Modernizing Caprock Integrity Regulations for Natural Gas Storage Sites to Mitigate Fugitive Gas Emissions

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Abstract

Natural gas is often considered to be clean alternative energy source when compared to other fossil fuels. It burns cleaner than coal, is abundantly available, and is relatively cheap for consumers. While it is an appealing alternative that could assist in Canada's pursuit of its Paris Agreement goals and net-zero ambitions, natural gas production and usage in the country has been relatively stagnant. As the pressure to reach climate change mitigation goals increases, Canada may wish to transition more of its energy production to natural gas. This increase in demand would then require more underground gas storage capacity. Alberta has the highest underground storage capacity with an abundance of depleted oil and gas reservoirs that could serve this purpose. A risk associated with underground storage is the structural integrity of caprock. Fractures in caprock caused by injecting pressurized gas have the potential to be pathways for fugitive gas migration. Natural gas, which is composed mostly of methane, could then migrate through these fractures into shallow aquifers and surrounding surface environments, posing a risk of contamination that can have detrimental impacts on the ecosystem and human health. If there is an increase in natural gas demand and a subsequent increase in demand for underground gas storage, is the current regulatory framework in Alberta able to maintain safe and efficient underground storage practices at higher volumes, or will policy modernization be necessary to accommodate for more volume? This paper provides a review of regulations that guide caprock integrity testing and scientific studies on underground gas storage incidents to analyze whether modernization of regulations would be necessary if natural gas storage demand increases in Canada. Following this analysis, we suggest several policy options to modernize Alberta's regulations that could accommodate for an increase in demand for natural gas storage capacity.

Key Words: Fugitive gas emissions, caprock, natural gas, underground gas storage, Alberta energy

1.0 Introduction

Climate change has become a defining feature of Canada's political, industrial, and social landscape. Canada, like most of the world, is attempting to reduce its contributions to global emissions and its impact on climate change through policies that incentivize emissions reductions and cleaner energy usage. The country's aim is to reach its Paris Agreement commitment of a 30% reduction of greenhouse gas emissions by 2030 (Government of Canada 2020b). The government of Canada also announced recently that it plans on developing a strategy to reach net-zero emissions by 2050 (Government of Canada 2020b).

Part of this transition can include the transition to more natural gas usage as a cleaner burning alternative. Canada ranks fourth in the world for natural gas production, but the production levels have remained relatively unchanged, especially compared to the United States, where natural gas production has increased steadily over time (Government of Canada 2020a). Current projections show natural gas production in Canada increasing through 2040, in line with the transition towards cleaner energy sources and lower greenhouse gas emissions (Canada Energy Regulator 2019). While natural gas burns cleaner when compared to other fossil fuels, an increase in production and demand will require an increase of underground gas storage capacity. But how safe is the underground storage of gases?

One possible risk with storing gases underground is the potential for the caprock above the storage reservoir to fracture. The injection of gas into reservoirs may compromise the integrity of the caprock, depending on the injection rate and pressure change in the reservoir. Fractures in caprock above a gas storage reservoir creates a pathway for the gases to migrate upwards, resulting in difficult to manage fugitive gas emissions. If there is an increase in natural gas demand and a subsequent increase in demand for underground gas storage, is the current regulatory framework able to maintain safe and efficient underground storage practices at higher volumes, or will policy modernization be necessary to accommodate for more volume?

This paper will explore the benefits and risks that come with increasing underground gas storage for the purpose of natural gas energy production and usage. The current directives that regulate underground gas storage projects in Alberta will be examined to identify potential areas for modernization after gaining a better understanding of how fractures in caprock are created and exacerbated by gas injection. Modernizing gas storage regulations may be required if Canada is to transition to more natural gas production and usage to ensure that any new storage projects that are intended to meet the increased demand do not sacrifice safety or pose significant risks to the surrounding environment or human health.

2.0 Natural Gas in Canada and Alberta

This paper focuses on Alberta's oil and gas industry. Alberta has the highest amount of oil and gas production in Canada at 3.91 million barrels per day of crude oil and 10.5 billion cubic feet (BCF) per day of natural gas, which is 65% of Canada's natural gas production. The province also holds the most natural gas storage capacity with twelve sites and the highest natural gas storage levels at 550 BCF (Canada Energy Regulator 2018).

