

What should be done with the carbon dioxide extracted from the atmosphere by Direct Air Capture technology?

Leila Davies, Simon Fraser University

Abstract

This paper was originally written for Professor Vivian Neal's Sustainable Energy Engineering 101W course Process, Form and Convention in Professional Genres. The assignment asked students to write a persuasive research paper that argues for a position that relates to the practice of engineering and has a significant sustainability dimension. The paper uses IEEE citation style.

Direct Air Capture (DAC) technology has become more greatly incentivized in Canada as a potential solution for mitigating climate change by extracting carbon dioxide (CO₂) directly from the atmosphere. Geological sequestration, chemical conversion, and enhanced oil recovery (EOR) represent the primary applications of captured CO₂. While chemical transformation and EOR offer economic advantages, they fail to provide the long-term climate benefits necessary to stabilize the global temperature. Geological storage aims to ensure the permanent sequestration of CO₂, mitigating the risk of re-emission and offering a scalable solution capable of achieving negative emissions. Despite challenges such as high costs and long-term monitoring requirements, geological sequestration is required to meet the Paris Agreement's climate goals. Therefore, Natural Resources Canada should prioritize and legislate policies mandating the permanent geological storage of captured CO₂, safeguarding a lasting climate solution.

1. Introduction

Without a serious reduction of greenhouse gas emissions, the global temperature is projected to rise, causing permanent and irreversible environmental change. Among numerous mitigation techniques, the development and adoption of Direct

Air Capture (DAC) technology, which involves extracting carbon dioxide (CO₂) directly from the atmosphere, has become incentivized. The three most general applications of captured CO₂ are enhanced oil recovery (EOR), chemical transformation, and geological storage. Currently, EOR, the process of injecting captured CO₂ into a reservoir to increase the amount of oil extracted, is ubiquitous because it is profitable. On the other hand, the chemical transformation of CO₂ into products such as synthetic fuels offers environmental advantages. Despite these benefits, Natural Resources Canada should develop a policy to present to Cabinet for approved bill drafting that enforces the permanent sequestration of captured CO₂ in geological formations instead. Geological storage remains the only long-term, scalable solution capable of achieving the negative emissions necessary to stabilize the global temperature.

2. Increased Adoption of DAC

Canadian legislation has incentivized the growing adoption and development of DAC. Although carbon dioxide only makes up 0.04% of the atmosphere, it is one of the most potent greenhouse gases because of the heat-trapping properties of its molecular structure and its 300 - 1000 year lifespan in the atmosphere [1]. To achieve the climate goals outlined in the Paris Agreement, Canadian Parliament passed Bill C-59, which established the Carbon Capture, Utilization, and Storage Investment Tax Credit. As a result, qualified expenditures for DAC are eligible for a 60% credit, prompting elevated interest in DAC technology [2]. With 18 DAC facilities operating across Canada, Europe, and the United States [3], the Canadian government must decide what should be done with the thousands of tonnes of CO₂ captured yearly.

3. Opportunities for Captured CO₂

Captured CO₂ offers a variety of potential benefits and applications, including chemical transformation, geological storage, and EOR.

3.1 Chemical Transformation

Companies internationally are repurposing captured CO₂ to create groundbreaking technologies and establish a circular economy, as illustrated in Figure 1.

Carbon nanotubes, for example, can serve as an alternative to metal and be used to make other products such as wind turbine blades, airplanes, bicycles, and more [4]. In addition, microorganisms are being used to pull out concentrated carbon from captured CO₂, which is then combined with hydrogen and oxygen to create a naturally occurring bioplastic to reduce single-use petroleum-based plastic. Most significantly, captured CO₂ can be used to produce hydrocarbons. As fossil fuels are gradually exhausted, there is a growing need for a sustainable alternative, driving support for the conversion of such hydrocarbons into drop-in compatible gasoline, diesel, and jet fuel [5].

