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The Role of CCUS in Accelerating Canada’s Transition to Net-Zero

OIES Research Paper

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Disclosure

I declare no conflict of interest in the publication of this paper. Although I am employed by Suncor Energy, all information contained in this paper pertaining to the latter has been researched from publicly available information only. The views expressed are mine alone and do not represent those of Suncor Energy or any other commercial entity.

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Executive summary

Canada has been an enthusiastic developer and implementer of carbon capture, utilization and storage (CCUS) technologies, currently accounting for nearly 20 per cent of installed CCUS capacity globally. However, many of the initial projects were treated as little more than science projects, with eye-watering costs that led them to be deemed uneconomic and unworthy of much attention. As a party to the Paris Agreement, the country's commitment to reducing its CO_2 emissions to 40 per cent of the 2005 level has been criticized as being at odds with its reliance on the oil and gas industry for a core part of its gross domestic product and export revenue.

Along with a steep hike in the federal carbon price announced in 2020, the government has crafted a hydrogen-centric strategy to support a decarbonized economic transition, with CCUS identified as a key enabler of both pathways. On the one hand, CCUS justifies continued investment in the oil and gas sector through the permanent sequestering of CO_2. On the other hand, creating additional economic value from the blue hydrogen generated from CCUS can demonstrate the viability of carbon-negative hydrogen production using bioenergy with carbon capture and storage (BECCS) or from electrolysis with offsets from direct air capture with carbon storage (DACCS). Oil and gas firms, supported by their peers in heavy industry, have announced blue hydrogen, oilsands CCUS, and carbon transportation projects which – if implemented – could transform the province of Alberta and disrupt the Canadian economy. Despite the bold vision of the government's strategy and the announced projects, there are potential challenges to widespread CCUS deployment, including technological scope, project finance, and regulatory assurance.

The collaborations that have been announced by oil and gas firms will go a long way towards bringing alignment on technology and driving down costs. In that regard, Canadian leadership in CCUS implementation provides a healthy head start. Carbon pricing will support project economics, but only up to a certain point, especially given the volatility of commodity markets and declines in Canadian oil and gas sector investment. And federal and provincial regulations – with the allied components of social, Indigenous and environmental support – will require clarity if announced projects are to be implemented. However, the industry's ability to shake off these barriers has been demonstrated by operational successes at recent CCUS projects, particularly at Shell Canada's Quest facility and the Alberta Carbon Trunk Line (ACTL). These provide some measure of comfort on the economic and environmental value of well-executed projects. The momentum will need to be sustained for Canada to achieve its vast CCUS potential, enable the commercialization of DACCS and BECCS, and successfully decarbonize heavy industry without adverse economic impacts.

1. Introduction

With the third-largest oil reserves and the fourth-largest natural gas deposits in the world, Canada has often found itself in the increasingly polarized roles of advocating for deep cuts in global greenhouse gas (GHG) emissions, while continuing to support the extraction of fossil-based energy sources domestically. The country's electricity grid has some of the lowest emissions per capita in the world, as most provinces have shut down their coal plants and almost all have announced that the remaining few will be closed by the end of this decade.[1] However, continued increases in the global demand for oil and natural gas – Canada's largest source of export revenue[2] – mean that Canada's energy reserves are generally viewed as a mainstay of the economy for years to come, and one that should be protected.[3]

The advent of CCUS technologies was greeted with open arms by federal and provincial governments, particularly in the oil and gas producing province of Alberta. The Quest project in Fort Saskatchewan, operated by Shell Canada and commissioned in 2015, is one of the world's largest commercial-scale CCUS operations, and the first to capture emissions from oilsands production. A significant part of this facility's C$1.35 billion cost was funded by the Canadian and Alberta governments, evidence of the political desire to see the technology succeed in that space. A few years later, both governments invested in expanding the capacity of the proposed ACTL in nearby Redwater, the world's largest CO_2 pipeline, which was commissioned in 2020 and can transport over 14 million tonnes of CO_2 ($MtCO_2$) per year, or nearly 20 per cent of the CO_2 emissions generated by Canada's oilsands.[4]

For many, including some in the political arena and industry, these projects were initially deemed to be impractical on a large scale and very costly. The Pembina Institute estimated that the all-in cost of carbon capture from Quest upon commissioning was C$80-100 per tonne of CO_2 equivalent (tCO_2e),[5] a price that would be prohibitive to firms, considering that the price of carbon was C$20/$tCO_2e$ in 2018. With the price of carbon set to increase dramatically, rising to C$170/$tCO_2e$ by 2030, that initial hurdle would appear to have been crossed. There does appear to be global momentum behind CCUS projects, with the announcement of projects such as the Northern Lights CCUS in Norway representing a potentially pivotal moment in shifting public perceptions of CCUS viability globally. Canada has doubled down on this pathway, releasing a hydrogen strategy report in 2020 that focused on the development of blue and green hydrogen. CCUS is a requirement for blue hydrogen, which – being further ahead in development – could support green hydrogen deployment by financing the buildout of the government's planned hydrogen infrastructure.[6]

The desire to build a low-emissions economy in the wake of the COVID-19 pandemic is evident, as is the imperative to rebuild the energy sector with a greater focus on environmental, social and governance (ESG) and Indigenous engagement. However, potential challenges with project financing and technology selection mean that industry collaboration, political commitment to the carbon price, and the development of commercial applications for CO_2 are all required if CCUS is to become a key

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[1] BBC News (2016). 'Canada announces plan to phase out coal by 2030', *British Broadcasting Corporation*, 21 November, https://www.bbc.com/news/world-us-canada-38056587 (accessed 3 July 2021).

[2] Quan, Holly (2020). 'Natural gas and oil: Canada's #1 export – and why it matters', *Canadian Association of Petroleum Producers*, 25 June, https://context.capp.ca/articles/2020/article-petroleum-101-exports/ (accessed 10 July 2021).

[3] Polls conducted by Ipsos in September 2020 and Research Co. in July 2021. In both polls, over 60 per cent of Canadians view the responsible development of oil and gas as fundamental to a 'green recovery'.

[4] Friedman, Gabriel (2020). 'New CO_2 pipeline capable of capturing 20% of oilsands emissions could hold key to Alberta's energy future', *Financial Post*, 4 June, https://financialpost.com/commodities/energy/a-new-transcanada-highway-albertas-new-co2-pipeline-could-offset-20-of-oilsands-emissions (accessed 7 June 2021).

[5] Kilpatrick, Ryan, Adam Goehner, Eli Angen, Matt McCulloch, and Duncan Kenyon (2014). 'CCS Potential in the Oilsands', report prepared by Pembina Institute for Government of Alberta, Alberta Innovates, Energy and Environmental Solutions, and Climate Change Emissions Management Corporation, https://eralberta.ca/wp-content/uploads/2017/05/2029-Pembina-CCS-Potential-in-the-Oilsands.pdf.

[6] Natural Resources Canada (2020). *Hydrogen Strategy for Canada*, December 2020, Government of Canada.

component of Canada's journey to net-zero emissions. This Energy Insight provides an in-depth look at current barriers, with a focus on enabling fiscal and regulatory policies, and business models that can be adopted by firms looking to incorporate CCUS into their strategic plans.

2. History of CCUS in Canada

CCUS has long been touted as one of the most obvious ways to capture emissions from industrial facilities, and for a resource- and industry-heavy economy like Canada's, there is a clear attraction to that. The country's ability to extract coal, oil, and natural gas from very challenging environments – particularly oilsands and shale gas – is considered noteworthy from a technological standpoint. However, the energy required to do so has come under increased scrutiny. CCUS possesses the potential to allow the country to meet its ambitious climate targets while continuing to sustain industries that are considered critical components of the economy.

In the Canadian context, CCUS efforts have, until recently, focused on two areas: the combustion of coal to produce power; and the combustion of natural gas to produce power, steam, and hydrogen. Most provinces have shut down their coal plants, and the remaining four – Alberta, Saskatchewan, New Brunswick, and Nova Scotia – have all announced plans to shut down their coal plants or convert them to natural gas.[7] The future focus of CCUS projects in Canada will be on facilities that have natural gas power plants.

