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APRIL 2021

CANADA'S CO_2 LANDSCAPE

A GUIDED MAP FOR SOURCES & SINKS

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At the International CCS Knowledge Centre (Knowledge Centre), we take climate action seriously. We are dedicated to advancing the understanding and use of large-scale carbon capture and storage (CCS) as a means of managing greenhouse (GHG) emissions, globally.

We know that the world can't get to net zero starting from ground zero – so we provide the know-how to implement large-scale CCS projects as well as CCS optimization. We house experts who were instrumental in the development and operations of the Boundary Dam 3 CCS Facility as well as the authors of the comprehensive second-generation CCS study, known as the Shand CCS Feasibility Study. We offer practical, hands-on experience-based guidance, technical advice for planning, design, construction, and operation of large-scale applications of CCS from thermal power to industrial processes.

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EXECUTIVE SUMMARY

Canada and its industries need to consider all the tools available in the strive to reduce carbon dioxide (CO_2) emissions and stimulate the economy to meet its climate change and sustainability commitments.

Analysis by the International Energy Agency (IEA) has determined that deployment of carbon capture technology is critical to achieve mid-century, global carbon reduction goals and temperature targets. It is clear that Canada is currently not on track to meeting its Paris Agreement targets. On April 22, 2021 (Earth Day), Canada announced an ambitious goal of 40-45% below 2005 levels by 2030.[1] Given this goal, what role will CCS play in the country?

CO_2, a greenhouse gas (GHG), is continually recycled. The emissions that factories, cars, and many power plants emit contains CO_2 which is released into the atmosphere. Those emitters are called CO_2 'sources'; when their CO_2 emissions are absorbed or put back in the ground the site is called a carbon 'sink'. This carbon cycle is something that is often taught in middle-school, though it should not be relegated to just a lesson in science class. Instead as countries around the globe hurry to meet Paris Agreement targets this basic principle – where sources reduce their emissions and sinks ramp up their carbon sequestering –needs to be an active part of the strategies to cut and prevent CO_2 in the atmosphere. This short report is a guide to what Canada's sources and sinks landscape looks like.

As the nation looks to reduce its emissions, knowing the sources and sinks is a vital combination for the application of carbon, capture, removal and storage. Considered necessary for both clean energy and to reduce industry-driven greenhouse gases, large-scale carbon capture and storage (CCS) is a multi-prong approach where there are many global successes.

While Canada has been a world leader in large-scale carbon capture since 1999, more needs to be done to tackle climate change.

> *"Climate change is the greatest long-term threat that we face as global community, but it is also our greatest economic opportunity."*[2]

In the world of CCS, geological sinks are of specific interest and Canada has some of the best geological formations for secure and permanent CO_2 storage. Access to appropriate storage is a definitive benefit for deploying this innovative technology and helps the country be at the forefront of achieving a cleaner, stronger future.

With net-zero commitments as a global priority topic, working toward negative emissions and the role bioenergy CCS can play, is something to pay attention to in Canada.

ACKNOWLEDGMENTS

The International CCS Knowledge Centre (the Knowledge Centre) acknowledges of the many experts in CO_2 emission sources and geological sinks whose research has informed this short report. The Knowledge Centre collaborated with Navius Research, to provide customized modeling of potential CO_2 sources, bioenergy sources, and sinks throughout the Canadian landscape. The Knowledge Centre also engaged carbon expert David Maenz, Ph.D., about how forest and agricultural sinks that also sequester carbon play a role in the future CCS landscape.

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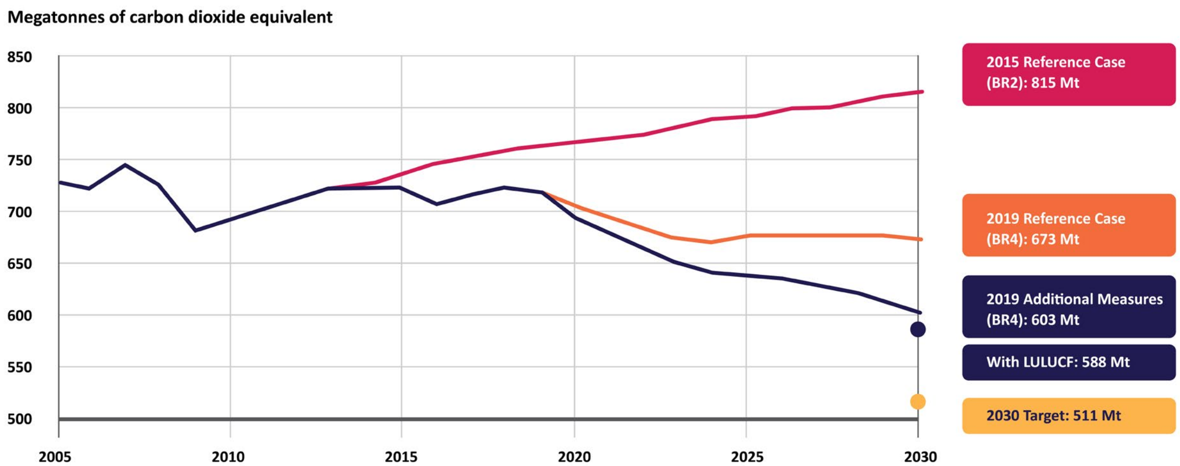
CANADA'S EMISSIONS

Canada reports annual emission sources and sinks yearly in its National Inventory Report. After hovering between 700 and 720 megatonnes (Mt) of CO_2 equivalent (Mt CO_2 eq) in recent years, in 2019 (the most recent annual dataset) Canada's GHG emissions were 730Mt CO_2 eq due to increases in both the transportation and oil and gas sectors.[3]

The white paper, Incentivizing Large-Scale CCS in Canada provides an overview of Canada's current emission reduction targets, climate policies, and the role CCS can play in Canada's climate mitigation actions. Canada's GHG emissions target is to reach 511Mt of CO_2 per year by 2030. Canada's GHGs are approximately the same level as 2005 (730Mt CO_2 per year), and without additional climate action, the CO_2 emissions level is projected to climb to an annual rate of 815Mt by 2030.[4] (See Figure 1: Historical Greenhouse Gas Emissions and Projects, Canada, 2005 to 2030).