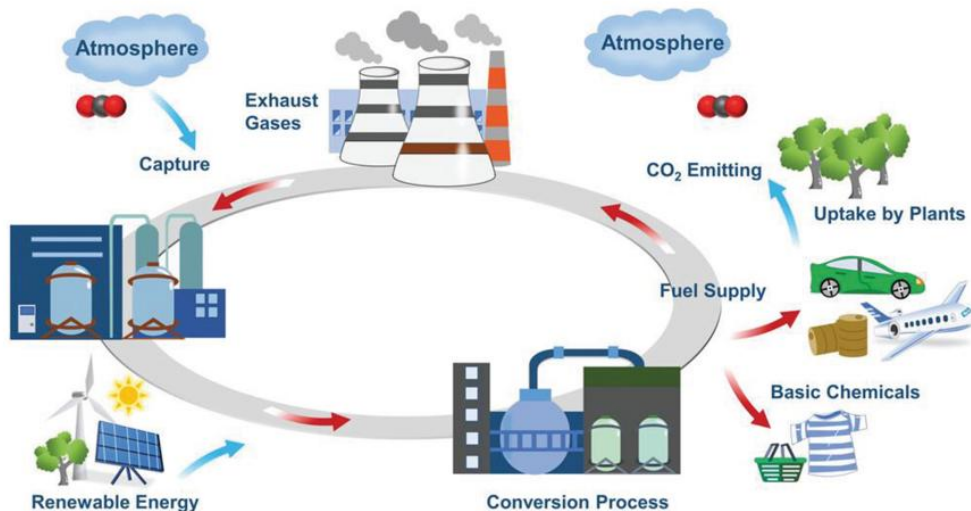


Figure 1. Circular Economy: Chemical conversion to reuse CO₂ [6]

3.2 Geological Storage

Carbon sequestration has been used to store more than 200 million tonnes of CO₂ in geological sites worldwide [7]. Research [3] suggests that carbon dioxide removed by DAC technology can be stored in natural rock formations, such as saline aquifers, or depleted oil and gas wells, demonstrated in Figure 2 (provided by Global CCS Institute, whose mission is to accelerate the storage of CO₂). Saline formations are large layers of porous rocks that contain salt water and are isolated deep underground. Once injected, the rock formations act as a physical barrier, and over time chemical reactions with surrounding minerals transform

CO₂ into immobile solid carbonates. Exhausted oil and gas wells have already been assessed for their trapping and storage capabilities from when they were operational, making them ideal carbon sequestration sites as well.

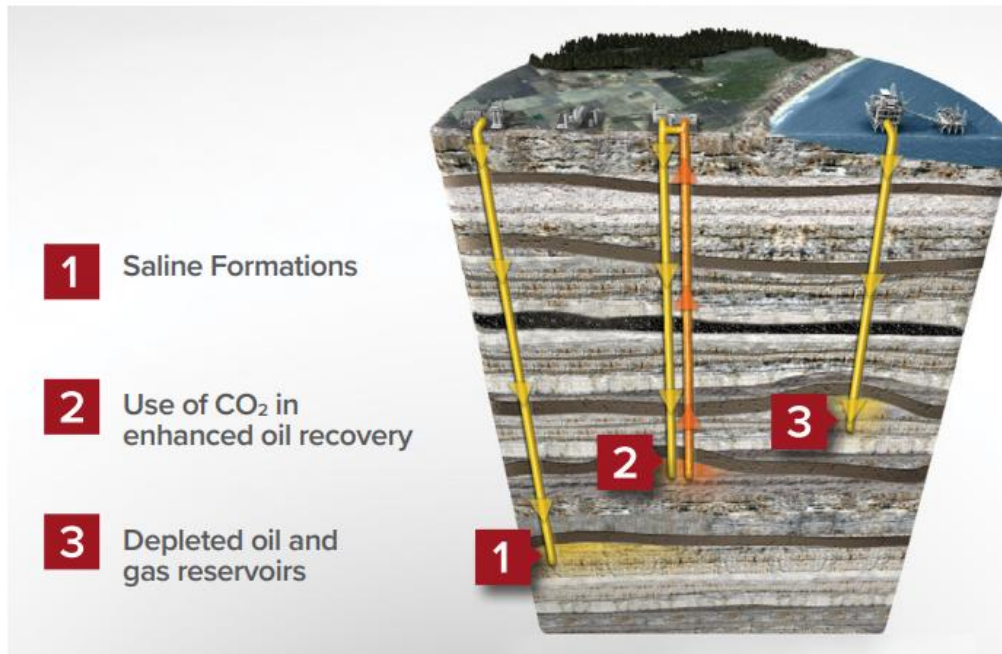


Figure 2. Storage options for CO₂ in deep underground geological formations [8]

3.3 Enhanced Oil Recovery

Another storage option includes injecting captured atmospheric CO₂ into oil reservoirs during oil production. The oil and gas industry has performed this process since the early 1960s [9]. EOR involves the injection of carbon dioxide gas into oil wells to pump out otherwise inaccessible oil (as shown in Figure 2). EOR can achieve net-zero carbon emissions when the injected CO₂ is equivalent to the emitted CO₂ byproduct of the recovered oil. However, because EOR was not established to achieve environmental benefits, the CO₂ injected into operational oil wells often is not permanently sequestered or is less than the amount of CO₂ released from burning recovered oil [9] (i.e., is not net-zero).

