"Carbon Capture and Sequestration:
In the Canadian Context"

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ABSTRACT

As nations attempt to address the issue of climate change, several strategies for its mitigation are developed and proposed. Among these strategies is the concept of Carbon Capture and Sequestration (CCS). Particularly attractive due to the technology's ability to allow expansion of fossil fuel energy consumption, CCS has fiercely entered the discussion in countries including Canada. With geological storage potential in the Western Canadian Sedimentary Basin (WCSB) identified as a world class storage site, Canada is aiming to take a leadership role in the development and deployment of the technology. The provincial governments of Alberta and Saskatchewan are actively embracing the technology and are pursuing it as a greenhouse gas emission reduction strategy. CCS is also receiving Federal support in terms of financing as well as incorporation into regulatory standards for future plant developments. Several technical options are available pertaining to CCS as they continue to develop. This paper examines the potential application of CCS in Canada in terms of the nation's resources, as well as the potential economic and environmental effects and related policy issues surrounding the implementation of CCS. Due to the lack of experience (on even the global scale) in CCS in a fully integrated commercial system, as well as long-term storage in any capacity, many gaps of knowledge surrounding CCS exist. Also important are the several outstanding policy issues relating to its usage which must be resolved before responsible and effective implementation can occur.

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1. THE PUSH FOR CCS

Although the Canadian government has chosen to abandon its previous Kyoto Protocol commitments of reducing its greenhouse gas emissions to 6% below 1990 levels by 2012 (CBC News 2007), and has instead set its own, more lenient target of 20% below 2006 levels by 2020, it is still far from reaching its reformed greenhouse gas emission goals (Environment Canada 2007). With 77% of its total primal energy being derived from fossil fuels, and the expansion of the oil sands in Alberta, prospects for reducing this reliance on fossil fuels remains low (ecoEnergy CCS Task Force 2008). Even with the current strides in renewable energy, renewable sources still only supply about 0.7% of the national energy supply (EIA 2007). Given that the price of several of these technologies remain high, and the existence of several technical concerns such as the intermittency of electricity produced by them, their growth within Canadian electricity infrastructure is expected to be slow (ecoEnergy CCS Task Force 2008).

The oil sands are the fastest growing source of domestic greenhouse gas emissions and are expected to continue to expand (ecoEnergy CCS Task Force 2008). Due to the economic gains of these reserves, particularly in the context of record breaking energy prices, curbing these developments is unlikely. For these reasons, carbon capture and sequestration proposals applied to such facilities seem particularly attractive because they allow for an otherwise business as usual scenario. In relation to this logic but within the general public domain, carbon emission reductions through CCS would not require lifestyle changes on the side of the public. Sacrifices in terms of energy conservation, for example, would not be required of the public; a point that would be both attractive to those who are not willing to make such changes, as well as attractive on the emission reduction management side since reliance would not have to be placed on often unpredictable individual behaviour.

So what is this apparent panacea? How does it work, and is it feasible for Canada? What are the benefits to its use and what are some outstanding concerns? This report aims to provide an overview of the discussion in terms of its technical, environmental, economic and political dimensions in the Canadian context. It will begin with a brief technical description of the technology to provide the reader with the necessary technical background for the discussion, and then cover the domestic potential for its use. This will be followed by discussion on the political standing of CCS in Canada, its economic benefits and disadvantages, environmental concerns and finally, the outstanding policy issues that must be addressed if CCS is to be made a practical and safe component of Canada's climate change strategy.

2. THE TECHNOLOGY

2.1 Capture of Carbon Dioxide

Carbon capture and sequestration (alternately called carbon capture and storage or CCS) technology has several forms. Clear from the name, it is generally explained as two main process steps: capture and sequestration. There are three main types of capture processes, each of which will be briefly explained.

Pre-combustion capture is usually carried out by one of two routes: the first is by adding steam, known as "steam forming," and the second by adding oxygen, known as "partial oxidation" to the primary fuel. The reactions for each route respectively are:

$C_xH_y + xH_2O \rightarrow xCO + (x+y/2)H_2$ and

$C_xH_y + x/2O_2 \rightarrow xCO + (y/2)H_2$

The steam forming or partial oxidation step is then followed by a reaction that converts the CO to CO_2 by adding steam ("water gas shift reaction").

$CO + H_2O \rightarrow CO_2 + H_2$

The now separated carbon dioxide can then be removed from the mixture (IPCC 2005).