Natural gas, a hydrocarbon composed mainly of methane, is a cleaner burning energy source when compared to other fossil fuels and is considered a clean energy alternative (Brinson 2012). It emits between 50 and 60 percent less carbon dioxide compared to coal power plants while being abundant and inexpensive relative to other sources of power (Union of Concerned Scientists 2014). Besides emitting less greenhouse gases, natural gas burning does not produce harmful particulates that can lead to human health and environmental issues (Brinson 2012). These features make natural gas usage an attractive energy source, particularly as a means to reduce greenhouse gas emissions while still sufficiently meeting energy demand.

Canada's natural gas usage accounts for over 30 percent of the total energy mix but fluctuates based on seasonal demand (Canadian Gas Association 2016). In the winter, demand is approximately 12 BCF per day compared to approximately 7 BCF per day in the summer (Canada Energy Regulator 2018). The fluctuating demand, coupled with continuous production, requires an immense amount of storage capacity. Canada has nearly 950 BCF of natural gas storage spread between Alberta, British Columbia, Saskatchewan, Ontario, Quebec (Canada Energy Regulator 2018). This accounts for roughly 30 percent of the country's annual demand (Canadian Gas Association 2016). Current increases in demand for natural gas has also led to the construction of a storage facility in Nova Scotia. This practice reduces price volatility and balances the flow in the pipeline system (Bruno et al. 2014). Alberta holds over half of Canada's total capacity at nearly 550 BCF stored in depleted oil and gas production reservoirs (Canada Energy Regulator 2018). The abundance of oil and gas activity in Alberta provides a high volume of depleted underground oil and gas reservoirs that could allow for more storage facilities in the future, if the demand for natural gas does increase.

Though natural gas may be a necessary factor in Canada's energy transition, there are risks associated with the production and use of it at higher volumes. An increased dependence on natural gas as a transitionary energy source would require an increased demand for natural gas storage capacity, which can lead to a higher risk of fugitive gas leaks from storage reservoirs (GWPC 2017).

Natural gas is composed primarily of methane, a greenhouse gas with stronger warming potential than an equivalent amount of carbon dioxide (Government of Canada 2019). According to the Government of Canada, methane accounts for 25% of anthropogenic global warming and is the second largest contributor to Canada's greenhouse gases at 15% of the total (Government of Canada 2019). Methane can escape into the environment near natural gas storage facilities through fractures in caprock. The oil and gas industry is currently responsible for 70% of Alberta's methane emissions, and fugitive gas migration is a significant contributor to those levels (Government of Alberta 2020). Due to the warming potential of methane and its share of total emissions in Alberta, it is important that the processes involved in the storage of natural gas can mitigate the risk of contributing to methane emissions.

3.0 Fugitive Emissions Risks Associated with Caprock Integrity

Fugitive gas emissions are unintended releases of gases from oil and gas operations which can contribute to greenhouse gas emissions when released into the atmosphere or contaminate shallow groundwater (Council of Canadian Academics 2014). Understanding gas migration into the atmosphere or groundwater is critical when considering an increase in natural gas usage and storage as a bridging fuel from more carbon intensive fossils fuels to cleaner energy sources.

Fugitive gas emissions occur along the whole lifecycle of natural gas production, from extraction to transportation, and underground gas storage. Corroded wells and faults in caprock are the primary sources of these fugitive gas migrations towards the surface (Adelman and Duncan 2011). The pressurized gas can migrate from underground storage reservoirs through fractures in the caprock which may form or spread when the reservoir pressure has changed during the injection process. Any amount of gas migration through these fractures poses a risk to the surrounding environment and communities because the fugitive gases are a contamination risk to groundwater, as well as a contributor to overall greenhouse gas emissions (Shukla et al. 2010, Roy et al. 2016). Furthermore, the large size of the underground storage facilities and the fact that natural gas is odourless and colourless makes these fugitive emissions difficult to detect and monitor. Once the fugitive gas has reached the surface or nearby aquifers, there is potential for ecosystem damage, and can be a threat to human health (Rinaldi et al. 2014).

