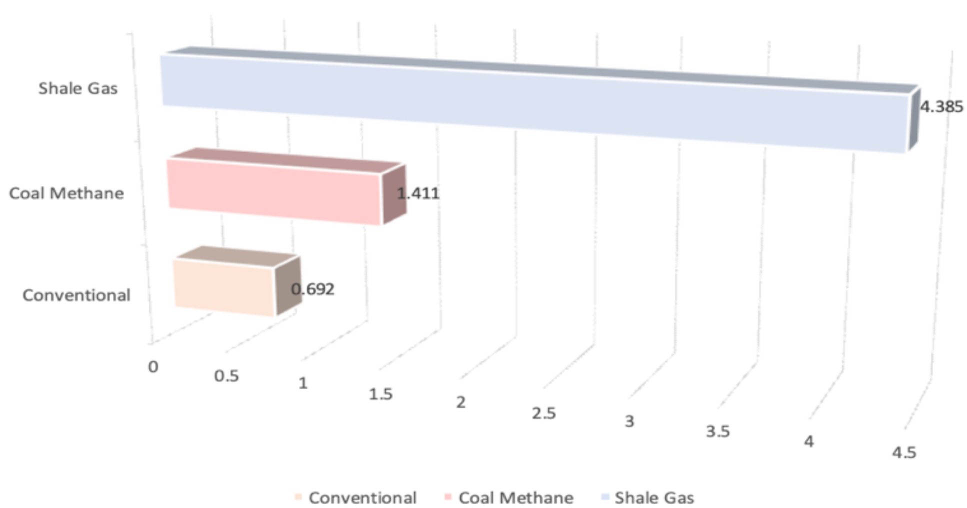

Figure 3.2: Predicted recoverable gas potential for the Windsor and Cumberland Basin Study. Areas of Shale gas (blue), coal methane (red), and conventional gas (orange) comprise the total 6.5 tcf potential (Keppie, 2017).

A comprehensive and methodical literature review has been conducted, focusing on studies published after the moratorium was introduced in 2014. The report explores numerous dimensions of USGD, including technological innovation as well as updated findings on the environmental, economic, social and health impacts. This research is supplemented by case studies sourced from jurisdictions similar to Cumberland County (Appendix A). Based on the findings of this review, a number of evidenced-based recommendations have been included to help the CEA inform their stance on USGD in Cumberland County.

4.0 Methodology

This report aims to answer one primary research question which asks what has been learned about hydraulic fracturing since Nova Scotia introduced the moratorium in 2014. This problem has been addressed in the context of changes to the technology involved, both environmental and economic impacts, as well as societal and health related implications. The 2014 Wheeler Report addressed a number of these factors however, the scope of this project included research published since that time, with a specific focus on the potential impacts of hydraulic fracturing in the Cumberland County region. Explicit objectives and additional research questions for this report include:

1. How has hydraulic fracturing and other formation stimulation technology for shale gas production changed since the 2014 moratorium?
2. What has been learned about the economic impacts that shale gas production and hydraulic fracturing have on communities?
3. What do we know about the quality of data and research around this topic, how has this changed since 2014 and what constitutes good evidence?
4. What lessons can be learned from case studies in Canada and beyond about how to navigate this complex topic in a way that best serves the communities, businesses and environment in Cumberland County?
5. What lessons can be learned from initiatives that have been undertaken in regard to policies, regulations or programs relating to these case studies?
6. Do knowledge gaps exist, and where should future studies be directed?

4.1 Research Design

To answer these questions data was acquired from a number of different fields of study that contribute to informing opinions about USGD. To address how hydraulic fracturing and other formation stimulation technologies have changed since 2014 our team gathered information from investigative reports from oilfield supply and drilling companies as well as academic and grey literature. A summary of the environmental impacts of USGD were also established as a necessary component to the report. It was anticipated that this summary would largely focus on changes to baseline conditions of methane gas (one of the primary constituents of natural gas) in the atmosphere, groundwater and soil surrounding drilling sites. Impacts to other important components such as land use, species at risk, migratory birds and induced seismicity were also designated as important topics of research related to hydraulic fracturing.

Additionally, economic impacts were established as an important consideration of oil and gas development. Areas of anticipated research included the economic benefit of royalties from developers, job creation and increased economic activity for regional businesses and suppliers, as well as the potential for economic risk to communities that permit oil and gas development. The research design was formulated to explore these potential economic merits and demerits, while also considering the potential damage to the environment and to communities that experience significant environmental disasters. Research considerations were also made to explore Nova Scotia's cap and trade agreement given the costs associated with introducing such a carbon intensive industry.

To conceptualize the major themes and issues surrounding hydraulic fracturing in Nova Scotia several sources have been considered, including the Wheeler Report, meetings and correspondence with CEA and preliminary research used to complete a PESTEL analysis of the Municipality of the County of Cumberland (Appendix B). The PESTEL analysis included a detailed review of the political, environmental, social, technological, economic and legal forces impacting the object of interest, in this case Cumberland County. By structuring the research design to focus on multidisciplinary fields, and the multidimensional merits and demerits that inform much of the debate around USGD, precautions were taken to remain unbiased in the research approach. Additionally, by establishing areas of expected information and research, while conducting a broad literature sweep, it was ensured that important topics were addressed while still allowing for the inclusion of new findings, technologies, and impacts into the literature file.

4.2 Systematic Literature Search

The majority of the data and information required to answer the key research questions were obtained from academic literature, reports and existing case studies. The team conducted a systematic literature search of relevant databases in order to compile a robust resource file identifying the pertinent research on hydraulic fracturing since 2014.

Given the necessity to review literature from a variety of disciplines (economic, environmental, technological, societal, etc.) our searches relied on multidisciplinary databases. These include Scopus and Web of Science, as well as Google Scholar to ensure that any grey literature, relevant local news sources, or conference proceedings that would assist in informing the report in a comprehensive way were captured. Additionally, a systematic search of GEOSCAN has been conducted to incorporate locally focused research.

Following the selection of the databases deemed most suitable for the nature and scope of the research, multiple thesauri and Library of Congress subject headings were consulted to ensure all applicable terms associated with hydraulic fracturing and USGD were accounted for. Given the varying searching capabilities of each database, search strings were modified to ensure that the most appropriate and robust list of results were compiled.

4.2.1 Established Keywords & Database Search Strings

The following keywords and search strings outline the details used in the research process. Each search string is listed according to the database used.

Table 4.1: Keywords used in search strings.

Keywords		
Hydraulic Fracturing	Fracking	Hydrofracking
USGD	Natural Gas	Horizontal Drilling
Nova Scotia	Canada	Impact
Assessment		

Scopus Search String: 203 Results

(TITLE-ABS-KEY ("hydraulic fracturing") OR TITLE-ABS-KEY ("fracking") OR TITLE-ABS-KEY ("hydofracking") OR TITLE-ABS-KEY ("unconventional shale gas development") OR TITLE-ABS-KEY ("natural gas") OR TITLE-ABS-KEY ("horizontal drilling") AND TITLE-ABS-KEY ("Nova Scotia") OR TITLE-ABS-KEY (canada) AND TITLE-ABS-KEY (impact) OR TITLE-ABS-KEY (assessment)) AND PUBYEAR > 2013

Web of Science Search String: 134 Results

Further refinement was necessary to reduce the 569,349 results the first search produced, so within those results a search focus was specified on “hydraulic fracturing” and “Canada”, and then again on “unconventional shale gas development” and “Canada”, which provided 134 results in total.

("hydraulic fracturing") *OR*TOPIC: (hydrofracking) *OR*TOPIC: ("unconventional shale gas development") *OR*TOPIC: ("natural gas") *OR* TOPIC: ("horizontal drilling") *AND* TOPIC: ("Nova Scotia") *OR* TOPIC: (Canada) *AND* TOPIC: (Impact) *OR* TOPIC: (Assessment)

Timespan: 2014 – 2018. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI.

GEOSCAN Search String: 102 Results

The searching capabilities are very limited within this database, so a very concise and specific search had to be conducted.

"hydraulic fracturing" > 2013

Google Scholar Search String: 202 Results

A more concise search string was constructed in Google Scholar due to the large amount of results returned (75,000+) with the use of the full list of keywords and the full date range.

"hydraulic fracturing" OR "unconventional shale gas development" AND "Nova Scotia" after 2017.

4.3 Screening Process

Once the systematic literature searching was complete, the references were compiled into a shared group file within the reference management software, Zotero. The comprehensive search of the databases captured 641 relevant results, however an initial screening for duplicates reduced the file to 532 unique references. The 532 references were then carefully screened against predetermined inclusion and exclusion criteria. These criteria were established through considerations of the requirements of the primary research question as informed by CEA's needs, the more general scope of the project, the PESTEL analysis, and the time constraints associated with the course. Each reference was reviewed at multiple levels, first by title, abstract, and keywording to quickly eliminate clear outliers, and then should the article seem appropriate for the study, a closer scan of the content was conducted.

4.3.1 Inclusion Criteria

The inclusion criteria used to screen the literature encompassed references written after the 2014 Nova Scotia moratorium on hydraulic fracturing, academic papers, grey literature, conference proceedings, and reports. Additionally, references that explicitly deal with the economic, environmental, legal, technological, health related, or societal repercussions of hydraulic fracturing were also included. The Wheeler Report as well as other content deemed informative towards any of the seven predetermined research questions also assisted in guiding the scope of the research and inclusion criteria.

4.3.2 Exclusion Criteria

All references written prior to the 2014 Nova Scotia moratorium on hydraulic fracturing as well as any non-English sources or obvious outlier topics that were not relevant to the scope of this project, were excluded. Additionally, any references that involved study areas that were not geographically, environmentally and/or socially similar to Nova Scotia or Cumberland County were also excluded. Lastly, references that did not represent legitimate and valid research, or those which contained outdated research or presented a clear agenda or bias in their presentation were also excluded.

4.4 Final Literature File

Following the comprehensive review of the literature, 256 references remained that were further divided by subject. Legal, environmental, economic, health, social, technological, and case study subfolders were created to divide the literature into areas of pertinent interest. When attempting to answer the research questions, the appropriate file was consulted, and the most recent research findings were given preference. Additionally, highly established, peer reviewed, and seminal literature has been used to inform the background of the report. Only the systematic literature search was used to inform recent findings, but older references were consulted to provide context and to create an informed foundation upon which any updates since the 2014 moratorium were presented.

4.5 State of the Data

The analysis of the reference files was well documented and systematic to ensure that all inclusion and exclusion criteria were applied, and the ensure that the final body of literature reflected all areas of relevant research. This level of diligence was necessary throughout the process to add further legitimacy to the final report, and to ensure that the research that informed the study was highly credible. Through the identification of appropriate search databases, careful literature screening, and diligent reference checking, the team has compiled a comprehensive report which aims to provide updates on the current literature. Any risks associated with the limitations in terms of the data available have been mitigated where possible through the diligence used in the research process.

Despite the lack of locally based research, specifically regarding technological developments, the trends in the industry are not geographically dependent. Additionally, as safety and environmental protection have increasingly become an expectation for USGD operations, it can be expected that any drilling that would take place in Cumberland would be held to best practice standards, using modern technology similar to the rest of North America. Although these factors do not currently impact Cumberland County, further research should be done of groundwater and seismic monitoring for long-term projects related to aquifer quality and seismicity.

4.6 Limitations of the Research

There are a number of limitations within the research that should be acknowledged. First, the contentious nature of hydraulic fracturing and the strong, polarized opinions surrounding its implementation creates a greater potential for biased literature. By closely screening references, efforts were made to mitigate this risk to compile a reference file that was factual, unbiased, and without any political or social agendas. For example, while a paper may not have been initially flagged as inappropriate through title, abstract and keyword screening, a closer read and careful reference check was conducted to ensure that only the most appropriate references were captured to inform the report.

