CarbonTech

A Primer on Carbon Capture, Conversion, Utilization and Storage Technologies

CARBONTECH

Turning Emissions into Profit through
Carbon Conversion Technologies

The publication was prepared by CMC Research Institutes (CMCRI) and Canadian Business for Social Responsibility (CBSR). *April 2019*

CMCRI and CBSR wish to thank all those that reviewed and contributed valuable content and feedback and input to this report. There are simply too many to list them all.

CMC Research Institutes leads clients to develop innovative carbon management technologies and strategies for competitive advantage. Through our carbon capture, conversion and storage RD&D facilities we help grow the Canadian economy, increase the country's competitiveness in world markets and create the low carbon future.

CBSR is a not-for-profit professional association and think tank that promotes sustainability and corporate responsibility leadership at the core of business strategy, to empower increased Canadian competitiveness and innovative solutions to major social, environmental and economic challenges.

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Please share your feedback with us.

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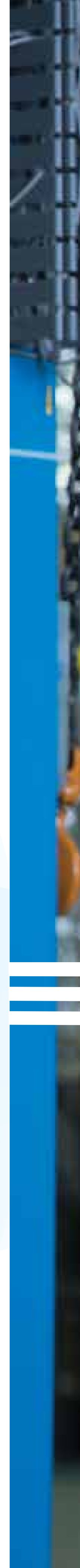
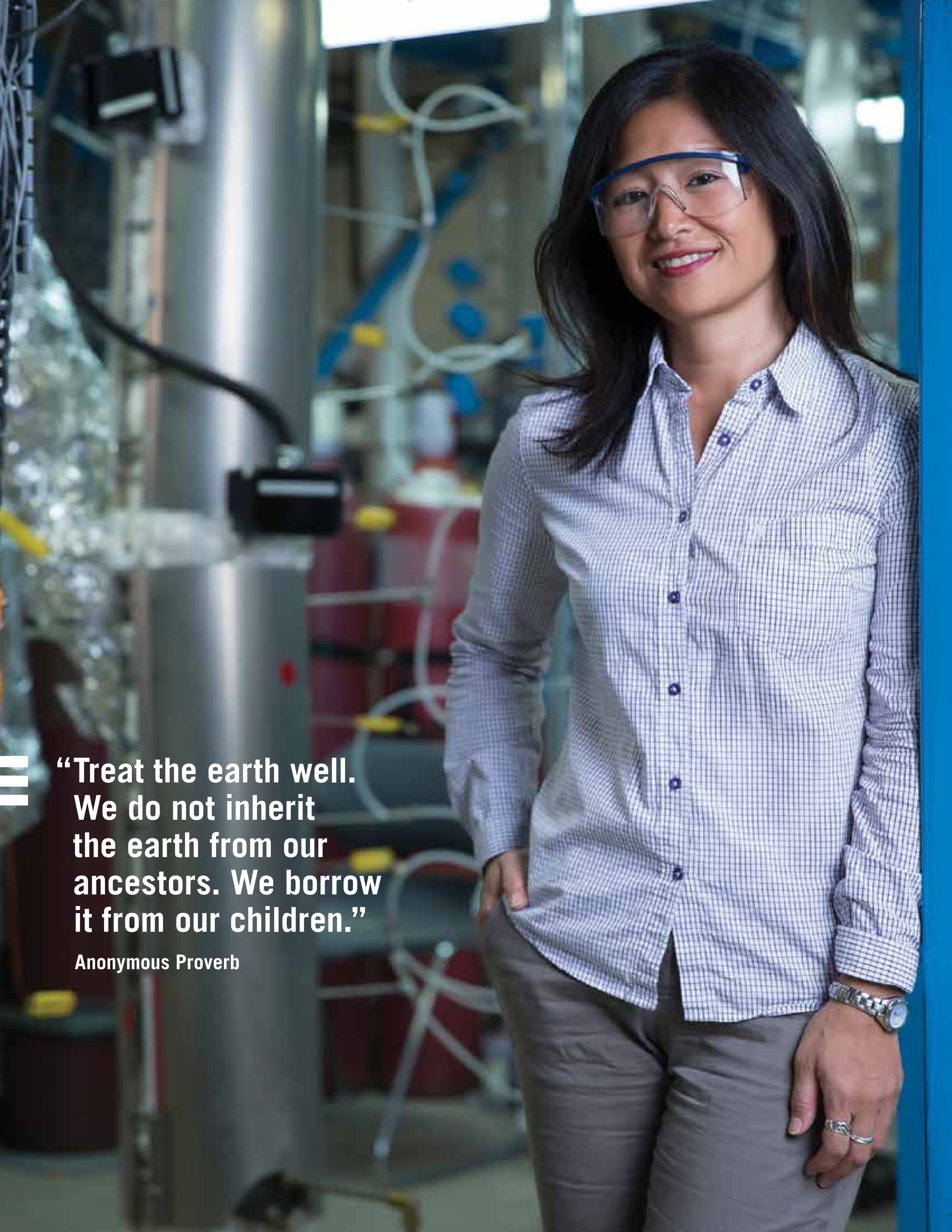




"Treat the earth well. We do not inherit the earth from our ancestors. We borrow it from our children."

Anonymous Proverb

A Message from Leor Rotchild,
Executive Director, Canadian Business for Social Responsibility

CBSR is proud to co-publish this report with CMC Research Institutes. The release of the report follows our national campaign, *Do Business #LikeACanadian*, which calls on business leaders to reframe economic, social and environmental challenges as opportunities to innovate and help Canada differentiate its global economy. It's also an invitation for all Canadians to unite around a common set of business values that include being collaborative, eco-conscious, ethical, gender-balanced, globally-minded, inclusive, innovative, and purpose driven.

CarbonTech is a constructive solution to the pressing challenges of our time and has the opportunity to create jobs and stimulate economic growth. Canada is especially well positioned as several Canadian companies are leading the development in this nascent sector. A number of them are finalists in the $20 million global NRG COSIA Carbon XPRIZE challenge to find a scalable, commercial application for CO_2 .

While carbon pricing can be politicized and polarizing, CarbonTech offers consumers the opportunity to reduce emissions by purchasing low carbon products and building materials. This choice might be positively influenced by the fact that many CarbonTech solutions offer features and benefits that are superior to traditional products in the same category.

When we think about what it looks like to Do Business #LikeACanadian, we are hard pressed to find a more compelling image than an innovative cluster of Canadian companies driving converting CO_2 into profitable, value-added products.

I hope you find this report to be enlightening and easy to share as we developed it with a wide audience in mind.

A Message from Sandra Odendahl,
President and CEO, CMC Research Institutes

The Intergovernmental Panel on Climate Change (IPCC) has been unambiguous in its message – we must cut global emissions 45% by 2030 and hit net zero by 2050 or risk an unprecedented global crisis. There are multiple technologies that can, and must, be employed to reduce carbon emissions - ranging from the deployment of renewable energy, to becoming more energy efficient, to planting more forests, and even direct air capture of CO_2. Although all of these solutions are necessary the industrial sector, which is responsible for over 40% of global emissions, cannot be decarbonized without Carbon Capture, Utilization and Storage (CCUS).

Capturing and storing carbon underground is a well-understood way to permanently remove large volumes of CO_2 from the atmosphere. Unfortunately, it is a direct cost to most companies – except those using it to coax more oil from nearly depleted reservoirs. On the other hand, carbon utilization and conversion technologies can demonstrate a business case for emissions reduction because the captured gas can be used to produce commercial goods. As countries and industries look for ways to reduce the amount of carbon dioxide released to the atmosphere, a global race has emerged to create technologies that can turn CO_2 into valuable goods.

As this report documents, Canada is well-positioned to play a leading role in this rapidly escalating interest in CCUS. We are one of the world's leaders in building and operating large-scale storage operations, have world-class testing and scale up facilities for capture and conversion technologies, a well-educated work force, and a public finance system that supports early-stage technology developers. And most critically, we have energetic innovators working to take advantage of the growing global appetite for technologies that will reduce emissions in cost effective ways.

We hope that the publication of this paper will stimulate interest in these critical technologies and lead to accelerated action. By sharing the benefits and challenges facing this sector, we want to encourage industry, government and financiers to put policies and programs in place to assist entrepreneurs building these risky but critical solutions to our carbon problem.

Sandra Odendahl

Table of Contents

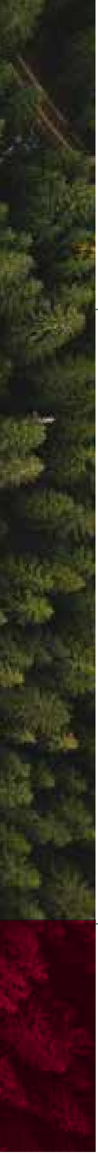
Executive Summary

1 The earth's climate is in peril.

The most recent United Nations Intergovernmental Panel on Climate Change report concluded that the world will feel extreme climate impacts by 2030 if global temperatures are not limited to a 1.5°C temperature rise. Despite the drive to transition from fossil fuels to renewable energy technology, the world is still travelling towards a 2°C or greater global warming scenario. Addressing global warming requires limiting the total sum of global man-made emissions of CO_2 to between 580 and 770 Gigatonnes (Gt) this century.[1] In 2018, global emissions of manmade CO_2 were approximately 37 Gt.[2]

2 Human activity has disrupted the earth's carbon cycle.

CO_2 is a naturally-occurring stable molecule used by various life forms to create energy. In nature, the carbon cycle represents a zero-waste system that moves carbon between Earth's atmosphere, land and oceans. However, human activity has altered the carbon cycle by adding extra CO_2 and depleting CO_2 natural sequestration pathways. CO_2 acts like glass on a greenhouse, trapping heat in Earth's atmosphere. Since humanity began burning fossil fuels, the average global temperature has increased 1°C.



3 There is no single solution to climate change mitigation.

A portfolio of solutions is required to slow the rate of climate change, including: reducing our reliance on fossil fuels, shifting our land use practices, and employing a wide range of carbon dioxide removal strategies. All pathways that limit global warming to 1.5°C project the use of carbon dioxide removal (CDR) on the order of 100–1000 $GtCO_2$ over the 21st century. This report focuses on the opportunity for using carbon capture, conversion, utilization and/or storage technology to mitigate the rate of climate change.

4 CarbonTech offers an opportunity to recycle industrial-waste CO_2 and reuse it in man-made products.

Canada is recognized as a leader in Carbon Capture Utilization and Storage (CCUS) technology research and development. However, in the absence of strict GHG regulations or a high carbon price, carbon capture and storage (CCS) is challenged by its high cost with little or no financial return. Carbon capture and conversion technologies, or "CarbonTech", use CO_2 captured from industrial flue gas as a feedstock to make valuable products, while preventing the CO_2 from entering the atmosphere.

5 There is an exciting opportunity for Canada to become a leader in CarbonTech.

There is a significant level of CarbonTech innovation occurring in Canada. Three of the top ten finalists in the NRG COSIA Carbon XPRIZE are Canadian. The XPRIZE is a $20 million global competition to find the most scalable carbon capture and conversion technology. This emerging sector can scale to its potential as a trillion-dollar global industry by 2030 through increased technology development, greater awareness, and a stable price on CO_2 enforced by long-term regulation.