Oxyfuel combustion works by combusting a carbonaceous fuel or hydrocarbon in either pure oxygen or a mixture of pure oxygen and CO2-rich recycled flue gas mixture. The main combustion products are water vapour, excess oxygen (required to ensure complete combustion) and carbon dioxide, which is then ready for removal (IPCC 2005).

Post-combustion is of particular interest to the application of CCS technology to reducing Canada's greenhouse gas emissions since CCS is being proposed as an end-of-pipe recovery solution to the harmful matter in the emitted flue gas of combusted fossil fuels, oil and gas. For this reason, post-combustion technologies will form a focus of the discussion.

The firing of fuel with air in a combustion chamber has for centuries remained the most economical process of extracting and using energy contained in the above mentioned fossil fuel sources, partly explaining their use which has been largely unaltered over modern history. The flue gas of large scale combustion systems is usually at atmospheric pressure and flows openly into the air with a large presence of nitrogen, generating very large flows of gas. For example, a natural gas combined cycle power plant can emit up to 5 million normal m^3/hour ("normal" measurements are taken at 1 atm and 0°C). The CO_2 contents of these emissions depend on the fuel type used. These figures (by volume) range from roughly 3% for a natural gas combined cycle to just less than 15% in a coal-fired combustion plant (IPCC 2005).

The "preferred" option for CO2 capture in combustion plants are absorption processes based on chemical solvents which "offer high capture efficiency and selectivity, and the lowest energy use and costs when compared with other existing post-combustion capture processes" (IPCC 2005, p114).

First, the flue gas is cooled and brought into contact with a solvent (in an absorber), typically amine to which it binds when the absorber temperature is set between 40 ºC and 60ºC. Next, the flue gas undergoes a water wash section which balances water in the system and removes left over solvent droplets and vapour before leaving the absorber. The solvent to which the CO2 is bound is then pumped to the top of a regeneration vessel (or stripper) where high temperatures (100 ºC to 140 ºC) and low pressure (just above atmospheric pressure) provide the desorption heat required to remove the chemically bound CO). The separated CO2 is then ready to leave the regeneration vessel and may then become prepared for the second phase of the CCS process, storage (IPCC 2005).

2.2 Storage/Sequestration of Carbon Dioxide

Two main proposals strategies are usually discussed in terms of the storage or sequestration of carbon dioxide: ocean storage and geological storage.

Ocean storage can be approached through two main avenues. The first is to first compress the CO2 and then inject it to, or just above, the sea floor. At this point, the CO2 could either be released to dissolve into the sea water and enter the ocean's carbon cycle, or could be engineered to form a "lake" of CO2 on the sea floor. It is predicted that the atmospheric pressure and low temperatures of the deep ocean environment could keep the liquid CO2 negatively buoyant and remain on the ocean floor. The IPCC has identified fixed or towed pipes as the most viable method of oceanic sequestration to date (IPCC 2005).

The second approach to oceanic carbon dioxide sequestration is through the dissolution of carbonate minerals which neutralizes the increasing sea water acidity brought upon by the addition of CO_2. The carbonate dissolution strategy aims to accelerate this process by promoting limestone to react with carbon dioxide and water in order to form calcium and bicarbonate ions. To date, experiments of this strategy have been restricted to laboratories and are still under early development (IPCC 2005).

The second type of carbon storage is geological storage. The three main geological formations identified for carbon dioxide storage include mature oil and gas reserves, the deep saline aquifers underlying these reserves and coal seams. Of all the storage options included within oceanic and geological depository sites, it is the mature oil and gas reserves and their underlying deep saline aquifers that are of particular interest with regards to carbon capture and sequestration applications in Canada (ecoEnergy CCS Task Force 2008) as will be further discussed in Section 3.

Oil and gas reserves are often regarded as the “prime candidates” for carbon dioxide storage (IPCC 2005, p215). This preferential designation is based on: the line of logic that the safety and effectiveness of carbon storage in these reserves are proven by the natural long-term entrapment of fossil fuel sources prior to their mining, the existing studies and characterization of these formations and the behaviour of hydrocarbons within it, and the existing infrastructure and wells already in place which can be used for storage applications (NRCan 2006).

Saline aquifers, which underlie many of the reservoirs discussed above, are formations of deep sedimentary rock. The water or brines found within these formations contain high concentrations of dissolved salts, making the water unsuitable for both human consumption and agriculture. The inability to use these water sources forms part of the rationale for using saline aquifers as depository basins in addition to their shear magnitude in terms of storage capacity (IPCC 2005).