Additionally, given the multitude of keywords established, the four-year research window, and the increasing body of literature surrounding hydraulic fracturing, search parameters needed to be established in order to create of literature file that could be reviewed by the course deadline. For example, Google Scholar and Web of Science initially returned thousands of results which the project team could not feasibly review to the high standard required within the time constraints. Therefore, additional filtering was required to reduce the results. It is possible that potentially valuable literature may have been missed when these additional search constraints were applied. To best mitigate this risk additional search parameters (keywords and dates) were carefully selected to ensure that the most relevant resources were still returned, while excluding dated literature or topics that fell beyond the scope of the research. Additional mitigation measures implemented to supplement any gaps identified in the results of the literature review included more general Google searches.

Finally, the geographical scope of the research was limited because much of the existing literature and empirical data dealing with hydraulic fracturing was conducted in the United States, China, or Western Canada. Given the lack of Atlantic Canadian based research, the project team attempted to locate data that could be extrapolated onto Cumberland County. As such, geographical areas of study with similar economic means, geological makeups, technological capabilities, and societal factors were given preference when informing the report. The project team attempted to mitigate geographical research limitations by selecting literature that aligned with the PESTEL forces that shape Cumberland County.

5.0 Background

This section describes the broad-scope aspects of USGD, and the specific process of hydraulic fracturing, also known as “fracking”. Additionally, this section will serve primarily as a tool to describe hydraulic fracturing at a high level and to introduce terminology which will be important throughout the remainder of the report. While hydraulic fracturing is used in many industries with various applications including groundwater development, CO2 sequestration and geothermal development, it is most well-known for its use in the oil and gas industry (Wheeler et al., 2014).

5.1 What is Unconventional Shale Gas Development?

Conventional shale gas development refers to the traditional process of drilling into porous geological formations and easily extracting oil and gas resources (Ajdukeiwicz & Lander, 2010). This process is considered to be relatively easy, as porous geological formations have high levels of interconnected pores and fractures in which oil and gas can easily be accessed (Ajdukeiwicz & Lander, 2010). Conversely, geological formations known as shales have extremely small pores and fractures, which are not interconnected within their geological formations, and are not easily accessible (Brown et al., 2011). Therefore, the process of hydraulic fracturing is applied, to create new fractures within shales, and open up existing fractures, allowing for easier access and the production of hydrocarbons (Wheeler et al., 2014).

5.2 What is Hydraulic Fracturing?

Hydraulic fracturing is a process in which fluids are pumped into a well at extremely high pressures to fracture non-porous rock formations (Wheeler et al., 2014). These non-porous rocks, better known as shales, are formed by the deposition of fine or clay sized particles which then undergo consolidation (Grim, 1951; Eugster et al., 1973). This process of consolidation of clay sized particles creates very thin layers ranging from approximately 15 to 60 meters thick (Murray et al., 1990; Arthur & Sageman, 1994). As such, shales require wells to be dug horizontally through the formation to increase the amount of exposure the well has to the shale (Brown et al., 2011). To do so, producers must drill vertically into the deep shale formation and then turn the well to begin drilling horizontally when the desired geological layer is penetrated. After the well has been drilled, large amounts of fracturing fluids mixed with proppants are pumped into the well at a high pressure to break open the formation. Proppants are typically sand or similar materials which are used to hold fractures open, allowing for the extraction of oil and gas from the newly formed fractures (Wheeler et al., 2014).

5.3 Comparing Conventional Drilling to Hydraulic Fracturing

Fossil fuels account for 80% of the world's primary energy source (Perduzzi & Harding, 2012, as cited in Wheeler et al., 2014). Fossil fuel reliance continues to increase as energy demands and global populations grow yearly. As a result, conventional drilling developments have begun depleting well-known oil reservoirs causing the industry to shift towards exploiting tight shale reservoirs that were previously thought to be inaccessible due to technological limitations (Li et al., 2016).

However, with the advancement of hydraulic fracturing, oil and gas producers are now able to access these previously untapped tight shale reservoirs. This has created an entirely new supply mechanism. Despite the significant controversy surrounding the processing of fossil fuels compared with renewable energy sources, this newfound supply of shale oil and gas has been used to meet the growing demands of the global population.

5.4 History of Unconventional Shale Gas Development & Fracking in Nova Scotia

Unconventional shale gas development is a contentious topic, that has largely divided the public (Wheeler et al., 2014). A 2013 poll by Corporate Research Associates, Inc. indicated that 53% of Nova Scotians were opposed to "hydraulic fracturing even if the Province had adequate regulations in place to protect the environment", 39% were not opposed, and 8% were undecided (Wheeler et al., 2014). Due to a lack of research and public support, a moratorium was later placed on hydraulic fracturing. As such, there is a limited history of USGD and fracking in Nova Scotia.

Approximately 35,000 horizontal wells were drilled in Canada between 2007 and 2013, most of which were hydraulically fractured (Council of Canadian Academics, 2014, as cited in Wheeler et al., 2014). During that time, only 11 wells in Nova Scotia were drilled and hydraulically fractured. Of these 11, only three were drilled for accessing shale gas potential, and the other eight were drilled for coal bed methane production and evaluation.

6.0 Research & Analysis

The following sections include a thorough overview and analysis of research findings identified after completing the systematic literature review. The main themes explored include technological developments since 2014, environmental and economic impacts of hydraulic fracturing, as well as the impacts of fracking on the societal and health related factors within communities.

6.1 Technological Developments

Hydraulic fracturing is the most impactful form of technology in USGD. Although the process of hydraulic fracturing is not new, its use in the oil and gas industry, and more specifically in USGD, is relatively recent and constantly developing (Wheeler et al., 2014). Safety and environmental protection are considered the two most important aspects of the energy industry (Robinson & Hsu, 2017). Technological advancements typically function to both increase the safety of energy operations, and decrease their environmental impacts (Grob & Maxwell, 2016).

Industry and environmental catastrophes primarily occur due to a failure to understand the technology used in energy operations (Robinson & Hsu, 2017). Given the consequences of the improper use of technology in energy operations, a thorough understanding of technological developments is a critical aspect of hydraulic fracturing. Furthermore, the energy industry generally follows similar technological trends prioritizing the use of the most recent technology to increase the safety, efficiency, and profitability of hydraulic fracturing operations. As such, these technology focused research findings are applicable to a diverse range of geographic locations including Cumberland County.

6.1.1 Horizontal Drilling

As briefly discussed in section 5.1, horizontal drilling is required in USGD in order to optimize the surface area contact with the thin gas-rich shale reservoirs. This differs from a conventional reservoir in which wells are drilled vertically into a single point of the oil or gas rich formation, allowing the natural pressure in the reservoir to trigger a flow of hydrocarbons into the well (Figure 6.1).

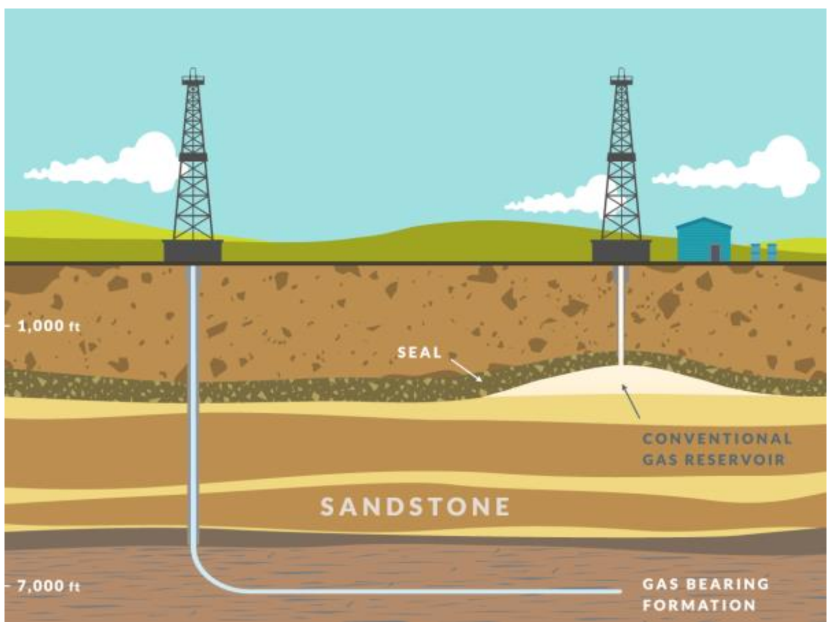

Figure 6.1: A horizontal well drilled through a tight shale (Left) and a conventional, vertical well drilled into a porous sandstone reservoir (Right) (Crone, 2015).

There are several instances in the literature which suggest that the advancement of drilling technology and techniques has been increasing the efficiency of USGD (Liston et al., 2014; Ogoke et al., 2014; Ibatullin, 2017; Robinson & Hsu, 2017). Most recently, the greatest horizontal drilling advancement has been the increase in the length of horizontal wells (Liston et al., 2014). This decreases the required operation at the surface, while increasing the contact a well has with a shale reservoir, potentially increasing production volumes.

Recently, the recorded lengths of horizontal wells has increased from 3600m to 5000m (Liston et al., 2014; Kallanish Energy, 2018). With fewer wells at the surface that are able to reach further into the reservoir, rather than many wells drilled to reach shorter sections, the impact of drilling at the surface could be significantly reduced. It will be important for operators in Cumberland to assess the length of the shale reservoirs and the feasibility of drilling fewer extended wells instead of many short horizontal wells.

6.1.2 Well Pads, Stacked Wells, Multilateral Wells & Multi-well Fracking

Many technologies and instruments are used at the surface of a drill site including well pads which are constructed and installed on location. Well pads are temporary sites capable of supporting multiple horizontal wells, as well as the necessary equipment and the different storage and containment units required (Ogoke et al., 2014). Horizontal well pads differ in size and can be between two to three hectares, which is three to four times greater than the surface space required at the site of a conventionally drilled vertical well (Wheeler et al., 2014). This is because conventional operations generally operate between six and eight wells simultaneously, all requiring separate well pads, and so requiring more space (Speight, 2013).

The consolidation of multiple wells to a single pad is believed to significantly decrease disturbance to the surrounding land. A single unconventional well pad hosting four horizontal wells is estimated to create only 10% of the disturbance created by the sixteen vertical wells required to produce the same volume of shale gas (Spellman, 2012, as cited in Wheeler, 2014). This decreased land use can minimize the impact that oil and gas operations have on the nearby environment including minimizing the impacts on wildlife, noise disturbance, dust, and traffic (Spellman, 2012; Speight, 2013; CCA, 2014, as cited in Wheeler et al., 2014).

Horizontal drilling offers three variations of lateral drilling techniques (1) stacked well drilling, (2) multilateral drilling, and (3) a combination of both. Multilateral drilling, which has been an increasingly popular technique, offers the possibility to run multiple horizontal wells at the same depth adjacent to each other, or at the same depth in different directions (Ogoke et al., 2014). Stacked drilling offers the possibility to drill multiple horizontal wells at different depths through the same formation or through multiple formations. All of these horizontal drilling techniques can originate from a single vertical well, running back to a single well pad at the surface. These advancements in multilateral well drilling have created the possibility to cost-effectively increase efficiency and minimize surface area impacts (Ogoke, 2014). This has become increasingly important for communities in more rural areas like Cumberland aiming to minimize environmental impacts.

6.1.3 Multi-Stage Fracking & Perforating

A single wellbore (the hole drilled in order to form the well) is capable of hosting multiple lateral wells. Additionally, within each lateral well there are multiple stages in which perforations can be made through the well and the well casing (Figure 6.2; Wheeler et al., 2014). Multi-stage fracking and perforation technologies are heavily patented and so they are not widely discussed in the literature. This is because operators do not want to disclose information about the technology that gives them their competitive advantage. An example of these technologies which has been discussed in the literature includes coiled tubing-activated frac sleeves which have been found to increase the efficiency of hydraulic fracturing operations (Algadi et al., 2014).