Fugitive gas migration risks may be associated with increases in natural gas storage sites. Public perception and acceptance of increasing the volume and number of underground gas storage sites could then be negatively impacted because of these potential environmental and health impacts (Rinaldi et al. 2014). Though most underground storage facilities have safe histories of operation, an accident can have dramatic impacts on public health and safety and the environment (GWPC 2017). The contaminated systems can have negative impacts on drinking water and air quality (Adelman and Duncan 2011, Cahill et al. 2019). These instances are generally related to well integrity problems, but some have occurred due to caprock integrity failure (Bruno et al. 2014). A study of 22 incidents of fugitive gas migration related to caprock integrity issues worldwide identified that the incidents were caused by an insufficiently capable caprock seal, undetected faults or fractures in the caprock prior to injection, or were the cause of both issues (Bruno et al. 2014).

The caprock of a storage site is defined as a seal rock that holds resources in a reservoir and is composed of low-permeability layers that can effectively prevent the migration of the stored gases towards the surface (Rezaeyan et al. 2015). Certain Alberta Energy Regulator (AER) regulations involve caprock testing prior to injection to ensure that the structural integrity of the caprock can withstand changes to reservoir pressure when injecting fluids, such as natural gas (Alberta Energy Regulator 2020). This testing is critical prior to injection because caprocks may include existing fractures or faults. These pre-existing features may make the caprock more permeable and subject to further changes when the reservoir pressure changes during injection (Rutqvist 2012). The pressure changes from injected gases can exacerbate the existing fractures or discontinuities and create a migration pathway for gases to move upwards, resulting in fugitive emission releases (Pan et al. 2013).

Underground natural gas storage must ensure the proper testing and characterization of caprock integrity before injection (Rezaeyan et al. 2015). Successful underground storage of natural gas requires reliable caprock seals with large vertical extensions or very low permeability, but ideally both, with sufficient overburden (Elkhoury et al. 2015). Additionally, the caprock should be a homogenous layer without existing faults or fractures (Rutqvist 2012).

Although the proper characterization of the reservoir's caprock is a requisite requirement for a gas storage project, the operating parameters are also critical to maintaining caprock integrity. A high injection pressure may be a factor in fracturing or exacerbating existing fractures and faults, causing fugitive gas migration (Rutqvist 2012). The frequency of injection and depletion of natural gas storage sites is also be a factor in caprock integrity degradation. A study of multiple underground gas storage facilities in California found that frequent gas injection and extraction caused stress on the reservoir due to the pressure fluctuations, which resulted in higher probabilities of caprock failures (Miyazaki 2009). This may pose a substantial risk if natural gas usage is increased and there is more frequent injection and extraction at the storage facilities. The daily gas injection and extraction cycles subject the caprock to multiple pressure fluctuations and could subsequently show a higher probability of developing fugitive gas migration pathways (Miyazaki 2009).

Depleted oil and gas fields from previous energy activities are typically used for natural gas storage in Albert and would likely be the chosen reservoir sites for new facilities. There is a direct association with gas migration risk and the inaccurate evaluation of the reservoir prior to the injection of natural gas (Miyazaki 2009). Thorough evaluation of all potential fugitive gas migration pathways is critical to ensure underground gas storage containment and public safety. The maximum sustainable injection pressure should then be estimated depending on the permeability and thickness of the reservoir, and the injection well should be located as far away from fractures as possible to minimize the chances of exacerbating the fractures near the injection well (Shukla et al. 2010).

4.0 Supporting Scientific Analysis

4.1 Purpose

As further dependence is placed on natural gas as an alternative to more carbon intensive energy sources, there will likely be an increase in demand for natural gas storage sites, resulting in more strains on the depleted reservoirs that are used to store the gas. This could increase the risk potential of fugitive gas emissions from storage reservoirs (GWPC 2017).

Depending on the nature of the storage reservoir and injection processes, fractures can form in the caprock above the reservoir and act as potential leakage pathways for fugitive gas migration. The scientific study related to this paper examines how injection rate, reservoir permeability, and injection temperature impacts caprock integrity. A better understanding of how these parameters might impact caprock during underground gas storage processes may help inform changes to the current requirements to better mitigate risks associated with the injection process.