FIGURE 1: Historical Greenhouse Gas Emissions and Projections, Canada, 2005 to 2020



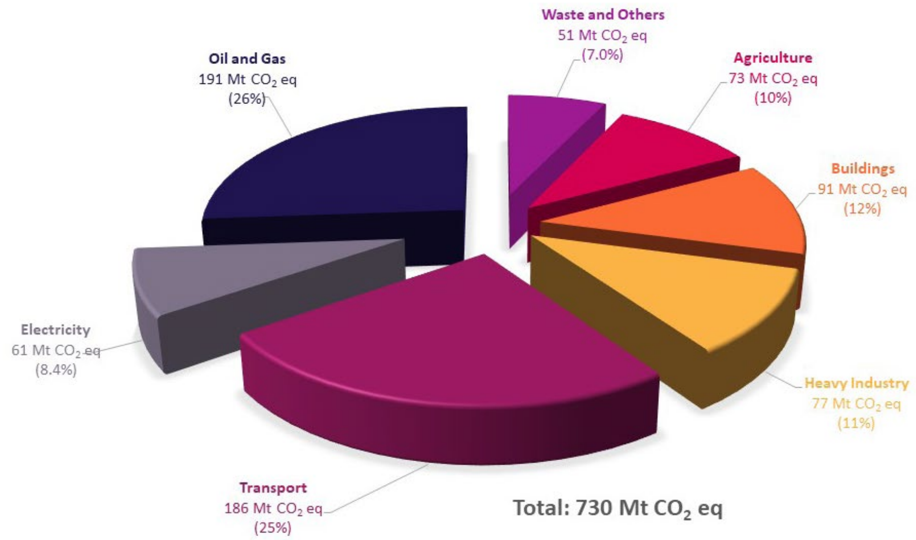
This graph summarizes GHG projections from 2005 to 2030 comparing scenarios in the 2015 reference case in the Second Biennial Report (BR2) and the 2019 reference case in the Fourth Biennial Report (BR4) with additional measures and LULUCF.

Source: UNFCC. "BR4", 2019, filed by Canada with UNFCC

WHERE DO ALL THESE EMISSIONS COME FROM IN CANADA?

In 2019, the oil and gas sector was Canada's highest emitting economic sector at 191Mt (26% of emissions), and transportation was a close second at 186Mt, a quarter of the country's total emissions. Buildings, heavy industry, agriculture, and electricity emissions were all under 100Mt seeing, respectively emissions as 91Mt, 77Mt, 73Mt, and 61Mt.[5] (See Figure 2: Breakdown of Canada's GHG Emissions by Economic Sector, 2019).

FIGURE 2: Breakdown of Canada's GHG Emissions by Economic Sector (2019)



This graph comes from the National Inventory Report 1990 –2018: Greenhouse Gas Sources and Sinks In Canada

Source: Environment and Climate Change Canada (2019)

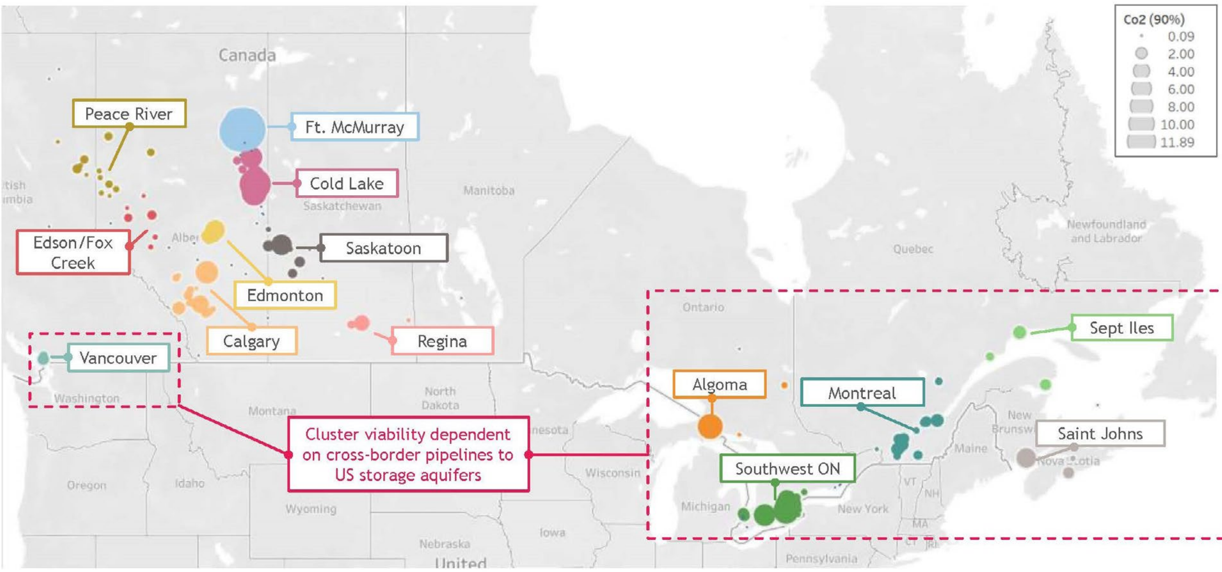
Reducing CO_2 emissions in the electricity and industrial sectors can be done through many means, including improved energy efficiency and the use of emissions reduction technologies like large-scale CCS. As evidenced by the high emissions from Canada's oil and gas sector, the world is still very dependent on fossil fuels, meaning CCS is a critical technology to meaningfully reduce the emissions arising from their use.