Gas molecules (in this, context carbon dioxide) can diffuse and be tightly adsorbed into the large number of micropores between the fractures (or "cleats") of solid coal. These seams can adsorb up to 25 normal m^3 of methane (CH_4) per tonne of coal at coal seam pressures. This adsorption capacity is higher for gaseous CO_2. The volumetric ratio between adsorbable CO_2 to CH_4 ranges between one and ten, depending on the type of coal. Little is understood about the entrapment process beyond the critical point, however, it is speculated that the process generally shifts to an absorption process where the CO_2 diffuses in the coal (IPCC 2005).

Although not a focus in the literature, it is important to mention before the closing of this section, salt caverns; a storage system that is referred to by Natural Resources Canada as a potential storage site for domestic emissions in addition to the geological formations discussed above (Natural Resources Canada 2006). Salt cavern use for CO2 storage purposes would involve technologies originally developed for liquid natural gas and petroleum product storage in salt beds and domes. Differences in the technology will have to somehow address drastically different time scale requirements since natural gas and petroleum products are "cyclically pressurized and depressurized on a daily-to-annual time scale, whereas CO2 storage must be effective on a centuries-to-millennia time scale" (IPCC p220). With CO2 in a supercritical phase and the creep properties of salt, the CO2 will decrease in volume until the internal cavern pressure is equal to the external stress in the salt bed. Storage in salt a cavern has a high capacity per unit volume, efficiency and flow rate (IPCC 2005).

3. DOMESTIC STORAGE POTENTIAL

In 2006, Natural Resources Canada released "Canada's CO2 Capture and Storage Technology Roadmap." One of the objectives of the report was to provide an overview of potential CCS applications and opportunities in Canada. The document identifies and ranks various possible sinks for carbon sequestration in the country based on various technical, safety, capacity, existing infrastructure and location criteria (NRCan 2006).

First, let it be mentioned that all offshore sinks received a low ranking, representative of the reasons behind the effective exclusion of oceanic storage from present as well as near-future plans and proposals for carbon storage in Canada. The low rankings were due to various reasons; but the most common reasons among the basins, and perhaps most importantly, were due to immaturity (i.e. not depleted), the fact that little exploratory research has been conducted on these areas, high costs associated with the transport and injection into these sinks, and unclear international legal status surrounding oceanic storage under the London Convention and the United Nations Convention on the Law of the Sea (NRCan 2006).

The Western Canada Sedimentary Basin (WCSB) was ranked as the top preferential location for domestic carbon storage based on the basin thickness, maturity of several of the containing reserves, accepted understanding of its geological characteristics, location with respect to proximity to greenhouse gas emitters and existing infrastructure which could be used for transport and injection processes (NRCan 2006).

This storage area mainly spans Alberta, North Eastern British Colombia, Saskatchewan and Manitoba with gas and oil reserve storage capacity of 2822 Mt CO2, 800 Mt CO2, 118 Mt CO2 and 1 Mt CO2 respectively, totalling approximately 4 000 Mt of storage capacity (NRCan 2006). Estimates by “The ecoEnergy Carbon Capture and Storage” which reported to the Alberta Minister of Energy and the Minister of Natural Resources via written submission in February 2008 gave a similar total estimate for oil and gas reserve storage capacity (ecoEnergy CCS Task Force 2008).