4. Evaluating the Trade-offs of CO₂ Applications

Assessing the long-term sequestration, scalability, economic incentive, and carbon re-emission of such CO₂ opportunities reveals that the short-term benefits of chemical transformation and EOR act as distractions, ultimately undermining the purpose of capturing CO₂.

4.1 Long-Term Sequestration

When geological storage sites are properly selected and regulated, injected CO₂ can be stored for thousands of years [10]. However, to store CO₂ underground, pipeline infrastructure is used, introducing the risk of pipeline leaks and groundwater contamination during the injection process. Additionally, increasing pressure in the surrounding rocks can induce earthquakes if the storage site is located near a fault line [9]. Furthermore, if the increased pressure creates cracks within the storage site, CO₂ can seep back into the atmosphere. Nonetheless, the sequestration of anthropogenic CO₂ emissions began in 1996, demonstrating that the technology is well understood and documented [9]. Supported by years of research, proper site selection renders the risk of leakage minimal. Moreover, any potential leakage associated with CO₂ transportation is present across all applications.

4.2 Scalability

Geological formations can accommodate immense amounts of CO₂, helping to achieve the carbon reductions required to limit a rise in global temperature. In Canada, geological sequestration has the capacity to store millions of tonnes of CO₂ annually. Projects like the Alberta Carbon Trunk Line, which has permanently sequestered over 5 million tonnes of CO₂, demonstrate that Canada has the infrastructure potential to rapidly scale-up carbon sequestration [11]. In contrast, enhanced oil recovery and synthetic fuel production are limited by market demand.

4.3 Economic Incentive

A drawback to geological sequestration is the required monetary investment. The ongoing need for monitoring geological sequestration sites could pose significant

economic and logistical challenges. Long-term site management and monitoring is required to ensure effective injection, verify quantity and condition, optimize efficiency, and detect leakage. To guarantee safety, sequestration sites require not only long-term management but also the operation of energy-intensive systems such as injection pumps and monitoring equipment, incurring high costs [9].

In contrast, chemical conversion of captured CO₂ has the potential to replace higher-emission processes and products; therefore, the market for CO₂-based products can foster significant economic growth. Additionally, EOR involves the injection of carbon dioxide gas into oil wells to pump out otherwise inaccessible oil. As oil remains a sought-after commodity, it could be argued that captured CO₂ would be better used in EOR as opposed to permanent and less economically viable geological storage [12].

4.4 Carbon Re-Emission

Sequestered CO₂ no longer contributes to global warming. This environmental benefit is critical for achieving long-term climate stabilization targets. Geological sequestration is the only method that ensures that CO₂ does not re-enter the carbon cycle. Over a period of 10,000 years, it is estimated that 98% of injected CO₂ will be retained in geological storage [13].

Conversely, consumed products, such as synthetic fuels, can result in CO₂ being re-emitted into the atmosphere when these products are used or degrade. In addition, using captured carbon in enhanced oil recovery undermines the goal of limiting the use of fossil fuels. The best chemical conversion of CO₂ into temporary carbon products or EOR could ever hope to achieve is net-zero emissions, which inadequately addresses the need to offset decades of past greenhouse gas accumulation. The Canadian government has demonstrated their understanding of these limitations by ruling EOR ineligible to receive the refundable tax credit offered under Bill C-59 [2].

5. Conclusion

While both the chemical conversion of CO₂ into products and the use of CO₂ in enhanced oil recovery offer economic benefits, they fail to address the urgency of

long-term climate stabilization. Only geological sequestration offers a scalable solution, guaranteeing the necessary removal of CO₂ from the atmosphere to counteract rising global temperatures. The risk of leakage is all but eliminated pending proper storage site selection, which has been carefully researched through decades of study. Despite high costs and energy demands, the long-term benefits of CO₂ sequestration in geological formations far outweigh the temporary solutions offered by synthetic fuels and EOR. As a result, it is essential that Natural Resources Canada develops a policy that ensures that captured CO₂ is permanently sequestered, safeguarding a lasting climate solution.