INDUSTRIAL HUBS AND SOURCES OF EMISSIONS

A mapping of CCS activity pulls to focus the Importance of Hubs and the exponential benefit of gathering industry (i.e., emitters) through shared infrastructure, an economic marketplace, and, in general, a cluster of activity happening around it. In the CCS space, the clustering of industry as a target for many emissions reductions can leverage potential lower cost because of their "hub" nature.

Site selection for capturing CO_2 emissions will depend on several factors but knowing whether there are opportunities for a hub of sources in proximity to ideal sinks, can help determine priority areas for development. Accordng to the Boston Consulting Group, Canada currently has several industrial regions that create low-cost clusters of emissions sources with associated ranges of cost from \$90-\$100/t CO_2 to as low as \$57/t CO_2.[6] (See Figure 3: Potential Hubs Across Canada). Knowing where the appropriate sinks are for these sources is the next step.

FIGURE 3: Potential Hubs Across Canada



Note: Key Industries Shown. Hubs may include other emitters.

Source: Boston Consulting Group (BCG) global hub identification and characterization tool; BCG analysis

Matching CO_2 sources and sinks is a core consideration for the feasibility of large-scale CCS, as deployment depends on the proximity of potential reservoirs to large point sources, and the terrain to traverse. The technical risks associated with capture and storage can be progressively reduced through learning-by-doing (i.e., with the deployment of scalable iterations), developing transport networks that can link multiple sources and sinks, and developing (or adopting) management systems to manage risks inherent in resource development.

SINKS

SEQUESTRATION (STORAGE)

The International Energy Agency's (IEA) CCUS in Clean Energy Transitions report, released in September 2020, states that in order to reach a Sustainable Development Scenario out to 2070, over 10 billion tonnes (Gt) of CO_2 will have to be captured, 90% of it must be stored, and only 8% to be used in other application.[7] In the IEA's Faster Innovation Case – getting to net-zero by 2050 – the world requires even more CCS in the energy mix (including more bioenergy CCS and direct air capture) with over 8Gt to be captured in that timeframe, and storing 200 times more than current levels.[8]

The Canadian geological landscape has the capacity for a large volume of permanent and secure CO_2 storage. This means capturing CO_2 produced by large industrial plants, compressing it for transportation and then injecting it deep into a rock formation at a carefully selected site. Four key elements are important for CO_2 storage:

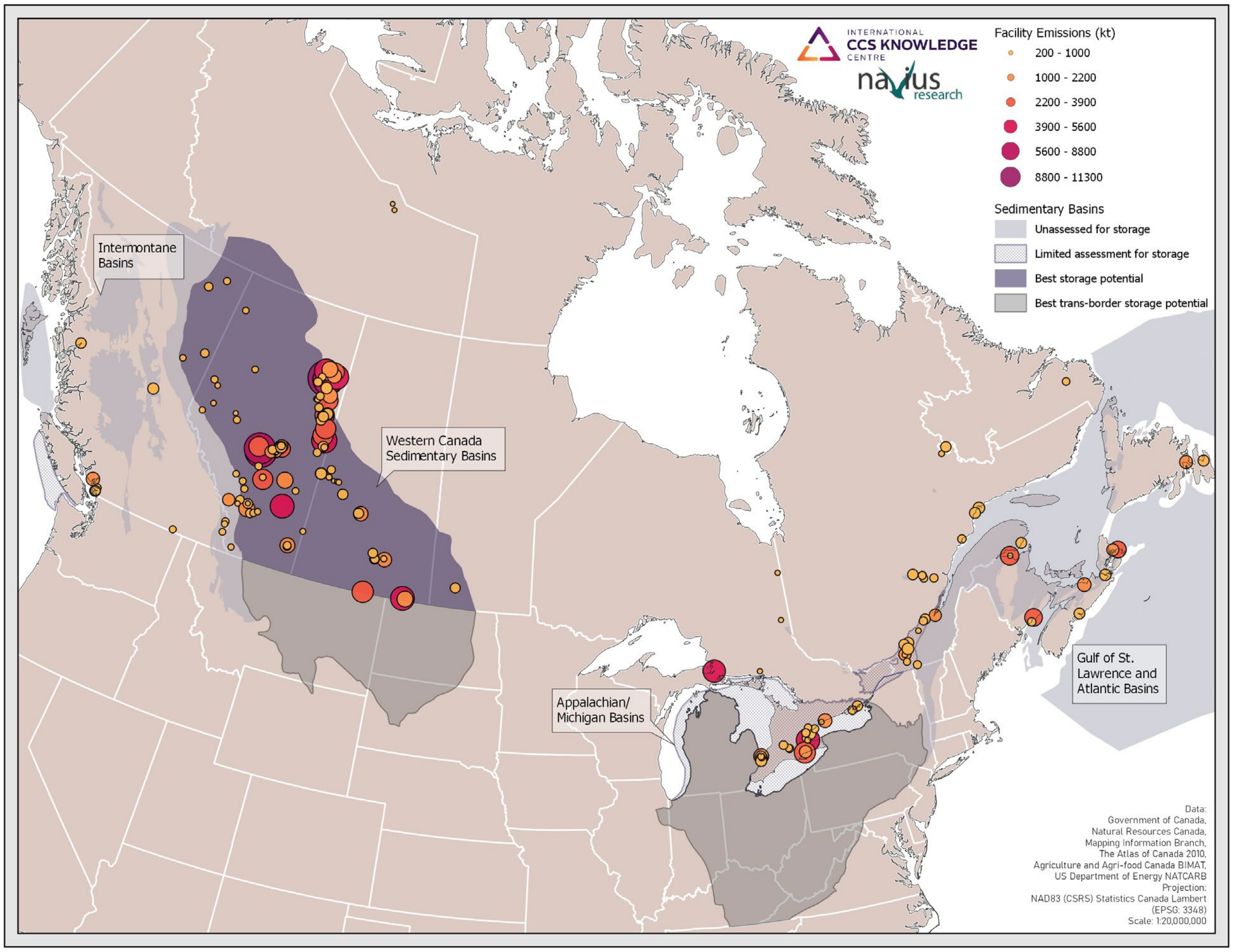
- **Depth and Location:** The storage location needs to be at sufficient depth and be made up of a micro-porous rock (a rock full of tiny holes) that is permeable (the holes are connected) so the CO_2 can move through the rock and be entrapped in the pores.