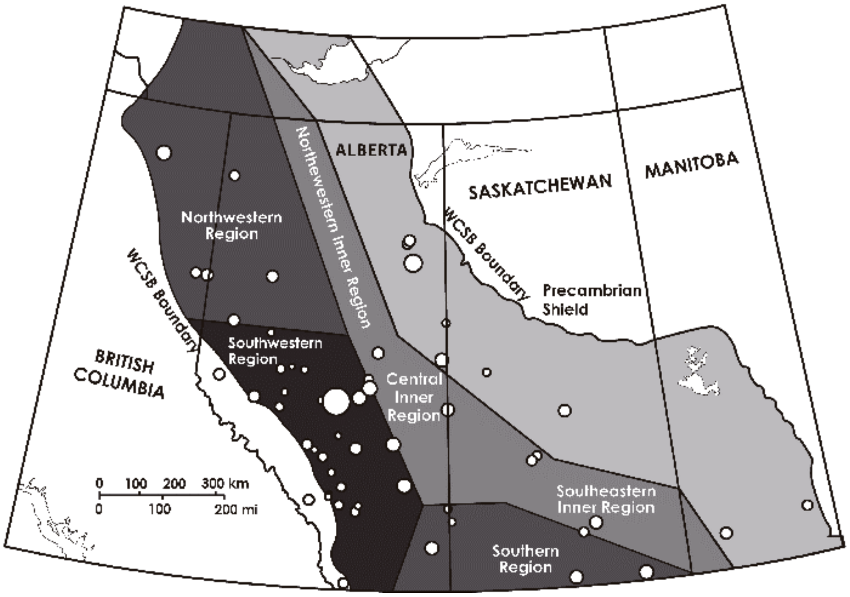

Figure 1Western Canada Sedimentary Basin (ecoENERGY CCS Task Force 2008, p12)

With respect to the underlying deep saline aquifers, the 2008 EcoEnergy Task force reported 1 mill Mt CO2 of storage capacity whereas the 2006 Roadmap stated a capacity in the order of 100 times larger than the oil and gas reserves, yielding an estimate around 400 000 Mt CO2 of storage capacity. One may be tempted to resolve this disparity by considering additional exploration and study over the two years, but it should at least be considered that IPCC says on estimates for deep saline aquifers in general: “upper limit estimates are uncertain due to lack of information and an agreed methodology" (IPCC 2005, p12).

Recognized as "world class" storage potential (ecoEnergy CCS Task Force 2008), the WCSB currently dominates as the recommended area for carbon sequestration in Canada; particularly its mature oil and gas reserves and underlying deep saline aquifers. Although not mentioned in the recent report addressed to Natural Resources Canada (NRCan), coal bed storage and salt caverns complete the list of potential domestic storage sites on the NRCan website NRCan 2006). The estimated capacity for Canadian coal beds stand at approximately 2 000 Mt CO2 (NRCan 2006). No estimates were found for domestic potential salt cavern capacity, but the IPCC states that a single cavern of 100m in diameter will typically only hold about 0.5 Mt of high density CO2 (IPCC 2005, p 220), demonstrating their low potential for storage and thus possibly explaining their minimal inclusion in the public and academic discussion of CCS.

Despite some disparity in the assessments and predictions, compared to the 747 Mt CO2e emitted in all of Canada in 2006, storage capacity is generally not viewed as a constraining factor; particularly since CCS is only targeted for major stationary emitters (Environment Canada 2007).

Estimates on the actual capacity of CCS technology itself to collect and transport carbon dioxide emissions for storage in the above basins range widely. The ecoEnergy Task Force reports an upper limit of approximately 600 Mt/year of CO2 by year 2050 while also recognizing lower estimates by the National Round Table on the Environment and the Economy and Integrated CO2 Network which predict CCS capacity to be 400 Mt/year and 100 Mt/year respectively (ecoEnergy CCS Task Force 2008). Since proponents of the technology are promoting the advancement and expansion of its use, these capacities are probably seen by them as flexible and expandable if given sufficient public support and funding. This is implied by the various proposals which emphasize adoption and advancement of these technologies as a strong opportunity for Canadian leadership in the international domain (ecoEnergy CCS Task Force 2008; NRCan 2006, Monte Solberg 2008).

4. CURRENT POLITICAL STATUS

Alberta's 2008 Climate Change Strategy which was released January 2008 outlines three fronts of action: greening energy production, conservation and energy efficiency and carbon capture and storage. With 70% of the targeted reductions by year 2050 mandated to occur through CCS, the province is taking a decisive stand on integrating the technology into its energy systems (Alberta Environment 2008). This is not surprising given the economic gain available through the expansion of the area's extensive oil and gas reserves (Please refer to section 5).

In March 2008, Prime Minister Harper announced that the federal government would be giving $240 million in trust to Saskatchewan for the world's first commercial scale carbon capture and storage facility. The announcement was made in accordance to the designation made in the 2008 budget. The province is supplying the other $758 million necessary for its development (Office of the Prime Minister 2008).

Also, in March 2008, the federal government released an enhanced version of the Regulatory Framework for greenhouse gas management first released in April 2007. The enhanced version incorporates CCS technology as a key component to the strategy of reducing greenhouse gas emissions, particularly (although not exclusively) in the oil sands and electricity sector (Denstedt et al 2008).