6 CarbonTech has the potential to reach commercial scale in Canada.

Canadian CarbonTech companies range from small-scale pilot size to industrial-scale testing, with few reaching commercial adoption. Each technology faces its own set of commercialization challenges. The high cost of carbon capture processes requires investment in developing lower cost, next-generation capture technologies. Any reluctance from industry end-users to invest in CarbonTech must be addressed by building and communicating a compelling business case.

7 Stronger communication and collaboration is required among government, industry, academia, and innovative small companies to scale CarbonTech's commercial applications.

Understanding and communicating CarbonTech's business case is essential to gaining support from investors, industry users, funding bodies, and government. Stakeholder engagement should be a priority to highlight the financial and environmental benefits of investing in CCUS technology.

1.0

Purpose of the Study

Carbon Capture, Utilization and Storage (CCUS) technologies can play a significant role in meeting national and international greenhouse gas (GHG) emission reduction targets. With research, development and scale-up infrastructure in place, along with many decades of experience in developing full-scale CCUS facilities, Canada has an opportunity to become a global leader and exporter of CCUS knowledge and technology.

This report seeks to provide an overview of the risks and opportunities for development, testing, implementation, and export of CCUS in Canada. By identifying barriers to national growth of CCUS, stakeholders can determine effective ways to build a national and international market for CCUS.

This report is intended to serve as a primer, and will:

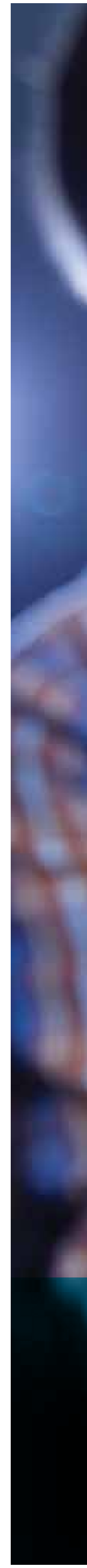
1. Provide an overview of the CCUS marketplace and recent CCUS technology developments (both in Canada and globally).
2. Identify who is developing innovative, commercially viable CCUS technology.
3. Highlight the challenges and opportunities to convert industrial CO_2 emissions into feedstock for value-added products.

1.1

Design and Methodology

This report used primary and secondary data to provide an understanding of the CCUS landscape, identify relevant stakeholders, describe the barriers and opportunities to scaling up CCUS in Canada and internationally, and analyze Canada's CCUS marketplace. Primary data was gathered through personal interviews with various stakeholders in the spring and summer of 2018. (See Appendix B for a list of interview questions). Secondary data sources are in the endnotes.

This report starts by providing background on why CCUS is so important, including the social, political, technological, and economic drivers for CCUS technologies in Canada. We then explore the challenges, opportunities, key players, and other important features of each of the CCUS elements: capture, utilization and storage, with a deeper dive into the new and exciting opportunities associated with carbon conversion in Canada.



2.0

Background

2.1

The Problem With Carbon Dioxide

Natural carbon dioxide

Carbon is the fourth most abundant element in the universe and is a fundamental building block of life on Earth. Carbon moves between the land, oceans, and atmosphere in a process known as the carbon cycle.[3] There are large reservoirs of stored carbon and natural fluxes throughout this cycle which help keep the Earth's temperature stable. The carbon cycle is a closed loop and waste-free system, and carbon only becomes a problem when large quantities of carbon dioxide are added to the carbon cycle through the burning of fossil fuels.

Man-made (anthropogenic) carbon dioxide

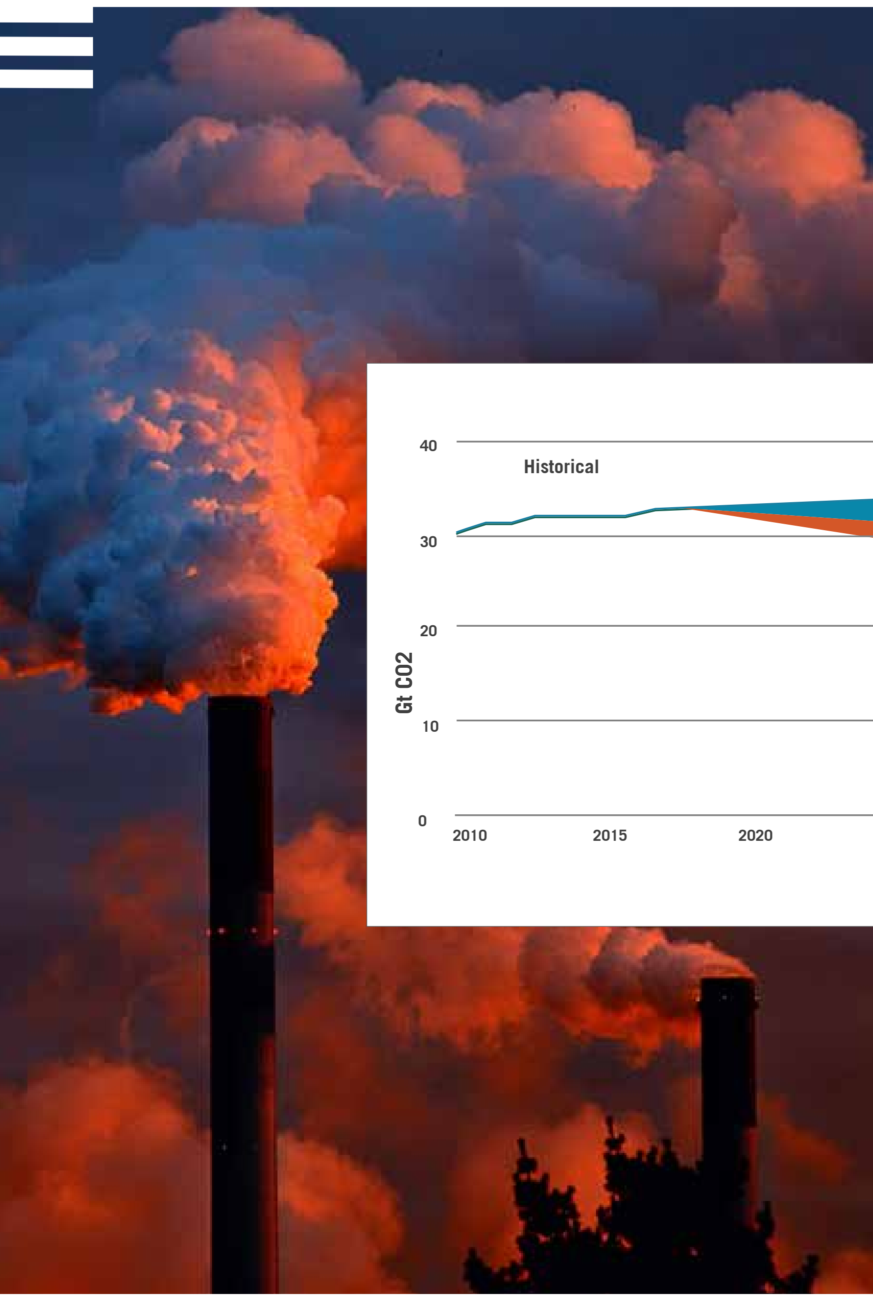
Carbon dioxide (CO_2) is one of many greenhouse gases (GHGs) that are emitted into Earth's atmosphere from both natural and human sources. GHGs are molecules that absorb and trap heat from the Sun, keeping the earth's atmosphere comfortable for human life.[4] Some GHGs, such as CO_2 and water vapour, are part of this natural process that warms the Earth. Since the industrial revolution however, man-made (anthropogenic) GHGs have increased from 280 parts per million (ppm) to current concentrations of over 400 ppm, higher than at any point in human history. This increase is mainly due to burning coal, oil and gas (fossil fuels) in industrial processes and electricity generation. Another important contributor has been the massive removal of forests, which act as large-scale carbon sinks to store CO_2. The rise in atmospheric GHGs has led to a steady rise in global temperatures and destabilization of Earth's climate.[5]

Since the mid-1700s and the start of the Industrial Age, the average global temperature has increased 1°C. According to NASA, "A one-degree global change is significant because it takes a vast amount of heat to warm all the oceans, atmosphere, and land by that much. In the past, a one- to two-degree drop was all it took to plunge the Earth into the Little Ice Age. A five-degree drop was enough to bury a large part of North America under a towering mass of ice 20,000 years ago."[6]

Impacts of climate change include stronger and more frequent extreme weather events, such as hurricanes, heat waves, flooding, drought, and earthquakes. Other impacts include glaciers melting, thus raising sea levels, ocean acidification, and biodiversity loss from ecosystem alteration. Virtually no ecosystem is being left untouched – all plant, animal, and fungal organisms on Earth are being forced to adapt or face extinction.

An urgent call to lower GHG emissions

In 2016, the United Nations Framework Convention on Climate Change (UNFCCC) announced its goal to limit global temperature rise to below 2ºC relative to pre-industrial levels.[7] A 2018 special report from the Intergovernmental Panel on Climate Change (IPCC) concluded that the world will feel extreme climate impacts by 2030 if urgent action is not taken to keep global average temperature rise below 1.5°C.[8]



Achieving this goal amid continued economic, industrial and human population growth will require a huge reduction in GHG emissions.

The IPCC estimate that the costs of climate change mitigation without technologies that capture and permanently store or utilize carbon will be significantly higher than with it.[9] Most climate change mitigation models forecast an important role for utilization and carbon storage in meeting the global target of keeping CO_2 emissions under 450 parts per million (ppm) by 2100.[10] The International Energy Agency's (IEA) emission reduction projections include energy efficiency, renewable power sources, and large-scale CCUS technologies as critical in meeting global climate change mitigation goals (Figure 1).