- **Containment:** A storage site must also have a layer of dense, impenetrable rock above it (called caprock) to prevent upward movement of CO_2.

- **Capacity:** The storage site must also have enough pore space to hold the amount of CO_2 planned to be injected over the life of a project.

According to the CO_2 Storage Resource Catalogue, which has compiled global storage potentials, Canada's sum of its storage resources is 398 Gt in deep subterrain geological formations, known as basins. The west's "Western Canada – Alberta" basin and "Williston" basin totaling 390Gt of storage resources; and the east's "Quebec" basin and "Michigan" basin make up the other 8Gt. All identified basins extend into the United States (US). A geological mapping of sinks shows a pairing with the mapping of geographical sources in Canada. (See Figure 4: Carbon Capture and Storage Potential).

FIGURE 4: Carbon Capture and Storage Potential



Map indicates large heavy industry emitters across Canada, as well as storage 'sink' potential.

Source: The International CCS Knowledge Centre

WEST VS EAST

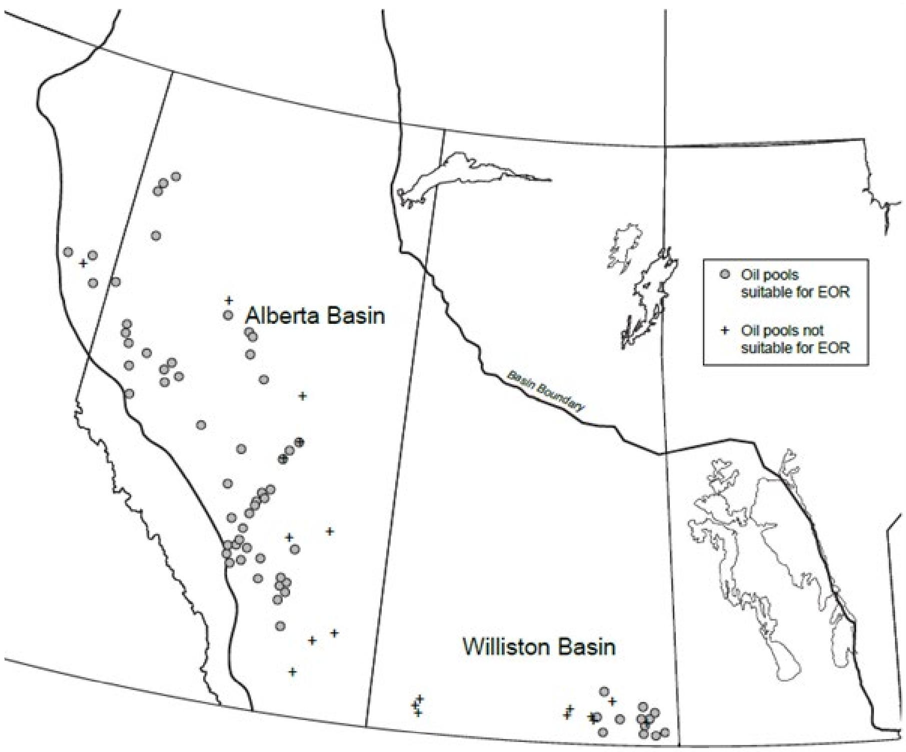
While not all potential storage basins are created equal, or offer the same potential, Canada is fortunate to have identified storage potential and regulatory systems which permit onshore storage, comprehensive monitoring practices, and ensures solutions for long term liability of sequestered CO_2.

As indicated, Alberta and Saskatchewan have the best storage potential because of the large extent of sedimentary basins that contain multiple types of storage (e.g., within oil and gas reservoirs, un-mineable coal, and saline aquifers) with well characterized geology and storage potential in the order of hundreds of gigatonnes of CO_2.[9]

For over two decades industrial-grade CO_2 has traveled 330km by pipeline from the Great Plains Synfuels Plant in Beulah, North Dakota, to the Weyburn and Midale oil fields in Saskatchewan for enhanced oil recovery (EOR). Using CO_2 for EOR is another form of sequestration of CO_2 when emissions are instead injected into an oil field, where the CO_2 becomes trapped permanently in the process. The use of CO_2 is often referred to as 'utilization' and in the acronym CCUS is represented by the letter 'U'. In addition to CO_2 crossing the international border from the US to Canada for the past two decades, CO_2 is also supplied to this oil field via a 66km pipeline from SaskPower's Boundary Dam 3 CCS facility in Estevan. The BD3 CCS Facility also provides CO^2 to a dedicated deep geological storage site, known as Aquistore.[10]

The Western Canadian Sedimentary Basin is estimated to exceed 600 billion tonnes of CO_2 storage potential, according to the National Energy Technology Laboratory. Only a fraction of this 'sink' potential would have usable capacity given various geological and economic considerations.[11] A visual of this for potential EOR sequestration options is depicted in Figure 5: Oil Reservoirs with >1Mt CO_2 Storage Capacity. As such, the Weyburn-Midale oil fields have trapped approximately 40Mt of CO_2 in the reservoirs, with an additional 2.8Mt added annually, making Saskatchewan home to the largest amount of injected anthropogenic CO_2 in the world.[12]

FIGURE 5: Oil Reservoirs with >1 Mt CO_2 Storage Capacity[13]