4.2 Observations and Conclusions

Using a 3D model to simulate caprock properties and a sensitivity analysis to simulate the impact of different parameters, the scientific study revealed several useful observations.

First, a low injection rate over 365 days did not result in any fractures, but a high injection rate resulted in fractures after one month. This shows that the gas injection rate used during these projects must be optimized to avoid high bending stresses and tensile fractures in the caprock.

Relatively low reservoir permeabilities results in fractures earlier than reservoirs with higher permeabilities due to pressure accumulation. Therefore, it is important to take the reservoir permeability into account when characterizing and testing a reservoir prior to gas injection.

Finally, cooling the injected gas resulted in delaying caprock failure, but can reactivate critically stressed faults in the injection zone. The cooled injected gas reduces the volumetric strain induced by injected gas pressure and can be used as a practice to reduce caprock failure risk. However, due to the risk of reactivating stressed faults, proper mapping of the faults in the storage reservoir is required before considering injecting cooled gas.

A literature review of similar scientific studies and studies on caprock failures found that many storage reservoir failures that released gas occurred because of improperly characterized geology in the area

(Jacquey et al. 2015). Improved geology characterization coupled with improved injection processes could help prevent caprock fractures that lead to fugitive emissions.

5.0 Review of Current Directives on Gas Storage Facilities from the Alberta Energy Regulator

The following directives from the Alberta Energy regulator are in place to ensure that underground gas storage is done safely and to preserve the integrity of the caprock.

5.1 AER Directive 065: Resources Applications for Oil and Gas Reservoirs

Directive 065 is the primary application directive for underground gas storage projects as per the AER. The purpose is to safely and efficiently regulate projects that deplete all or part of reservoir pools, but also contains an application section for Underground Gas Storage. Within section 4.2 are the details and requirements that an applicant must fulfill in order to be approved to store natural gas underground. The AER states in section 4.2.1 that underground gas storage is either motivated by production efficiencies or commercial operations. Production efficiencies include storing gas to free production and processing capacity. Commercial operations that store gas are used to balance supply and demand during market fluctuations, such as for seasonal demand changes.

Pertinent to caprock integrity is section 4.2.3, which outlines the application requirements for underground gas storage. A requirement within this section is to outline the formation fracture pressure, the continuity and thickness of the caprock, evidence of fracturing, a comment on the integrity of the caprock, and the caprock threshold pressure. This information is required to determine if storing gas underground will cause any fractures to the formation and how the fractures might spread. Furthermore, additional information is required if there is an active aquifer system above the reservoir, as fugitive gas migrating into the aquifer is a concern for the surrounding environment.

To address the concerns of caprock integrity failures during underground gas storage projects, the AER outlines the maximum wellhead injection pressure requirement (MWHIP). MWHIP can be determined through step-rate injectivity tests, in-situ stress tests, or reliable offset data. The common method used is the step-rate injectivity tests. The presence or absence of fractures in the caprock are determined by injecting at five successively higher rates to identify pressure inflection points. If the step-rate injectivity test, in-situ stress test, or reliable data is unavailable, the AER provides maximum allowable wellhead injection pressures based on the depth of the reservoir. This pressure is set at 90% of the formation fracture pressure to allow for safety, which is a parameter seen in other AER directives for injection pressure requirements. Beyond the caprock integrity testing, the AER may require applicants to outline a gas migration mitigation plan, especially if there are neighboring abandoned wells.

Directive 065 is the primary source of guidance for caprock characterization and testing prior to natural gas injection. The aforementioned tests are in place to ensure the reservoir maintains its integrity throughout the injection and storage processes.

5.2 AER Directive 023: DRAFT Oil Sands Project Applications

Directive 023, while currently listed as a draft, does mention stipulations for reservoir containment and maximum operating pressures that would apply to shallow SAGD operations or cyclical steam stimulation operations. Section 7.10 of this directive states that certain applications may require a 3-D seismic evaluation to support its caprock integrity study to identify faults. This process is used to determine the maximum operating pressure for projects that intend to extract resources from the reservoir. The 3-D seismic evaluation used to support certain applications would likely be a beneficial addition to other caprock integrity tests as a requirement to further ensure proper caprock characterization.