These advancements are more applicable to companies considering the potential of USGD in Cumberland County. However, for the government of Cumberland, it is important to consider that advancements in perforation technology have not only increased efficiency in production, they have also increased overall safety (Grob & Maxwell, 2016). By creating multiple smaller fractures along a well, instead of fewer and larger fractures, operators are much more capable of reducing the risk of seismic activity or inducing earthquakes (Grob & Maxwell, 2016).

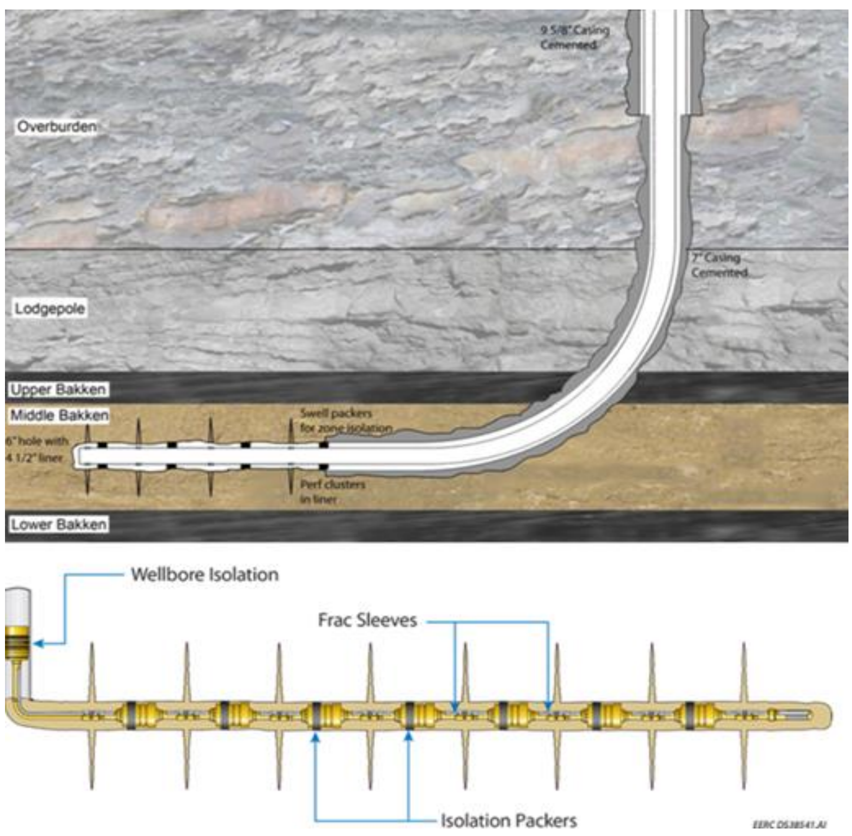

Figure 6.2: Perforations being made through the casing of a horizontal well. Fracking fluids are sent through these perforations to create fracture in the shale reservoir where gas is produced (Oil & Gas Portal, 2018).

6.1.4 Mircoseismicity

Earthquakes are naturally occurring events caused when energy is released within the Earth's lithosphere, from a point-source called the "epicenter", in the form of seismic waves (Gutenberg, 1955). This typically occurs at fracture zones where potential energy is built up as a function of two massive rock bodies moving against each other, before finally slipping and releasing the built-up energy (Kanamori, 1977). "Human-induced earthquakes" or microseismicity are a byproduct of energy-related activities such as underground gas storage, enhanced oil recovery, geothermal operations and hydraulic fracturing (Gutenberg, 1955). Microseismic events in hydraulic fracturing occur due to the over pressurizing of shale reservoirs and the resulting fracturing of the reservoir rock (Wheeler et al., 2014).

Microseismic monitoring, used as a tool to measure amplitude of seismic wave, length of the seismic waves, direction of seismicity, and extent of fractures, is an important technological application for determining the surface outcome of hydraulic fractures (NEB, 2009 as cited in Wheeler et al., 2014). Microseismic monitors are most often placed within the initial wellbore of a new hydraulic fracturing site in order to gain pertinent information. Once the initial frack has been completed and the reservoir properties have been compiled, operators are better able to continue their fracturing while minimizing microseismic activity, and the monitoring generally ceases (CCA, 2014 as per Wheeler et al., 2014). If considered necessary later during the operation, a monitoring well may be drilled to satisfy the need for additional monitoring during, or post-fracturing, however, this is uncommon (Wheeler et al., 2014).

Site specific detection and analysis of induced seismicity can be performed through downhole monitoring of a well at a hydraulic fracturing site (Caffagni et al., 2016; Ghofrani & Atkinson, 2016). Caffagni et al. (2016) explain that progression in this type of monitoring is less dependant on improving the physical instrumentation but rather on developing better algorithms and methods to analyse and interpret the data produced through the monitoring process. This study further developed a "Match Filtered Algorithm" which they believe improves current seismic monitoring (Caffagni et al., 2016).

There has been no significant update on seismic modelling and predictability since the 2014 Wheeler Report. However, Ghofrani & Atkinson (2016) suggest that it is inherently impossible to create any form of instrumentation or model to accurately predict the relationship between an energy operation and induced seismicity. This is due to specific areas having varying stress fields and reservoirs having different lithological properties (Ghofrani & Atkinson, 2016).

6.1.5 Upstream Technological Considerations in Cumberland

A significant portion of upstream oil and gas production such as USGD occurs at the subsurface, as such, physical instrumentation is not the only major technological component of hydraulic fracturing. Technological considerations should also include the mathematical modelling techniques used to increase the accuracy of subsurface predictions (Caffagani et al., 2016; Robinson & Hsu, 2017). Apart from the technology relevant on and beneath the well pad of a USGD site, there are several infrastructure related considerations that will be important for Cumberland, as part of any typical oil and gas operation. These include onsite storage, pipelines and compressor stations. Significant research will need to be done focusing on the requirement for local pipelines which may need to be built and supported in Cumberland. Additionally, further research dealing with onsite-storage and gas compressors will need to be undertaken.

6.1.6 Alternatives to Hydraulic Fracturing in Unconventional Shale Gas Development

Due to pressure from environmental groups, and in an attempt to lower the costs associated with USGD projects, operators have investigated alternative techniques to access and process tight shale reservoirs. Both existing and developing alternative technologies are often considered trade secrets, limiting the research available on these topics. Research is also limited in terms of publicly known and researched alternative technologies. This is largely because these alternatives including high-voltage electrohydraulic discharge (Ren et al., 2018), electro-fracturing (Bauer et al., 2015), foam fracturing (Wanniarachchi et al., 2015) and high energy gas fracturing (Warpinski et al., 1979; Yang et al., 1992) are considered to be inefficient when compared to hydraulic fracturing (Table 6.1).

Table 6.1: Details of the publicly known and researched alternative technologies.

Alternative Technologies	
High-Voltage Fracturing	Can achieve fracturing of reservoir rock, but at very short lengths & without the ability to maintain high permeability (Ren et al., 2018).
Foam Fracturing	Useful for water-sensitive formations, but can only be done in a low pressure, shallow depth reservoir, less than 1500 m depth from surface (Wanniarachchi et al., 2015; Li et al., 2016).
High Energy Gas Fracturing	An excellent alternative to brittle reservoir formations, but not plastic formations; can only create very small cracks in the proximity of the wellbore (Yang et al., 1992).

Hydraulic fracturing is considered to be more efficient than the alternatives listed in Table 6.1 because the water used in the fracturing process is also used to transport additives (as needed to treat the reservoir) as well as the proppants used to hold the fractures open. However, the use of water is also considerably wasteful, as extremely large quantities are required and are usually contaminated after use.

This is partially because pumping water into subsurface reservoirs results in "clay hydration swelling" which occurs when the clays existing in the reservoir decrease the permeability (Li et al., 2016). Clay hydration swelling is usually offset by adding certain additives and chemicals into the fracturing fluid which increases the permeability while further contaminating the water (Li et al., 2016).

Liquid nitrogen gasification fracturing ("LNGF") may be a viable alternative that would better manage the issues related to wastewater while still achieving the large-scale efficiency associated with hydraulic fracturing (Li et al., 2016). LNGF uses liquid nitrogen to overpressure the reservoir rock in order to create fractures (Li et al., 2016). The liquid nitrogen is then heated causing the liquid to turn into a gaseous state (Li et al., 2016). The gas then continues extending the fractures to keep them open (Li et al., 2016). There are several advantages of LNGF compared to hydraulic fracturing including the following:

1. No water resource limitations;
2. No clay hydration swelling;
3. No environmental pollution;
4. No corrosive effects to the reservoirs;
5. Can produce large-scale fractures; and
6. Nitrogen is low cost due to its abundant supply (Li et al., 2016).

However, more research is needed to clearly identify the limitations and issues associated with LNGF.

6.2 Environmental Considerations

The potential environmental impacts of hydraulic fracturing on water, land, and biodiversity are an important area of research. This section analyzes the environmental impacts that should be taken into consideration if hydraulic fracturing is to occur in Cumberland County. Special focus has been given to impacts on water, air, climate change, biodiversity and inducement of seismic events, which are the major environmental considerations that were outlined in the 2014 Wheeler Report. This section attempts to draw connections to more recent literature in order to assess whether these findings have altered the significance of the environmental threats discussed in the 2014 Wheeler Report. The potential impacts to the quantity and quality of surface and groundwater, wastewater considerations, impacts to the local atmosphere, contribution to climate change, potential seismicity and impacts on biodiversity are discussed in detail in this section.

6.2.1 Impacts on Water

The rise of shale gas development has triggered continuous public debate regarding potential human health and environmental impacts that can be caused from hydraulic fracturing. A study by Vengosh et al. (2014) critically reviews the risks to water resources from USGD and hydraulic fracturing with an emphasis on several case studies from US, used to identify four potential risks for water resources including the following;

1. Contamination of shallow aquifers with fugitive hydrocarbon gases (stray gas contamination), which can also lead to the salinization of shallow groundwater through leaking natural gas wells and subsurface flow;
2. Contamination of surface water and shallow groundwater from spills, leaks, and/or the disposal of inadequately treated shale gas wastewater;
3. Accumulation of toxic and radioactive elements in soil or stream sediments near disposal or spill sites; and
4. Over-extraction of water resources for high-volume hydraulic fracturing that could induce water shortages or conflicts with other users, particularly in water-scarce areas (Vengosh et al., 2014).

Moreover, this study has subdivided these risks into smaller more comprehensive factors illustrating them in a single schematic diagram for the ease of understanding (Figure 6.3). This section will review available literature in detail regarding each of the potential risks identified, with special reference to Nova Scotia, and Cumberland Country.

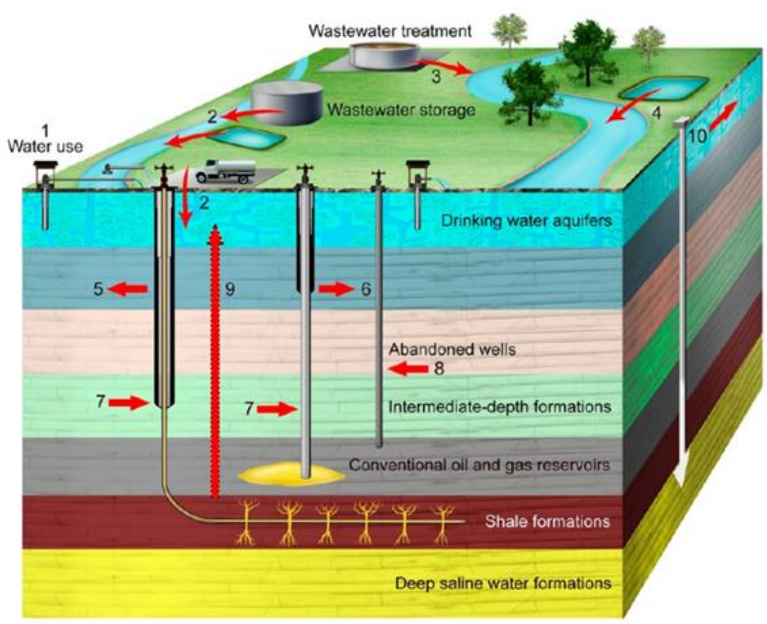

Figure 6.3: Possible water impacts associated with shale gas development (Vengosh et al., 2014)

6.2.2 Impacts on Water Quantity

Hydraulic fracturing is often considered a water intensive operation as it requires a significant amount of water throughout the entire cycle of operation (Wheeler et al., 2014). Surface water from sources such as lakes and rivers, and groundwater from aquifers can be used for these operations depending on the availability. Water quantity has become a prominent concern in unconventional oil and gas development as extensive extraction of water can lead to the drying out of aquifers (Wheeler et al., 2014). If this occurs in a coastal region, sea water intrusion can also occur (Wheeler et al., 2014).