The framework mandates that in situ oil sands projects and upgrades, and coal-fired power plants built after 2012 have emissions profiles equivalent to facilities using CCS by 2018. This regulation is very important and representative of the government stance on CCS technology since it is using facilities that incorporate the technology as the future legal baseline in terms of carbon emissions to which future developments will be compared. The government further promotes the technology by offering relief of up to 100% of a firm's regulatory obligations through to 2017 if they incorporate the technology for investments in pre-certified CCS projects (Denstedt et al 2008).

The fact that existing facilities are not required to conform to this standard, even in the future, suggests the government may recognize the technical difficulty and high costs of incorporating CCS on plants that were not originally designed for their integration (Please see Section 6). Further details on the reduction targets associated with CCS implementation will be finalized in 2009 (Denstedt et al 2008). Since oceanic storage does not currently have a place in domestic policy relating to CCS storage, it will from here on be excluded from the discussion.

5. ECONOMIC BENEFITS

One of the potential economic benefits to CCS technology is its application in enhanced oil recovery (EOR, i.e. using a gas such as carbon dioxide rather than traditional mediums such was water to extract oil from reserves). The resulting storage capacity related to its application in EOR is quite limited: a total in Canada of about 450 Mt CO2e, translating to approximately 10 Mt/year of storage for 50 years. The economic benefits, however, are being pursued by the EnCana EOR project in the Weyburn oilfield in Saskatchewan (IEA Greenhouse Gas R&D Program n.d).

The project which commenced in October 2000 uses injected carbon dioxide in order to increase the oil recovered from the basin and is estimated to store about 20 Mt of carbon dioxide in the process over its 25 year period (IEA Greenhouse Gas R&D Program n.d). The estimates for incremental production at the site stand at approximately 15% of initial oil in place, speculatively producing an additional 130 million barrels of oil over the 25 year project period (Brown et al n.d.).

The second and larger economic opportunity provided by CCS is the allowance for continued expansion of Canada's fossil fuel reserves in the face of climate change concerns and greenhouse gas emission reduction expectations. The highest profile of these expansion opportunities are the nation's oil reserves. As of January 2007, Canada ranks second to Saudi Arabia in proven oil reserves at 179.2 billion barrels (EIA 2007). The economic viability of Canada's crude oil reserves is said to have increased due to improvements in the extraction technology and rising oil prices which hit $100 per barrel (of crude oil) in January 2008 (Polczer 2008). The ability to extract and develop Canada's fossil energy reserves is clearly a very important issue to industry and government given the enormous amount of these resources within our borders at a time of projected oil scarcity and the consequent market price increases.

6. ECONOMIC CONCERNS

The economic effects of CCS technology, however, are not all positive. Applying CCS to a new gas-fired or coal-fired power plant increases the cost of generated electricity by between 37% and 91%. This translates to a carbon mitigation cost of

$30/tonne to $91/tonne in US dollars (IPCC 2005). Estimates could not be found for retrofitting old plants to use CCS, but the costs associated with this option are stated to be dramatically higher. Roughly 90% of these costs to CCS relate to the capture phase (IPCC 2005).

As should be clear from the above discussion, the financial costs of implementing the technology are simply too high to be economically feasible for a plant to undertake alone. As a result, industry is appealing to the government for public funding (as granted to Saskatchewan). The ecoEnergy Task Force recommends that the Federal and Alberta Provincial government "allocate $2 billion in new public funding to leverage the billions of dollars of industry investment in the first CCS projects" (ecoEnergy CCS Task Force 2008, p24). In its rationale for the need for public investment, the task force states that "this financial gap is what currently prevents the commercial application of a series of first-phase CCS projects today, as it is simply not possible for private sector players to commit additional hundreds of millions of investors' money on an activity (emissions reductions) that is essentially a public good" (ecoEnergy CCS Task Force 2008, p18). This requirement for public funding to incorporate CCS in emission reduction strategies ties into several policy considerations and will therefore be further discussed in Section 8.

7. ENVIRONMENTAL & HEALTH CONCERNS

Injection and long-term storage of carbon dioxide emissions is a relatively new concept and has not yet been carried out on a long enough time frame to conclusively report on the environmental and health effects of storage. Studies are, however, currently underway which attempt to uncover any detrimental effects and provide preliminary insight on potential environmental and health concerns that may be associated with the emission technology use.

First, the ability of storage sites to effectively trap the gas in its formations is integral to the effectiveness of the strategy to mitigate climate change as well as to the protection of humans upon potential release of the gas.