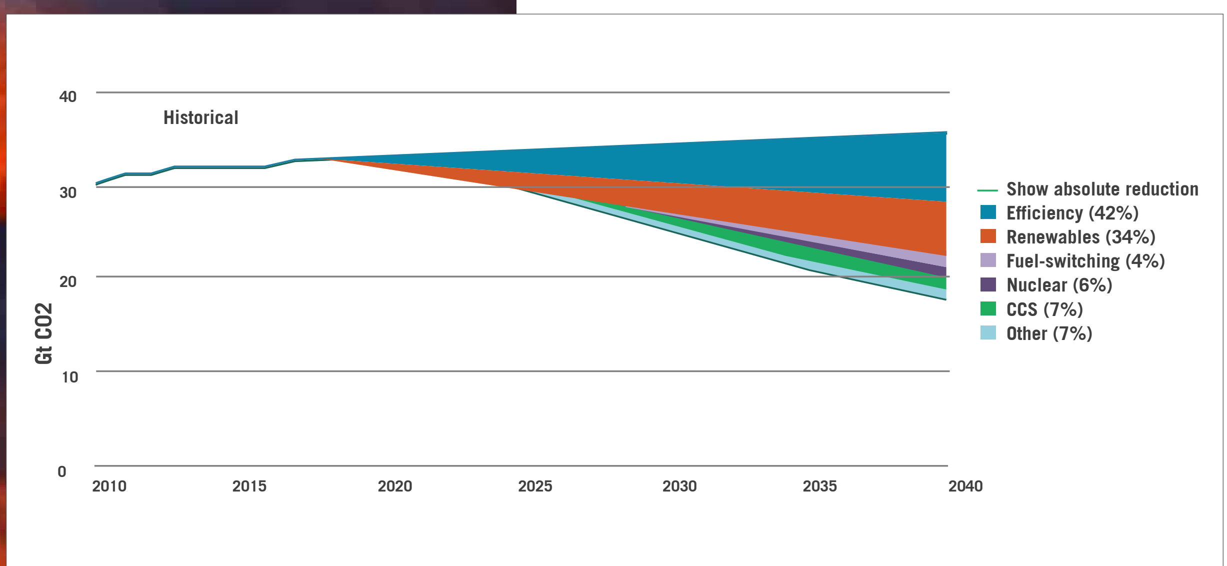
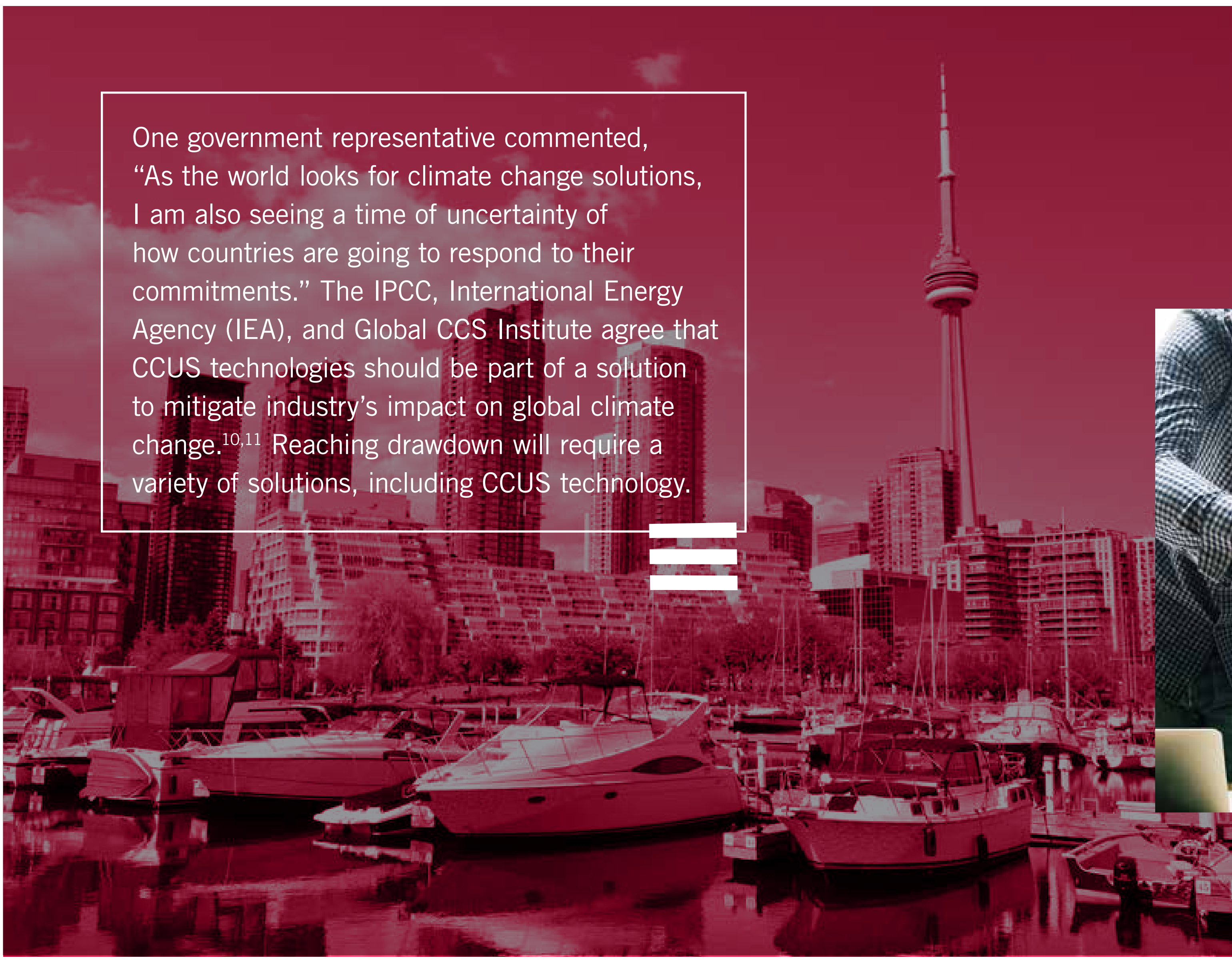


Figure 1. International Energy Agency (IEA) historical and future projection of the required combination of energy efficiency and technologies to reduce global carbon dioxide emissions, measured in Gigatonnes (Gt) of CO_2, by 2040. Source: IEA, 2018.[11]

Signing the Paris Agreement on Climate Change in 2015 marked Canada's commitment to meet emission reduction commitments and engagement in technological solutions. One participant stated, "We should be pushing the demonstration of technologies as potential solutions." Paul Hawken, in his book Drawdown, suggests framing climate change action by defining when drawdown will be reached.[12]

Hawken defines drawdown as "the point in time when the concentration of atmospheric greenhouse gases begins to decline on a year to year basis".[12] Although there is global debate concerning the best combination of methods to reduce atmospheric GHG concentrations, there is global agreement that drawdown needs to be achieved as soon as possible.



One government representative commented, "As the world looks for climate change solutions, I am also seeing a time of uncertainty of how countries are going to respond to their commitments." The IPCC, International Energy Agency (IEA), and Global CCS Institute agree that CCUS technologies should be part of a solution to mitigate industry's impact on global climate change.[10,11] Reaching drawdown will require a variety of solutions, including CCUS technology.

2.2

The Regulatory Context

Countries around the world continue to implement regulations and incentives to drive down greenhouse gas emissions. In many jurisdictions, carbon pricing and emissions trading regimes are designed to reduce emissions from large emitters, municipalities, and consumers. However, the regulatory landscape shifts with political cycles. Carbon pricing rules are uncertain in many countries including Canada, and in most parts of the world, carbon markets fail to provide strong enough incentives for industries to aggressively reduce emissions.

The Government of Canada has implemented a national climate change strategy known as the Pan-Canadian Framework on Climate Change, which includes carbon pricing as one of its four pillars. The federal strategy allows provinces to design their own carbon pricing systems provided they meet certain principles. Provinces that do not develop their own carbon-pricing regime will be subject to the federal one. The federal carbon levy has two components. The first, which came into effect on January 1, 2019, is an output-based pricing system that taxes a small portion of emissions from industrial facilities. The second component, effective April 1, 2019, is a broad-based tax on gasoline and heating fuels pricing carbon at $20 a tonne, or 4.4 cents per litre.[13] The other pillars of the national climate change strategy are: complementary measures to further reduce emissions across the economy; measures to adapt to the impacts of climate change and build resilience; and actions to accelerate innovation, support clean technology, and create jobs.

2.3

An Opportunity for Canada as a Global CCUS Leader

Canada has existing research, development and scale-up infrastructure that position it to be a global leader in Carbon Capture Utilization and Storage. These include commercial and large-scale CCS, enhanced oil recovery (EOR), and CO_2 transportation projects underway and plans to continue to leverage resources and invest in CCUS technologies. As the country moves toward its greenhouse gas reduction goals under the Paris Agreement, government, the private sector, and the public must be actively engaged in facilitating low-carbon employment opportunities and skill diversification. This will allow us to compete globally as the world creates new markets in a low-carbon economy.[14]

Industry emissions

The Government of Canada's GHG Reporting Program found that "In 2016, 263 megatonnes (Mt) of GHGs in carbon dioxide equivalent (CO_2e) were emitted by 596 facilities reporting to the GHG Reporting Program […] account[ing] for over one third (37%) of Canada's total GHG emissions."[15] High-emitting industry clusters were identified across Alberta, southern Ontario, and southern Quebec. Research and development of CCUS technologies has been focused in western Canada because of its concentration of CO_2 emitting industries, particularly oil and gas extraction and processing facilities, and its vast underground storage capacity. However, manufacturing, cement, and chemical industries are also top polluters in central and eastern Canada. Identifying the location of concentrated industry emissions at a national level provides an opportunity to maximize the impact of CCUS technology applications.

Technology leaders

Canada is recognized as a leader in CCUS technology research and development. Canada has several technology innovation hubs across the country, along with internationally-unique testing facilities such as CMC Research Institutes' Carbon Capture and Conversion Institute (CCCI) in Vancouver, which offers resources and infrastructure to test and scale-up CCC technologies.

Carbon utilization for enhanced oil recovery (EOR) has been practiced in North America for decades. For example, Canadian Natural Resources Limited (CNRL) operates a gas plant in Taber, Alberta where they capture 12,200 tonnes of produced CO_2 per year for use in their nearby Enchant EOR operations to increase the amount of crude oil that can be extracted from the field. CNRL is also a 50% partner in the North West Redwater (NWR) Sturgeon Refinery. The NWR will supply over 1 million t/year of CO_2 as a feedstock to the Alberta Carbon Trunk Line (ACTL) that will pipe CO_2 to existing mature oil fields throughout South-Central Alberta for EOR.[16] The capture and permanent storage of CO_2 will result in significant reductions in emissions of greenhouse gases in Alberta.[17]

There are several large-scale pilot and commercial CCS projects underway in Canada, including Shell's QUEST project, the SaskPower-funded Boundary Dam coal-fired power plant, and the Weyburn-Midale enhanced oil recovery projects operated by Whitecap Resources and Cardinal Energy. CMC Research Institutes also operates a unique field research station for developing and demonstrating technologies for monitoring CO_2 that is stored underground at the site.

Geographic context

Canada's greenhouse gas emissions are found in clusters across the country. This clustering provides an opportunity to create a network for CO_2 transportation between large point-source CO_2 emitters, processing facilities, and end-users of CO_2. Efficient CO_2 transportation from industrial emission clusters to large-scale users of CO_2 offers an opportunity to minimize costs of CCUS implementation.

3.0 Carbon Capture

All carbon utilization, conversion, and storage technologies begin with carbon capture (Figure 2). Canada has many large CO_2-point sources, including coal and natural gas-fired power plants, cement plants, refineries, iron and steel operations, and petrochemical facilities. The concentration of CO_2 from processes in these industries can vary widely, and carbon capture is the necessary first step in creating a concentrated CO_2 stream for storage, conversion, and utilization operations. As CO_2 capture is a first step in CCUS technology, the carbon capture market is driven by demand from industries looking to store, use, or convert CO_2.