A recent study reported that the annual average water consumption per hydraulic fracturing well in the US varies from 1,000 to 30,000 cubic meters (He et al., 2017). However, in the context of Atlantic Canada, the total amount of water needed for the development of unconventional oil and gas may not be threateningly large with respect to the Canadian hydrology (Wheeler et al., 2014).

6.2.3 Impacts on Water Quality

According to the 2014 Wheeler Report, direct contamination of aquifers from hydraulic fracturing fluids is less likely than other pathways such as accidental spills and wellbore stability. Hydraulic fracturing for unconventional oil and gas production usually occurs around 900 to 1500m below the surface, while the drinking water aquifers of Nova Scotia are confined to less than 150m below the surface (Wheeler et al., 2014). Due to the low permeability and flow rates, estimated travel time for hydraulic fracturing fluids to travel a distance of 100m within the fracture will approximately exceed 100,000 years (Wheeler et al., 2014).

It is not likely for the fracturing fluids to move through fractures and so the existence of methane in groundwater wells is likely a result of leaky well casings and naturally occurring methane (Osborn et al., 2011, as cited in Wheeler et al., 2014). A recent study in Saint-Edouard, Quebec also supports this argument, further stating that there is no indication of deep thermogenic gas from Utica shale reaching the shallow aquifers (Bordeleau et al., 2018). Nevertheless, this study has found out that 96% of the 48 sampling locations over a 500 kilometer squared area contain methane in highly variable concentrations (from < 0.006 mg/L to above 80 mg/L), corresponding to bedrock geology and specific hydrogeochemical conditions (Bordeleau et al., 2018).

Moreover, one of the most recent studies in a Utica shale reservoir in St. Lawrence Lowlands, eastern Canada used a multi-disciplinary dataset which implied that there is no evidence of upward fluid migration from a shale reservoir towards the shallow aquifers (Rivard et al., 2018). The study reported that as the aquifers are made of organic rich, fractured sedimentary rocks, it is possible that groundwater contains naturally occurring microbial and thermogenic methane (Rivard et al., 2018).

A similar study which integrated data from geology, geophysics, hydrology, and rock geochemistry in Sussex area, southern New Brunswick had studied the potential of hydrocarbon migration through natural pathways or fracking induced fractures from deep shale reservoirs to shallow aquifers (Rivard, 2017). This study also confirmed the previous argument, as only a few wells contained methane, and the concentrations were below 5 mg/L (Rivard, 2017). It was also discovered that the methane had either a thermogenic or microbial origin (Rivard, 2017). According to the 3D seismic data, the study concluded that the intermediate zone provides an effective barrier to induced fractures, preventing groundwater contamination from fracturing fluids (Rivard, 2017).

Considering these findings, there is a low risk of direct groundwater contamination as a result of the actual fracking process. However, there is still a risk of groundwater contamination associated with poor operational practices such as improper chemical handling and waste management (Wheeler et al., 2014). For example, chemical spills can occur during transportation, storage or use (Gandhi, 2017). Additionally, flowback from the producing well can also result in spills of condensates. Flowback water includes both fracturing fluids and saline formation water which can pose a severe threat to water quality if leakages occur (Gandhi, 2017; Torres et al., 2015). As such it is recommended that a strong regulatory framework regarding chemical safety and waste handling is developed. Additionally, in the case of on-site holding ponds used to store flowback water, operators should be required to use clay or other low permeability construction material as a geo-membrane or lining of the pond.

6.2.4 Handling of Wastewater

Flowback water and produced water are the two main types of wastewater produced by the unconventional oil and gas industry. Flowback water has a short-term higher flow rate as it is generated following the fracturing operations. It is comprised of fracturing fluid and formation water that can contain acids, corrosion inhibitors, gelling agents, scale inhibitors, surfactants, petroleum hydrocarbons, high salinity and naturally occurring radioactive material ("NORM") (Wheeler et al., 2014). The presence of these hydrocarbons and NORM significantly differentiates hydraulic fracturing wastewater from regular municipal wastewater (Wheeler et al., 2014).

In typical hydraulic fracturing operations, flowback water is stored on site in storage tanks before it is transported for reuse or disposal. According to historical data, the majority of flowback water release incidents occur during storage (Gandhi, 2017). Several studies have pointed out that accidental release of flowback water and hydraulic fracturing fluid chemicals may affect the quality of surface water resources (Gandhi, 2017; Torres et al., 2015; Vengosh et al., 2014). Therefore, it is reasonable to believe that accidental release of wastewater could be a potential risk of hydraulic fracturing in Cumberland County.

Although the Wheeler report (2014) did not elaborate on possible environmental impacts of the accidental release of flowback and produced water, more recent research has outlined some potential effects. Gandhi (2017) reports that contamination of surface water sources can result in the uptake of harmful constituents from flowback water by aquatic organisms and this can pose lethal and sublethal effects on native species. Additionally, a study done on rainbow trout suggested that flowback and produced water can affect the oxidative stress, biotransformation, and endocrine disruption of the species, and thus causes adverse impacts on fish populations (He et al., 2017). Finally, it has also been observed that over a 21-day chronic exposure to 0.04% flowback and produced water, freshwater crustacean, *Daphina magna*, showed sharp decrease in reproduction and delay of time to first breed (He at al., 2017).

However, according to estimates from the Wheeler report, 70% of flowback and produced waters are reused in USGD in order to reduce the net volume of wastewater generation (Wheeler et al., 2014). Though this reusing reduces wastewater production, it results in a highly concentrated waste fluid that cannot feasibly be treated in municipal wastewater treatment processes. The Wheeler report further anticipates that the cost of wastewater transformation and treatment will decline within the next five years when the water technologies improve. However, as of 2018 further empirical research is required to identify whether the geology of Nova Scotia will allow for these improvements to saline underground aquifer operations and the processes of injecting treated water back into the aquifer.

Additional reports from the United States have demonstrated the difficulty of sufficiently processing hydraulic fracturing wastewater in a conventional wastewater treatment plant to meet discharge standards (Mao et al., 2018; Weaver et al., 2016). The research suggests that bromide is difficult to remove from the effluent (liquid waste), and that it can pose serious implications to drinking water quality and aquatic life if discharged directly into water bodies. The conventional commercial wastewater treatment plants might not be capable of removing bromide from the effluent, and thus, even treated wastewater can cause elevated levels of disinfection byproducts in water bodies (Mao et al., 2018).

While the 2014 Wheeler Report identifies Atlantic Industrial Services as having successfully returned wastewater back to acceptable environmental standards, uncertainty about the approaches to the handling and disposal of wastewater from hydraulic fracturing still exists in 2018. Though the industry preferred method is to dispose wastewater using deep well injection, this practice is frequently regarded as unsuitable, especially due to concerns regarding the geology of Nova Scotia (Wheeler et al., 2014). Furthermore, while Cumberland is tectonically stable (Wheeler et al., 2014), increasing wastewater injection into the subsurface could potentially change the tectonic mechanisms of the basin and increase seismic activity in the future (Wheeler et al. 2014; Ghofrani & Atkinson, 2016). Ultimately, more research into wastewater treatment must be conducted to identify potential solutions and to ensure that hydraulic fracturing adheres to the legislation pertaining to wastewater production by USGD.

6.2.5 Impacts on Air Quality

As Wheeler et al. (2014) reported, industrial processes involved in hydraulic fracturing can result in a number of airborne pollutants, posing severe threats to the air quality of the local atmosphere. Hydraulic fracturing involves heavy use of diesel fueled machinery which produce significant amounts of particulate matter, carbon monoxide, and nitrogen oxide emissions (Wheeler et al., 2014). Moreover, onsite emissions include volatile organic compounds (VOCs) and fugitive emissions that lead to methane release (Wheeler et al., 2014).

The large amount of truck transportations to and from the USGD sites take place in order to deliver water, chemicals, cement, and huge volumes of wastewater that can results in extensive amounts of fossil fuel emissions (Gandhi, 2017). Further, flaring and venting during drilling and well completion can also result in emissions (Gandhi, 2017). Additionally, the Wheeler report (Wheeler et al., 2014) outlines the additional impacts caused when pollutants such as ozone come into contact with air contaminants associated with hydraulic fracturing. Ozone, which is a causative factor for respiratory illnesses, can be formed by the mixing of gases such as methane, nitrous oxides, and VOCs (Wheeler et al., 2014). Thus it has been suggested that large scale hydraulic fracturing development can significantly increase local and regional ozone levels, which can lead to respiratory health impacts of local communities (Gandhi et al., 2017).

More recent data presented in the New Brunswick Commission on Hydraulic Fracturing (NBChydraulic fracturing) have emphasized that shale gas extraction through hydraulic fracturing can cause emissions of nitrogen oxides and volatile organic compounds (VOC) including alkanes, benzene, formaldehyde, xylene, ethane, toluene, propane, butane, pentane, and methylene chloride, polycyclic aromatic hydrocarbons (PAHs), ozone, hydrogen sulfide, and particulates including silica dust. The identified sources of these emissions are drill rigs, hydraulic pump engines, vehicles, compressors, dust from sand used as proppant, fumes, and flashing emissions from condensate storage tanks, and venting during flowback flaring (NBChydraulic fracturing, 2016).

It is estimated that 0.42% to 1.7% of recovered gas through hydraulic fracturing is lost to the environment and that elevated levels of ethane have been observed near areas of unconventional oil and gas production (Vinciguerra et al., 2015). Moreover, the study conducted at Marcellus Shale exploration site at West Virginia, United States has predicted that emissions from hydraulic fracturing are so severe that they would, on average, account for 12% of the total NOx and VOC emissions, and 14% of the total particulate matter emissions of the region and thus, could complicate attainment of Particulate Matter (PM) and ozone emission standards (Williams et al., 2018).

Vinciguerra et al. (2015) also reported that the major reason for elevated levels of VOC emissions on oil and gas well pads are leaks from dehydrators, storage tanks, compressor stations, and pneumatic devices and pumps, as well as evaporation of flowback water from storage tanks. Abandoned wells which are no longer active in the production process are also a source of methane emission which are non-negligible (Williams et al., 2018). According one study from the United States, abandoned wells in Pennsylvania could account for 7% of the annual anthropogenic methane emissions in the state (Vinciguerra et al., 2015).

However, some contradictory results have been reported. A study conducted in Washington County, Pennsylvania, United States, has reported that the local air concentrations of total and individual VOC in the vicinity were not affected by hydraulic fracturing operations (Maskrey et al., 2016). This 3-month air monitoring study was conducted at the request of local community members, and continuous air monitoring for total VOCs was carried out at two sampling sites located within 900 m of the hydraulic fracturing site (Maskrey et al., 2016). Air quality monitoring was done at four distinct periods, two inactive periods prior and post operation, and two operational periods, during fracturing and flaring (Maskrey et al., 2016). Interestingly, the results indicated that total VOC concentrations were almost similar in inactive and active periods (Table 6.2). Results observed for individual VOCs and the comparative risk ratios are included in Appendix C.