At oilsands sites, natural gas is burned to produce steam – and associated electricity – which is used to warm the bitumen lines in extraction operations. This thaws the *in-situ* reservoirs of bitumen (oil that is too heavy or thick to flow on its own), which contain 80 per cent of the oilsands' resource. Oilsands sites also use natural gas to produce hydrogen, a core ingredient in the production of lighter, sweeter synthetic crude grades that are easier to transport and command a price premium on the market. In refining, natural gas is combusted in similar ways – in boilers for site utilities and to produce hydrogen used in the crude refining process. Globally, these processes represent ~25 per cent of well-to-wheel (WTW) emissions associated with transport (see Figure 1). In Canada, the absolute number is even higher, as the oilsands resource has a higher energy intensity than most other global crude grades.

While there is a lot of renewed interest and renewed interest around CCUS, it is not new to industry, with oil and gas major Canadian Natural Resources Limited (CNRL) currently capturing CO_2 emissions at its Horizon facility and using them for enhanced oil recovery (EOR) from oilsands *in situ* reservoirs.[8] CCUS for EOR has many critics since it generally increases total liquids production without reducing absolute emissions. However, it does result in lower emissions intensity per barrel. It has also proved to be a low-risk way to demonstrate that carbon can be securely stored underground and in reservoirs with no losses. Part of the justification for the 240 kilometre-long ACTL is that it can be used to stimulate depleted and ageing wells in central and southern Alberta, minimizing the liabilities associated with their abandonment, while unlocking cheap barrels of oil with near-zero incremental emissions excluding those from end-use.[9]

Interestingly, the first commercial CCUS project in Canada was at the Boundary Dam coal plant in Saskatchewan, with the ability to capture 1 $MtCO_2e$/year. The captured carbon from Boundary Dam is used in EOR. This was followed by the Quest facility at Shell's Scotford Upgrader in 2015, which was the first plant to capture oilsands emissions, and the first to sequester carbon without the option for EOR. Figure 2 summarizes operational CCUS projects in Canada and their capacity.

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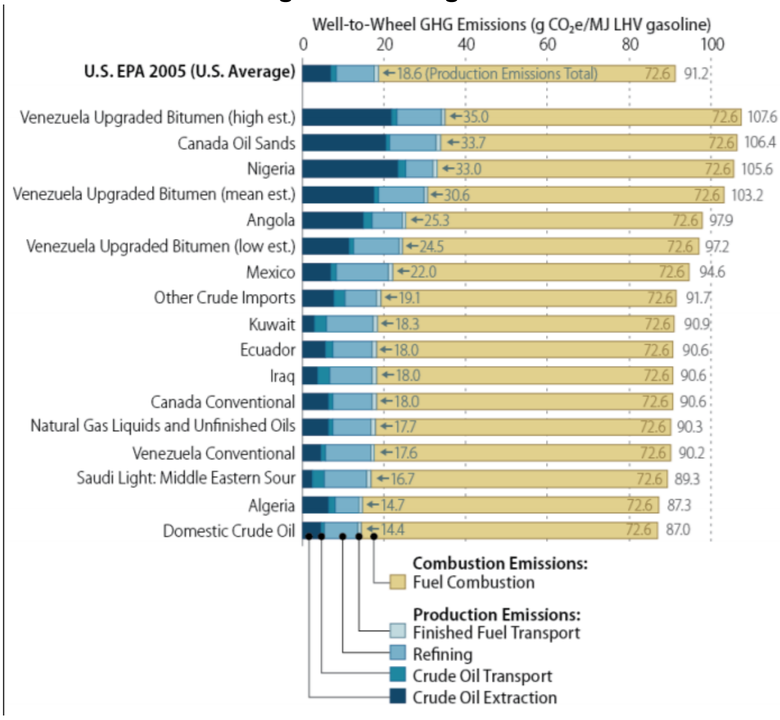
[7] Canada Energy Regulator (2020). *Canada's Energy Future 2020*, 2 December, https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2020/index.html (accessed 3 July 2021).
[8] Canadian Natural Resources Limited (2020). *2019 Stewardship Report to Stakeholders*.
[9] Author interview with Ian MacGregor, Chair and CEO of North West Refining and Co-Founder of the ACTL.

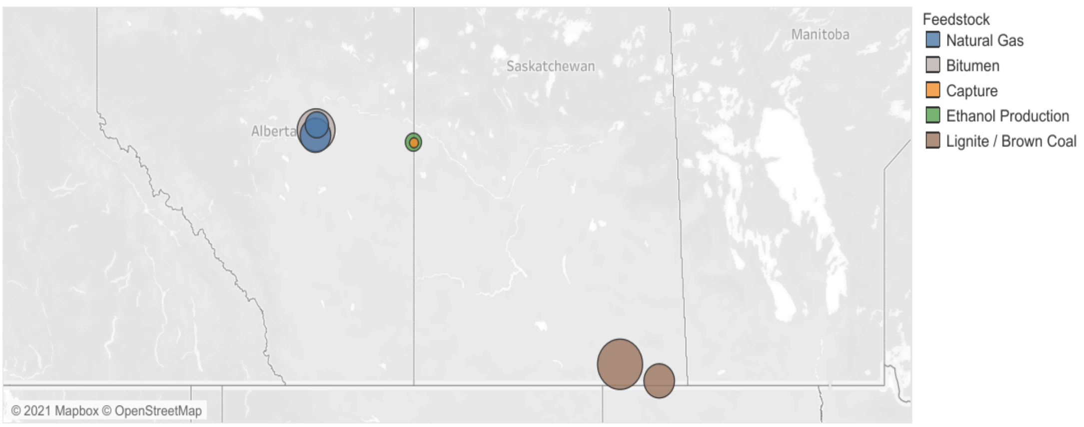
Figure 1: Lifecycle GHG emissions of global crude grades



Notes: gCO_2e = gram of CO_2 equivalent; LHV = lower heating value; MJ = megajoule.
Source: Lattanzio, Richard (2014). Canadian Oil Sands: Life-Cycle Assessments of Greenhouse Gas Emissions. *Congressional Record Service*, March 10. www.sgp.fas.org/crs/misc/R42537.pdf (accessed 3 July 2021).

Figure 2: CCUS projects in Canada

Facility name (click on link to view)	CO2 capture capacity (Mtpa)	Primary storage type
Alberta Carbon Trunk Line ("ACTL") with North West Sturgeon Refinery CO2 Stream	1.2-1.4	Enhanced oil recovery
Alberta Carbon Trunk Line ("ACTL") with Nutrien CO2 Stream	0.3-0.6	Enhanced oil recovery
Boundary Dam Carbon Capture and Storage	1.0	Enhanced oil recovery
Great Plains Synfuel Plant and Weyburn-Midale	3.0	Enhanced oil recovery
Husky Energy Lashburn and Tangleflags CO2 Injection in Heavy Oil Reservoirs Proje..	0.2	Enhanced oil recovery
Inventys and Husky Energy VeloxoTherm Capture Process Test	0.1	Enhanced oil recovery
Quest	1.0	Dedicated geological storage - onshore deep saline formation

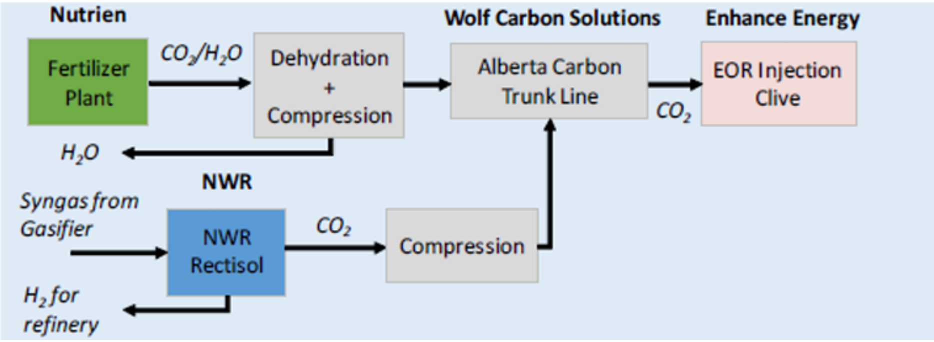


Note: Mtpa = million tonnes per annum.
Source: Canada Energy Regulator.