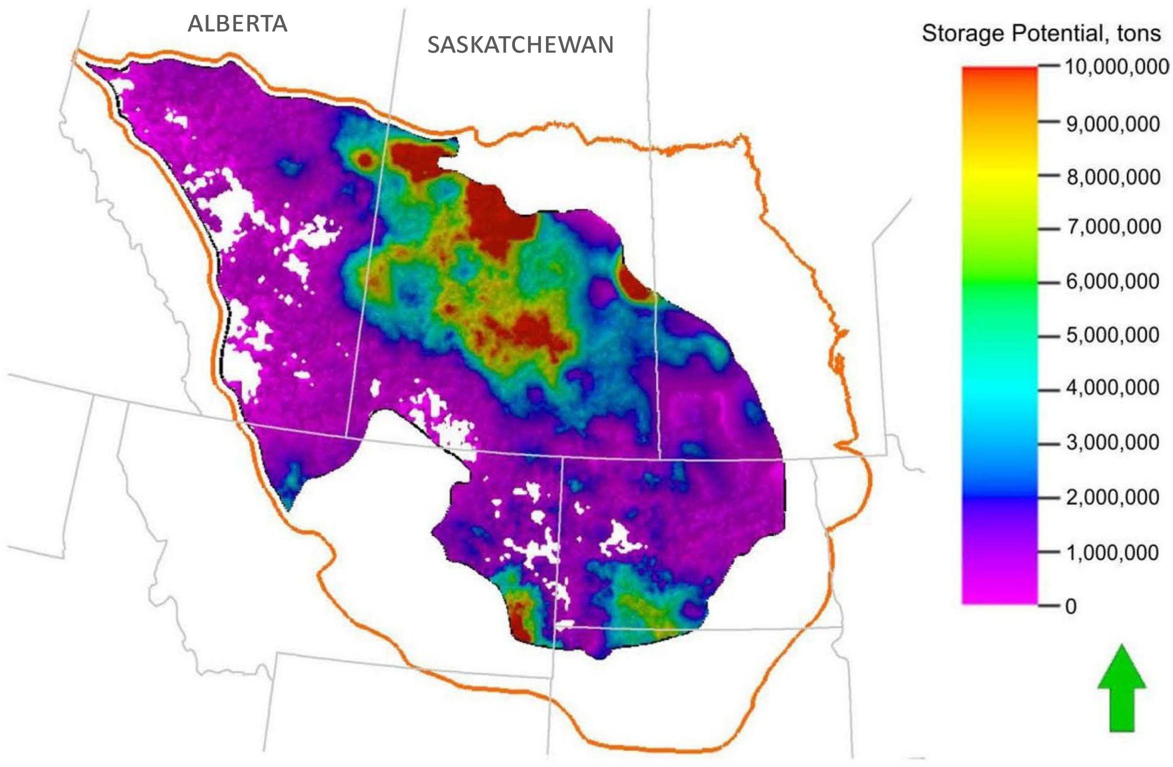
CO_2 Storage potential when considering EOR opportunities.

Sources: Bachu, S. & Shaw, J. "CO_2 Storage in Oil and Gas Reservoirs in Western Canada: Effect of Aquifers, Potential for CO_2-Flood Enhanced Oil Recovery and Practical Capacity", Peters & Co. Limited

Until recently, the vast majority of CCS/CCUS projects have relied on revenue from the sale of CO_2 for use in EOR. However, increased carbon pricing in many regions and the implementation of low carbon fuel standards have resulted in additional revenue streams and improved economics for CCS/CCUS projects.[14] It is important to note that CCS/CCUS was highlighted as a key component in the Canadian Federal Government's Budget 2021 proposal (April 19, 2021). While a new investment tax credit was introduced for capital invested in CCS/CCUS projects, EOR was NOT included.

In Alberta, there are four active CO_2 storage projects, which combined, can currently store up to 2.95Mtpa – Quest Storage, Chigwell EOR, Clive EOR, and Joffre EOR. In 2020, Alberta stored about 3.1Mt of CO_2 – which represents about 2.1% of its 2018 industrial emissions. In the five years since its start up in 2015, the Quest CCS facility has captured and safely stored over 5Mt of CO_2. This is the most any onshore CCS/CCUS facility has stored globally – proving that "… large-scale CO_2 storage is a safe and effective measure to reduce CO_2 emissions from industrial sources."[15] Analysis of basin maps, illustrate that there is likely still "tonnes" of storage available. (See Figure 6: Storage Potential (tons) of Basal Saline System).

FIGURE 6: Storage Potential (tons) of Basal Saline System



Storage potential (tons) of the basal saline system using P50 efficiency factor of 9.1%

Source: The Plains CO_2 Reduction (PCOR) Partnership, "Evaluation of large-scale carbon dioxide storage potential in the basal saline system in the Alberta and Williston Basins in North America" (2014).

While yet unproven, databases show that Alberta and Saskatchewan are not the only places with potential for CO_2 storage for Canadian emissions. Southern Ontario sits in the midst of potential storage opportunities. The Appalachian and Michigan basins, two of the largest sedimentary basins in eastern North America, stretch across multiple US states and reach into Ontario at its southern border.[16] On the Ontario side of these basins, saline aquifers have been identified as potential carbon storage options.[17] While the assessed storage potential in Ontario itself is comparatively small, site specific studies indicate that the potential could be larger with some associated complications - a Climate Ontario review in 2004, estimated that about 805Mt of CO_2 could be stored between the two saline aquifer reservoirs in the middle of Lake Huron and Lake Erie.[18]

CCS/CCUS potential in Canada may not be limited to these two regions. Pre-screening analysis has already been conducted off the west coast of Vancouver Island, as well as a preliminary assessment for storage potential in southern Quebec. Exploration of storage options could also be conducted in Atlantic Canada. While this area is surrounded by offshore sedimentary basins, there has been minimal consideration of the CO_2 storage potential. Furthermore, the region generally does not have clusters of large heavy emitters like some of the other regions across the country. However, there is still the possibility for CCS/CCUS in Atlantic provinces and this abatement potential should not be ruled out.