6.0 Regulatory Modernization Recommendations

Current regulations on natural gas storage control factors such as maximum operating pressures and caprock testing (Alberta Energy Regulator 2020). Although the directives are meant to mitigate caprock failures that could lead to fugitive emissions, there may be gaps to be filled if natural gas production, usage, and storage increases significantly in the future. The scientific findings could inform regulatory modernization to ensure that any new storage facilities can safely store natural gas with lower risks of fractures that lead to fugitive emissions. Reduced fugitive gas migration potential could lower the risk of environmental contamination and impacts on human health, especially for more vulnerable communities or indigenous communities who rely heavily on traditional land use (Miyazaki 2009). Based on the policy and scientific analysis, the following areas of focus could benefit from modernization if there is an increase in natural gas storage demand.

6.1 Site Selection and Characterization

Of the 415 natural gas storage facilities in the U.S., 15 percent have experienced leaks at some point in their operational life-cycle through 2005 (GWPC 2017). If Canada increased its natural gas usage to near the amount that the US currently has, regulators should be aware of this risk and the potential impact for gas leaks. A study of caprock failures identified that the two main issues leading to the failures were improper site characterization or that the pressure in the storage reservoir was too high (Bruno et al. 2014).

The regulator’s application review efforts should ensure that any storage project is properly characterized to be protective of human health and the environment. Natural gas storage will place large volumes of gas in underground formations, which may contain existing fractures and faults that are either natural or from past well activity. Sufficient characterization may include detailed modeling of the site as proposed by Bruno et al., utilizing well log data, seismic data, and drilling data to determine risk (Bruno et al. 2014). Ensuring the stored gas does not have avenues for migration may benefit from making the 3-D characterization a requirement for all cases, rather than an additional requirement that is only used in some instances. Geological characterization of reservoirs can potentially identify risks for potential fugitive gas migration including faults, fractures, and discontinuities. In addition to caprock fractures, wellbores represent gas migration pathways and can also impact caprock integrity (Miyazaki 2009). Careful site selection that avoids old wells or improperly abandoned wells can also reduce the potential for fugitive gas migration. Due to poor construction practices and deterioration over time, old wells are especially prone to leak development (Miyazaki 2009). Even when plugged in accordance with current government regulations, most abandoned oil and gas wells eventually develop leaks. Caprock integrity and reservoir testing should include identifying nearby abandoned wells as a requirement and potentially make it a requirement that underground gas storage projects avoid these areas.

6.2 Operating Parameters

Injection rate and initial stress state were found to have a significant impact on the caprock failure (Karimnezhad et al. 2014). Injection induced geomechanical changes occur rapidly at the early times of injection (Karimnezhad et al. 2014). Gas migration caused by pressure levels should be a consideration in establishing the maximum storage pressure. In U.S. regulatory standards regarding the injection pressures, it is the current practice to keep the maximum injection pressure less than the measured fracture-closure pressure of the caprock (US EPA 1994). Below that fracture-closure pressure, no existing fractures can open, and no new fractures can form, reducing the potential for fugitive gas migration (US EPA 1994). AER directives also limit pressures to 90% of the fracturing pressure. Though AER directives have similar stipulations on maximum pressures, it could be modernized to include the option for cooled gas. The scientific findings showed that the cooled gas had less impacts on caprock integrity when there are no existing faults or fractures that could be exacerbated by the cooled gas. While further studies will be necessary to demonstrate the feasibility and safety of the cooled gas storage process, it should be considered if natural gas storage increases significantly. Additionally, the low number of publications regarding general underground natural gas storage in Canada would benefit from additional research.

6.3 Monitoring

Underground gas storage projects require monitoring to ensure that gas is not leaking from the gas storage reservoir or zone. This can be done with both above ground and below ground monitoring systems (GWPC 2017). Numerical simulations in a study observed responses in pressure and displacements as soon as fractures broke through the lower caprock, but there was no obvious indication in injection pressure or displacement before fracturing happened, demonstrating that the fracturing of the lower caprock can proceed unnoticed for several months of injection (Pan et al. 2013). The distinct responses in pressure and vertical displacement upon caprock fracturing would be a good monitoring indicator that could be used at future gas storage facilities. In such a case, shallow aquifers would still be protected by the additional caprock layers.