Table 6.2: VOC continuous air monitoring results from Washington County, Pennsylvania (Maskrey et al., 2016)

Site	**Sampling Period**	**24 Hour Concentration Measurments (ppb)**		
		Mean	**Standard Deviation**	**Range**
A	Baseline	41	53	0 – 120
	Fracturing	7.3	10	0 – 30
	Flaring	4.6	6.8	0 – 22
	Post Flaring	80	53	0 – 160
B	Baseline	22	48	0 – 160
	Fracturing	27	37	0 – 130
	Flaring	0.16	0.32	0 – 1.0
	Post Flaring	10	14	0 – 44

Furthermore, a study conducted in 2015 confirmed that elevated ethane concentrations in the local atmosphere are associated with hydraulic fracturing operations (Vinciguerra et al., 2015). This indicates that a substantial fraction of un-combusted natural gas is escaping the exploration sites and that the signal is detectable hundreds of kilometers downwind (Vinciguerra et al., 2015). Although ethane is not a critical pollutant, this could indicate that other, more hazardous airborne pollutants from hydraulic fracturing could also be transported at increasing rates. This would potentially create complications related to the rise of Particulate Matter and ozone, consequently depleting the air quality of areas downwind (Vinciguerra et al., 2015).

6.2.6 Implications for Climate Change

The generation of greenhouse gases which contribute to global climate change is also an important environmental consideration of hydraulic fracturing. As Wheeler et al. (2014) states, although greenhouse gas emissions per unit of natural gas are less than that for coal, no information was available regarding the total life cycle impacts of natural gas from hydraulic fracturing. Another global concern is that although it is possible to reduce fugitive emissions of greenhouse gases through regulations and engineering solutions during hydraulic fracturing operation, the long-term effects of well decommissioning has not yet been understood (Wheeler et al., 2014).

According to more recent studies, the latest scientific advancements that have enabled companies to target low permeability reservoirs, have resulted in CO_2 emissions from natural gas reaching levels 50% to 60% less than coal combustion (Vinciguerra et al., 2015; Williams et al., 2018). Unfortunately, however, given that CH_4 has a global warming potential which is 28-34 times higher than CO_2 (on a hundred-year horizon), if the CH_4 emissions exceed 3% production over the lifespan of the well, the above mentioned emission savings become useless (Vinciguerra et al., 2015).

Additionally, studies from the United States have estimated that the total amount of fugitive methane across the full life cycle of natural gas production through hydraulic fracturing is as high as 12% (Williams et al., 2018). Williams et al., (2018) used a multi-gas mobile surveying technique to analyze the concentration of atmospheric gases in the urban areas located in close proximity to hydraulic fracturing sites in the city of Morgantown, West Virginia.

This study was able to identify the clear evolution of CH_4 emissions within a complex urban environment throughout the development of shale gas wells. It was observed that combustion anomalies are highest during drilling and production stages and are distributed across an area more than 1 km away from the wells. Figure 6.4 indicates the spatial interpolations of enriched CH_4 and CO_2 anomalies near the hydraulic fracturing site, with the highest concentrations observed slightly north of the well pad, possibly due to the predominantly northern winds during the days of surveys (Williams et al., 2018).

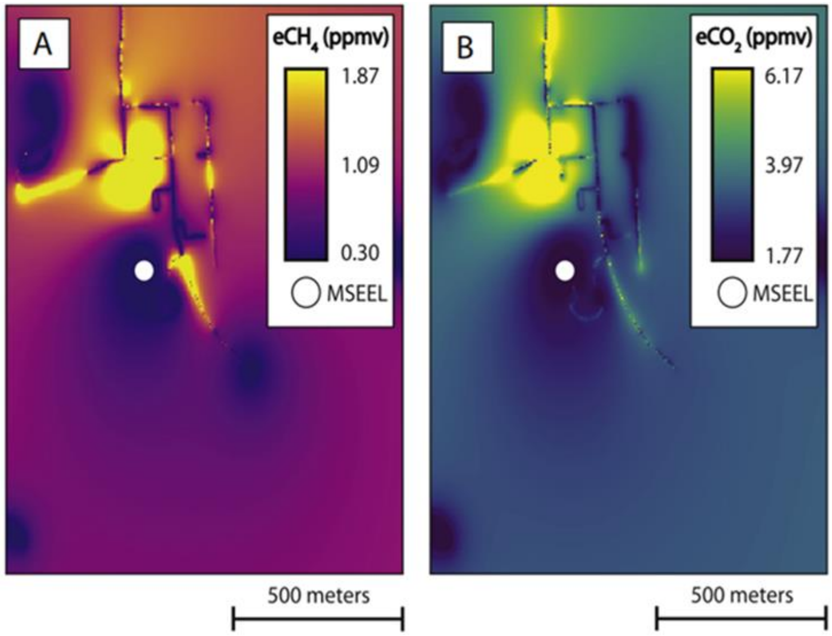

Figure 6.4: Spatial interpolations of excess CH_4 anomalies (A) and excess CO_2 anomalies (B) within 1 km of a hydraulic fracturing site at west Virginia, US as indicated by a white dot (Williams et al., 2018).

However, studies from the United States have indicated that fugitive emissions from hydraulically fractured gas wells have reduced significantly since 2011, as a result of broadly targeted emission control regulations (Vinciguerra et al., 2015). Thus, if hydraulic fracturing occurs in Cumberland County, it will be important to develop regulations that ensure life cycle fugitive emissions of greenhouse gases are kept below 3% of the production.

In Canada it is estimated that methane emissions can be reduced by approximately 50% using existing technologies, and when emission reduction measures are targeted at reducing methane release, they will also reduce emissions from other harmful pollutants (NBChydraulic fracturing, 2016). Canada implemented federal greenhouse gas emission regulations last year targeted at cutting down 2012 emission levels from the oil and gas sector from 40 to 45% by 2025. Several of these regulations deal specifically with hydraulic fracturing. Therefore, if hydraulic fracturing occurs Cumberland County, these regulations which are applicable to Nova Scotia's oil and gas sector, would hopefully contribute to mitigating the increased greenhouse gas emissions associated with hydraulic fracturing.

6.2.7 Considerations Regarding Induced Seismicity

A major environmental concern associated with hydraulic fracturing is the potential for seismic activity creating unintended earthquakes. The Wheeler Report suggested that this happens through the injection of liquids into wells under pressure which can create new fractures, and induce a seismic event related to a pre-existing geological formation (Wheeler et al., 2014). According to the knowledge prevailing at the time, Wheeler et al. (2014) had associated the well fluid injection of wastewater as the activity that most contributes to induced seismicity. However, the report acknowledged that specific reasons for earthquake occurrences in eastern Canada are yet to be understood (Wheeler et al., 2014). Since that time, the New Brunswick Commission on Hydraulic Fracturing (2016) has presented evidence that associates hydraulic fracturing with induced earthquakes (Table 6.3).

Table 6.3: List of seismic activities that were found to be associated with hydraulic fracturing (New Brunswick Commission on Hydraulic Fracturing, 2016).

Year	Location	Description
2016	Alberta	Alberta Energy Regulator concluded that an earthquake of 4.8 magnitude which occurred in January 2016 was associated with a well completion operation.
2015	Oklahoma, US	More than 5,700 earthquakes occurred in a single year and strong evidence is present to connect these with intensified hydraulic fracturing.
2015	British Columbia	A 4.6 magnitude earthquake was found to be caused by fluid injection during hydraulic fracturing.
2013/2014	British Columbia	11 seismic events in Montney Region were associated with hydraulic fracture stages and the occurrences were observed to be severe in certain areas due to pre-existing stressed faults, which are susceptible to reactivation.

These studies from western Canada further validate the argument that hydraulic fracturing results in increased frequency of induced seismic activities in Canada (Bao & Eaton, 2016). Figure 6.5 illustrates the magnitude and occurrence rate of seismicity in northwestern Alberta, Canada between 1985 and 2016.

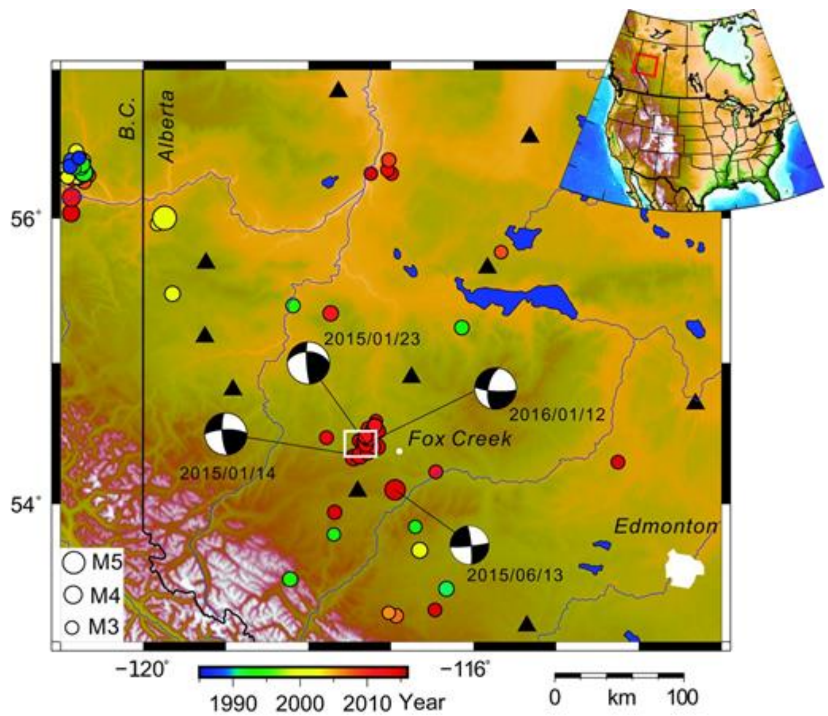

Figure 6.5: Seismicity of northwestern Alberta, Canada between 1985 to 2016. Symbol size indicates magnitude, and color denotes date of occurrence (Bao & Eaton, 2016).

This study by Bao and Eaton (2016) has paired comprehensive injection data during a four month interval, with a template based earthquake catalog from seismically active Canadian shale play. This revealed that earthquakes in northwestern Canada are tightly clustered in space and time near hydraulic fracturing sites (Figure 6.6) (Bao and Eaton, 2016). One of the largest, events with a magnitude of 3.9, occurred several weeks after the injection along a fault that connects the injection zone into crystalline basement (Bao and Eaton, 2016).

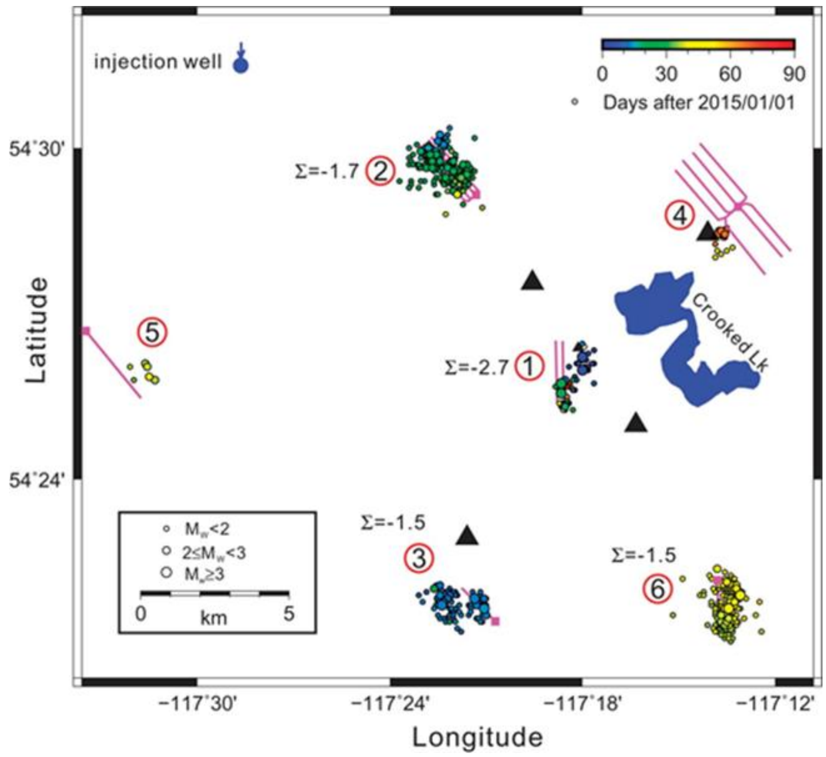

Figure 6.6: Details of seismicity induced by hydraulic fracturing at six well pads from December 2014 to March 2015 in northwestern Alberta. Event symbols are colored by date of occurrence and are scaled on the basis of magnitude. Well pads are numbered sequentially by initiation of hydraulic-fracturing operation. Local broadband seismograph stations are shown in black triangles (Bao & Eaton, 2016).