BIOENERGY WITH CARBON CAPTURE AND STORAGE (BECCS)

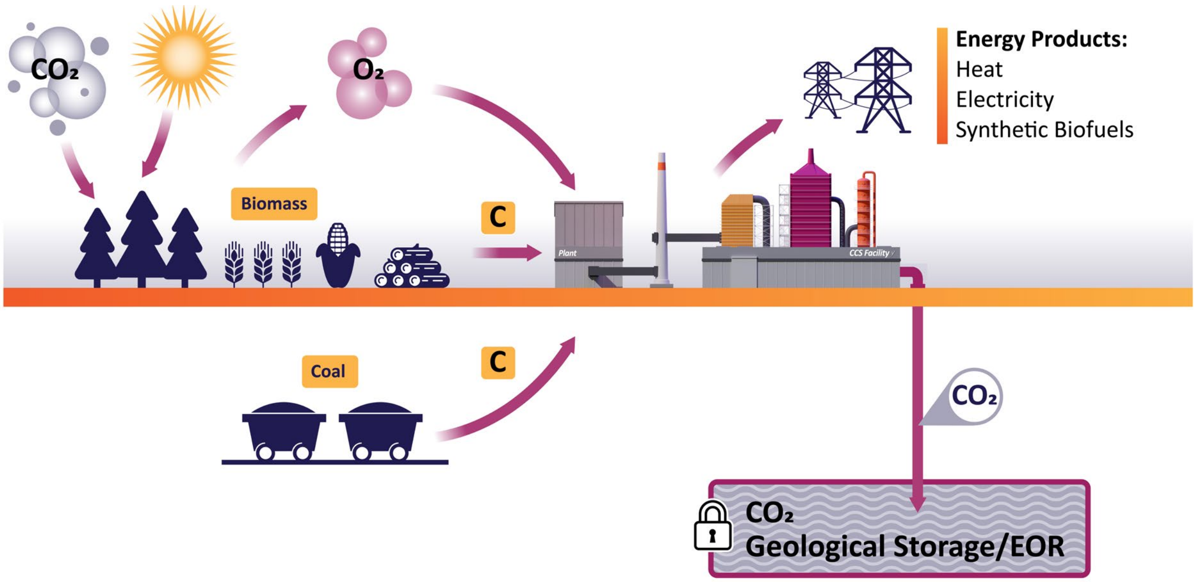
Much of the information presented in this section of the report was provided by Dr. David Maenz, of Maenz Consulting and author of The Price of Carbon.

Most modeling scenarios show that in order to achieve emission targets significant deployment of negative emissions technologies is required. Bioenergy with CCS (or BECCS) is one of the few available that can deliver to the necessary scale. Canada has an abundance of storage opportunities, but it also has a formidable land mass with forests, marsh and wetlands, farmland, and other natural CO_2 sinks. There is an opportunity for Canada to consider the bioenergy solutions that could be paired with CCS/CCUS in order to achieve negative emissions in the country.

In fact, BECCS leaders such as Drax in the UK, recently acquired Canada-based Pinnacle Renewable Energy, a large producer of compressed bioenergy pellets; with 2.9Mt of pellets earmarked for its biomass power plant in the UK.[19]

Utilizing bioenergy from biomass to produce heat by extracting energy from biomass (such as wood, energy crops and waste from forests, yards, or farms) and capturing and storing the carbon is a familiar practice globally.

FIGURE 7: Bioenergy with Carbon Capture and Storage (BECCS)



BECCS provides an opportunity to utilize existing coal plant infrastructure to produce reliable power with negative CO_2 emissions.

Source: The International CCS Knowledge Centre

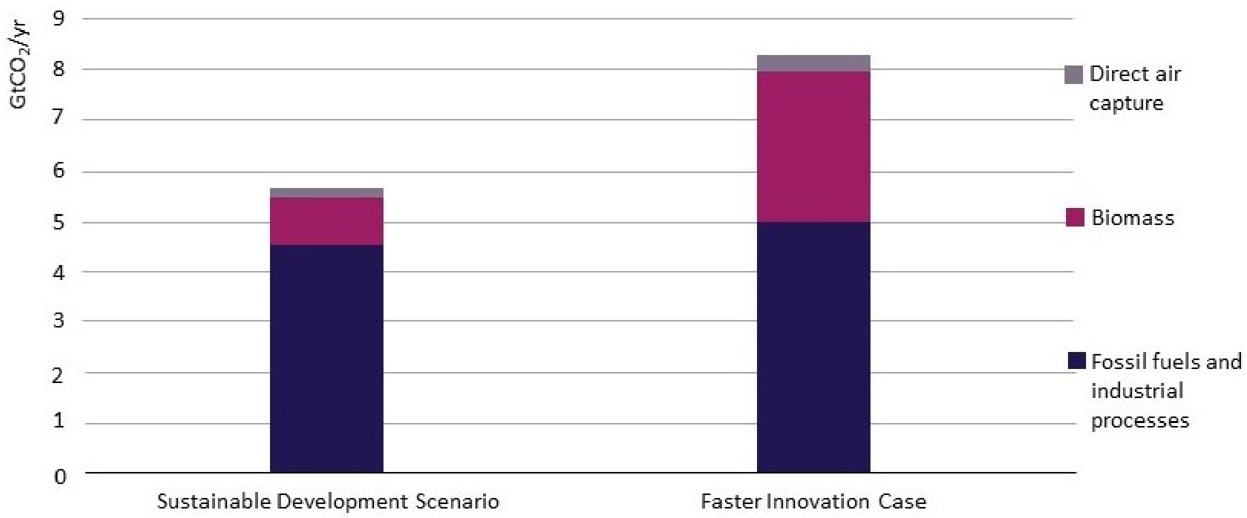
Today, bioenergy is used to fuel vehicles through bioethanol and provide electricity by burning biomass; ultimately, enabling CO_2 capture and sequestration and making BECCS a negative emissions technology. This negative emission process can be described as a cycle: the biomass is a natural carbon sink; it is used for energy feedstock to supplement and/or replace coal to generate energy products; then the CO_2 is capture and transported for permanent storage in either geological or in EOR; and in doing so, returns the carbon to the earth. (See Figure 7: Bioenergy with Carbon Capture and Storage (BECCS)).