The 4 $MtCO_2e$/year captured from coal generation stand out, but they do not receive as much attention owing to the imminent retirement of coal generation plants in Canada, and the fact that the emissions captured at Weyburn are actually generated in a North Dakota-based coal-fired plant. Altogether, Canada currently has the capacity to capture and either utilize (for EOR) or store 7 $MtCO_2e$/year. This represents about 17 per cent of global CCUS operational capacity as of 2020.[10]

Future growth of CCUS in Canada is expected to be spurred by increased deployment of capture technologies in mature industries such as the oilsands extraction, refining, and fertilizer and cement manufacturing. As shown in Figure 3, the ACTL is fed by both the oilsands-based NWR Sturgeon refinery and the Nutrien fertilizer plant. Growth is also expected from DACCS and BECCS, with Canadian firm Carbon Engineering considered a pioneer of the former. Until recently, the deep decarbonization of these industries in the near to medium term was viewed as a longshot. Recent events have come together to change that dynamic, particularly in the oil and gas sector.

Figure 3: Process and material flows for the ACTL



Source: Government of Canada Hydrogen Strategy Report.

3. Heavy industry in Canada: Current status

From an industrial standpoint, Canada has two main categories of GHG emissions:

- The extraction of fossil fuels
- The combustion of these fuels in the utilities, petrochemicals, fertilizer, and cement industries.

A brief look at each is important in setting the stage for new and proposed CCUS developments in Canada.

Energy extraction: Declining investment amidst ESG concerns

Emissions intensity in Canada's oil and gas sector has decreased by over 30 per cent since 2000, driven by oilsands efficiency (see Figure 4), yet significant production growth during that period has resulted in sector emissions increasing from 157 $MtCO_2e$ in 2000 to 194 Mt CO_2e in 2019,[11] as shown in Figure 5.

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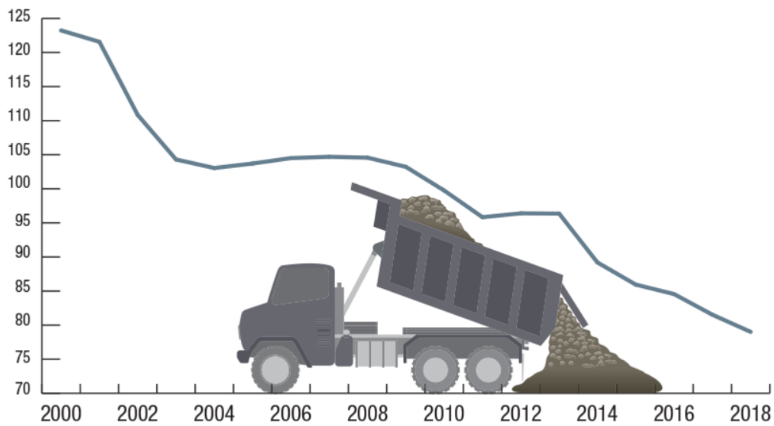
[10] IEA (2020). 'Global capacity of large-scale CCUS facilities by application, as of June 2020', International Energy Agency, Paris, https://www.iea.org/data-and-statistics/charts/global-capacity-of-large-scale-ccus-facilities-by-application-as-of-june-2020 (accessed 3 July 2021).

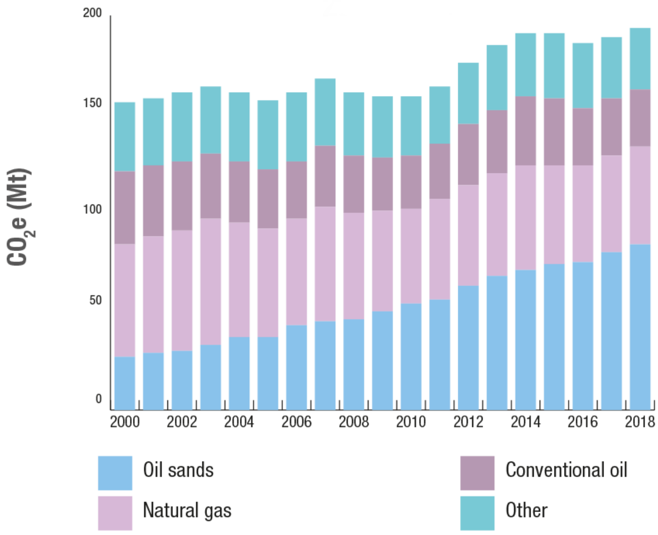
[11] Natural Resources Canada (2020). 'Energy and Greenhouse Gas Emissions', 6 October, https://www.nrcan.gc.ca/science-and-data/data-and-analysis/energy-data-and-analysis/energy-facts/energy-and-greenhouse-gas-emissions-ghgs/20063 (accessed 10 July 2021).

Figure 4: Canadian oilsands emissions intensity (2000-2018)



Note: Unit is kilograms of CO_2 equivalent per barrel of synthetic crude oil and bitumen.
Source: Natural Resources Canada.

Figure 5: Canadian oil and gas sector emissions (2000-2018)



Source: Natural Resources Canada.

This has led to accusations of hypocrisy from environmental groups[12] and a significant socio-political debate about the sustainability of a sector that is challenging to decarbonize. Oil and gas firms, under pressure, initially focused on setting targets that aligned with the Canadian target of a 30 per cent emissions reduction from 2005 levels by 2030. However, critics pointed out that this commitment only covered Scope 1 and 2 emissions. With over 75 per cent of emissions occurring in end-use combustion (Scope 3), it was felt that these firms should make deeper cuts to their direct emissions for a larger

[12] Dyer, Evan (2021). 'Ottawa's promising a tax credit for carbon capture – but is the tech worth the money?', *CBC News*, 28 April, https://www.cbc.ca/news/politics/carbon-capture-storage-fossil-fuel-climate-change-2021-budget-1.6003427 (accessed 25 July 2021).

impact on overall sector emissions.[13] The Canadian government has since announced that it is targeting a 40-45 per cent decrease in national GHG emissions from 2005 levels by 2030.[14]

Economically, oil and gas firms have faced the same challenges as global peers since the oil price collapse in 2014, with volatile earnings and increasing debt levels.[15] The COVID-19 pandemic exacerbated the situation, just when a modest recovery appeared to be taking root. Unlike its peers, however, the Canadian resource sector has seen a mass exodus of international firms and a continual decline in foreign investment.[16] Sector heavyweights – including Royal Dutch Shell, Total, Chevron, Statoil (now Equinor), and Devon Energy – divested or wrote off most of their oilsands assets and reduced operating shares in the few partnerships that remained.[17] Initially, this appeared to be a strictly financial decision linked to the higher cost of operating in the oilsands and the need to rebuild cash reserves. Some even billed this development as a victory of sorts for Canadian firms, with the likes of Suncor Energy, CNRL, and Cenovus Energy increasing their asset base significantly.[18] It has become clear that prior to some of these decisions, concerns were expressed by shareholders about the wisdom of investing in the energy-intensive oilsands, given corporate emissions reduction targets.[19]

These ESG-related concerns have also been at the heart of decisions made by banks and investment funds to stop investing in, or lending money to, firms that operate in the oilsands. In 2020 Norges Bank, the world's largest sovereign wealth fund, announced that it was delisting from its portfolio the four largest Canadian producers – Suncor, CNRL, Imperial Oil, and Cenovus – because of high GHG emissions.[20] Tight takeaway space and lower forecasted demand for global crude, including Canadian oilsands, indicate that large oilsands projects are unlikely to be constructed in the future. However, with a long-lived asset base and significant infrastructure, capital needs to be expended to sustain operations. Several firms have solved this problem over the last few years by utilizing free cash flow from operations and taking on increased debt. This is unlikely to be a sustainable approach, particularly when it results in dividend cuts and declining share prices. A stronger statement of intent from an ESG perspective is likely to be the only way to bring investors back on board.