A case study conducted in the Horn River basin, Canada (Woo et al., 2017) has attempted to elucidate the nature of microseismic generation in relation to pre-existing natural faults and hydraulic fracturing. It was clearly observed that hydraulic fracturing has induced most of the seismic events as most strikes of the best fitting planes of selected hypocenters are consistent with the direction of local horizontal stress maximum (Woo et al., 2017). Moreover, pre-existing natural faults or fractures were found to be contributing towards seismic activities as the best fitting planes of several seismic clusters were observed to be similar to pre-existing faults or fractures (Woo et al., 2017). In addition, this study has observed several important spatial occurrence patterns which appears to be connected with the existing natural fractures (Woo et al., 2017). The graphical illustrations of the results are included in further detail in Appendix A as Case Study A1.

This evidence suggest that the occurrence of induced earthquakes are reported to be associated with two key factors, the geology of the region, including existing fractures, and the nature of operational practices such as volume and pressure of injected fluids (Woo et al., 2017). Though the east coast is considered to be tectonically stable and less prone to earthquakes (Wheeler et al., 2014), long term consequences of deep well wastewater injection, and hydraulic fracturing are not entirely understood.

6.2.5 Impacts on Biodiversity

Changes in land use patterns and the construction of production sites for hydraulic fracturing operations can result in habitat loss and fragmentation, which can threaten the character of the landscape, its ecological structure and function, and native biodiversity (Wheeler et al., 2014). Moreover, hydrological patterns, agricultural productivity, and flows of energy and nutrients in the local ecosystem may also be significantly affected due to large scale land use alterations (Wheeler et al., 2014). In a natural ecosystem where hydraulic fracturing takes place, there can be certain species which are overly sensitive to habitat disturbances due to their limited population size or specialized habitat requirements (NBChydraulic fracturing, 2016). These species are often observed to be more sensitive to impacts from all human activities, including shale gas explorations (NBChydraulic fracturing, 2016). Habitat fragmentation in Nova Scotia has already lead to species such as the mainland moose, American marten, and Canada lynx becoming listed as endangered species (Wheeler et al., 2014). It is possible that further disturbances to these habitats from hydraulic fracturing may lead to intensified pressure and thus possible extinction (Wheeler et al., 2014).

Research carried out in Wyoming and Pennsylvania found that intensified natural gas development in the local environment is connected with increased activity of nest predator species, elevating predation rates, and thereby threatening the songbird populations (NBChydraulic fracturing, 2016). Furthermore, minor alteration in forest cover and edge effect are recorded to also have significant negative impacts on songbird populations (Yoo et al., 2017). This was depicted in a study conducted in southeastern Alberta, which monitored two grassland songbird species, the Savannah sparrow (Passerculus sandwichensis) and chestnut-collared longspur (Calcarius ornatus) (Yoo et al., 2017). Through this research, it appears evident that the nest success of Savannah sparrow is significantly impacted from proximity to roads or trails (Figure 6.7) (Yoo et al., 2017).

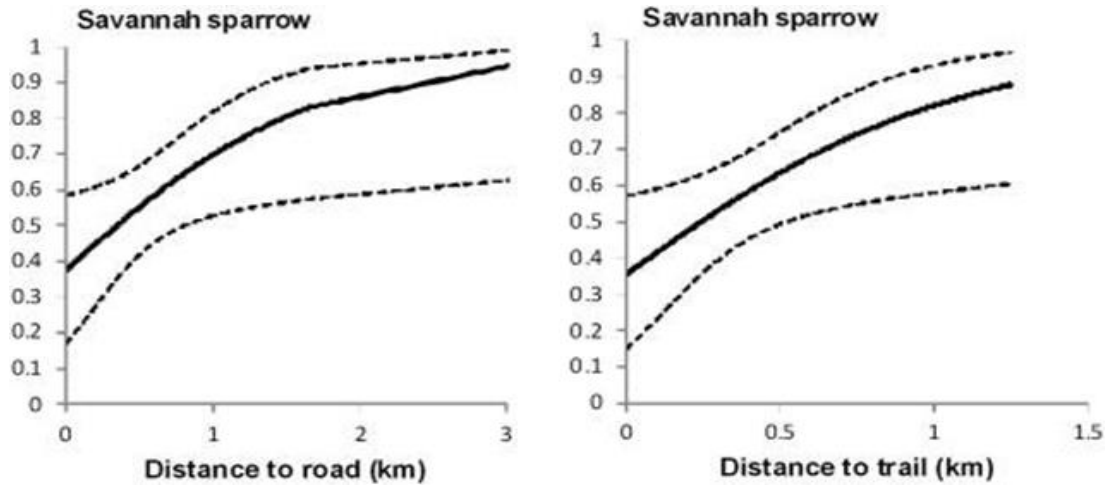

Figure 6.7: Effects of proximity to roads and trails on the nest success of the Savannah Sparrow in southern Alberta, Canada (Yoo et al., 2017).

Not only birds, but also certain large terrestrial mammals can be impacted from shale gas related activities. A study which examined the habitat selection patterns of mule deer in Colorado found that more than 50% of their winter range and habitat selection was influenced by the natural oil and gas activities in the region (NBChydraulic fracturing, 2016; Northup et al., 2015). The New Brunswick commission on Hydraulic fracturing has reported three ways that fish and aquatic organisms can be affected by shale gas development: (1) hydrological pathways due to water withdrawal, (2) chemical pathways due to contamination of water bodies from fracturing fluids and wastewater, and (3) physical pathways due to sedimentation and suspended solids (NBChydraulic fracturing, 2016). Moreover, stream water acidity and bromide pollution can result in toxicity to fish and macroinvertebrates, and also the bioaccumulation of toxic compounds across several trophic levels of the food chain (NBChydraulic fracturing, 2016).

6.3 Economic Implications

As a result of the moratorium on hydraulic fracturing instituted in 2014, research findings regarding the economic analysis of these operations, specifically dealing with Nova Scotia, are extremely limited. This section builds on the 2014 Wheeler Report discussion of unconventional gas and oil development scenarios, petroleum operational costs and opportunities as well as the impacts of the royalty scheme within the province.

6.3.1 Market Analysis Including Supply & Demand Considerations

When identifying potential economic impacts with respect to USGD in Nova Scotia, a market analysis is an important consideration. The 2014 Wheeler Report included a forecast of anticipated natural gas consumption in North America considering supply and demand until 2035 (Figure 6.8). Figure 6.8 shows that forecasted demand of natural gas in Canada is expected to increase from 10 Bcf/d in 2020, up to 12 bcf/d in 2035 which is considerably lower in comparison to the supply of natural gas which falls around 16 bcf/d in 2020, increasing to 17 bcf/d in 2035. Considering the large gap between supply and demand, it can be expected that the price of natural gas in Canada will continue to be relatively low. However, it is important to note that the global demand for natural gas also continues to increase which helps to reduce the overall impact of this supply and demand gap.

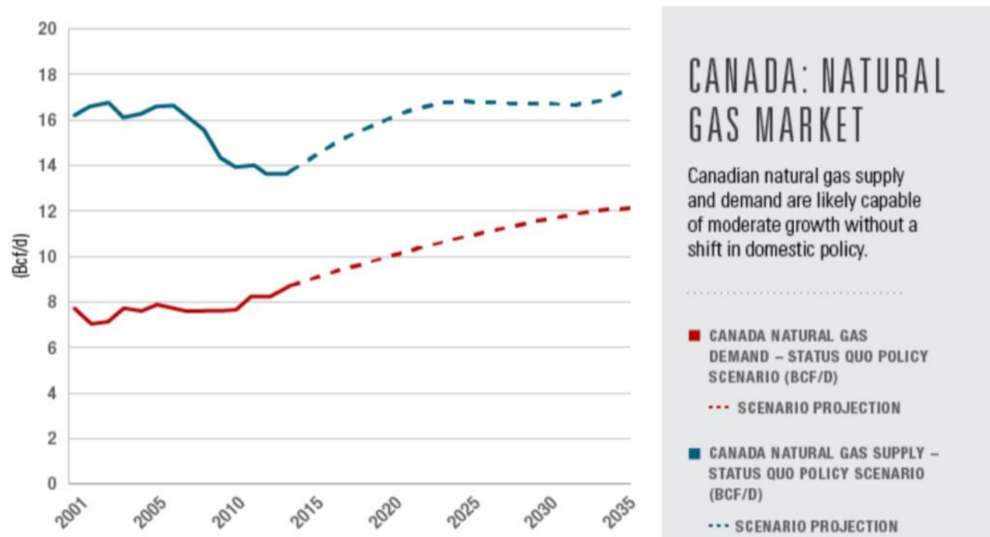

Figure 6.8: Canadian natural gas market forecasted until 2035 (Wheeler et al., 2014).

The supply increase is a result of the global adoption of hydraulic fracturing technologies which have been used to increase natural gas production by 25% (Christenson, Goldfarb, & Kriner, 2017). As a result, natural gas prices have decreased by more than 40% (Christenson, Goldfarb, & Kriner, 2017). This forecast should be considered in comparison to an updated forecast of the production of natural gas in North America from the 2017 World Energy Outlook Report (Table 6.4).

This 2017 forecast suggests that the Canadian supply of natural gas in 2035 is expected to be 18.38 bcf/d (International Energy Authority, 2017). Additionally, the 2018 forecast suggests that the Canadian supply of natural gas in 2035 will only be 0.15% of the total North American supply. Considering the gap between the forecasted supply and demand, Cumberland County must keep in mind the likelihood that the prices of Canadian natural gas will remain relatively low and will likely decrease as environmentally sustainable energy solutions increase in popularity and usage.

Table 6.4: Natural gas production by region converted from bcm to bcf/d (IEA, 2017).

	2000	2016	2025	2030	2035	2040	2016 to 240	
							Change	**CAAGR**
North America	73.79	92.84	112.77	117.22	123.99	129.40	36.65	1.4%
Canada	17.60	16.83	15.38	15.96	18.38	21.47	4.74	1.0%
Mexico	3.58	3.58	3.38	3.68	4.64	5.61	2.03	1.9%
United States	52.61	72.44	93.91	97.58	100.87	102.32	29.88	1.4%

The 2014 Wheeler Report outlined four potential scenarios for USGD in Nova Scotia including the following:

1. **Zero Case**: No commercial development established in any basin.
2. **Lower/Medium Case**: One basin fully developed.
   - 10 TCF Recoverable Resource Plus Condensate
   - 4,000 Wells Within One Basin Likely Windsor-Kennetcook or Cumberland
3. **Upper/Medium Case**: three basins fully developed.
   - 30 TCF Recoverable Plus Condensate
   - 4,000 Wells Within Each Basin (Total of 12,000);
   - Cumberland, Windsor-Kennetcook & Stellarton/Debert-Kemptown/Minas
4. **Maximum Case**: Five basins successfully developed for gas and one for oil.
   - 50 TCF Recoverable – 4,000 Wells in the Five Gas Bearing Basins (Total of 20,000)
   - 50 MMBO Recoverable – 250 Wells in the Oil-Bearing Basin

Each scenario would require significant funding to explore the basins and begin any sort of major development. Since 2014, the efficiency of hydrocarbon production and development has increased significantly resulting in a 25 to 30% reduction in the associated costs (Brasier et al., 2014). The economic efficiency of these operations which continues to improve within the industry, is an important consideration for Cumberland County as this may help to counteract the low prices of natural gas in the Canadian market.