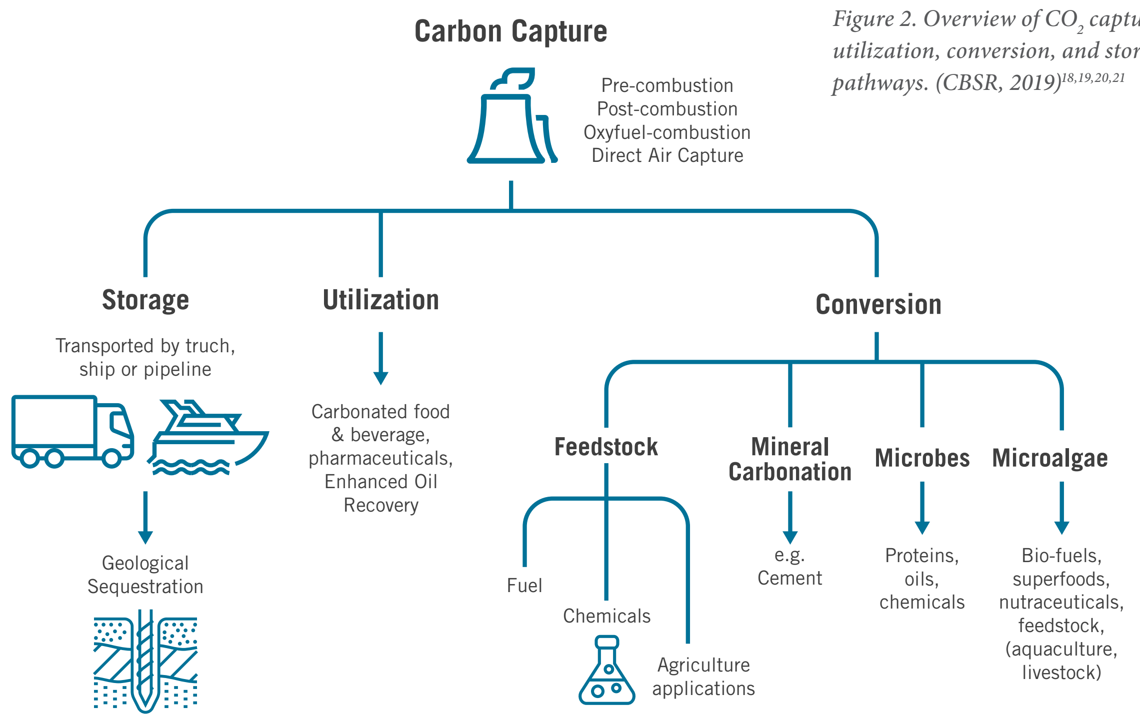


Figure 2. Overview of CO_2 capture, utilization, conversion, and storage pathways. (CBSR, 2019)[18,19,20,21]

3.1

Technologies

Point-source carbon dioxide capture systems

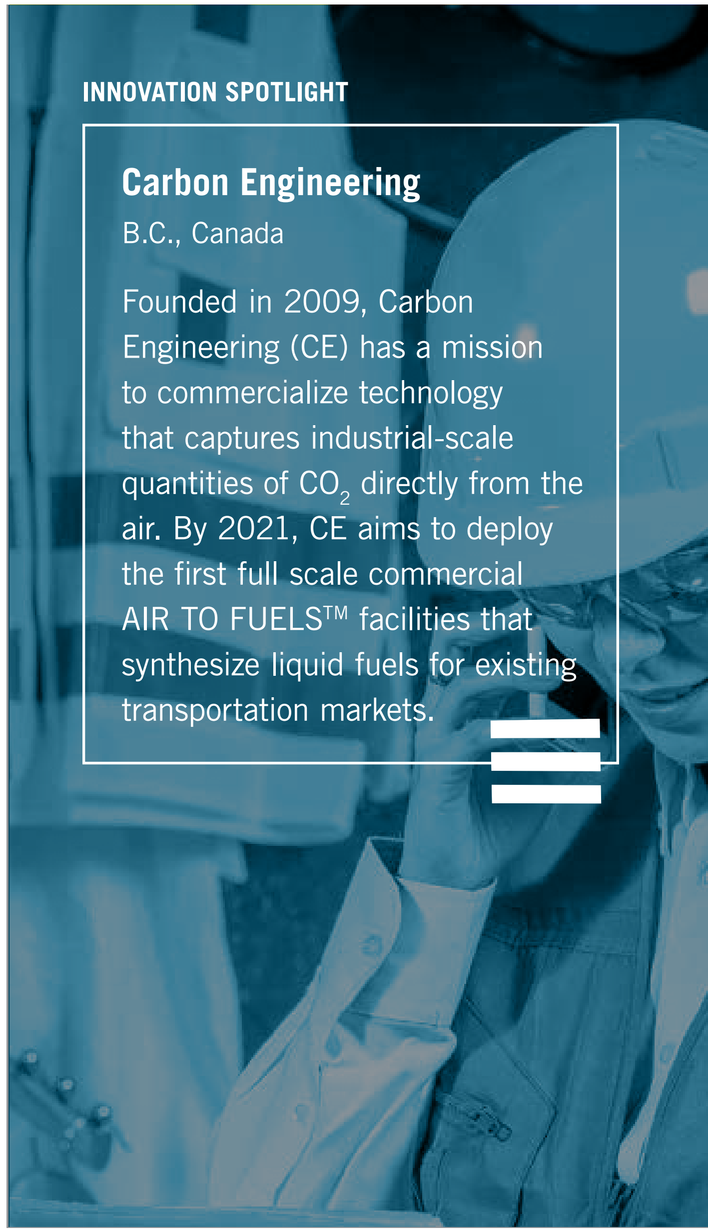
There are three pathways for capturing carbon dioxide from industrial sources:

- post-combustion which involves separating CO_2 from a flue gas;
- pre-combustion which separates CO_2 from a fuel prior to combustion; and
- oxy-combustion, in which a fuel is combusted with oxygen (O_2) and the resulting CO_2 captured for use or storage.

Several processes can be used to capture or separate CO_2 from pre- or post-combustion gases, with two of the most common being the use of solvent and membranes.[22] Designing improved solvents, sorbent and membrane capture technologies is the current focus in carbon capture research. For instance, new sorbents, which reduce both energy requirements and infrastructure needs, are showing promise in significantly reducing capture costs.[23] Two Canadian companies, CO_2 Solutions and Inventys, are pioneering carbon capture technologies.[24]

Stripping CO_2 out of the air

The majority of carbon capture technologies focus on capturing CO_2 emissions from industrial facilities before they reach the atmosphere. However, emerging technologies can strip CO_2 from the atmosphere by filtering enormous quantities of air (which has a 400 ppm concentration of CO_2) and condensing it to produce liquid CO_2. Carbon Engineering is a Canadian-based company leading the development of direct air capture (DAC) technology.[25]

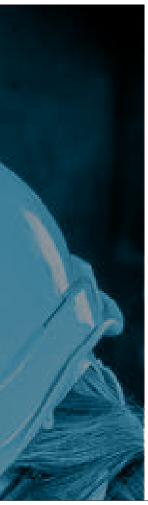


INNOVATION SPOTLIGHT

Carbon Engineering

B.C., Canada

Founded in 2009, Carbon Engineering (CE) has a mission to commercialize technology that captures industrial-scale quantities of CO_2 directly from the air. By 2021, CE aims to deploy the first full scale commercial AIR TO FUELS™ facilities that synthesize liquid fuels for existing transportation markets.



3.2

Industry Context

Point-source CO_2 capture technologies are ideally suited for industries with large emissions such as: natural gas fired power plants, coal fired power plants, cement plants, oil and gas refineries, iron and steel mills, and petrochemical facilities.

The chemical industry has been a leader in carbon capture technology adoption, mainly due to the cost effectiveness of capturing and recycling CO_2 in its industrial processes. Up to 100,000 tonnes of CO_2 equivalent are captured annually at NOVA Chemicals Canada's petrochemical facilities in Canada and the USA and sold for Enhanced Oil Recovery.[26]

The high infrastructure and operating costs of carbon capture are fuelling a surge in global research and development, supported by funding from different levels of government and large industrial emitters (Figure 3). Canada is taking part in Mission Innovation – a collaborative international effort to accelerate global clean energy innovation. Mission Innovation is focused on research and development in several clean energy technology "challenge" areas – one of which is carbon capture, utilization and storage.[27] These research efforts concentrate on discovering new uses for CO_2, and reducing energy requirements, capital and operating costs.

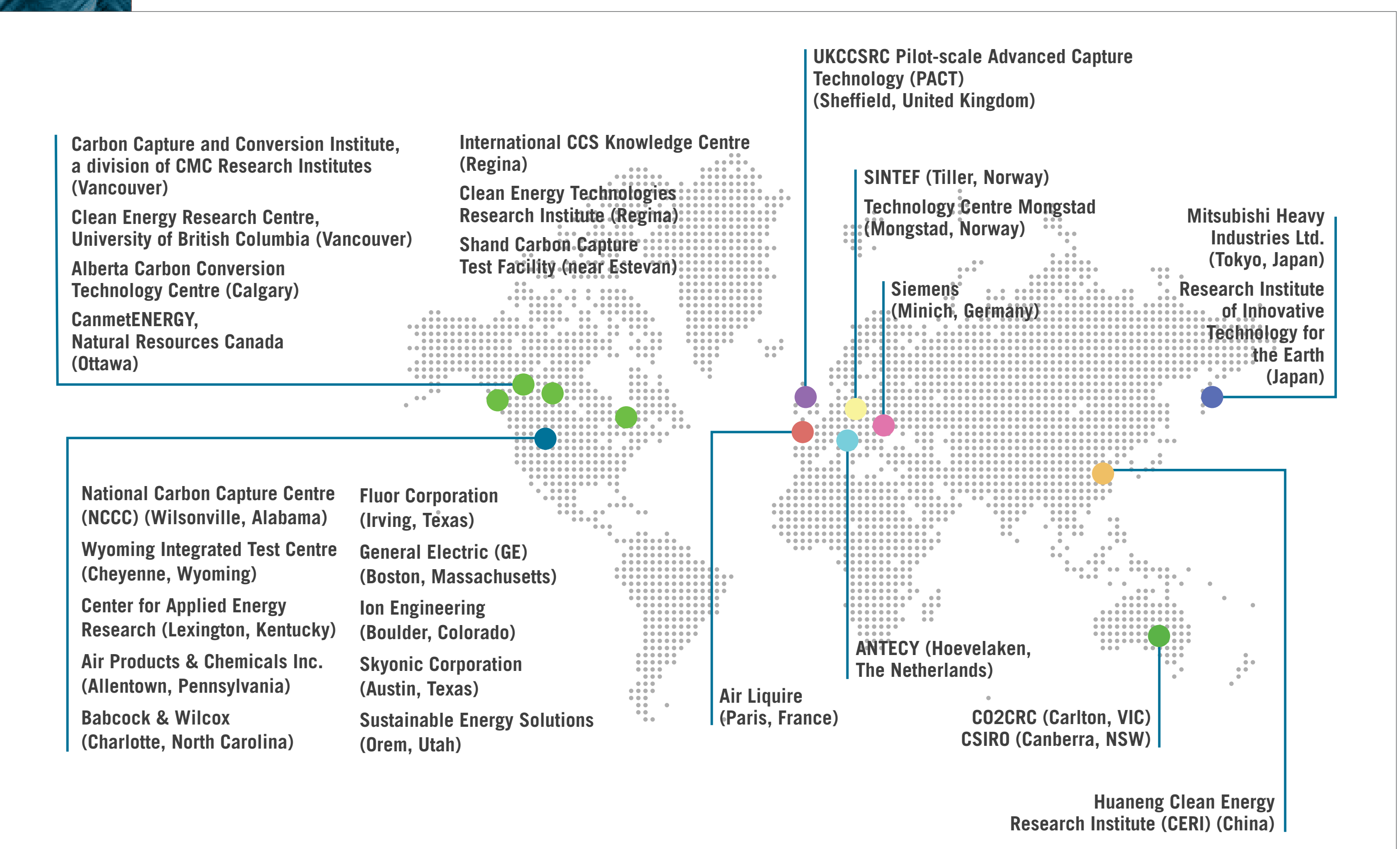


Figure 3. A sample of global institutes, industries and companies researching carbon capture technologies. CBSR, 2019

3.3

Barriers and Opportunities

Barriers

Barriers to lowering the cost and accelerating the commercialisation of carbon capture are similar to those experienced by many innovative clean technologies. These include: infrastructure cost, long investment cycles, availability of funding, limited commercially-viable models, and reliance on regulation.