End-use industries: No longer under the radar

Most of the focus on reducing industrial emissions in Canada has been on the production and refining of oilsands, and methane leakage during natural gas extraction. Other industrial sectors considered difficult to decarbonize were often ignored, primarily because their visibility and market impact pale in comparison to oil and gas. Their emissions impact is nonetheless significant, with electricity generation

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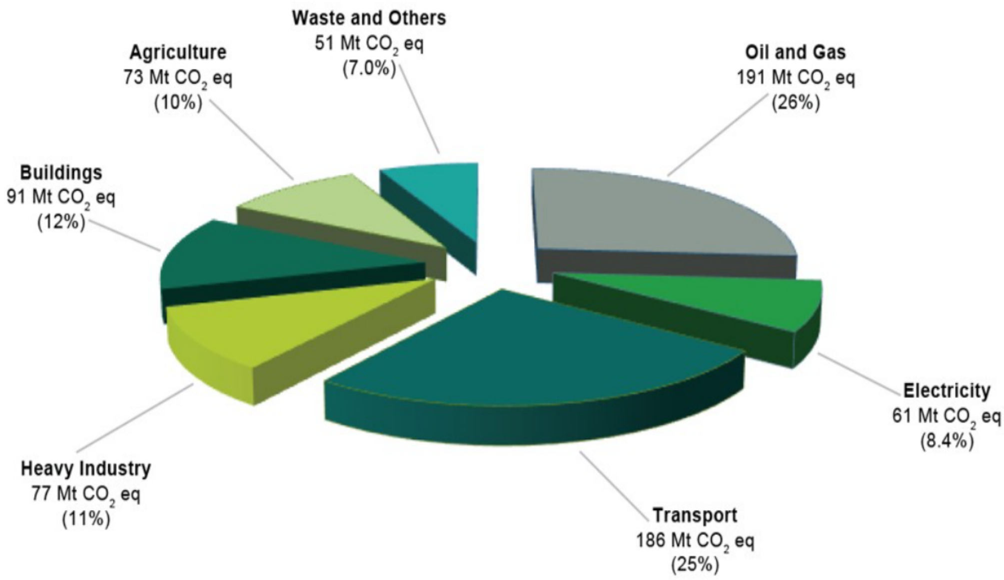
[13] Israel, Benjamin (2020). 'Evaluating the climate ambitions of Canadian oil companies', Pembina Institute, 18 November, https://www.pembina.org/blog/climate-ambitions-canadian-oil, (accessed 28 July 2021).
[14] Gilmore, Rachel (2021), 'Canada has upped its emissions reductions target. How do we achieve it?', *Global News*, 22 April, https://globalnews.ca/news/7780966/climate-change-emissions-reduction-45-2030-canada/ (accessed 10 July 2021).
[15] Ihejirika, Nnaziri (2021). 'Canada's carbon tax hike and strategic implications for oil and gas firms', *OIES Energy Insight*, No. 83, February, Oxford Institute for Energy Studies, Oxford.
[16] Deveau, Scott (2017). 'Mergers, acquisitions hit decade-high as foreign owners flee oilsands', *Calgary Herald*, 27 June, https://calgaryherald.com/business/energy/mergers-acquisitions-hit-decade-high-as-foreign-owners-flee-oilsands (accessed 22 December 2020).
[17] Herron, James (2020). 'Total takes US$7-billion write down on oilsands projects', *Financial Post*, 30 July, https://financialpost.com/commodities/energy/total-takes-8-1-billion-writedown-as-pandemic-devalues-oil-gas (accessed 1 February 2021).
[18] Deveau, Scott (2017). 'Mergers, acquisitions hit decade-high as foreign owners flee oilsands', *Calgary Herald*, 27 June, https://calgaryherald.com/business/energy/mergers-acquisitions-hit-decade-high-as-foreign-owners-flee-oilsands (accessed 22 December 2020).
[19] Healing, Dan (2020). 'Total writes off $9.3B in oilsands assets, cancels CAPP membership', *Global News*, 29 July, https://globalnews.ca/news/7233046/total-writes-off-oilsands-assets-alberta-capp (accessed 3 July 2021).
[20] Saldanha, Ruth (2020). 'Canadian energy hits an ESG roadblock', *Morningstar*, 19 May, https://www.morningstar.ca/ca/news/202403/canadian-energy-hits-an-esg-roadblock.aspx (accessed 22 July 2021).

and heavy industry contributing 138 $MtCO_2e$, or 18 per cent of all Canadian emissions, in 2019 as shown in Figure 6.

Figure 6: Breakdown of Canadian emissions by sector (2019)



Source: Government of Canada.

Renewable energy technologies are not considered fit for purpose in heavy industry – the temperatures and pressures required to produce fertilizer, concrete, and lubricants call for thermal combustion. Energy efficiency and the development of alternative materials have long been considered the best ways to decarbonize these industries. Energy efficiency is effective – the IEA estimates that 39 per cent of emissions reduction will come from improved efficiency[21] – but any decline in OECD countries is likely to be offset by increased consumption in emerging economies. Alternative materials have been proposed, and some are in development, but there are no commercial alternatives to fertilizers, lubricants, and concrete that are produced at scale and readily acceptable. The emergence of CCUS is attractive to these industries, with some in the cement industry estimating that the combination of carbon capture at the calcination kilns and DACCS for storage in concrete could result in up to 65 per cent emissions reduction.[22] Combined with research that suggests concrete embedded with CO_2 has stronger mechanical properties, material efficiencies could result in close to carbon-neutral concrete in the future.[23]

Electricity generation – primarily from natural gas – faces the same challenges as oilsands extraction and refining. While natural gas is still considered a bridge fuel to enable the energy transition, it is likely to face the scrutiny that coal has undergone over the last two decades. Utilities making investment decisions on natural gas-fired plants are looking at CCUS as an option not only to maintain investor and public support in the short term, but also to secure long-term viability and economic value.

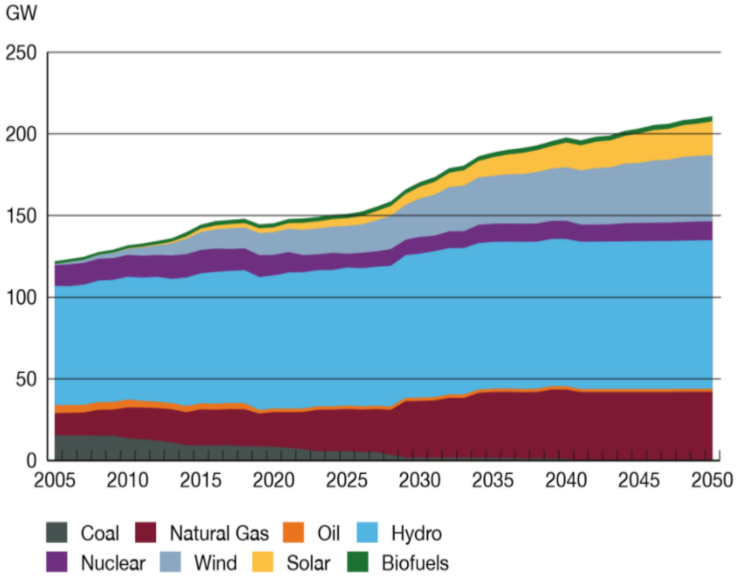
[21] IEA (2019). *The Role of CO_2 Storage*, IEA, Paris, https://www.iea.org/reports/the-role-of-co2-storage (accessed 10 July 2021).
[22] Pennsylvania Aggregates and Concrete Association (2020), 'Concrete's role in Carbon Capture, Utilization and Storage (CCUS)', *Specify Concrete*, 1 October, https://www.specifyconcrete.org/blog/concretes-role-in-carbon-capture-utilization-and-storage-ccus (accessed 3 July 2021).
[23] Ibid.

4. CCUS in Canada: Recent developments

The release of the Canadian government's hydrogen strategy report in 2020 unleashed a spate of frenetic activity among players in the energy extraction and end-use sectors. While carbon-negative green hydrogen – produced by combining hydrolysis with processes like BECCS or electrolysis offset by DACCS – is the end state in Canada's journey to net zero by 2050, there is pragmatism in the desire to leverage current grey hydrogen production in heavy industry and the expertise that comes with it. Combining current hydrogen production with CCUS technologies is expected to reduce upstream oil and gas emissions by as much as 50 per cent[24] and emissions from secondary heavy industry by up to 90 per cent. Given the relatively high proportion of energy extraction, utility, and heavy industry sector emissions in the Canadian total, CCUS has the potential to set Canada well on its way to meeting its Paris climate targets. The resultant blue hydrogen is touted as a low-emission source of energy in Canada that can accelerate the commercialization of fuel-cell vehicles, be blended into natural gas for heat and power, and spur increased economic activity in the manufacturing and chemical sectors.

It is also expected that the expertise and cost learning from producing blue hydrogen, as well as knowledge transfer, will be used to drive development in green hydrogen.[25] Realistically, DACCS applications are well behind CCUS in scale and cost. The largest electrolyser being developed for green hydrogen production by Air Liquide has a capacity of 20 megawatts (MW), compared with the installed capacity of gas turbine generators often exceeding 500 MW at a single utility plant. Canada itself has an installed natural gas power generation capacity of over 25 gigawatts (GW).[26] Natural gas is expected to remain an important part of the electricity generation mix, potentially growing to over 40 GW of installed capacity by 2050 (see Figure 7).