The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report suggests a potential range of negative emissions from BECCS of zero to 22Gt per year. Yet wide deployment of BECCS is constrained by cost and availability of biomass.[20] The Knowledge Centre further explored the findings of its Shand CCS Feasibility Study and evaluated the potential impact of bioenergy with CCS – indicating that when these two technologies work in tandem, emissions move to the negative side of the equation. Coal co-firing with biomass is being done throughout the world and accommodates the development of biomass supply (see article: Beyond Coal).

BECCS is considered a mature carbon removal option because bioenergy and CCS are both proven technologies. The IEA's CCUS in Clean Energy Transitions report also believes that BECCS will be a critical part of its Sustainable Development Scenario and even more so in its Faster Innovation Case. It notes that by 2100, cumulative carbon removal potential by BECCS is 100-1170Gt.[21] It also compares the CO_2 capture rate in gigatonnes per year between the scenarios (Sustainable Development and Faster Innovation Case) where emission reductions from CCS/CCUS on fossil fuels, biomass, and direct air capture (DAC) are considered. Emissions captured from bioenergy see a tripling in the Faster Innovation Case. (See Figure 8: Global CO_2 Capture in the Sustainable Development Scenario and Faster Innovation Case, 2050).

The IEA does note some limitations for BECCS due to cost-competitiveness constraints with other mitigation measures and (potentially) access to suitable storage as well as by the availability of sustainable bioenergy.[22]

FIGURE 8: Global CO_2 Capture in the Sustainable Development Scenario and Faster Innovation Case, 2050



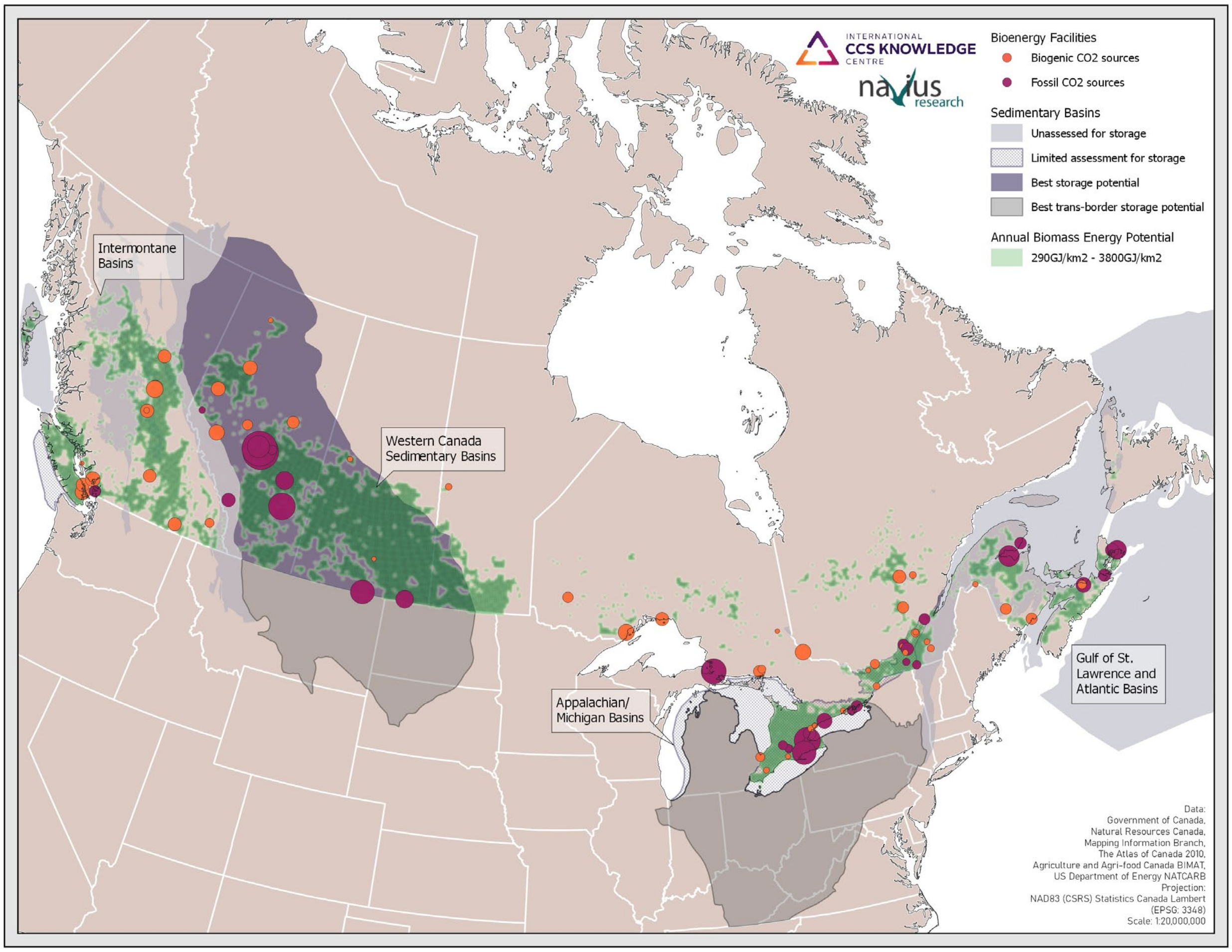
Negative emissions technologies, namely DACS and BECCS, account for the bulk of increased capture volume and are critical in offsetting residual emissions from long-distance transport and heavy industry. Emissions captured from bioenergy and the air in 2050 would triple relative to the Sustainable Development Scenario. Around 7 DACS facilities of 1 Mt capture capacity would need to be commissioned every year.