Cost

Substantial up-front capital investment is required to support CO_2 capture's high infrastructure and operating costs due to capture's high energy needs.[28,29] Costs of capture have been prohibitively expensive but are expected to decline as new technologies are developed. For example, the International CCS Knowledge Centre estimated that the cost of capture at SaskPower's Shand plant could be USD$45/t CO_2 using next-generation technologies. This represents a 67% cost reduction over operations at SaskPower's capture plant at its Boundary Dam 3 site, which has been operating since 2014.[30] Higher capture costs are associated with flue gas streams that have low concentrations of CO_2 like those from coal and natural gas-fired power plants.

Long investment cycles

Technology developers struggle to secure investments due to the long scale-up and commercialization periods for CO_2 capture technologies. One survey respondent noted, "The investment cycle is longer than many investors are willing to take on. We're competing for dollars against software apps that have fast payoffs and high revenue generating cycles . . . It took us 20 years and $50 million to get to the point of revenue generation. The venture capital community has no appetite for that kind of timeframe."

Grant restrictions

Government funding is typically designed to cover infrastructure costs associated with piloting and demonstrating clean technologies including carbon capture, but often fails to cover operating expenses. Several of the capture technology experts we interviewed said that while it was straightforward to get government grants for specific projects, they struggle to secure funds for ongoing expenses. One study participant said, "It's not funding for projects that's the problem, there are a lot of subsidies for project funding opportunities. What is really difficult is to pay for overhead. We are all pre-revenue and we're all struggling to pay to keep the lights on and to pay our staff."

Few commercially-viable models

Many technologies currently under development have only been tested under controlled laboratory settings which do not replicate real-world industrial conditions.[31] For example, capture technologies that use raw flue gas as an input to conversion technologies have limited testing in an applied commercial context. Industry end users are deterred from adopting bench-scale technologies when technologies have not been funded and demonstrated in a commercial environment.

Flue gas conditioning unit at CMCRI's carbon capture and conversion facilities in Vancouver.

Regulatory uncertainty

The lack of clear and consistent greenhouse gas regulations is a significant barrier to the development of carbon capture technologies. Without stable and depoliticized regulation or pollution pricing, there is no business driver to incite industrial emitters to invest in CO_2-reduction technologies.

Opportunities

Researchers continue to seek ways to improve efficiency and lower costs of CO_2 capture, since CO_2 capture technologies preface utilization, conversion and storage technologies. The outlook for lowering the cost of carbon capture is improving as innovators develop carbon conversion technologies with a business case that relies on lower carbon capture costs. Some of the more recent and exciting developments in carbon capture technology include.[32]

Electrochemical capture technologies

One promising area of research is using an oxygen-assisted aluminium/carbon dioxide power cell that uses electrochemical reactions to sequester carbon and produce electricity.[33]

Metal organic frameworks (MOF)

A class of highly absorbent, nanoporous materials with vast internal surface areas, allowing them to capture large volumes of gas.

Nanosponges

Low-toxicity, highly effective carbon-trapping "sponges" that are made from silica scaffold with nanoscale pores for maximum surface area. The scaffold is dipped into liquid amine, and the finished product can capture CO_2 even in the presence of moisture.

Hybrid membranes

Hybrid membranes are part polymer and part MOF, and many times more CO_2-permeable than polymer membranes. Boosting CO_2 permeability helps make carbon capture more energy efficient and cost competitive

Crystals

Swedish scientists have created copper silicate crystals that capture CO_2 much more efficiently than previously known materials, even in the presence of water.

4.0

Carbon Storage

International experts agree that climate targets set under the Paris Agreement cannot be met without Carbon Capture and Storage (CCS). Faith Birol, Executive Director of the International Energy Agency (IEA), said recently that CCS is essential to meeting global warming mitigation targets and IEA findings show that to reach 2°C by 2060, at least 14% of reductions must be attained through CCS.[34] Globally, there is more than enough geological storage capacity to reach targets, and much of it is in high emitting countries. However, despite the importance of CCS and its technical feasibility, there are significant hurdles that must be overcome.

4.1

Technologies

Carbon storage is a significant CO_2 emissions reduction strategy that started 45 years ago as a way to re-pressurize nearly depleted reservoirs to extract more oil or gas.[35] Carbon storage starts with CO_2 capture and purification, after which the concentrated CO_2 is transported as a liquid via truck, pipeline or ship to a suitable injection site for storage (Figure 4).

Operators monitor storage sites during and after injection to track how the CO_2 is behaving.[36,37] Monitoring that has been underway since 1972 shows that CO_2 can be stored deep underground safely and effectively for many decades. Storage technology is well understood and studies show a storage site should meet four main criteria:

1. the underground formation should be porous with good permeability;
2. the storage formation must be at least 800 metres below ground;
3. the target formation must have an impermeable layer of cap rock to prevent CO_2 from rising to the surface; and
4. the formation must be deep and wide for storing large volumes of CO_2.[38]

Depleted and active oil and gas reserves, and deep saline aquifers, are usually suitable for storage. There are geographical, political, and infrastructure factors that make sites strong candidates for CCS. These factors include: existing transportation infrastructure (i.e. pipelines), proximity to storage locations, high density of industrial CO_2 emitters, and government regulations or policies that support carbon regulation.

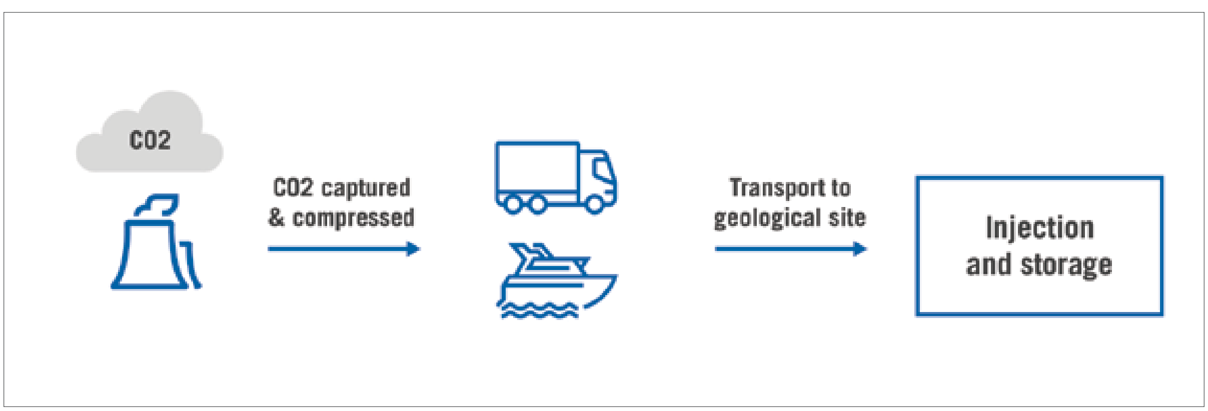


Figure 4. Carbon capture and storage chain of events. (CBSR, 2019)

Bioenergy with CCS (BECCS)

Bio-Energy with Carbon Capture and Storage (BECCS) is a technology that combines the natural CO_2 capture process in trees and plants, with the benefits of geological carbon storage, or CCS. In BECCS, CO_2 is captured from the atmosphere by trees, crops, or other biomass as they grow, the biomass is used in processing industries or power plants, and any CO_2 emitted is geologically sequestered.

BECCS may provide an opportunity to create permanent negative carbon emissions, i.e. the net removal of CO_2 from the atmosphere. The IPCC reports that to limit global warming to 1.5°C, BECCS deployment should sequester up to 8 Gt/year of CO_2 by 2050.[1] Large-scale deployment of BECCS would be undertaken only after a full life cycle assessment of impacts on biodiversity, food production, land use and other sustainability factors.

Storage capacity

Canada has a large geological CO_2 storage capacity, giving it an opportunity to use CCS to meet our country's national GHG reduction targets.[39] Data from the 2012 North America Carbon Storage Atlas estimate Canada and the US combined have 500 to 5,000 years of CO2 storage space available in reservoirs.[40] Globally, there is also significant storage capacity in China, Australia, and off the coast of Norway.[10]

4.2

Industry Context

Carbon storage is a well-researched technology with the largest opportunity for industrial climate change mitigation when compared with utilization and conversion technologies. The strongest business case for using CCS to address industrial CO_2 emissions will likely be identified by oil and gas facilities in Canadian provinces with CO_2 pricing, greenhouse gas regulations, or other regulations that incentivise investment in CCS. Large emitters looking to reduce their GHGs can benefit from CCS technology. Examples of large scale and commercial CCS operations in Canada include Shell's QUEST Facility in Alberta, and the Boundary Dam facility in Saskatchewan.

4.3

Barriers and Opportunities

Barriers to lowering the cost and accelerating the commercialisation of carbon capture and storage include: infrastructure cost, long term liability, risk of CO_2 leaks, public acceptance, and reliance on regulatory certainty.

Cost

CO_2 capture and storage requires major infrastructure investment and provides no financial return unless the CO_2 is used for Enhanced Oil Recovery, or the regulatory framework provides a financial incentive, such as a price on carbon.

Long-term liability

Monitoring the CO_2 storage site after injection is an ongoing commitment. Determining the responsible party for monitoring can be challenging. One industry end user of CCS technology commented, “The legal issues of who owns the CO_2 once it’s put into the ground is a key consideration”. To move CCS projects ahead, clear liability frameworks must be developed that outline who is responsible and liable for monitoring CO_2 storage sites. One of Canada’s strengths in CCS is its comprehensive environmental, safety and monitoring requirements for the safe deployment of CCS. This is due in part to the recommendations developed through Alberta’s Regulatory Framework Assessment.[41]

Leakage

There is a very small possibility of CO_2 leakage post-injection, which could cause drinking water or soil contamination, and potentially harm humans or flora and fauna.[42] Precautions must be taken to minimize leakage risks as much as possible.