Figure 7: Canada's generation capacity forecast to 2050



Source: Canada Energy Regulator (2020). *Canada's Energy Future 2020*, 2 December, https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2020/index.html (accessed 3 July 2021).

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[24] Kilpatrick, Ryan, Adam Goehner, Eli Angen, Matt McCulloch, and Duncan Kenyon (2014). 'CCS Potential in the Oilsands', report prepared by Pembina Institute for Government of Alberta, Alberta Innovates, Energy and Environmental Solutions, and Climate Change Emissions Management Corporation, https://eralberta.ca/wp-content/uploads/2017/05/2029-Pembina-CCS-Potential-in-the-Oilsands.pdf.

[25] Natural Resources Canada (2020). *Hydrogen Strategy for Canada*, December 2020, Government of Canada.

[26] Canada Energy Regulator (2020). *Canada's Energy Future 2020*, 2 December, https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2020/index.html (accessed 3 July 2021).

In its 2021 federal budget, the Canadian government promised C$319 million in credits over seven years for the development and commercialization of CCUS, and an additional C$5 billion over seven years in funding for a Net Zero Accelerator initiative focused on decarbonizing heavy industry. These amounts would support CCUS advancements, but specifically exclude projects where captured CO_2 is utilized for EOR.[27] With the budget announcement, the government also announced the start of a 90-day consultation period, during which it would work with stakeholders to design an investment tax credit to stimulate CCUS development activity.[28] The government has announced that the credit will be applicable to DACCS and CCUS projects across various industries, but is not intended to be used for CCUS projects where the sequestered carbon is used for EOR. In this regard, the credit is likely to differ from the Section 45Q production tax credit that has been implemented in the United States for CCUS projects, where a reduced credit is provided for CCUS projects used for EOR.[29]

To coincide with the start of the government's consultation period, several projects were announced for the production of hydrogen from decarbonized natural gas, the transport of CO_2 for sequestration, alongside promises of future green hydrogen projects. Given the scale of the projects and partnerships involved, it is clear that firms were waiting for the government to signal a commitment to CCUS funding and investment support. Newly announced projects are highlighted in Tables 1 and 2.

Table 1: Proposed blue hydrogen projects in Canada

Project	Partners	Location	Carbon capture	Start date
Blue hydrogen plant	Air Products, Alberta and Canadian governments	Edmonton, AB	3 Mt/year	2024
Polaris Phase 1 (blue hydrogen)	Shell Canada	Fort Saskatchewan, AB	0.75Mt/year	2025
Blue hydrogen plant	Suncor and ATCO	Edmonton, AB	2 Mt/year	2028

Sources: Corporate announcements.

Table 2: Proposed CO_2 pipelines in Canada

Project	Partners	Hub	Capacity	Start Date
Alberta Carbon Grid	TC Energy and Pembina Pipeline	Fort Saskatchewan, AB	20 Mt/year	2025
CO2 Trunkline	Cenovus, CNRL, Imperial, MEG and Suncor	Cold Lake, AB	40 Mt/year	TBA

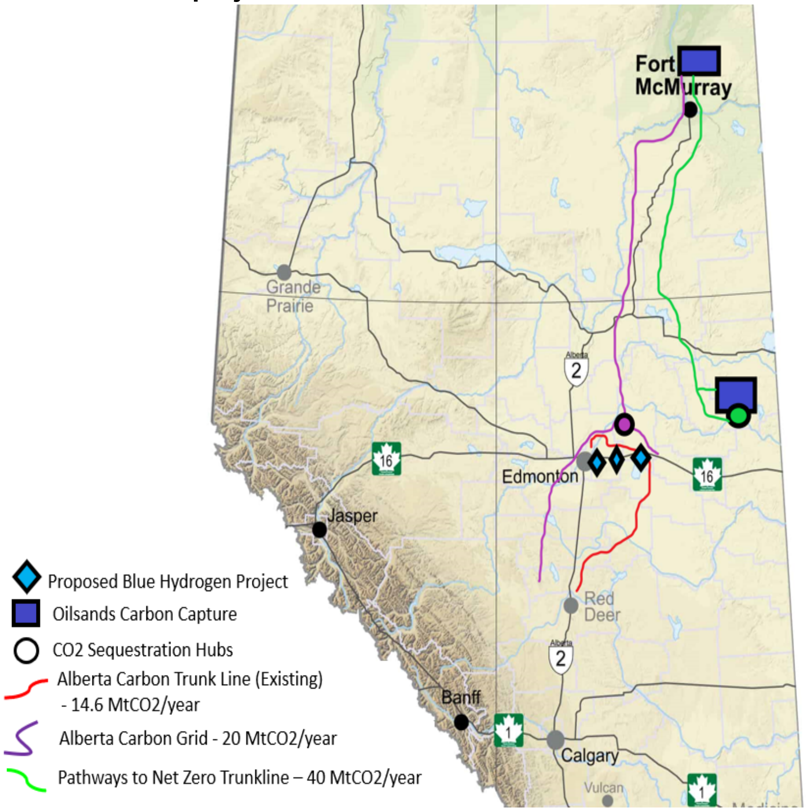
Sources: Corporate announcements.

The most important of these announcements was the alliance of the five largest oilsands-based energy firms to form the Oilsands Pathways to Net Zero Initiative.[30] Together, these firms – Cenovus, CNRL, Imperial, MEG Energy, and Suncor – control over 90 per cent of Canada's oilsands production. While they have previously demonstrated a willingness to collaborate, as seen in the technology-driven Canada's Oilsands Innovation Alliance (COSIA), this would mark the first time that they all partner to deliver major projects of this size and scale. If all the announced blue hydrogen projects are sanctioned,

[27] Yedlin, Deborah (2021). 'On carbon capture, federal budget delivers promise, if not funds', *CBC News*, 20 April, https://www.cbc.ca/news/canada/calgary/road-ahead-carbon-capture-storage-federal-budget-yedlin-1.5994628 (accessed 2 July 2021).
[28] Kuski, Deron, Jodi Wildeman, Andrew Konopelny and Bennet Misskey (2021). 'Carbon capture tax credit consultation process underway', MLT Aikins, 26 May, https://www.mltaikins.com/energy/carbon-capture-tax-credit-consultation-process-underway/?utm_source=Mondaq&utm_medium=syndication&utm_campaign=LinkedIn-integration (accessed 7 June 2021).
[29] Ibid.
[30] Imperial Oil Canada (2021). 'Canada's largest oil sands producers announce unprecedented alliance to achieve net zero greenhouse gas emissions', 9 June, https://news.imperialoil.ca/news-releases/news-releases/2021/Canadas-largest-oil-sands-producers-announce-unprecedented-alliance-to-achieve-net-zero-greenhouse-gas-emissions/default.aspx (accessed 2 July 2021).

Canada's CO_2 capture capacity would increase from 7 $MtCO_2$/year to nearly 13 $MtCO_2$/year by 2028. The capacity of the proposed Fort McMurray–Cold Lake CO2 trunkline was not disclosed at the time of the Pathways to Net Zero coalition announcement, but it has been reported to be up to 40 MtCO2/year.31 Combined with the TC Energy/Pembina CO2 pipeline, this would significantly increase takeaway space for captured carbon from the current 14.6 MtCO2/year to 74 MtCO2/year by the end of this decade.32 Significantly, all these projects are planned for Alberta, currently home to facilities that are responsible for about 194 MtCO2e of industrial emissions annually, or 25 per cent of Canada's total. Figure 8 shows the newly announced blue hydrogen projects and the capacity of the new and existing CO2 pipelines. The location of the projects and the volume of spare capacity provide an incentive for several more industrial-based CCUS projects to be announced in Alberta. There is also the potential to stimulate DACC development, with the ready availability of takeaway space further improving project economics.

Figure 8: Proposed CO_2-based projects in Alberta



Source: Author's rendering based on corporate announcements.

It is important to note that these projects are not just about removing carbon and storing it in an underground reservoir. A key plank of the business case being made by these firms is the importance of rebuilding the Alberta economy and sustaining the contribution of the oil and gas industry to the

[31] Smith, Sheldon (2021). 'MEG Energy making contribution to the Pathways to Net Zero Initiative', *BOE Report*, 15 July, https://boereport.com/2021/07/15/meg-energy-making-contribution-to-the-pathways-to-net-zero-initiative/ (accessed 17 July 2021).

