A Short Guide to Carbon Capture & Storage

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The purpose of this short guide is to inform the reader of the industrial process known as **Carbon Capture and (geological) Storage – CCS** in shorthand.

Canada is legally committed to meeting net-zero carbon dioxide (CO_2) emissions by 2050 under the 2015 Paris Agreement, which was adopted by 196 nations. The Paris Agreement works on a five-year cycle of increasingly ambitious climate action to be undertaken by each nation. Every five years, each country is expected to submit an updated climate action plan -- known as their Nationally Determined Contribution.

Consequently, Canadian provincial governments have begun to implement regulations to govern how CCS is to be managed within their borders. Alberta was the first to enact CCS regulations in 2010 that prescribed how ***dedicated geological storage*** would permanently sequester CO_2 in deep rock formations. Saskatchewan and British Columbia are also recognized by the Federal Government as having effective regulations for dedicated geological storage of CO_2. No province in central or eastern Canada has adopted CCS regulations as of mid-2024, i.e., received royal assent in a provincial legislature and become law.

This short guide explains:

- Why CO_2 must be prevented from being emitted by industrial processes – i.e., captured – and stored geologically.
- How ***carbon (CO_2) capture*** works at industrial plants.
- How this CO_2 is transported from industrial plants to storage hubs for dedicated geological storage.
- The requirements for safe geological storage.
- The hazards to life and property that may arise in CCS operations.

Why capture CO_2 emissions?

CO_2 emissions – as well as emissions from other greenhouse gases (GHGs) – have caused the temperature of the Earth to rise substantially since pre-industrial times, which is defined as the average temperature for 1850-1900. The World Meteorological Organization has stated that 2023 was the hottest year on record with temperatures approximately 1.45°C above the pre-industrial levels. Other international climate monitoring agencies agree.

Accompanying this climate change are the hazards and costs of a warmer climate are shown in Figure 1 below and include:

- forest firestorms from British Columbia to Labrador,
- drought on the Prairies,
- infestations by invasive species carrying disease,
- ice loss from the Arctic Ocean,
- tropical storms in the Atlantic Provinces,
- shoreline erosion in PEI and the Arctic with sea-level rise, and
- tornadoes, flooding and heat waves across Canada.