Regulatory framework

Stable government policy and regulation helps to establish the business case for adopting and operating new carbon technologies, and can help SMEs build sales pipelines for domestic and global markets. However, attracting CCS investors is difficult due to a lack of clear and predictable regulatory and legal frameworks on several fronts. First, we need regulations to assign liability for long-term storage of CO_2. Secondly, fiscal incentives such as the USA’s 45Q tax credit for storing CO_2, do not currently exist in Canada. Lastly, a strong, consistent national price on carbon is needed to provide economic incentive for industries to invest in costly CCS technology.[43]

Public acceptance

Public opposition to CCS has slowed down or stopped projects in some countries. Key concerns are carbon leakage, groundwater contamination, risk of earthquakes or explosions, and general uncertainty about long-term environmental impacts of underground storage. There is also a lack of understanding about the importance of CCS in climate mitigation plans.[44,45,46] These concerns and knowledge gaps need to be addressed to gain support for CCS technology deployment.

Opportunities

Canada has an opportunity to strengthen its global leadership role as a CCS knowledge and technology exporter. Globally, there are 18 large-scale CCS facilities in operation, five under construction and another 20 in various stages of development.[10] Canada has a competitive advantage in accelerating CCS commercialisation due to its leading expertise in scale-up, testing and commercialisation, as well as our extensive geologic reservoirs.

Advanced commercialization

Canada is considered a global leader in CCS technology research and deployment, with successful full-scale CCS operations that include Saskatchewan's Boundary Dam, and Alberta's Shell QUEST Facility. The country also boasts a world-leading carbon storage testing and monitoring field research station owned by CMC Research Institutes. CCS research and development is now focused on achieving lower costs to encourage more commercial applications.

Extensive geological reservoirs

North America has the capacity to store all emissions, at current levels, for 500 to 5000 years.[40] The Global CCS Institute's data visualization shows that North America has a strong readiness for CCS deployment (Figure 5).[47] Many other countries also have the right geological features to store large quantities of industrial CO_2 emissions.

Job creation

The prospect of job creation is a key factor in driving policy support and public acceptance for carbon capture, conversion, utilization and storage technologies. The potential for increasing employment opportunities in Canada is demonstrated through Shell's QUEST carbon capture and storage project which created 2,000 jobs in total, including 800 construction jobs in the initial phase and 400 long term jobs.

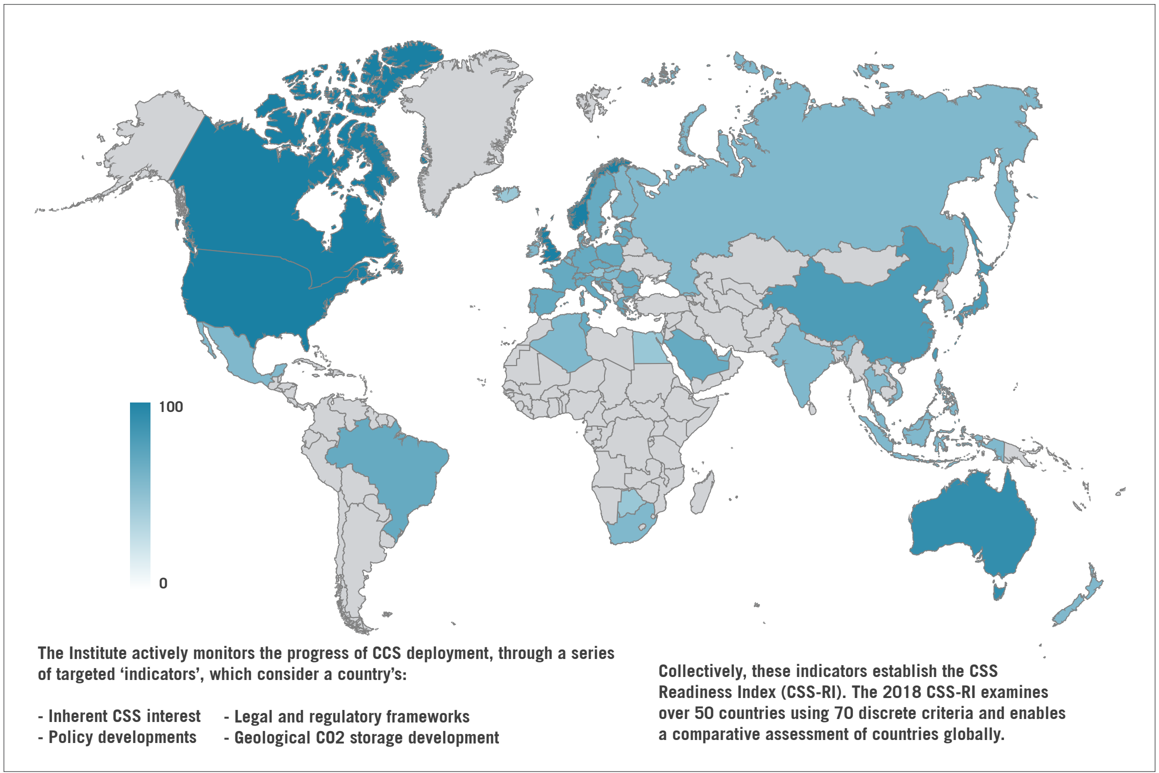


Figure 5. Carbon capture and storage readiness, measured from 0 (not at all ready) to 100 (extremely ready) by country, based on each country's interest in CCS, policy, regulations, and geological storage. (The Global CCS Institute)[47]

5.0

Carbon Utilization

The term “carbon capture and utilization” (CCU) is often used to describe two types of technologies. Carbon Capture and Utilization (CCU) technologies capture CO_2 emissions for processing, enhanced oil recovery, or other direct uses. Carbon Capture and Conversion (CCC) technologies convert CO_2 into entirely new products with commercial value.[48] For the purposes of this paper, CCU and CCC are separated into two sections, with the first focusing on CCU.

5.1

Carbon Utilization Technologies

Direct Utilization of CO_2

CO_2 is utilized in several products and processes including carbonated soda and sparkling mineral water. The CO_2 dissolves in the water and is responsible for the ‘fizz’ when consumed. Other examples include dry ice (a solid form of CO_2) and fire extinguishers that contain gaseous CO_2. Substitution of CO_2 for refrigerants in vehicle cooling systems is another application being explored by the European Commission.[21]

It is important to note that these direct applications of CO_2 are not considered to be useful in reducing atmospheric CO_2 concentrations, as the CO_2 in these products is released back into the atmosphere within a short time frame.

Enhanced Oil Recovery

The main users of CCU technologies are oil and gas companies using CO_2 for Enhanced Oil Recovery. The current global CO_2 demand is estimated to be 80 million tonnes/year, of which 50 million tonnes/year is used for EOR in North America.[52] Enhanced Oil Recovery injects CO_2 into oil reserves deep underground. The gas can either expand and push through the reservoir, or mix with the oil, decreasing viscosity and increasing flow. Suitable oil reserves include operational oil reserves that are near end of production life, or reserves that have very heavy and viscous oil.[49]

The CO_2 used in EOR operations often comes from one of three sources: natural gas processing, fertilizer production or coal gasification. Companies that are capturing CO_2 can recover costs either by selling the captured CO_2 to a company using EOR or by using it in their own EOR operations.

5.2

Industry Context

Carbon utilization for Enhanced Oil Recovery has been practiced in North America for decades. For example, Canadian Natural Resources Limited (CNRL) operates a gas plant in Taber, Alberta where they capture 12,200 tonnes of produced CO_2 per year for use in their nearby Enhance EOR operations to increase the amount of crude oil that can be extracted from the field.[51] The Alberta Carbon Trunk Line (ACTL) will soon be a pipeline transportation network connecting industry-CO_2 emitters to CO_2 end-users. The ACTL is scheduled to be operational in 2019. The ACTL will connect a dense industry cluster north of Edmonton to a CO_2 compression and cooling facility. The compressed CO_2 will then travel by pipeline to a veteran oil field south of Edmonton to be used for EOR.[52]

There are an estimated 375 EOR projects operating globally, producing just over 2 million barrels per day (mb/d) of oil. EOR's share of global crude production has remained stable over time, at about 2% of global oil production.[53]

Carbon capture and utilization is also an important technology for buyers of CO_2 for beverage carbonation. The beverage industry is one of the few places where there is a mass market for CO_2. At present, the industry typically sources CO_2 from suppliers that use natural gas as a feedstock. In 2018, Coca-Cola collaborated with Climeworks, a pioneer of direct air capture of CO_2, as a new supplier.[54] While the total global demand for CO_2 from soda and food companies is a very modest 6 million tons a year, and CO_2 in soft drinks is not permanently sequestered, it offers an opportunity to bring in revenue and scale up CO_2 capture operations until markets in reuse and/or sequestration of carbon emissions mature.

5.3

Barriers and Opportunities

Barriers

EOR is influenced by the price of oil

The price of oil influences cost-benefit analyses for EOR facility applications. For example, EOR is a less attractive option when the price of oil is low, or when supplies are unconstrained, as is currently the case in North America.[49]

Many CCU applications are a temporary solution

The CO_2 used in non-EOR CCU operations, such as beverage carbonation or flash-freezing food, is released back into the atmosphere.

Leakage

There is a very small possibility of CO_2 leakage post-injection, which could cause drinking water or soil contamination, and potentially harm humans or flora and fauna. Precautions must be taken to minimize leakage risks as much as possible.

Geography

Enhanced Oil Recovery is a prominent option for utilization, but proximity of point sources of CO_2 to depleted oil fields is often a challenge, with one industrial partner stating, "The biggest challenge to EOR is in the transportation. The pipelining of CO_2 is the biggest challenge because of the distance required to transport between emission sources and sequestration fields."

Opportunities

Value-added output

EOR allows users to extract oil and gas from reservoirs that would otherwise not be accessible. This provides a financial incentive for emitters to capture, compress, and use CO_2.

Long-term storage opportunity with EOR

Monitoring data from well-established EOR operations show that large volumes of CO_2 can be stored safely for decades.

Incentive to innovate

The growth of EOR operations, including the Alberta Carbon Trunk Line CO_2 transportation network, has fostered the development of more advanced CO_2 handling technology, which may be useful for other CCUS applications.

6.0

Carbon Conversion: An Emerging Solution

Carbon Capture and Conversion (CCC) has emerged as growth sector over the last decade. CCC technology, or “CarbonTech”, uses CO_2 captured from industrial flue gas as a feedstock to make valuable products, thereby preventing the CO_2 from entering the atmosphere. In order to have a positive impact on climate mitigation, CCC technologies must result in a net reduction in CO_2 emitted to the atmosphere over the life cycle of the product.

The Global CO_2 Initiative has predicted that carbon conversion will scale to a $1 trillion industry and reduce global atmospheric GHG’s by up to 15% by 2030.[55] Currently the most common CarbonTech products are building materials, fuels and chemicals.

6.1

Technologies

Conversion of CO_2 into chemicals and fuels

Concentrated waste CO_2 can be used as an input to commodity products such as chemicals and fuels. Two of the largest sinks for CO_2 conversion are methane and urea. However, as soon as fertilizer (with methane and urea) is applied, or methane is burned as fuel, CO_2 is released back into the atmosphere.[56] Products such as concrete or graphene have a longer storage life.

A large quantity of energy is required to convert CO_2 into chemicals and fuels, so it is important that these processes use energy from non-emitting sources such as hydro or wind. Conversion into chemicals and fuels will need to become more efficient for this technology to become adopted more widely.