[32] TC Energy (2021). 'Pembina and TC Energy partner to create world-scale carbon transportation and sequestration solution: The Alberta Carbon Grid', 17 June, https://www.tcenergy.com/announcements/2021-06-17-pembina-and-tc-energy-partner-to-create-world-scale-carbon-transportation-and-sequestration-solution--the-alberta-carbon-grid (accessed 16 July 2021).

Canadian economy, estimated at C$3 trillion over the next 30 years.[33] These projects could also address three of the main issues affecting the oil and gas industry in Canada today – creating local demand for excess natural gas production given challenges with LNG project delivery, attracting investment into the sector, and maintaining its social licence to operate, including the opportunity to engage Indigenous and environmental protection groups meaningfully and proactively. That the projects are 'Made in Canada' and build on Canadian expertise in the CCUS space is also encouraging, at a time when there is significant uncertainty about the future of fossil fuel extraction and Canada's approach to decarbonization.

5. Is CCUS too good to be true?

While the governments of Canada and Alberta joined the CEOs of the Pathways to Net Zero initiative in releasing optimistic statements, the tone struck outside those official communiqués has been more moderate.[34] This is because there are several challenges that must be overcome, or at least be mitigated, for these projects to see the light of day and be profitable. These challenges run the gamut of financing, technology choice, carbon pricing, and other regulatory frameworks, Indigenous support and, finally, social acceptance.

Financing

There is broad acknowledgement of the role to be played by CCUS in significantly reducing emissions in industries that are hard to decarbonize. But there has been a hesitancy – particularly from oil and gas firms – to invest heavily in the technology. This is due to the belief that CCUS alone is not profitable, since it does not add reserves or increase the netback on a barrel of oil, two key balance sheet metrics for oil and gas firms. The Quest project cost C$1.35 billion, with up to C$865 million financed by the government for an estimated all-in cost of around C$80/t$CO_2$e. Given that the CO_2 stream from Quest is relatively pure, that would translate into much higher carbon capture costs for industries with less pure streams, such as the steel and cement industries. Beyond Quest, most carbon capture and storage (CCS) and CCUS projects in the oil and gas sector are small scale and primarily targeted at EOR, where the CCUS pays for itself by delivering near-zero-cost oil that would not otherwise be extracted. EOR is largely restricted to facilities that can be connected to depleted wells, making it unattractive to oilsands miners as well as to most refineries. Integrated projects like the ACTL, which delivers waste CO_2 streams from a fertilizer plant and upgrader/refinery to ageing reservoirs in central and southern Alberta, are an option. However, the likely exclusion of EOR as a designated use of captured CO_2 under the government's investment scheme means that most new projects will be based on sequestration or carbon utilization. This will be enabled by the significant cost learning that has occurred since Quest, which it is estimated would cost 30 per cent less if built today.[35] This cost learning is reflected in the comparison of estimated capital costs for existing and proposed projects, with a sharp decrease between Boundary Dam and Quest on the one hand, and the ACTL and Polaris on the other (see Figure 9). The Sturgeon refinery was built with CCUS technology incorporated, and those capital costs are not included in the ACTL costs shown; however the entire ACTL system captures, transports, and stores carbon at a lower cost than Quest.

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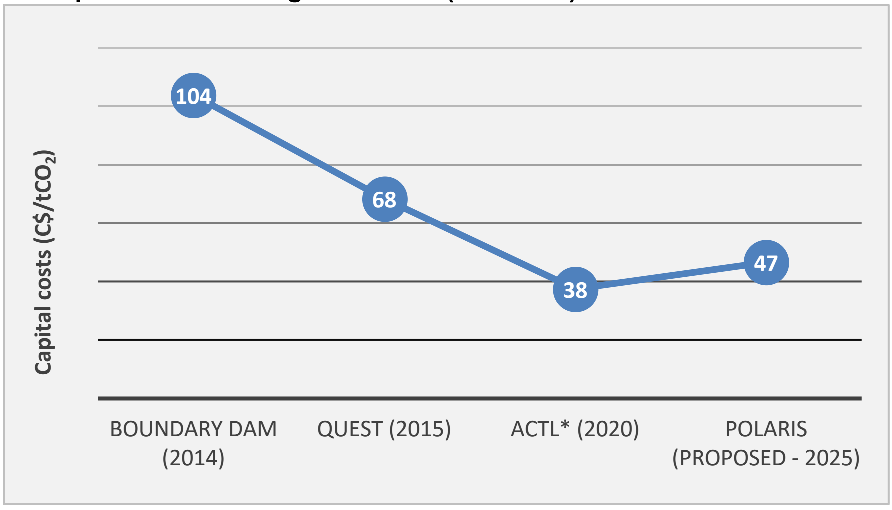
[33] Imperial Oil Canada (2021). 'Canada's largest oil sands producers announce unprecedented alliance to achieve net zero greenhouse gas emissions', 9 June, https://news.imperialoil.ca/news-releases/news-releases/2021/Canadas-largest-oil-sands-producers-announce-unprecedented-alliance-to-achieve-net-zero-greenhouse-gas-emissions/default.aspx (accessed 2 July 2021).

[34] Tuttle, Robert (2021). 'Net-zero emissions from oil sands to cost $60B, say Cenovus, Suncor CEOs', *World Oil Magazine*, 8 July, https://www.worldoil.com/news/2021/7/8/net-zero-emissions-from-oil-sands-to-cost-60b-say-cenovus-suncor-ceos (accessed 17 July 2021).

[35] Bakx, Kyle (2021). 'Shell unveils new carbon capture project amid wave of new CCS proposals in Alberta'," *CBC News*, 13 July, https://www.cbc.ca/news/business/shell-carbon-capture-alberta-government-1.6099797 (accessed 14 July 2021).

Figure 9: CCUS capital cost learning in Canada (C$/t$CO_2$e)



Source: Author calculations, assuming 20-year asset life and design capture rates.

Combined with the price of carbon increasing yearly to C$170/t$CO_2$e in 2030, there is optimism that more of these projects can be built, with better economics.

Technological scope

Carbon capture is often interpreted to be a single type of technology, but in reality is a catch-all for several types of technologies that perform the same function. The most common technologies include the use of chemical or physical solvents, solid adsorbents, membrane separation, oxy-fuel separation, chemical looping, and physical separation.[36] There are also choices to be made about whether the carbon should be captured pre-combustion or post-combustion, while the use of oxy-fuel separation typically involves the addition of nearly pure oxygen to the process.[37] It is generally accepted that retrofitting existing facilities with pre-combustion carbon capture is more challenging, thus most CCS projects implemented at existing facilities in Canada are fitted with post-combustion technology. Sturgeon refinery, which was built with the ACTL in mind, utilizes pre-combustion gasification.[38] Svante, the carbon capture start-up firm that has received investment from both Suncor and Cenovus, utilizes a solid adsorbent for capture and appears to be designed for post-combustion capture.[39]

New facilities are almost certain to be designed with pre-combustion or oxy-fuel combustion in mind, especially since the CO_2 content in the process is higher at those stages and thus easier to separate out. However, firms looking at retrofitting existing facilities are most likely to opt for post-combustion. Even then, there are processes which, while theoretically possible to fit with carbon capture, are unlikely to be realized. This includes fired heaters in fuel refining, where the low CO_2 content post-combustion and the fact that carbon removal is relatively limited combine to make it impractical. While CCUS can be applied broadly, the limitations created by these choices of process and stage are a potential

[36] IEA (2020). *Energy Technology Perspectives 2020 – CCUS in Clean Energy Transitions*, IEA, Paris, https://iea.blob.core.windows.net/assets/181b48b4-323f-454d-96fb-0bb1889d96a9/CCUS_in_clean_energy_transitions.pdf, (accessed 18 July 2021).

[37] Natural Resources Canada (2016). *CO_2 Capture Pathways*, 5 January, https://www.nrcan.gc.ca/energy/energy-sources-distribution/coal-and-co2-capture-storage/carbon-capture-storage/co2-capture-pathways/4289 (accessed 17 July 2021).

[38] Northwest Redwater Partnership (2021). *Carbon Capture and Storage*, https://nwrsturgeonrefinery.com/project/carbon-capture-and-storage/ (accessed 14 July 2021).

[39] Svante (2021). *Our Innovative Carbon Capture Technology*, https://svanteinc.com/carbon-capture-technology/ (accessed 14 July 2021).

challenge for firms already feeling pressure to make the right call on this strategic direction. This is also why the maximum penetration of CCUS in the oil and gas sector is expected to be around 50 per cent despite the technology removing up to 90 per cent of the CO_2 emissions in the processes fitted with it.