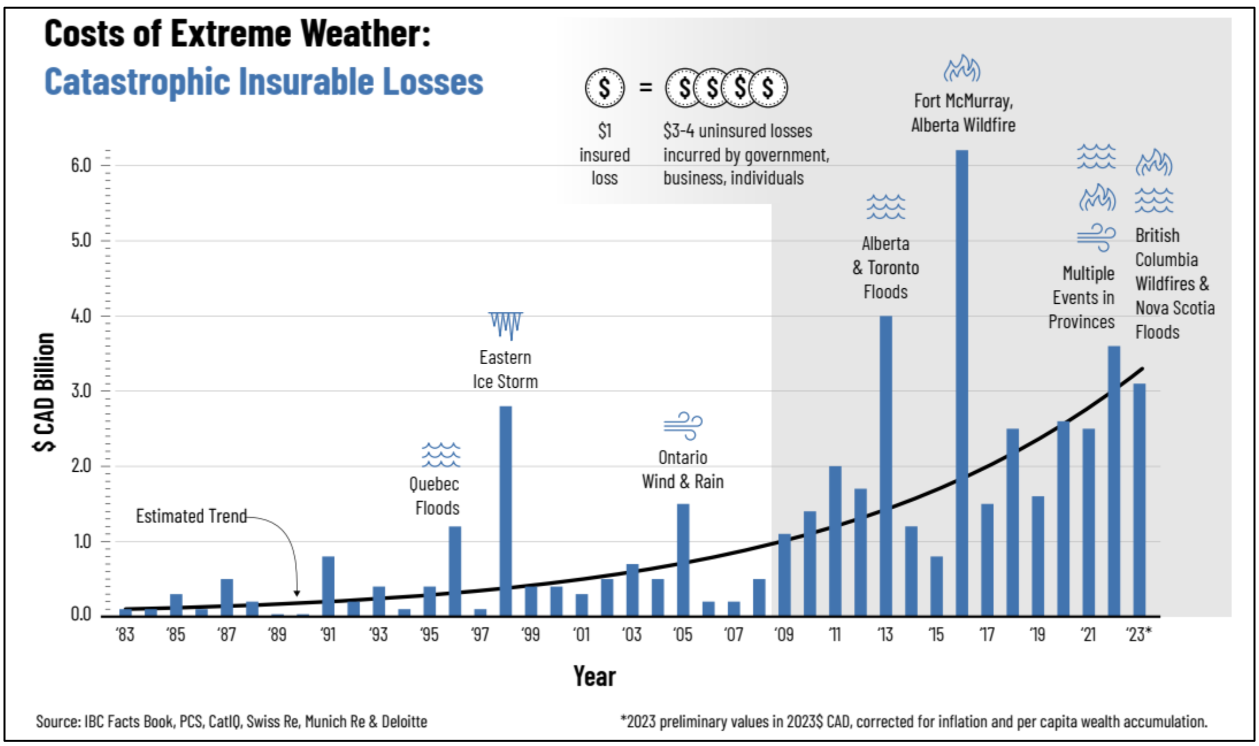

Figure 1: Catastrophic insured losses in Canada, 1983-2023, and estimate of uninsured losses (courtesy Intact Centre on Climate Adaptation, University of Waterloo and from CatIQ and IBC).

Figure 2: *Highway bridge washout, Bella Coola, British Columbia in 2010 cost $45 million to repair (courtesy, B.C. Ministry of Transportation & Infrastructure).*

Without capturing CO_2 emissions, temperatures will climb further and the hazards and costs of climate change will be much worse:

- Home insurance premiums rose 64% in Ontario and 140% in Alberta between 2011 and 2021 according to www.Rates.ca.
- Ten per cent of Canadian homes are uninsurable for basement flooding according to University of Waterloo's Intact Centre on Climate Adaptation.
- As of 2024, the average cost of a flooded basement is $54,000.
- The Intact Centre also reported that a $700,000 Canadian home in those communities affected by catastrophic flooding was sold in June 2024 for 8% less – or about $58,000 less – than those not in flooded areas.
- Severe flooding has already raised insurance premiums by over 10% in B.C. and Nova Scotia according to Statistics Canada.

The total costs of climate change are extraordinary and will be borne by the Canadian taxpayer directly or indirectly:

- Annual wildfire-fighting costs have exceeded \$1 billion when averaged over the last decade.
- Queen's University's Institute for Sustainable Finance estimated in 2022 that a 2°C rise above the pre-industrial levels will cause a loss of about \$2.7 trillion in capital costs within Canada.
- However, were Canada to transition to a low-carbon economy, the cost of transitioning would be considerably less than the cost due to anticipated infrastructure and biodiversity damages.

If Canada does not honour its commitments to decarbonization in the Paris Agreement, our trading partners might impose border tariffs on our exports. By 2026 the industrial cost of CO_2 emissions to Canadian industry is expected to be over \$100/tonne. Consequently, the Canadian system of industrial carbon pricing should provide a tariff shield for much Canadian export trade but perhaps not all. All Canadians must appreciate that Canadian prosperity is dependent upon our export products being deemed equally carbon efficient to those of the USA, EU and UK. That implies industrial carbon capture based on an industrial carbon price.

How carbon (CO_2) capture works at industrial plants

Carbon capture is an industrial process that removes the CO_2 from flue-gas emissions from a stationary source, such as from a cement plant, oil refinery or steel mill. The method of removal is to channel the CO_2 emissions into a chemical reactor in which the CO_2 emissions are exposed to an absorbent, typically an amine solvent. The chemical engineering process is shown Figure 3.

The Quest carbon capture facility in Scotford, Alberta is shown in Figure 4. It has a capacity of 1 MT/yr with ~77% CO_2 capture efficiency producing an effluent stream of almost pure CO_2. These chemical plants cost about \$1 billion to build for every 1 million tonnes per year (MT/yr) of CO_2 captured.