Source: Box 2.3 A faster transition requires more CCUS, pg. 54, IEA (2019)

BECCS FOR NETZERO IN CANADA

Achieving Canada's target of net zero emissions by mid-century will require a significant deployment of CO_2 reductions to offset residual emissions from agriculture and other difficult to abate niche sources. Natural solutions, such as increased forested areas, are unlikely to provide sufficient CO_2 reduction capacity and must be supplement by industrial processes such as DAC or BECCS .

FIGURE 9: Bioenergy Carbon Capture and Storage (BECCS) Potential



Map indicates biomass potential across Canada, along with heavy industry emitters where BECCS might be possible.

Source: The International CCS Knowledge Centre

Canada is rich in the resources required for successful implementation of BECCS. The Western Canada Sedimentary Basin is a vast, readily accessible, geologically stable formation with a limitless capacity for storage of captured carbon. This resource is supplementted by an abundance of forestry and agriculture residues.

Based on existing facilities, the theoretical emissions abatement potential of BECCS across economic sectors is enormous. Emissions-intensive industry combusting fossil fuels include coal-fired power plants in Alberta, Saskatchewan and Atlantic Canada, iron and steel mills, primarily located in Southern Ontario along with cement and lime kilns. If these industries were to fuel switch to biomass with CCS, the emissions abatement potential approximates 20% of current national emissions and would consist of 70Mt/year of CO_2 in avoided emissions from fossil fuel combustion plus an equivalent quantity of negative emissions biogenic CO_2 that would be captured and stored from biomass use. Capture and storage of biogenic carbon from existing facilities that currently process biomass extends the abatement potential by another 35Mt/year.

Actual implementation of BECCS will be constrained by access to geological storage and biomass supply. Biomass must be sustainably sourced without impacting land use for food and feed production or existing ecosystems. These restrictions focus supply to forestry and agriculture residues. However, even with these restrictions, the potential for biomass supply could readily support broad scale implementation. The coal-fired power plants in Alberta are ideally situated for geological storage and supply of sustainably harvested biomass. If half of these facilities were retrofitted to biomass fuel with CCS, national emissions would be cut by 36 Mt annually. Using CCS at forest products facilities and ethanol plants in that region could reduce emissions by another 6MtCO_2/yr.

Optimum implementation of BECCS would be dependent on establishing ideally located hubs/clusters of industry attracted by the potential of zero or negative emissions. Negative emissions electricity could service these facilities. These hubs could produce negative emissions hydrogen through gasification of biomass. The potential would exist for export of negative emissions electricity or other energy carriers along with goods produced by zero or negative emissions facilities. Based on the combination of geological storage and biomass supply options, Alberta and Saskatchewan have obvious potential for locating industrial hubs based on BECCS.
Carbon pricing and other fiscal drivers will be required to attract industries and build BECCS based hubs. Industry could be paid per Mt of CO_2 removed from the atmosphere. With carbon prices more than $65 USD, the value of the carbon removal potential of one tonne of biomass exceeds the energy value of a barrel of oil. This revenue would cover the costs of biomass supply plus carbon capture and storage. In Canada, carbon pricing will reach $170 by 2030. Revenue generated from atmospheric carbon removal would ensure electricity costs for consumers and industry remain competitive.

Currently, there is one small-scale BECCS pilot in Canada operated by Husky Energy CO_2 Injection: 250 tonnes per day of CO_2 is compressed and trucked from an ethanol plant in Saskatchewan to nearby Lashburn and Tangleflags oil field for (EOR; the fields are shallow (~500mm) and comprise heavy oil.

LETTING IT SINK IN

Arriving at net-zero emissions in under 30 years is a lofty ambition. Broad scale implementation of BECCS would make good use of Canada's potential for sustainable supply of biomass along with geological storage of captured carbon. Establishing industrial hubs based on BECCS in Western Canada and elsewhere could be an essential pillar of Canada's roadmap to net zero emissions. And while bioenergy continues to feature prominently in the IPCC report, it has become a more controversial topic of consideration. Concerns that the scale of future biomass feedstock and land-use demand may also have negative societal and environmental impacts.

That being said, as Canada, and other countries around the globe, look to cut their emissions, it's clear that understanding sources and access to sinks is essential, with so much still needed in order to reach target goals. While total emissions in Canada have decreased by 9Mt (or 1.1%) between 2005 and 2019, we have also seen a significant amount of growth in the economy. Incentives can spur many projects with far ranging economic and environmental benefits. Broadly, government regulation and incentive programs are expected to support further CCS/CCUS development and infrastructure – notably the Canadian carbon pricing system, Alberta's Technology Innovation and Emissions Reduction (TIER) regulation and the federal Clean Fuel Standard, along with the proposed investment tax credit. With ample sequestration opportunities, CCS/CCUS projects in western Canada in particular, are ideal. This is compounded by the current realities of related idle resources stemming from oil price decline and as a result of the pandemic.

While emissions vary significantly by province and territory, factoring in population, energy sources and economic structure, resource extraction and reducing emissions is a national imperative.

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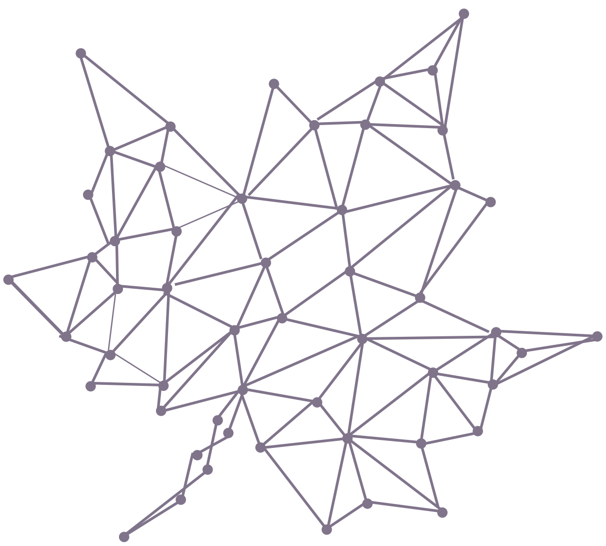

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