Mineral carbonation

Mineral carbonation is a natural process in which minerals take CO_2 from the air and create carbonate rock. This process naturally occurs over millions of years but researchers are working to accelerate the process in industry, especially in mining where some waste products have an inherent ability to transform CO_2 into rock. In Canada, direct emissions from metal and non-metal mines accounted for 1.2% of the country's total GHG emissions in 2015. Some mining companies hope they can become carbon neutral through mineralization and other innovative initiatives.[57] Researchers are working with mining companies to accelerate the natural mineralization process by increasing the concentration of CO_2 coming into contact with the minerals and also using enzymes to accelerate the reaction rate.

CO_2 can also be injected into underground rock formations where it is mineralized at various speeds depending on the rock. In Iceland, for instance, mineralization occurs in less than two years because the CO_2 is injected into highly-reactive basalt rock.[58]

There are several variations to mineral carbonation that can use pure CO_2 or raw industrial flue gas. Under both scenarios, the output is stable carbonate rock which stores CO_2 for centuries. Scaling this process will require overcoming high-energy demands and costs, and reducing the environmental impacts of mining, processing and transporting minerals such as serpentine and olivine.

Biochemical processes

Most land-based plants and algae (biomass) use CO_2 and sunlight to create chemical energy to grow and thrive. Using variations of this process in bioreactors, CO_2 can help to grow biomass, which can then be used as a feedstock for the production of biofuels (like ethanol, butanol, methanol and diesel), bioplastics, food additives, oils and other consumer goods.[51,60]

Many first-generation biofuel systems used food crops such as corn and soybeans for energy production, which had negative effects on global food prices. Recently, there has been growing investment in the development of microalgae to produce biofuels. Microalgae are abundant, simple organisms that can use the CO_2 in industrial flue gas to create energy and produce biomass. Algal biofuel production systems can be controlled for temperature, pH, nutrient and CO_2 concentrations that maximize biomass and oil yields. One tonne of algal biomass can sequester 1.83 tonnes of CO_2.[61] The algae biomass can then be harvested and converted into liquid fuel or nutritional products via chemical and biological reactions.

6.2

Industry Context

CarbonTech is bustling with innovative opportunities to create materials such as concrete and building materials, fuels, chemicals, and plastics with waste CO_2. Researchers and innovators are developing these products for end users who want a climate-friendly product that sequesters CO_2, and for industrial CO_2 emitters that want to reduce CO_2 emissions, or want to capture CO_2 from their operations to use as a feedstock for other products. For example, Capital Power, a North American energy producer, recently acquired an equity interest in C_2CNT, a start-up that captures CO_2 from flue streams and transforms it into carbon nanotubes. Carbon nanotubes are an extremely high value product that can be used in a number of applications ranging from bullet-proof vests to carbon composites for jetliners.

In some instances, CO_2 can be used to develop superior products. Canadian company CarbonCure has developed and is marketing a technology that uses captured CO_2 to improve the strength of concrete. Several concrete companies in North America have purchased and are using the technology.[62]

Because there is such a wide variety of products that can be produced from captured CO_2, the market is broad and diverse. The different types of CCC allow for a customized approach to finding the most suitable technology for each client and therefore early consultation and partnerships between technology developers and industry end-users is of paramount importance.

6.3

Barriers and Opportunities

Carbon conversion technologies are emerging globally at different stages of technological readiness. There is greater mobilization in the CarbonTech space in recent years because of large-scale initiatives such as the NRG COSIA Carbon XPRIZE[63] and a focus on building awareness of the opportunities in this space. Canadian organizations producing CarbonTech materials and reports include CBSR, CMC Research Institutes, the Pembina Institute, and the Delphi Group.

Barriers

Like other clean technologies, CarbonTech is challenged by regulatory uncertainty and low or no carbon price. However, it also faces other unique barriers:

Capital investment

The availability of capital investment is a common barrier for many carbon conversion innovators, especially at the pilot and scale up stages. While the CarbonTech industry has been successful in securing funding through government agencies and academic institution partnerships, private sector investment is crucial to CCC commercialization.

The cost of carbon capture

Carbon capture is an expensive component of CarbonTech. Technologies that can use CO_2 in flue gas directly from the source, rather than requiring CO_2 to be separated, are less costly, require less capital, and have a faster scale-up cycle.

Energy requirements

Carbon capture and conversion technologies face high energy requirements, such as the energy needed for electrolysis. High energy requirements mean high costs, and can also mean CO_2 emissions to the atmosphere if fossil fuels are burned for energy generation. Access to low cost renewable energy, combined with economies of scale, is expected to lower production costs and energy intensity of CCU, and help overcome the commercial adoption barrier. Technology that performs at ambient temperature and pressure conditions requires much less energy. Furthermore, combining capture and utilization can minimize energy demands, particularly if the processes are done at the same temperature.[64]

Permanence

CarbonTech applications vary in the permanence of CO_2 sequestration. Fuels and fertilizers produced by CarbonTech release CO_2 when they are used, giving them a short storage life. In comparison, plastics and building materials will store CO_2 for decades if not centuries. Carbon mineralization, which involves using CO_2 to accelerate the natural process of rock formation, will store CO_2 permanently.

Geographic proximity to CO_2 sources

It is most cost-effective to have CarbonTech near emission point sources to reduce transportation costs. One respondent to our survey suggested that, "Utilization is so dependent on geography and application. What would be ideal is if CMC could develop a toolbox of utilization companies and look at which industrial applications to which they best apply."

Communication and knowledge sharing

Tackling global climate change and reaching a point of drawdown in emissions will require mobilization in all sectors and multi-stakeholder collaboration. As stated by a respondent, "Each industry could benefit from the communal knowledge and then apply those to specific industrial applications. There is no value in each industry doing their own thing."

Opportunities

Job creation

The prospect of job creation is a key factor in driving policy support and public acceptance for carbon capture, conversion, utilization and storage technologies. The CarbonTech space presents opportunities for jobs for highly qualified professionals and skilled tradespeople.

Demonstrate climate change mitigation

It is critical to demonstrate that these new carbon conversion technologies can play a role in climate change mitigation if we are to attract investment and public sector support.

Business case

Unlike carbon capture and storage, carbon conversion technologies can demonstrate a solid business case because they use waste CO_2 as a feedstock, and create saleable products. CarbonTech is generating public sector and private sector interest and support in Canada, because it has the potential to generate employment in clean manufacturing.

Technological variety

There are a wide range of industrial applications for capture and conversion technologies. Policy makers, industry users, and investors should be shown the opportunities for customized technology solutions for different industries, geographies and markets.

Technology developers are less dependent on carbon policy

Carbon policy is very influential in economic analyses for CCS technology. CCC, in comparison, creates economic value for end users, making CCC commercialization less reliant on carbon taxation.

Public sector procurement can spur growth and lower emissions

As more governments use a life-cycle approach for procurement decisions, they can source from Canadian providers of steel and concrete derived from CO2 for more durable and low-carbon infrastructure investments.


Source: carboncure.com

INNOVATION SPOTLIGHT

CarbonCure
N.S., Canada

CarbonCure was founded in 2007 by CEO Rob Niven and has a mission to lead a global movement to transform CO_2 into concrete. CarbonCure's utilization technology chemically-mineralizes waste CO_2 to make stronger concrete and minimize cement's carbon footprint.

6.4

Key Players

A wide range of stakeholders play a role in developing and commercialising new CO_2 conversion technologies and processes.

Technology innovators

Carbon conversion technologies are being developed by a variety of innovators. In universities, experts in a number of disciplines are working on early stage capture and conversion research. This research occurs at a very small scale and is often funded through grants from government programs aimed at clean technology growth or through government agencies such as the National Sciences and Engineering Research Council (NSERC) of Canada. Occasionally, industry partners fund specific research initiatives. Many universities incentivize researchers to move their innovations toward commercialization. For instance, the federal Canada First Research Excellence Fund (CFREF) was developed in part to accelerate the commercialization of university research.

There are numerous instances of university research moving through the development stage to commercialization, but that is not the only innovation pathway. Entrepreneurs start small businesses to develop conversion or capture products, and large-scale industries have their own research and development departments where low carbon technologies are under development. Industries also collaborate with both university and private innovators to push technology development forward. Below is a sampling of Canadian innovators working on carbon conversion technologies:

CVMR Corporation
Toronto, Ontario
CVMR uses methane (CH4) and CO_2 to produce graphene, a material used for manufacturing.[65]

Mangrove Water Technologies
Vancouver, British Columbia
creates chemicals from industrial flue gas and saline water.[66]

Quantiam Technologies

Edmonton, Alberta

develops nanomaterials, surfaces, catalysts, and coatings for clients in the industrial sector.[67]

Pond Technologies

Markham, Ontario

creates algae in photo-bioreactors attached to industry flue gas outputs. Algae is harvested and used for as a feedstock for biofuels, plastics, and nutritional products.[68]

CleanO$_2$ Carbon Capture Technologies

Calgary, Alberta

reduces the energy usage of commercial boilers that use natural gas, and captures carbon dioxide (CO_2) and converts it into sodium carbonate.[69]

Tandem Technical

Ottawa, Ontario

creates mineral by-products, such as calcium carbonate, by recycling CO_2 from industrial waste streams.[70]

Terra CO_2 Technologies

Vancouver, British Columbia

creates geopolymer cement from mine tailings ponds.[71]

Capital Power

Edmonton, Alberta

investment in C2CNT, which uses CO_2 emissions to create carbon nanotubes, a carbon fibre product. Carbon nanotubes have various applications, including use as a light-weight alternative to metal in industrial applications.[72]

CMC Research Institutes

Calgary, Alberta

an independent organization that offers two facilities in Western Canada to CCUS technology innovators to test and scale up their technologies.

The public

Research suggests that broad social acceptance of CarbonTech is influenced by individual expertise and opinion, bottom line considerations, policy support and media coverage. Public awareness of CarbonTech is low, with mixed support among those aware of the technology. One study, which asked consumers to consider purchasing hypothetical CO-based products, revealed that perceived health and environmental risk was low while overall perception of the product was positive.[73] Conversely, a second study found evidence that some individuals assumed that CO_2 could be released from the products and adversely impact their health and the environment.[74] As the CarbonTech industry grows, it will become important to understand and help shape public perception of the CCC industry.

Investors

The investment prospects for CarbonTech are looking increasingly positive. Groups such as Breakthrough Energy Ventures, the Oil and Gas Climate Initiative, Y-Combinator, CarbonTech Labs, Circular Carbon Network, CO_2 Value Europe and Lawrence Livermore National Laboratory are actively supporting and driving private investment, private sector engagement and policy. Investor decisions regarding CarbonTech will be strategically driven by profit expectations, policy direction, key performance indicators (KPIs) and measurable results.

Commercial sector

CarbonTech provides a unique opportunity for businesses to reduce their CO_2 emissions while demonstrating support for innovation, by financing and/or adopting carbon conversion innovations. This could include purchasing carbon-absorbing carpeting such as that produced by Interface, or using low carbon concrete, like CarbonCure concrete, in construction.