The CO_2 is separated from a flue gas stream and captured by the amine absorber. Absorption is the chemical reaction by which CO_2 from the flue gas is absorbed by an amine-absorption unit, thus removing CO_2 from the feed stream. The concentrated CO_2 is then released from the amine solvent in the regenerator (or CO_2 stripper) by heating, which also regenerates the solvent that is then cooled and sent back to the absorber. The captured CO_2 is then compressed, dehydrated and transmitted by pipeline either to a depleted oil field for enhanced oil recovery (EOR) or to a saline aquifer for dedicated geological storage. EOR is widely used in Western Canada.

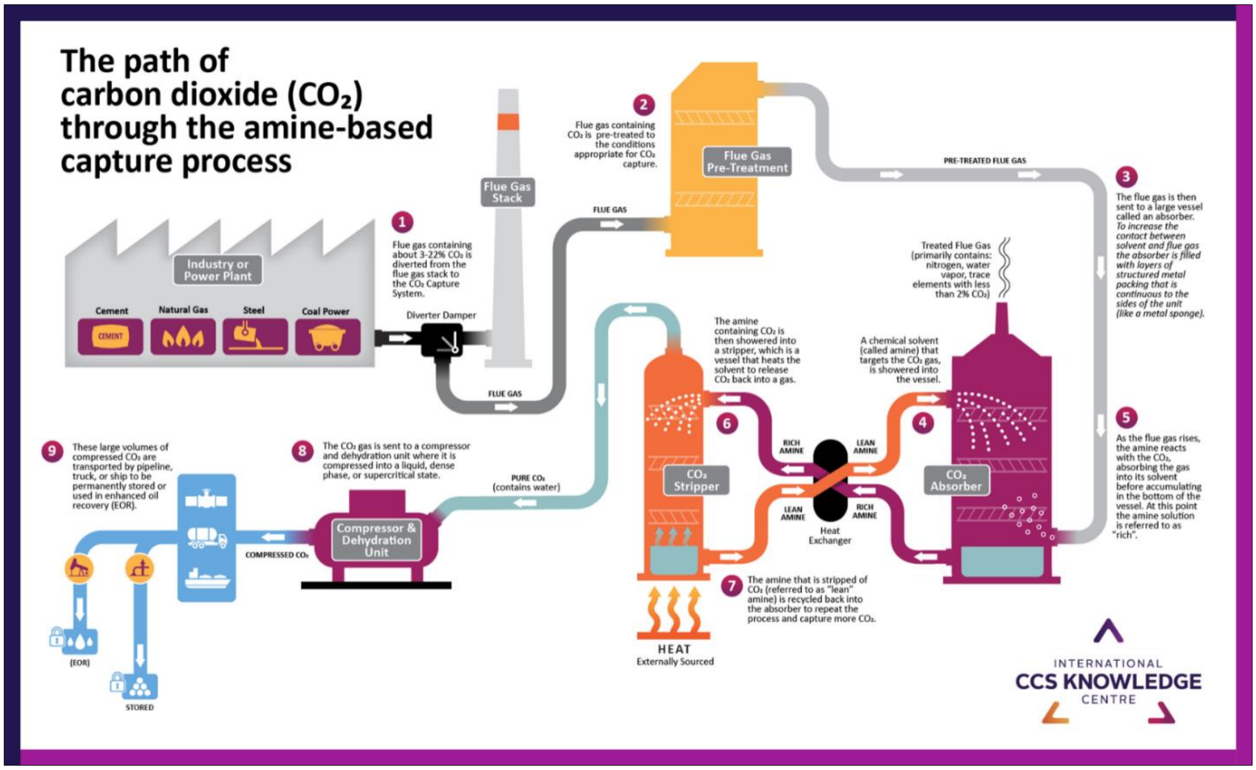

Figure 3: This figure of an amine-absorption unit is reproduced courtesy of the International CCS Knowledge Centre, Regina, Saskatchewan.