> *"Physiological and toxicological responses to elevated CO2 concentrations are relatively well understood… At concentrations above about 2%, CO2 has a strong effect on respiratory physiology and at concentrations above 7–10%, it can cause unconsciousness and death…Natural and engineered analogues show that it is possible, though improbable, that slow releases from CO2 storage reservoirs will pose a threat to humans"* (IPCC 2005, p247).

The integrity and ability of these formations to securely store the carbon dioxide is compromised by drilling and structural changes from the extraction of hydrocarbon resources (Johnston & Santillo, n.d.). Of particular concern in terms of unintentional release of carbon dioxide is the potential for accidentally mining or drilling into a pipeline or storage site (IPCC 2005). Although this may seem like an improbable or negligent scenario, it cannot be ruled out, particularly in the long-term if a long-term strategy to prevent such occurrences is not developed, adopted and effective, as will be discussed in Section 8.

Release of carbon dioxide from salt caverns is also a serious concern since release could occur suddenly and directly due to system failure of the cavern roof. Also, the disposal of brine from a solution cavity in order to supply storage space within it is itself environmentally degrading (IPCC 2005). Discussion on the environmental effects of salt caverns will be limited to the above discussion since salt caverns do not seem to be frequently referenced in domestic plans and proposals involving CCS and is therefore of limited relevance to the present paper.

A study conducted under the leadership of the University of Texas monitored the (short-term) effects of carbon storage in a geological brine formation. The researchers found that the reaction of CO2 with reservoir minerals decreased the pH levels in the formation, leading to the dissolution of minerals including carbonate and iron oxyhydroxides. The carbonate minerals are responsible for sealing pores and fractures in the rock, consequentially meaning that their dissolution creates pathways in the rock and well cement for CO2 leakage affecting the formations permeability and porosity. Also of concern to these observations is that that

"*dissolution of minerals, especially iron oxyhydroxides, could mobilize toxic trace metals and, where residual oil or suitable organics are present, the injected CO2 could also mobilize toxic organic compounds. Environmental impacts could be major if large brine volumes with mobilized toxic metals and organics migrated into potable groundwater"* (Kharaka et al 2006, p1).

Leakage of CO2 into the surface above the formation is also expected to have negative environmental implications, particularly because it is a very "biologically active area" (Goerne 2004, p7). Soil gas usually contains between 0.2% to 4% of carbon dioxide. A concentration of 5% is considered dangerous for vegetation. Recognized risks associated with these levels include die-off of vegetated areas and root anoxia although it is also reported that the animals in the soil are also somehow affected. The literature is lacking studies on the effects of CO2 leakage on sub-soil ecosystems and is an area that requires further research for the proper assessment of CCS to be carried out (Johnston & Santillo n.d).

Also generally missing from studies on the environmental impacts of geological carbon dioxide storage is the impact of impurities in the sequestered gas. Since no engineering system is perfect, it must be expected that the sequestered stream is not purely carbon dioxide, but also contains traces of other gases such as hydrogen sulphides, sulphur dioxides and nitrous oxides. H2S, for example is:

> *"considerably more toxic than CO2 and well blow-outs containing H2S may present higher risks than well blow-outs from storage sites that contain only CO2. Similarly, dissolution of SO2 in groundwater creates a far stronger acid than does dissolution of CO2; hence, the mobilization of metals in groundwater and soils may be higher, leading to greater risk of exposure to hazardous levels of trace metals"* (IPCC 2005, p250).

Beyond the above speculative account from the IPCC, little can be found in the literature on the effects of impurities in the gas stream on the storing and surrounding environment.

Finally, a risk associated with the injection process is the potential for induced seismicity. The high pressures required for injection, (which are much higher than the formation pressures) may lead to fracturing and movement along fault lines. This could result in increasing fracture permeability, increasing the risks associated with gas leakage discussed above. Fracturing and movement along fault lines could also lead to earthquakes "large enough to cause damage" (IPCC 2005, p 249).

8. OUTSTANDING POLICY ISSUES

It should not be surprising that given the relative novelty of CCS technology and thus the lack of experience with its development and usage, the policies surrounding the technology are not well developed. In fact, considering that the Canadian and Alberta government have embraced the technology as part of its climate change strategy, the regulatory framework in which it is incorporated is quite weak. The status and issues surrounding CCS fit into several larger political controversies, consist of several gaps of knowledge and are also based on a weak regulatory framework. These issues make implementation of CCS difficult, risky and pre-emptive if they are not first resolved.