6.3.2 Exploration Costs

When identifying the specific location and abundance of hydrocarbon resources, there are three main considerations impacting cost. These considerations rely on data related to the geologic, geochemical and geophysical characteristics of the reservoir in question (Wheeler et al., 2014). To collect and analyze this data typically costs between $1 and 2 Million dollars (Wheeler et al., 2014). These exploration costs are quite significant and if the resulting findings indicate that the basin is not profitable, they are essentially sunk costs with little associated benefit. However, there have been profitable operations that have not required overly burdensome exploration costs (Table 6.5).

Table 6.5: Mecellus Unconventional Shale Gas Development Cost Breakdown (Hefley & Wang, 2015).

Phase Description	Cost
Acquisition & Leasing	$2,191,125
Permitting	$10,075
Site Preparation	$400,000
Vertical Drilling	$663,275
Horizontal Drilling	$1,214,850
Fracturing	$2,500,000
Completion	$200,000
Production to Gathering	$472,500
Total	**$7,651,825**

Without including the acquisition and leasing costs, the US Marcellus USGD involved hydraulic fracturing operations with only $410,075 in associated exploration costs (Hefley & Wang, 2015). The Marcellus USGD provides a useful example outlining the cost of a hydraulic fracturing operation. The decrease in the costs associated with USGD is an important consideration for Cumberland County, although the County itself would not be impacted by these costs should the mortarium be lifted. This is because the companies choosing to enter the Nova Scotia energy sector would actually pay for the exploration and development.

6.3.3 Royalties

A major component of the economic benefits associated with USGD, is the financial returns from royalties. Exploration, drilling and production projects have translated into approximately $1.5 to 2 Billion in royalty payments made to the province of Nova Scotia (Wheeler et al., 2014). The provincial legislation requires that any petroleum production in Nova Scotia is subject to a royalty rate of 10% of the fair market value of the petroleum produced each month (Wheeler et al., 2014). More recently, New Brunswick reviewed the potential royalty revenues they would benefit from if they chose to pursue hydraulic fracturing (Figure 6.9).

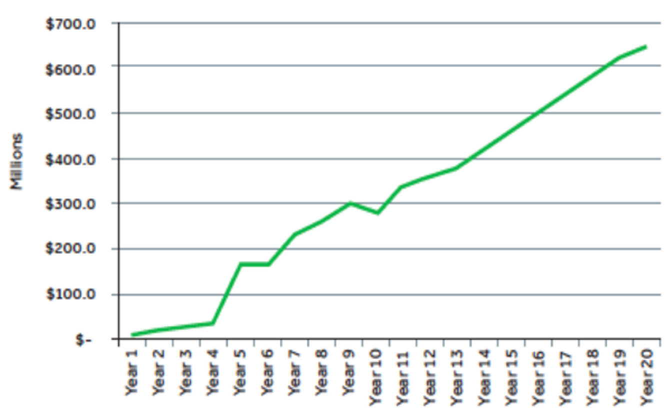

Figure 6.9: Potential royalty revenues for New Brunswick between 2015 and 2025 (New Brunswick Commission on Hydraulic Fracturing, 2016).

This study predicts that New Brunswick could earn up to approximately $650 Million in 2035 (NB Commission on Hydraulic Fracturing, 2016). These potential revenue from royalty payments is significant. However, these payments are made directly to the province which should be a major consideration for Cumberland County. Should the province lift the moratorium and allow development of the Cumberland County natural gas reservoirs, the local communities will deal with the environmental and social impacts of the fracturing operations and may receive only a fraction of the potential economic benefits.

6.3.4 Job Creation

To make a decision about whether to pursue hydraulic fracturing in Cumberland County, a comprehensive cost-benefit analysis is required to determine if the potential revenue is sufficient enough to justify the development of onshore natural gas reserves. In considering the interests of the Municipality, factors including the costs and benefits associated with the economic, environmental and social impacts of hydraulic fracturing should be considered.

There are clearly uncertainties associated with the market, the value and size of the potential USGD resource as well as the environmental and social impacts of hydraulic fracturing (Wheeler et al., 2014). However, to the extent that the industry follows certain trends, and considering the research findings that have been discussed, including the price of natural gas in the Canadian market, the 10% royalty payments required and the general increase in economic efficiency that has been observed in the industry, it is possible to generally consider the economic impacts specific to Cumberland County.

The main factor that would lead to economic benefits for Cumberland County specifically, is the creation of jobs. In Williston, North Dakota, in 2000 before any significant growth in the energy sector, the percentage of the population employed in the oil industry was 8.5% (Strangeland, 2016). In 2016 after a boom in the energy sector, the percentage of the population employed in the oil industry was 19.4% (Strangeland, 2016). This study found that as the oil and natural gas prices increased, job creation also increased (Strangeland, 2016). Job creation also increased more generally as more companies became involved in supplying and the transportation of goods as required by the oil industry (Strangeland, 2016).

Some have argued that the oil and gas industry also steals jobs from different industries because of the overly-competitive wages offered throughout the energy sector (Strangeland, 2016). It is difficult to confidently estimate the job creation that would occur in Cumberland County specifically with the development of the onshore natural gas reserves. However, significant job creation can be anticipated both in the natural gas industry as well as more generally within the County. This is simply because as the population increases, there will be increased demand for almost all industries.

Additional research found that when Germany passed legislation in 2016 allowing companies to pursue hydraulic fracturing (D'Amato, Shastri, Spathopoulos, Spisto & Zoli, 2017). This resulted in the creation of more than 300 jobs (D'Amato et al., 2017). In the United States, USGD is projected to increase from 42% of the total natural gas production to 64% in 2020 (Christenson, Goldfarb & Kriner, 2017). This growth is projected to create roughly 52,000 jobs within the State of Pennsylvania alone (Christenson, Goldfarb & Kriner, 2017). This type of job creation would significantly benefit Cumberland County, particularly if residents of Cumberland County currently working out west, could be brought home to take advantage of the local natural gas opportunities.

6.4 Social Considerations

Unconventional shale gas development has several impacts on individuals and communities over various spatial and temporal time scales and among different social groups. This section discusses these social considerations including the socio-economic impacts, social and physical infrastructure implications as well as both the environmental and public health aspects of hydraulic fracturing. The socio-economic impacts that will be discussed include the creation of jobs and the increase of business activity. The social and physical infrastructure implications include overextended hospitals, housing, law enforcement and road infrastructure and the environmental considerations include how environmental degradation impacts communities.

When assessing the social considerations of USGD, it is important to acknowledge that many of the studies to date have been conducted in the United States. The 2014 Wheeler Report points out three contextual items when evaluating the applicability of these studies to Nova Scotia:

1. Most landowners in the US own the rights to subsurface minerals on their land and may choose to lease their land to oil and gas companies which may accentuate conflict and inequality within communities. In Canada mineral rights are mainly held by the Crown such that individual landowners do not stand to benefit in the same way that they do in the US (Wheeler et al., 2014).
2. The regulatory regimes in Canada tend to be more restrictive compared with those of the US (Wheeler et al., 2014).
3. There is a patriotic theme underlying the decision by some US citizens to allow for oil and gas development on their land, in the interest of reducing American dependence on foreign energy. Canadians are unlikely to exhibit similar behaviors (Wheeler et al., 2014).

6.4.1 Socio-Economic Impacts

The 2014 Wheeler Report describes various socio-economic impacts from USGD, such as job creation, population growth, and increased sociocultural diversity. These impacts may have several residual effects, including increased rental prices on housing which will have a negative impact on low-income renters, but will also increase the revenue of landowners (Wheeler et al., 2014). Since 2014, a number of researchers have studied the socio-economic impacts that hydraulic fracturing has on communities. A 2016 study in Williston, North Dakota, assessed the socio-economic impacts from hydraulic fracturing, by collecting data on population growth, housing, tax structure, revenue distribution, infrastructure demands and crime (Stangeland, 2016).

The study compared social indicators of well-being before and after development between 2000 and 2016. As a result of the hydraulic fracturing operations, the community experienced an increase in population, a housing shortage, increased infrastructure demands, and an elevated crime rate (Stangeland, 2016). However, the community also enjoyed several benefits, including increased employment, access to better paying jobs, increased income and tax revenue, and a growth in government services (Stangeland, 2016). This study has been included in Appendix A as Case Study A2.

6.4.2 Social & Physical Infrastructure

As outlined in the 2014 Wheeler Report, the impacts on social and physical infrastructure associated with hydraulic fracturing are largely attributed to population growth. However, recent studies have identified additional factors that contribute to pressures on social infrastructure. For example, Jemielita et al. (2015) studied the relationship between hospital inpatient records, and the number and density of natural gas wells in Pennsylvania from 2007 to 2011.

The study found that areas with a greater number of active wells had an increased inpatient prevalence rate during the period of study (Jemielita et al., 2015). The elevated inpatient prevalence rates were attributed to the increased potential toxicant exposure and stress responses in residents resulting from the influx in migrant workers as well as the use of diesel engines in nearby oil and gas developments (Jemielita et al., 2015). However, it is possible that the inpatient increase was partially due to regional population growth (Jemielita et al., 2015). In an attempt to isolate population growth, the inpatient prevalence rates only accounted for those who were permanent residents of Pennsylvania and excluded transient workers (Jemielita et al., 2015). Additionally, as transient workers were not included in the study, it is possible that hospital-use may have been even greater (Jemielita et al., 2015).

A similar study in 2014 focused on hydraulic fracturing in four locations across north central and southwest Pennsylvania and further suggested that hydraulic fracturing increases the pressure on health care infrastructure (Brasier et al., 2014). This study identified that communities impacted by hydraulic fracturing tend to observe increased rates of hospitalization, visits to healthcare professionals, emergency room visits, neurological visits and primary care visits (Brasier et al., 2014). In addition to the impacts that hydraulic fracturing had on regional healthcare infrastructure, the study identified impacts on a range of social factors, including population, education, youth, housing, crime, and regional economics. A detailed account of these findings has been provided in Appendix A as Case Study A3.

6.4.3 Cultural Impacts

Deterioration of the natural environment can have both direct, and indirect impacts on human health, as well as on social and cultural values. Indigenous peoples, for example, have a strong relationship with land and water, which draws on their ways of knowing, and ways of being in the world (Moore, Von der Porten, & Castelden, 2016). Many Indigenous cultures in Canada maintain that beyond survival, their connections to land and water are tied to their cultural identity (Moore et al., 2016). Indigenous peoples in Canada are already disproportionately affected by environmental issues such as unsafe drinking water, and a lack of properly functioning wastewater systems, and have previously been systematically marginalized as a result of resource extraction (Moore et al., 2016). The effects of environmental degradation from hydraulic fracturing on Indigenous peoples is thus disproportionate to the impacts felt by other communities.

A recent study interviewed land managers from Treaty 8 First Nation territory, regarding the impacts that shale gas development has had on their community (Garvie & Shaw, 2016). Those that were interviewed unanimously consider present day USGD to be environmentally and culturally destructive (Garvie & Shaw, 2016). Those interviewed also expressed concern that the industry would impact their community's ability to enforce treaty rights. The phrase "death by a thousand cuts" was used by one land manager to describe the impact that USGD was having on their community (Garvie & Shaw, 2016).

Land managers of the Treaty 8 First Nation specified that the absence of any landscape-scale planning and management to monitor cumulative impacts as each new development chips away at the integrity of the environment, is a substantial point of concern (Garvie & Shaw, 2016). The struggle to balance economic opportunities with environmental degradation has been a challenge to the northern community, as there are few other employment opportunities in the area (Garvie & Shaw, 2016). Despite the Treaty 8 First Nation's view that USGD is environmentally and culturally destructive, the Fort Nelson First Nation band council is currently in support of the industry, as long as conditions for balanced development are met (Garvie & Shaw, 2016). These conditions include, but are not limited to:

1. Regional baseline studies before permits are issued;
2. Multi-year pre-development plans from industry and government;
3. Cumulative environmental assessments;
4. The protection of culturally significant areas and resources; and
5. Third-party, independent monitoring and enforcement of all activities (Garvie & Shaw, 2016).