Figure 4: Quest Amine Absorption Unit, Scotford Refinery (courtesy Shell Canada)

The net amount of CO_2 avoided is less than 1 MT/yr because (i) the amount captured is constrained by other operations at this chemical plant and (ii) losses of CO_2 during subsequent transmission and storage operations. During 2022, Quest reported that although it captured 0.971 MT CO_2, the operating CO_2 losses from capture, transmission and storage amounted to 0.215 MT, yielding a net capture of 0.755 MT CO_2 not emitted. The captured CO_2 is compressed into a dense fluid before being piped 65 km under high pressure to a CO_2-injection wellfield north of Scotford.

The International Energy Agency reported in 2023 there were approximately 40 commercial carbon capture facilities in operation globally having a total annual capture capacity of more than 45 MT of CO_2.

This seems to be a lot, but Ontario annually emits 45 MT CO_2 from manufacturing, power plants, mines, etc., plus over 100 MT/yr from buildings and transportation. None of these emissions are currently (2024) captured and geologically stored.

What is emitted in Central and Eastern Canada?

Figure 5 illustrates the manufacturing, oil and gas extraction, and electricity-generating utility emissions of CO_2 for central and eastern Canada, are shown for the 2021 emissions. These shown amount to ~85 MT CO_2, which is 30% of the Canadian total. The bulk of the remaining 70% is associated with the western Canadian oil and gas industry, particularly bitumen extraction in the Athabasca Oil Sands.

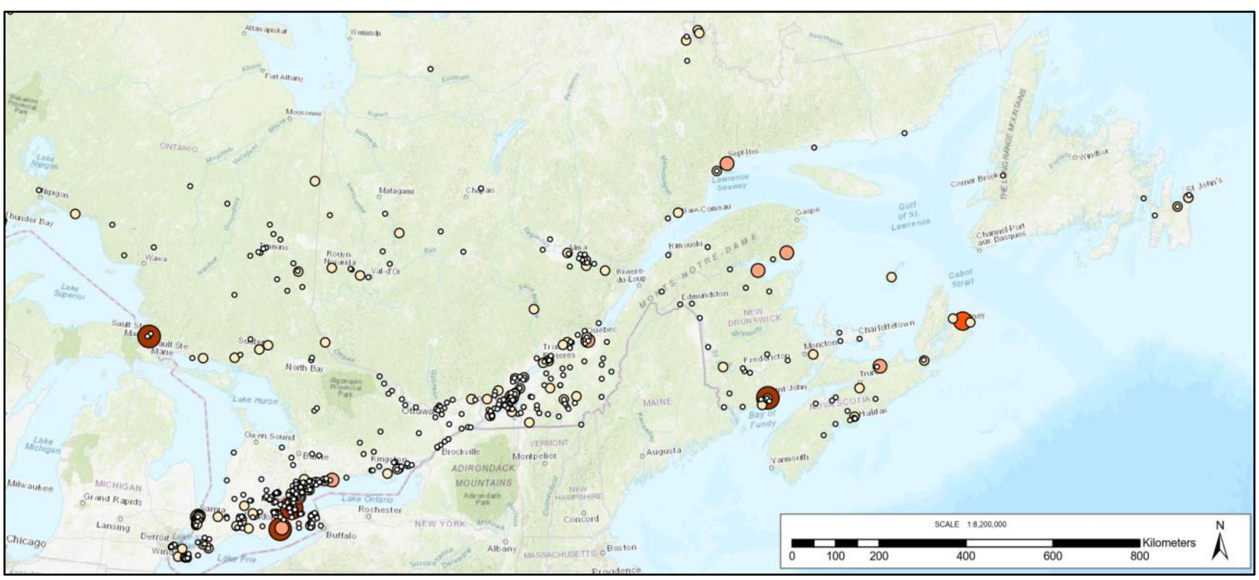

Figure 5: Emission Sources in 2021, Central and Eastern Canada

How industrial CO_2 is transported from industrial plants to storage hubs

Figure 6 shows the various transport modes that might move captured CO_2 to a geological storage hub.

The existence of pipeline rights-of-way for natural gas, favorable transportation costs and the large CO_2 volumes that pipelines can transmit will make pipelines the preferred transport mode. However, the cost of a new CO_2 pipeline will be about $5-10 million per kilometre depending upon whether the pipeline route is through urban or hilly areas or through flat rural land. The Canada Infrastructure Bank began (2024) a cost analysis of various pipeline routes from southwestern Ontario to Montreal followed by shipping to potential reservoirs offshore Nova Scotia.