First, in light of the fact that industry is requesting government support to implement technologies that will allow them to meet their emission reduction obligations, the responsibility of who is truly responsible for these costs becomes highly contentious. This debate is characteristic of the classic policy problem which asks: who pays? Does the polluter pay because the emissions are a result of their commercial operation, or rather, should the public front the costs since the emission reductions have positive implications for the good of society (and not for commercial operation)? Until this question is answered, industry will continue to pressure government for funds, while any granted funds will remain highly controversial in the public and political domain.

This issue of funding also ties in closely to the effects of allocating funds to CCS on other policy initiatives. Assuming that these funds will be allocated from funds designated for climate change strategies, decisions related to CCS fund grants could potentially affect funding of other climate change strategies. As the root cause of the climate change issue becomes hidden (i.e. the burning of fossil fuels), incentive to promote strategies that actually decrease the emissions will lessen. Strategies that target emissions from the source such as through non-emitting and renewable electricity generation and conservation management and promotion programs could be sidelined and suffer in terms of financial funding as well as regulatory attention.

With little knowledge of the environmental and safety implications of CCS coupled with some preliminary disconcerting assessments on these issues, the government is clearly neglecting to apply the concept of the precautionary principle. Beyond the possible harm this could ensue in the future should CCS usage become expanded in Canada, the current political decisions that demonstrate the government is embracing the technology sets a dangerous and very clear precedent to discount the precautionary principle in general.

The question of liability should something go wrong with the use of the technology in the short or long term has not yet been addressed. One of the recommendations by the ecoEnergy Carbon Capture and Storage Task Force is to transfer liability obligations to the government post site abandonment (ecoEnergy CCS Task Force 2008). Similar to the discussion on the debate of financial responsibility, this issue would also pose difficulties in determining who is rightfully liable for the stored carbon dioxide post-abandonment. Aside from the above ethical question, given the unpredictable lifetime of a company that uses CCS, it may not be practically feasible to expect companies to maintain liability in the long term.

Even if it becomes agreed upon that long-term liability should be placed on the government, it too does not currently have the regulatory framework or capacity to ensure the long-term safety of these sites. Geological sequestration is intended to hold the gases for hundreds or millions of years (IPCC 2005), a time-frame that current Canadian government policies simply do not cover. Nonetheless, this time-frame of responsibility is necessary in order to ensure the long-term isolation of these sites from both industrial and explorative exhibitions such as mining or excavation into the sites, as well future developments that would place humans in close proximity to these sites and consequentially increase their risk in terms of the environmental and safety risks associated with the storage.

The issue of liability in perpetuity would require some type of continual transfer of liability over time, and has not received much attention in domestic CCS proposals and plans to date. In any case, these plans could present problems with respect to effectively maintaining robust management and oversight of the sites over a long period of time and changing regulatory frameworks. It also brings concern to the inherent fact that the original parties responsible for the storage could be unfairly freed of responsibility for damage that may occur as a result of their commercial operations.

9. CONCLUSIONS

If Canada wants to play a true leadership role in the deployment of CCS technology as demonstrated in “Canada’s Feature Day – CO_2 Capture and Storage” at the December 2005 United Nations Climate Change Conference (NRCan 2005), it must go beyond embracing it financially and in its emission reduction target baselines, but must also properly integrate it into the country in a holistic and responsible manner. Being a leader in CCS must also mean being a leader in assessing, and if possible, ensuring the safety of its usage. Voids in research such as the effects of CO2 leakage into subsoil systems and the effects of gases other than carbon dioxides on the storage basins and surrounding environment, must be properly assessed. Gaps in the regulatory framework for properly implementing CCS such as the requirement for long-term safety planning must also be addressed.

Canada must also ensure that CCS development and deployment does not sacrifice other climate change strategy initiatives that most effectively address the root of the greenhouse gas emissions problem. It would also be well-advised to carry out an assessment of the economic advantages to advancing CCS compared to the effects this allocation could have on the advancement of renewable energy and conservation management programs.

Without further analyzing the feasibility in terms of its economic, environmental and political domains, Canada is irresponsibly promoting the technology. The technical, environmental and policy issues must be more extensively considered before continuing the wide-scale promotion of CCS technology as a key approach to Canada’s climate change strategies.

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