References

- [1] A. Buis. “The atmosphere: Getting a handle on carbon dioxide.” Nasa.gov. Accessed: Nov. 16, 2024. [Online]. Available: <https://science.nasa.gov/earth/climate-change/greenhouse-gases/the-atmosphere-getting-a-handle-on-carbon-dioxide/>
- [2] P. De Luna. “How U.S. and Canadian government direct air capture incentives compare.” Forbes. Accessed: Nov. 16, 2024. [Online]. Available: <https://www.forbes.com/sites/phildeluna/2024/09/03/how-us-and-canadian-government-carbon-removal-incentives-compare/>
- [3] S. Budinis et al., *Direct Air Capture: A key technology for net zero*. Paris, France: OECD, 2022.
- [4] C. Sweet. “5 surprising products companies are making from carbon dioxide.” Trellis. Accessed: Nov. 16, 2024. [Online]. Available: <https://www.greenbiz.com/article/5-surprising-products-companies-are-making-carbon-dioxide>
- [5] Q. A. Nwabueze and S. Leggett, “Advancements in the application of CO₂ capture and utilization technologies—A comprehensive review,” *Fuels*, vol. 5, no. 3, pp. 508–532, Sep. 2024, doi: 10.3390/fuels5030028.
- [6] A. Goksu, H. Li, J. Liu, and M. S. Duyar, “Nanoreactor engineering can unlock new possibilities for CO₂ tandem catalytic conversion to C-C coupled products,” *Global Chall.*, vol. 7, no. 6, p. 2300004, May. 2023, doi: 10.1002/gch2.202300004.
- [7] S. McCulloch et al., *20 Years of Carbon Capture and Storage - Accelerating Future Deployment*. IEA, Paris, France: IEA, 2016.
- [8] “Geological Storage of CO₂: Safe, Permanent, and Abundant.” Globalccsinstitute.com. Accessed: Nov. 16, 2024. [Online]. Available:

- https://www.globalccsinstitute.com/wp-content/uploads/2018/12/Global-CCS-Institute-Fact-Sheet_Geological-Storage-of-CO2.pdf
- [9] J. Ma et al., “Carbon capture and storage: History and the road ahead,” *Engineering*, vol. 14, pp. 33–43, Jul. 2022, doi: 10.1016/j.eng.2021.11.024.
- [10] N. Kampman et al., “Observational evidence confirms modelling of the long-term integrity of CO₂-reservoir caprocks,” *Nat. Commun.*, vol. 7, p. 12268, Jul. 2016, doi: 10.1038/ncomms12268.
- [11] “Market Snapshot: Canadian carbon capture and storage projects will soon sequester up to 6.4 million tonnes of CO₂ per year.” *Cer-rec.gc.ca*. Accessed: Nov. 16, 2024. [Online]. Available: <https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2016/market-snapshot-canadian-carbon-capture-storage-projects-will-soon-sequester-up-6-4-million-tonnes-co2-per-year.html>
- [12] J. Sekera and A. Lichtenberger, “Assessing carbon capture: Public policy, science, and societal need: A review of the literature on industrial carbon removal,” *Biophys. Econ. Sust.*, vol. 5, no. 3, Oct. 2020, doi: 10.1007/s41247-020-00080-5.
- [13] J. Alcalde et al., “Estimating geological CO₂ storage security to deliver on climate mitigation,” *Nat. Commun.*, vol. 9, no. 1, p. 2201, Jun. 2018, doi: 10.1038/s41467-018-04423-1.

By submitting this essay, I attest that it is my own work, completed in accordance with University regulations. I also give permission for the Student Learning Commons to publish all or part of my essay as an example of good writing in a particular course or discipline, or to provide models of specific writing techniques for use in teaching. This permission applies whether or not I win a prize, and includes publication on the Simon Fraser University website or in the SLC Writing Contest Open Journal.

This work is licensed under a [Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License](https://creativecommons.org/licenses/by-nc-nd/4.0/).

© Leila Davies, 2024

Available from: <https://journals.lib.sfu.ca/index.php/slc-uwc>