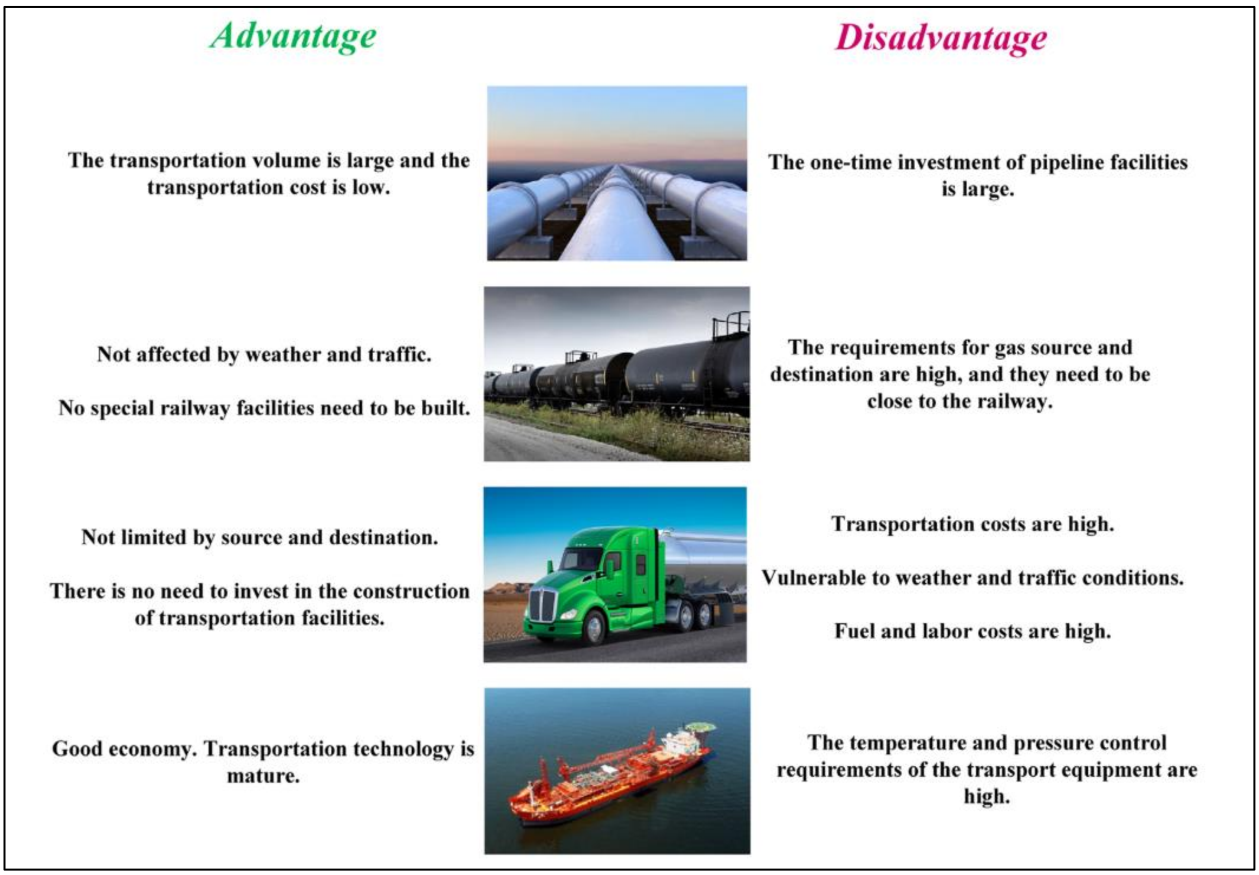

Figure 6: Advantages and Disadvantages of the Different Modes of CO_2 Transport

Rail transport is likely to be an attractive option for smaller industrial sources where pipeline costs would be high. Marine transport on the Great Lakes or from tidal ports to the vast offshore geological storage reservoirs on the continental shelf 50-100 km off Nova Scotia or Newfoundland may also play significant roles by 2050.