7.0 Indigenous Community Impacts

Indigenous communities have an economic and cultural dependence on the land and water sources that surround their communities, making them particularly vulnerable to natural resource developments (Atlin and Gibson 2017). Knowing the risks associated with fugitive gas emissions and the impacts it can have on the environment and human health, it is important to consider the livelihood of the Indigenous communities who live on or near these developments. While Indigenous communities can and do benefit from the oil and gas industry, there are still environmental and health risks associated with nearby resource developments. The oil and gas industry has been a contentious subject with regards to its relationship with these Indigenous communities. Despite the economic benefits of cooperating with the industry, the well-being of these communities and their ability to maintain their way of life relies heavily on traditional practices, such as hunting and fishing. Increased resource development that pose risks of contamination through fugitive emissions could exacerbate the difficulties that Indigenous communities have.

Water security, for example, is critical for Indigenous communities. A study from 2018 highlighted that over 50 Indigenous communities in Canada have long-term drinking water advisories (Datta and Hurlbert 2019). Fugitive emissions into water sources can further impact vulnerable communities through contaminated drinking water, as well as water sources used for hunting and fishing practices. The inability to use safe sources of water negatively impacts Indigenous communities by making them more vulnerable to waterborne diseases and other health risks associated with contaminated water sources (Datta and Hurlbert 2019).

Though there are consultations and economic impact assessment reports in the process before a project is approved, there are arguments that these reflect a colonial viewpoint in which the projects benefits provide substantial benefits, so Indigenous traditions can be "refined to points on maps that can be avoided or mitigated with few long-term impacts" (Baker and Westman 2018). Furthermore, Indigenous communities' participation and perspectives on the oil and gas industry are still considered lacking in Canada (Datta and Hurlbert 2019). Consequentially, the gaps in Indigenous consultation have resulted in many Indigenous communities suffering number of negative impacts in their drinking water, health and environment (Datta and Hurlbert 2019).

Indigenous communities' demand for increased control and compensation to mitigate the impact on the land and protect their traditions is increasing. The use of already depleted reservoirs for the purpose of natural gas storage presents an opportunity for the industry and government to improve the consultation process. An improved process for consultation would increase the representation of control and input from Indigenous communities. Putting more control in the hands of communities, who would help direct the assessment and determine its findings, would be beneficial for reconciliation and sustainability (Baker and Westman 2018). The goal of Indigenous consultations could also benefit from improving their purpose from simply mitigating negative impacts so that they include a focus on how the project may improve the livelihood of the nearby communities (Atlin and Gibson 2017).

7.1 Recommendations

Increased Indigenous inclusion in the decision-making process, and adherence to the UN Declaration on the Rights of Indigenous Peoples would improve the traditional land use consultation and impact assessment processes (Baker and Westman 2018). This would help recognize the rights and traditions of Indigenous communities in the areas that could hold future natural gas storage. Vulnerable or impacted communities could then weigh these risks and benefits and make decisions appropriate for their unique circumstances, histories, values, and goals (Wright and White 2018).

8.0 Conclusions

Canada's ambition to reduce emissions by 30% of 2015 levels by 2030 and be net-zero by 2050 will mean a transition to cleaner energy sources and large-scale emissions reduction technologies. This could involve an increase in natural gas usage as an alternative energy source.

More natural gas usage will require more underground gas storage. Alberta has an abundance of depleted oil and gas reservoirs that could meet this need, but a risk associated with these projects is fugitive gas emissions caused by caprock fracturing during the gas injection process, which allows the gas to migrate towards the surface through the fractures. Underground gas storage projects are guided by several Alberta Energy Regulator Directives. These directives ensure that applicants prove that the caprock's integrity will hold up to gas injection and aim to prevent fractures that can cause fugitive gas migration.

An increased use of natural gas energy can help Canada reach its climate change goals, but regulations may need to be modernized to accommodate for the increased volume of storage capacity. The scientific and policy analysis highlighted potential areas for modernization. This could involve stricter testing, injection processes, location restrictions, and monitoring. These measures could help prevent fractures and fugitive gas migration to protect the environment and surrounding communities. These projects can also be used as an opportunity to improve Indigenous consultation processes by increasing Indigenous representation, control, and respect for traditional land uses.

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