Governments and policy-makers

Government has an important role to play supporting the commercial scaling of CarbonTech. As is the case with virtually all clean technology, CarbonTech requires stable, long term policies, programs and investments aimed at boosting low-carbon innovation. Government plays an important role in implementing policies that help stimulate market demand for clean innovation – for example tax credits for technology adoption, pollution pricing, smart environmental regulations, or targeted procurement policies.[75] These policies can provide a critical business driver to encourage industrial emitters to invest in CO_2-reduction technologies.

Another important role for government is supplying grants, loans, and growth capital. Federally, this is done through agencies such as Sustainable Development Technology Canada (SDTC), Export Development Canada (EDC) and The Business Development Bank of Canada (BDC). Several provinces, including Alberta, B.C, Ontario and Quebec, have funding available to support the demonstration and scale up of clean technologies such as CarbonTech.

6.5

Initiatives

Smart CO_2 Technology (SCOT) Project

SCOT was a collaborative European project operational between 2013-2016 and focused on the conversion of CO_2 into valuable products via chemical or biological technologies. The project had two major outcomes: 1) an assessment of the five regions involved in the project highlighting strengths and weaknesses, opportunities and aspirations for transformation and recovery of CO_2; and 2) a socio-economic analysis to identify market, technology and regulatory challenges. These outcomes served as a foundation for various strategic documents including a 2030-2050 vision for Europe which highlights the important role of recycling CO_2 in the development of a circular economy.[76]

ERA Grand Challenge: Innovative carbon uses

In 2016, Emissions Reduction Alberta (ERA) launched a $35 million multi-stage competition to support innovative technologies to convert CO_2 into useful products. ERA searched the world for the best solutions for Alberta to transform CO_2 from a waste stream to an asset. In the first stage, ERA committed up to $12 million through 24 grants of $500,000. In March 2017, four winners in the second stage each received a commitment of up to $3 million as a development grant and were eligible to advance to the final round in 2019, for an additional $10 million in funding.[77]

Clean Energy Ministerial

Canada is a member of the international Clean Energy Ministerial (CEM)[78] which gathers 25 countries plus the European Commission to accelerate the development of clean energy transformation. There are 14 clean energy initiatives underway through the CEM, one of which is CCUS. The four objectives of this initiative include: expanding the spectrum of clean energy technologies to include CCUS; creating a collaboration platform for the private sector, governments and the investment community; identifying investment opportunities for CCUS to improve the business case; and disseminating best practices in policy, investment and regulation.

Mission Innovation

Canada is a member country of Mission Innovation[27] – an initiative to accelerate clean energy innovation with the objective of making clean energy widely affordable. Mission Innovation hopes to enable near-zero CO_2 emissions from power plants and carbon intensive industries by identifying breakthrough technologies and recommending research, development and demonstration pathways and collaborative mechanisms. One of the directions under Mission Innovation is Carbon Capture, Utilization and Storage.

NRG COSIA Carbon XPRIZE

An XPRIZE is a widely recognized, incentivized competition that pushes innovation to its fullest potential in the pursuit of positive world change. It is designed for problems that have no clear path towards a solution and are in the midst of market failure, but must also be achievable by a small team within a set time.

The NRG COSIA Carbon XPRIZE, launched in September 2015, is a global competition with a $20 million prize for the conversion of CO_2 into useable products. At the time of writing, ten selected finalists are fundraising and scaling their systems. Each team is required to build and operate a large-scale demonstration of their project at either the Alberta Carbon Conversion Test Centre or the Wyoming Integrated Test Centre. Final demonstrations will take place from June 2019 until February 2020 with a winner announced in March 2020.[79]

Canada was a key player in deployment of the Carbon XPRIZE, and of the top ten finalists, three are Canadian: CarbonCure, Carbon Upcycling Technologies and Carbon Electrocatalytic Recycling Toronto. Capital Power, a North American power producer headquartered in Edmonton, recently invested in C2CNT, a U.S. start up and XPRIZE finalist.[79]

“The XPRIZE helps to bring innovations forward that were previously a laboratory project and also helps to legitimise the CarbonTech Industry to the public and engage important players especially financial ones.”

- Study Participant

7.0

Conclusion

The world must reduce industrial CO_2 emissions and achieve net negative global emissions to mitigate the worst effects of climate change. Although this is a challenging goal, it is possible through a portfolio of innovative solutions, deployed at a massive scale. There is a growing consensus that a combination of carbon conversion, utilization and storage technologies can contribute to mitigating climate change. This report proposes that CCUS technologies must be part of the solution and illustrates how different CCUS technologies present their own unique challenges and opportunities.

Carbon Capture and Storage (CCS) is presently the most effective technology in reducing and permanently storing atmospheric CO_2. However, CCS requires significant capital investment and government support, and provides limited incentive for businesses and investors to engage.

Enhanced Oil Recovery is the most commonly used form of Carbon Utilization (CCU). It provides a business driver for CCS, if waste CO_2 is used to extract oil from depleted fields, and then sealed in geologic formations. However EOR makes most sense economically when oil prices are high and oil supplies are scarce.

A whole new suite of carbon conversion technologies, or CarbonTech, are emerging to use waste CO2 as a feedstock to create value-added products. Global innovation competitions have brought CarbonTech into the spotlight and stimulated investment to scale-up these technologies. Although the CarbonTech sector faces challenges, several technologies present commercially attractive opportunities. CarbonTech, like all clean technology, will benefit from private sector investment, smart policy and regulation, and strong cross-sectoral collaboration to support development, scale-up and mass deployment. And without mass deployment of all kinds of carbon mitigating solutions, the world has little chance of avoiding catastrophic climate change.

Let's get to work.

Appendices

Appendix A: Supplementary Figures and Tables

Table 1. International and Canadian facilities for testing and scale-up of carbon capture and utilization technologies.

Facility name	Facility description
CanmetENERGY Ottawa (Ottawa, Ontario)	A national laboratory under Natural Resources Canada (NRCan). Develops bench and pilot scale oxyfuel combustion capture and conversion technologies.
CMC Research Institutes' Carbon Capture and Conversion Institute (Richmond, British Columbia)	Accelerates the development, piloting, scale-up and validation of carbon capture and conversion technologies. Capacity from grams of CO2 to one tonne of CO2 processed per day.
Clean Energy Technologies Research Institute (CETRi) (Regina, Saskatchewan)	The University of Regina Clean Energy Technologies Research Institute researches and demonstrates carbon capture and conversion technologies to reduce costs and prove technologies.
Innotech Alberta – Alberta's Carbon Conversion Technology Centre (Calgary, Alberta)	Demonstrates small-scale CO2 capture and utilization technologies using flue gas. Flue gas is generated from the ENMAX Sheppard Energy (natural gas) Facility. Capacity is 25 tonnes of CO2 processing per day.
SaskPower's Shand Carbon Capture Test Facility (Estevan, Saskatchewan)	Provides testing and validation to investigate amine-based post-combustion capture technologies at a near commercial setting. CO2 capture capacity of 120 tonnes per day.
Center for Applied Energy Research (Lexington, Kentucky)	The University of Kentucky houses the Center for Applied Energy Research equipped with a 0.1MWth pilot plant with coal-derived flue gas. Solvent-based technologies can be evaluated with these facilities and benchmarked against monoethanolamine.
CO2CRC (Carlton, Austraila)	Reduces the cost of carbon capture by focusing research on the power penalty of operating a capture plant. The organization researches capture technologies from bench scale through to pilot scale in the field at power stations and the Otway Research Facility.
CSIRO (Canberra, Australia)	A research program since 2005 that is supported by the Australian Government, the State governments of Victoria and New South Wales and industrial stakeholders. The program is based on technology demonstration using pilot plants and laboratory-based technology development that operates on flue gases from brown or black coal combustion.
Huaneng Clean Energy Research Institute (CERI) (China)	CERI is the innovation center of China Huaneng Group (CHNG), the largest power company in China. CERI advances power generation technology including renewable energy, coal gasification, and CO2 capture technology.
National Carbon Capture Center (NCCC) (Wilsonville, Alabama)	A world-class carbon capture testing facility managed by Southern Company on behalf of the United States Department of Energy. The NCCC tests post-combustion carbon capture using flue gas. Technology developers have access to a fully integrated solvent unit for advanced testing or seven bench and pilot-scale test bays.
SINTEF (Tiller, Norway)	A highly equipped test facility for developing post-combustion capture technologies and a research lab for flue gas pre-treatment analysis and emission research. The facility has a 30 metre indoor CO2 adsorber/desorber pilot plant with a capacity of 50 kg CO2 per hour.
Technology Centre Mongstad (Mongstad, Norway)	The largest global facility for testing and improving CO2 capture technologies with a focus on the final stages of testing before full-scale operation.
UKCCSRC Pilot-scale Advanced Capture Technology (PACT) (Sheffield, United Kingdom)	The UK Carbon Capture and Storage Research Centre pilot-scale Advanced Capture Technology facilities testing for post-combustion capture of coal, biomass and gas with a gas mixing facility to simulate industrial flue gas compositions. Core facilities are connected to a capture plant with a 1 tonne of CO2 capture per day capacity.
Wyoming Integrated Test Center (Cheyenne, Wyoming)	This test center will provide space for researches to test CCU technologies using 20 MW of coal-based flue gas. Research will look at turning flue gas into a marketable commodity.

Appendices

Appendix B: CCUS Market Study Interview Questions

How have you/your company been involved with CCUS?

What are the three most interesting developments in carbon capture/utilization/storage that you are aware of?

Capture

What challenges do you think are faced by carbon capture technology?

What are the biggest opportunities related to capture? What still needs to be done?

Utilization

What role do you see for carbon utilization in Canada meeting its climate change goals?

What role do you see for carbon utilization in developing countries meeting their climate change goals?

What role do you see for carbon utilization in other OECD countries meeting their climate change goals?

Which carbon utilization options are most promising and why?

What are the biggest hurdles in scaling up carbon utilization in Canada?

Opportunities in Canada? What industrial sectors hold most promise as users of carbon utilization technology? Why?

Does Canada have a competitive advantage in any aspect of carbon utilization, and why?

How do we maintain it?

Storage

What role do you see for carbon storage in Canada meeting its climate change goals?

What role do you see for carbon storage in developing countries meeting their climate change goals?

What role do you see for carbon storage in other OECD countries meeting their climate change goals?

What do you think are the top 2-3 barriers to broader implementation of carbon storage? In Canada? Globally?

Biggest opportunity?

Does Canada have a competitive advantage in carbon storage, and why?

How do we develop/maintain our advantage?

CMCRI

What do you know about CMCRI?

What would make CMCRI's services indispensable for a company's successful technology scale-up?

Policy

What would you advise policy makers to do to help accelerate the full-scale implementation of carbon utilization? Carbon storage?

How can Canada lead in the CCUS space? What are our competitive advantages in your opinion?

For tech developers

What are the top three challenges you face with your CCUS technology scale up and deployment?

What would help overcome the challenges?

What do you need to succeed?

For large emitters

What are the top three challenges CO2 challenges you face?

Would CC, U or S help you? How?

What are the barriers for your company implementing CC, U or S?

What would help overcome the challenges?

Endnotes

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