The requirements for safe geological storage

Geological storage of captured CO_2 is considered to be a proven and safe option for industrial decarbonization. This is supported by the trapping of natural gas and petroleum in the subsurface over tens of millions of years. Natural gas, being buoyant, would not remain in ancient rocks for today's use if it wasn't trapped effectively. The same applies to the geological storage of CO_2 in deep brine-saturated reservoirs.

The standard practice for CO_2 storage worldwide requires that geological storage reservoirs (and their confining caprock) are sufficiently deep to allow the CO_2 to be injected and confined as a dense fluid. This allows efficient use of the storage reservoir. Consequently, it is standard practice that the storage reservoir will be:

- ✓ Greater than 800 m deep (or 2500+ ft deep) to allow sufficient pressure (9 MPa or 1300 psi or more) so that the CO_2 is injected as a dense fluid.
- ✓ Sealed by a sufficient thickness of competent caprock above the storage reservoir, so that the CO_2 is permanently trapped within the reservoir.

The Canadian Standards Association issued CSA Z741-12 ***Geological Storage of Carbon Dioxide*** in 2012 to guide safe geological CO_2 storage. It was reaffirmed in 2022 and is widely used in North America because it was developed on the basis of experience with geological storage of toxic sour gas (i.e., CO_2 and SO_2) in western Canada. It is primarily applicable to saline aquifers (i.e., permeable rock reservoirs saturated with brine) and depleted hydrocarbon reservoirs, of which there are many in eastern Canada. Furthermore, it promotes practices that minimize risks to the environment and human health.

The CSA standard recommends choosing a storage reservoir that will be:

- ✓ *Preferably,* located near major CO_2 emitters & pipelines to minimize costs.
- ✓ *Preferably,* penetrated by few oil and/or gas wells that will require plugging to prevent release of the injected CO_2.
- ✓ *Preferably,* containing large pore volumes available for CO_2 storage, so that there will be limited pressure change as the injected CO_2 displaces the brine that exists in these geological reservoirs.
- ✓ *Preferably,* containing few geological faults that might slip with fluid injection and cause felt earthquakes.

Provincial regulations, when they are enacted, will no doubt follow the CSA standard as has been the case in Alberta, British Columbia and Saskatchewan.