These conditions outline important considerations the province could take into account when considering how to mitigate impacts on Indigenous communities, should future USGD take place in Nova Scotia.

6.5 Public Health Considerations

Hydraulic fracturing is unlikely to pose catastrophic risk to human health in the short or medium term, however it is less evident how long-term environmental effects such as climate change will influence the health of current and future generations (Wheeler et al., 2014). This report is aligned with the 2014 Wheeler Report in that the World Health Organization's (1948) definition of health has been adopted. As such, health is defined as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (Wheeler et al., 2014).

This section discusses a number of health risks that should inform government decision-making in terms of the potential adoption of hydraulic fracturing in Nova Scotia. The following subsections outline the direct pathways and health concerns associated with chemical contamination from hydraulic fracturing, the indirect pathways and effects of the drilling and fracturing processes, the broad impacts on communities as well as concerns about mental health and community relationships for transient workers.

6.5.1 Health Concerns from Direct Pathways

There are two primary direct pathways of chemical contamination from hydraulic fracturing, air pollution and the contamination of drinking water supplies (Wheeler et al., 2014). Chemical contamination may occur from a variety of hydraulic fracturing process steps, and the contamination of drinking water specifically, may occur after industrial accidents, surface spills, or well-bore or surface casing failures resulting in chemicals coming into contact with drinking water supplies (Wheeler et al., 2014). Rigorous research regarding the health implications of hydraulic fracturing is limited by the recency of the technology, as well as regulatory gaps preventing effective health impact assessments (Wheeler et al., 2014). Despite these limitations, in recent years the number of studies concerning the health effects of hydraulic fracturing have increased (Hirsch et al., 2018).

The Wheeler report provided preliminary insight into the effects of hydraulic fracturing operations on cancer rates and reproductive outcomes; however, recommended that further research be conducted on the subject. A systematic review of 45 published research articles related to oil and gas extraction and human reproductive outcomes revealed that there is moderate evidence suggesting an increased risk of prostate cancer, decreased semen quality, birth defects, preterm birth and miscarriage from exposure to oil and gas activities (Balise et al., 2016). The studies consulted included a number of exposure types including residential proximity, occupational exposure and experimental, in a number of locations such as Taiwan, USA, Sweden, France, Brazil and others (Balise et al., 2016). The study also reported that there is sufficient evidence for the disruption of estrogen, androgen and progesterone receptors from oil and gas chemicals (Balise et al., 2016). While many of the studies consulted were drawn from conventional oil and gas operations, unconventional activities may have a greater negative impact on human health, as many of the processes are the same, yet more endocrine-disrupting chemicals are used in hydraulic fracturing (Balise et al., 2016).

Recent studies have also revealed that individuals in communities with hydraulic fracturing developments experience an array of physical symptoms, including fatigue, headaches, ocular and dermatologic irritation, confusion and delirium, and a variety of respiratory, gastrointestinal, immunological, endocrine and sensory maladies (Cabrera, Tesluk, Chakraborti, Matthews & Illes, 2016; Colborn, Schultz, Herrick & Kwiatkowski, 2014; Hirsch et al., 2018). Health impacts such as decreased lung function, asthma, silicosis and other respiratory problems have also been attributed to long-term exposure to a variety of airborne contaminants, including fine particulate matter ($PM_{2.5}$) from diesel emissions, respirable silica from hydraulic fracturing sands, and surface level ozone (O_3) from increased Nitrous Oxides (NO_x) and Volatile Organic Compounds (VOCs) (Moore et al., 2014).

6.5.2 Health Concerns from Indirect Pathways

In addition to concerns associated with chemical contamination, health concerns also arise from indirect pathways. These indirect pathways include factors such as increased traffic, increased noise and light and additional fracturing impacts which have the potential to reduce the quality of life for individuals living near drilling operations (Wheeler et al., 2014). Light pollution is often more regional to the drilling sight, in comparison noise is capable of contributing to sleep disturbance and can be heard at distances of up to 1.5 km from the site (Wheeler et al., 2014). Increased traffic contributes to noise pollution and increases the likelihood for accidents and collisions (Wheeler et al., 2014). Additionally, increased traffic is detrimental to regional air quality as a result of increased diesel emissions (Wheeler et al., 2014). The aforementioned factors can result in increased fatigue and blood pressure, sleep deprivation, mental anguish and stress-related illnesses (Wheeler et al., 2014). Recent studies have identified additional health implications from indirect pathways associated with hydraulic fracturing operations. For example, increased cardiology and neurology inpatient prevalence rates were found to be correlated with the number of wells, and well density (Jemielita et al., 2015).

6.5.3 Community Impacts

While few studies have emerged to quantify physical illnesses associated with hydraulic fracturing, a number of qualitative studies have been conducted on the psychosocial community health implications of hydraulic fracturing (Appendix D, Table D1). Although psychosocial health impacts are less tangible than physical illnesses, a great deal of research is being conducted to identify the impacts that hydraulic fracturing may have on community bonds, and the mental health of residents. Several more recent studies have attempted to identify the factors that influence psychosocial health. For example, it was found that psychosocial impacts are largely shaped by one's perception (Lai, Lyons, Gudergan & Grimstad, 2017). This study surveyed community members impacted by hydraulic fracturing and found that those who held a positive perception of hydraulic fracturing were more likely to experience positive emotions and well-being compared with those with a negative perception of hydraulic fracturing (Lai et al., 2017). The study found that regardless of their validity, perceptions about hydraulic fracturing influence the experiences of each community member (Lai et al., 2017).

Recent research suggests that community members are susceptible to distress about the unknown relating to dangerous chemicals, environmental safety, land and housing prices, job assurances and future livelihoods (Drummond & Grubert, 2017; Hirsch et al., 2018; Watterson & Dinan, 2015). These concerns can result in feelings of anger, anxiety, helplessness, and diminished trust in industry and government (Drummond & Grubert, 2017; Hirsch et al., 2018; Watterson & Dinan, 2015). Furthermore, differences in perceptions amongst community members regarding the introduction of hydraulic fracturing operations in the community can contribute to psychosocial distress (Evensen & Stedman, 2018).

A recent study surveyed 104 residents of a rural community in the Appalachia region of the United States where hydraulic fracturing operations are ongoing (Morrone, Chadwick & Kruse, 2015). Residents reported that they experienced disruptions to social cohesion, community pride, and shared community values, and felt as though they were being exploited (Morrone et al., 2015). The influx of migratory workers resulting from hydraulic fracturing also tends to contribute to community tensions by introducing gender imbalances and eliciting fear in community members, ultimately contributing to collective community trauma (Hirsch et al., 2018).

6.5.4 Mental Health & Community Relationships of Transient Workers

Substantial research exists regarding the impacts of contaminants on the health of oil and gas operators. However, the literature on the mental health of those working in the industry, and their relationships with host communities has historically been overlooked (Hirsch et al., 2018). A review of hydraulic fracturing-related health risks observed that migrant oil and gas workers tend to suffer from social isolation, which among other factors, may contribute to substance misuse and violence (Moss, Coram, & Blashki, 2016). Additionally, transient workers experiencing psychological distress often do not to have access to resources or health benefits in their host communities (Hirsch et al., 2018). Furthermore, these individuals are often faced with hostility from locals, depriving them of opportunities to socially engage with the community (Filteau, 2015). Literature on the mental health of oil and gas workers is sparse, suggesting future research is needed.

6.6 Mitigating Societal & Public Health Implications

It has been suggested that four key mitigative measures could help to reduce the impacts of hydraulic fracturing on public health include (1) conducting a health impact assessment, (2) monitoring health status, (3) emergency preparedness and (4) conducting additional research (Wheeler et al., 2014). Since 2014, several human health and environmental risk management options have emerged in the literature. Larkin et al. (2018) presents regulatory, economic, advisory, community-based, and technological (REACT) strategies for environmental and health risk management options concerning USGD using hydraulic fracturing technology in Alberta and British Columbia. The risk management options address several issues associated with hydraulic fracturing, including the project approval process, environmental monitoring, the protection of air and water quality, fracturing fluid composition, seismicity, human health surveillance, worker and public safety, and information and site management (Larkin et al., 2018). The REACT risk management strategy is included in Appendix D, Table D2.

7.0 Recommendations & Conclusions

In order to evaluate the factors contributing to a final recommendation, a decision matrix was constructed (Table 7.1). The decision matrix illustrates the scores of between one and five, assigned to each factor including economy, social, technology and the environment. A higher score indicates that the considerations for that factor weigh positively in favor of the option being assessed. Three options are considered including (1) supporting hydraulic fracturing in Cumberland County, (2) taking a position against hydraulic fracturing and (3) pursuing additional research. The decision matrix helps to illustrate whether each factor supports the listed options based on the research findings discussed at length throughout this report.

Table 7.1: Decision Matrix

Option	Economy	Technology	Social	Environment	Total
Support Hydraulic Fracturing	4	3	2	2	**11**
Do Not Support Hydraulic Fracturing	3	3	4	2	12
Conduct More Research	1	3	3	4	**11**

In terms of the economy, there are both costs and benefits associated with hydraulic fracturing. There is a significant potential for revenue through royalties, although most of this would go to the province of Nova Scotia. Of more importance to Cumberland County, there will likely be considerable job creation within the local communities both associated with and aside from the hydraulic fracturing operations. It is also important to consider the potential for remediation costs and other financial commitments that will be required into the long-term.

Overall, the potential for job creation and provincial revenues associated with hydraulic fracturing outweighs the associated and uncertain future costs resulting in a score of four in support of hydraulic fracturing operations. Taking into account the disproportionate effects that have been observed on local communities in terms of the benefits they actually receive, taking a position against hydraulic fracturing received a score of three.

There have been very few technological developments since the 2014 Wheeler Report. However, there have been advancements in the overall efficiency, general safety and environmental safety of the hydraulic fracturing process. Despite these advancements, there are still associated risks to hydraulic fracturing operations, particularly in areas such as chemical storage and treatment, as well as transportation where there is more room for human error. As such, a hydraulic fracturing operation and the associated technology is not guaranteed to provide 100% safety and efficiency. As the technology does exist to efficiently and (generally) safely pursue hydraulic fracturing in Cumberland County should the moratorium be lifted, and because there have been few developments since 2014, each option received a relatively neutral score of three.

The impacts on communities tend to be disproportionate to the benefits actually received in those communities largely due to the increased pressures on social and physical infrastructure from growing populations, the deterioration of public health from airborne and aquatic contamination and the psychosocial community distress resulting from environmental degradation combined with the effects of the rapid introduction of migrant workers. While job creation and population growth would benefit Cumberland County, it is unclear whether the local communities will be prepared to deal with the social implications and the long-term burdens associated with hydraulic fracturing. Considering the balance required between economic security and societal longevity, taking a position against hydraulic fracturing has received a score of four followed by conducting more research which received a score of three.

The risk of direct contamination of groundwater through hydraulic fracturing is relatively low. The risk of environmental degradation through chemical contamination, as previously mentioned, is largely associated with improper chemical use and storage. It may be possible to mitigate these risks with strong regulations and improved technology. However, there is also a significant risk of induced seismicity, air pollution, negative impacts on biodiversity as well as an increased potential of global warming. Considering these environmental concerns, it would seem that further research is needed to identify potential mitigation strategies and to better understand the long-term impacts of continuously pumping pressurized fluids into the earth.

After considering all of these factors, a total score has been provided for each option in the decision matrix (Table 7.1). Taking a position against hydraulic fracturing has achieved the highest score. However, both alternate options also scored almost equally as highly. As such, it is recommended that the Cumberland Energy Authority cautiously considers the potential of hydraulic fracturing operations and how they would impact the local communities in the long-term. A strong case can be made both for and against hydraulic fracturing which is why it is such a contentious topic. It is absolutely critical to inform and educate both the local government and decision makers as well as the public in order to come to a well thought out and reasonable decision about how to proceed.

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