Regulatory support

The Canadian government has put a high-level framework in place for the broad adoption of CCUS. The carbon price hike, the clean fuel standard, and the hydrogen strategy have sent a clear message about where industry's attention should be directed. However, there are concerns that these policies are aspirational, and are not backed by enabling support or practical targets. The lack of regulatory support for EOR-based carbon capture projects increases the risk that potential investment will be diverted to the United States, with the 45Q regulation there considered to be a more practical and business-friendly approach. It should also be pointed out that the Canadian Conservative party has announced plans to roll back the GHGPPA if elected,[40] while other political parties have proposals that may result in a higher carbon price. There is a risk that firms invest significant amounts in CCUS, only for the goalposts to shift or for the government to focus on DACCS or BECCS at the expense of carbon capture from industry. To counter this, firms are seeking guarantees in the form of credits and grants from the government before proceeding with investment decisions.[41] There is a significant financial benefit to having this support, but that may not be the main benefit. The ACTL was built with less than 50 per cent government backing, and almost all that funding was for the expansion of the line beyond its original capacity.[42] For larger firms, it has been shown that the economics behind CCS already exist under the GHGPPA, even if it is simply as a carbon cost mitigation tool. It is likely that the main reason behind the push for federal financing is to bind the government to the policies that it has announced and ensure project certainty into the future. Such support can also reduce the cost of entry for other small and medium-sized industrial firms that would otherwise have no way to transport and sequester emissions, even if they could afford to capture them. A carbon price on its own does not guarantee that such firms implement CCUS without the guarantee that the captured emissions can be taken off their hands.

Social and environmental acceptance

Amidst the positive statements from industry and the government on the announcement of each CCUS project comes a steady thread of concerns expressed by citizen and environmental groups. These concerns appear to centre on the fear that CCUS funding takes away from support that should go to renewable energy deployment, especially with the apparent focus on blue hydrogen over green hydrogen in the short to medium term. Some researchers have also suggested that blue hydrogen is more detrimental than natural gas from an emissions standpoint.[43] This view appears to be based on the belief that the former can fully displace the latter in the energy value chain, which is unlikely. Such analyses often assume high CO_2 leakage rates, higher actual fugitive emission rates than from increased natural gas production and lower than advertised carbon capture rates. Canadian CCUS projects have demonstrated that all three challenges can be met with the right technological and financial input. However, since Scope 3 emissions constitute the vast majority of WTW emissions in the transport sector, there are those who insist that the only meaningful emissions reduction in this sector will come from significant declines in the use of fossil fuels. Similar to how energy efficiency did not significantly alter overall emissions in the resource extraction sector, there are worries that the success

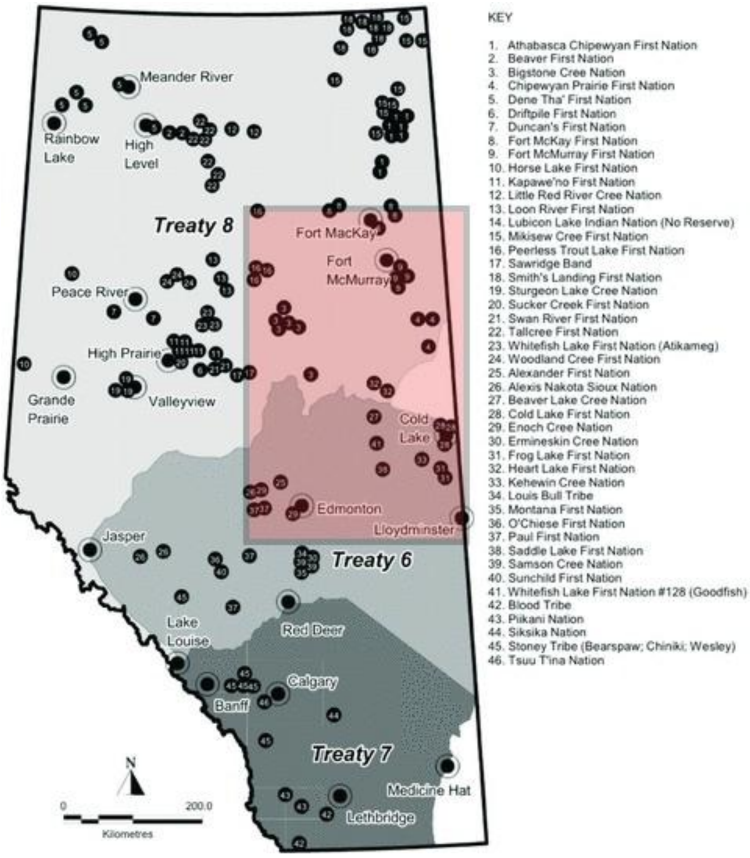
[40] The Greenhouse Gas Pollution Pricing Act is a Canadian federal law establishing a set of minimum national standards for carbon pricing to meet emission reduction targets under the Paris Agreement.
[41] Maier, Stewart, and George Hua (2021). 'Alberta carbon sequestration tenure and CCUS developments', 19 May, https://www.dentons.com/en/insights/articles/2021/may/18/alberta-carbon-sequestration-tenure-and-ccus-developments (accessed 2 July 2021).
[42] Author interview with Ian MacGregor, Co-Founder of the ACTL.
[43] Howarth, Robert W., and Mark Z. Jacobson (2021). 'How green is blue hydrogen?'. *Energy Science & Engineering.*

of CCUS could lead to an increase in the consumption of oil and gas. The recently announced plan to eliminate the sale of new fossil fuel-powered vehicles in Canada after 2035 may allay some of those concerns,[44] but this resistance is one that is likely to continue until there is a meaningful reduction in Canadian GHG emissions.

Indigenous support

Like the regulatory environment, the requirement for meaningful Indigenous engagement has increased exponentially in Canada over the past decade. Article 32 of the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) explicitly requires free, prior, and informed consent for projects and initiatives that occur on Indigenous land. Buttressing that, Canada's Indigenous Truth and Reconciliation Commission released a call to action, which requires corporate partners to ensure constant consultation and ensure sustainable benefits accrue to the community.

Figure 10: Numbered Treaty regions in Alberta



Notes: In Western Canada the Numbered Treaties 1 to 11 are a series of post-Confederation treaties made during 1871-1921 between First Nations peoples and the Crown (Canada). The red box represents Indigenous communities on whose lands proposed CCUS projects will be sited.
Source: Aboriginal Affairs and Northern Development Canada.

Some Indigenous communities are exploring nature-based carbon capture solutions, relying on Canada's vast forests, which are some of the largest carbon sinks in the world. There is an opportunity

[44] Scherer, Steve (2021). 'Canada to ban sale of new fuel-powered cars and light trucks from 2035', *Reuters*, 29 June, https://www.reuters.com/world/americas/canada-ban-sale-new-fuel-powered-cars-light-trucks-2035-2021-06-29/ (accessed 10 July 2021).

for both Indigenous and corporate collaborations on carbon capture. Nature-based (non-CCUS) developments could provide a carbon offset mechanism in which carbon credits are preferentially purchased by heavy industry, contributing towards the restoration of the natural environment.[45] In parallel, as CCUS projects go from concept selection to development, construction, and operation, the relationships that have been built with Indigenous groups will be critical.[46] As seen with the Keystone and TransMountain pipelines, lack of engagement and community support can derail projects and result in significant financial losses.[47]

Figure 10 shows the many Indigenous groups in Alberta in the industrial belt where these new CCUS and blue hydrogen projects will be located. Their support will be particularly important for the construction of new CO_2 and hydrogen pipelines, or the retrofitting of existing natural gas pipelines to carry either hydrogen or a blend of natural gas and hydrogen.

6. Industrial decarbonization using CCUS: A strategic opportunity

Despite these challenges, there is significant energy and momentum behind CCUS in Canada. The experience that Canadian oil and gas firms have gained from using technology to unlock unconventional and costly resources in harsh environments is driving a high degree of confidence in the widespread operational deployment of CCUS. However, it should be noted that the business and social implications are different this time. CCUS does not add economic value to oil and gas firms without a continuing market for the commodities they produce. This does not apply to the same degree to the steel, concrete, and chemical industries; but it highlights a major challenge for the firms that have committed to CCUS development. There is an imperative to maintain their social licence – and attractiveness to potential investors – by progressing as many emission reduction pathways as possible. This also helps cover off the possibility that one or more pathways end up not being profitable. A strategic overview of the sequential strategies industrial emitters can deploy over the next decade has been developed and is shown in Figure 11.