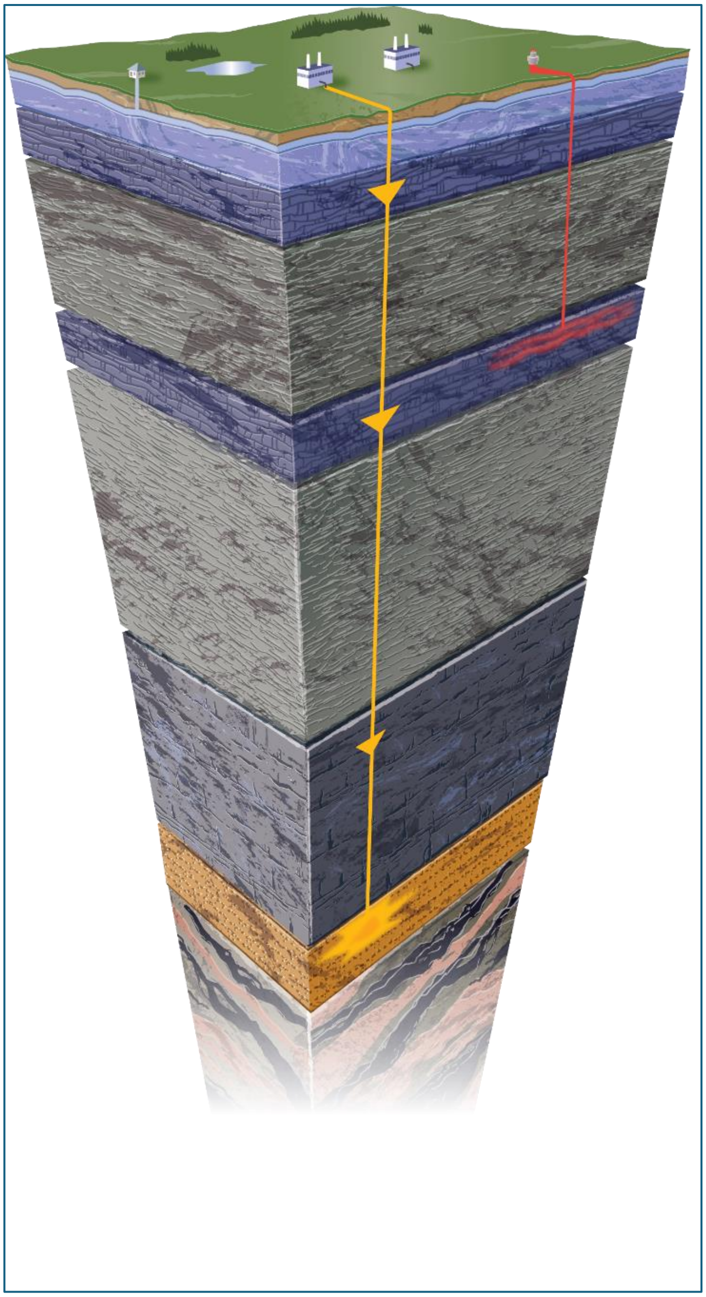

Figure 7: The CSA requirements for geological storage protect shallow fresh-water aquifers (blue) and communities from the upward migration of CO_2 from the deep reservoir at the base of this figure.

The depleted oil and gas reservoirs common in eastern Canada are shown opposite at 300-400 metre depth as purple rock with a red producing well.

At intermediate depth and immediately above the CO_2 storage reservoir is the caprock, shown opposite as purple and grey rock. The caprock prevents upward leakage of the buoyant CO_2 that has been injected into the storage reservoir below. It must be impermeable to CO_2 and lacking in faults that would allow CO_2 to escape.

The preferred depth of CO_2 storage in Canada will be at least 1 km below ground surface as shown by the yellow injection well opposite. Here, the CO_2 storage reservoir, also shown in a dirty yellow, is a sandstone that is both permeable and porous. It will be saturated with brine that the injected CO_2 will have to displace, causing the pressure in the storage reservoir to increase over an area known as the Area of Review. Several injection wells may be needed for each storage hub.

Risks and Potential Hazards

There are risks and hazards associated with CCS, but they appear manageable on the basis of experience in western Canada and the USA. By following CSA standards, risks to the environment and human health will be minimized.

Hazards include the potential for minor earthquakes, the vast majority of which will be too weak to be felt by someone on the ground surface. However, some maybe felt and noticed by the rattling of dishes on a shelf. A second hazard is that associated with leakage from legacy oil and gas wells that were not properly plugged upon abandonment years ago. These must be located and plugged prior to any CO_2 injection. Pipelines will have to be constructed from special high quality steel.

To ensure that CO_2 injection and storage operations are safely conducted and hazards minimized, the project developer will be expected to institute a program of ***Measurement, Monitoring and Verification.*** This MMV program will begin before the initiation of CO_2 injection to establish a baseline of measurements. The monitoring will continue for the lifetime of the project and beyond into the post-closure period when CO_2 injection will have ceased. The results of measurement and monitoring will be verified by independent third parties and results made public. Any significant variations from the measured baseline values within the Area of Review will be subject to investigation by the provincial regulatory agency as well as the project developer. This area will extend 10-20 km beyond each injection well.

For More Information

On Insurance Costs for Canadians:

- ✓ https://www.canadianunderwriter.ca/insurance/where-home-insurance-premiums-are-trending-upwards-in-2022-1004223267/
- ✓ https://rates.ca/resources/frustrated-rising-home-insurance-premiums-blame-climate-change

Further Reading:

- ✓ ***Carbon Capture***, by Howard Herzog, MIT Press, Cnd$22, 2018.
- ✓ ***What We Know About Climate Change***, by Kerry Emanuel, MIT Press, Cnd$22, 2018.
- ✓ ***The Citizen's Guide to Climate Success***, by Mark Jaccard, Cambridge University Press, Cnd$28, 2020.