The IEA estimates that CCUS can effectively decarbonize 13 per cent of global emissions under its Clean Technology Scenario.[48] In Canada that proportion is higher, given the significance of the country's resource extraction industry not only to the country's economy, but also to its emissions profile. For example, by installing CCUS scrubbers at cogeneration boilers, upgraders, and hydrogen plants, up to 50 per cent of all upstream lifecycle emissions in the oilsands can be removed assuming moderate penetration (50 per cent) of the technology.[49] This would represent about 13 per cent of all WTW emissions associated with the combustion of fossil fuels. In other chemical and heavy manufacturing sectors, capture rates could average 15-35 per cent of total emissions. Blending blue hydrogen into natural gas would also support further decarbonization of the power sector. Figure 12

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[45] Nitah, Steven, and Mary-Kate Craig (2020). 'Indigenous-led nature based greenhouse gas offsets: One route towards reconciliation in Canada', Conservation through Reconciliation Partnership, 8 July. https://conservation-reconciliation.ca/crp-blog/indigenous-led-nature-based-greenhouse-gas-offset-one-route-towards-reconciliation-in-canada (accessed 2 July 2021).
[46] Townsend, Justine, and Mary-Kate Craig (2020). 'Nature-based solutions: Indigenous-led conservation and carbon storage in Canada', Conservation Through Reconciliation Partnership, https://metcalffoundation.com/site/uploads/2020/02/CRP_Indig_NatureBasedSolutions_2020Report_final.pdf.
[47] Williams, Nia, and Shariq Khan (2021). 'TC Energy posts C$1 bln quarterly loss on Keystone XL suspension', *Reuters*, 7 May, https://www.reuters.com/world/americas/tc-energy-posts-c1-billion-quarterly-loss-keystone-xl-suspension-2021-05-07/ (accessed 2 July 2021).
[48] IEA (2019). *The Role of CO_2 Storage*, IEA, Paris, https://www.iea.org/reports/the-role-of-co2-storage (accessed 10 July 2021).
[49] Kilpatrick, Ryan, Adam Goehner, Eli Angen, Matt McCulloch, and Duncan Kenyon (2014). 'CCS Potential in the Oilsands', report prepared by Pembina Institute for Government of Alberta, Alberta Innovates, Energy and Environmental Solutions, and Climate Change Emissions Management Corporation, https://eralberta.ca/wp-content/uploads/2017/05/2029-Pembina-CCS-Potential-in-the-Oilsands.pdf.

highlights the potential impact of CCUS in helping Canada reach its stated emissions reduction target by 2030.

Figure 11: Sequential strategies for CCUS adoption in heavy industry

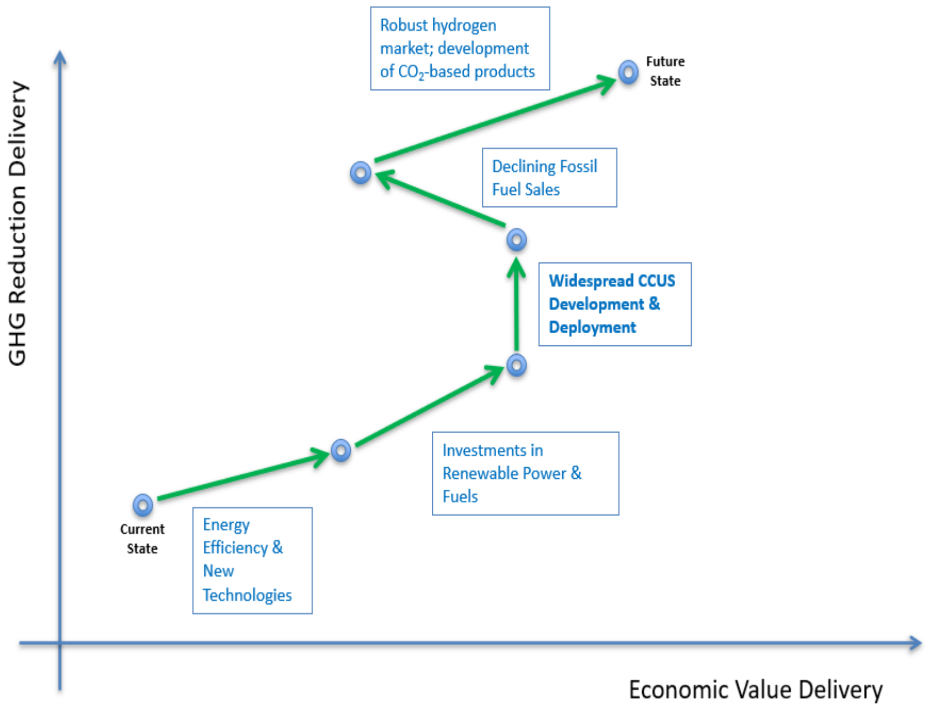
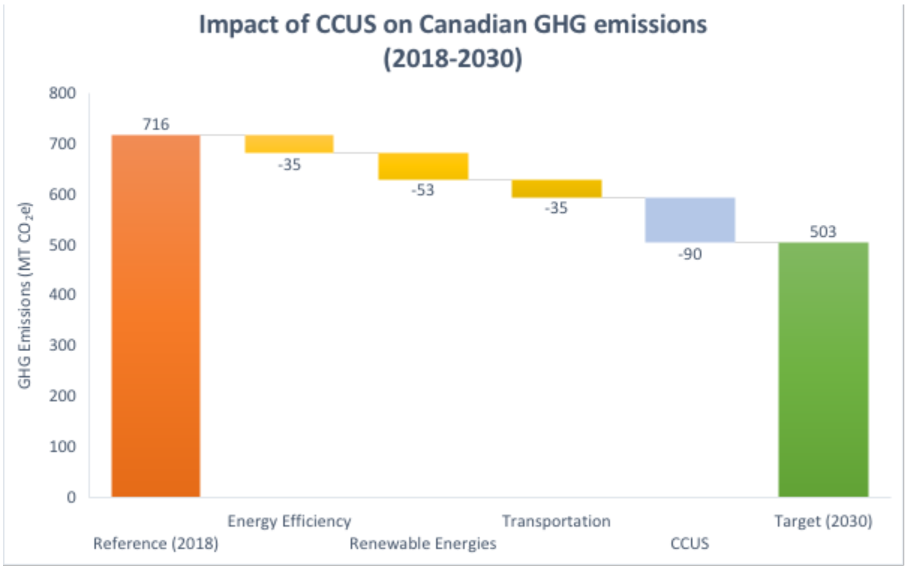


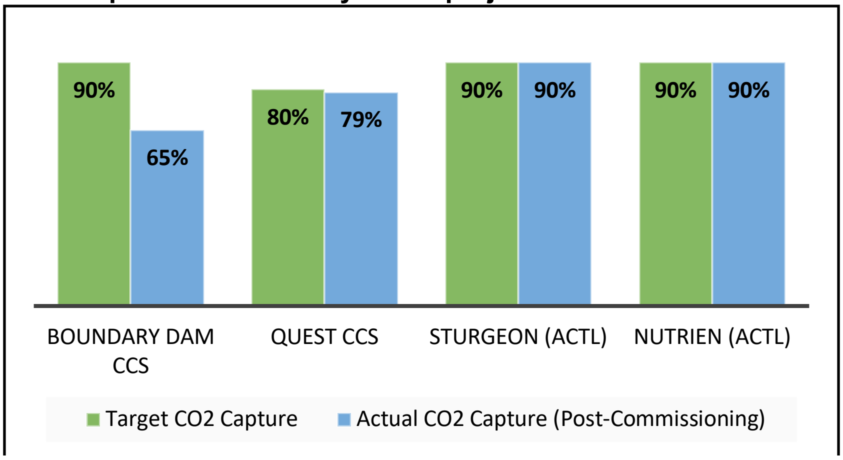
Figure 12: Potential impact of CCUS on Canadian GHG emission reductions (2018-2030)



Sources: Author calculations, based on several Canadian government reports.

There is some scepticism about whether the high capture rates quoted by industry can be achieved, especially after significant project delivery and operational failures in some jurisdictions.[50] The challenges associated with Chevron's Gorgon project in Australia highlight the importance of selecting the right geography and identifying the right capture technology. The operational performance of the three world-class CCUS projects in Canada, relative to the original design, can be seen in Figure 13.

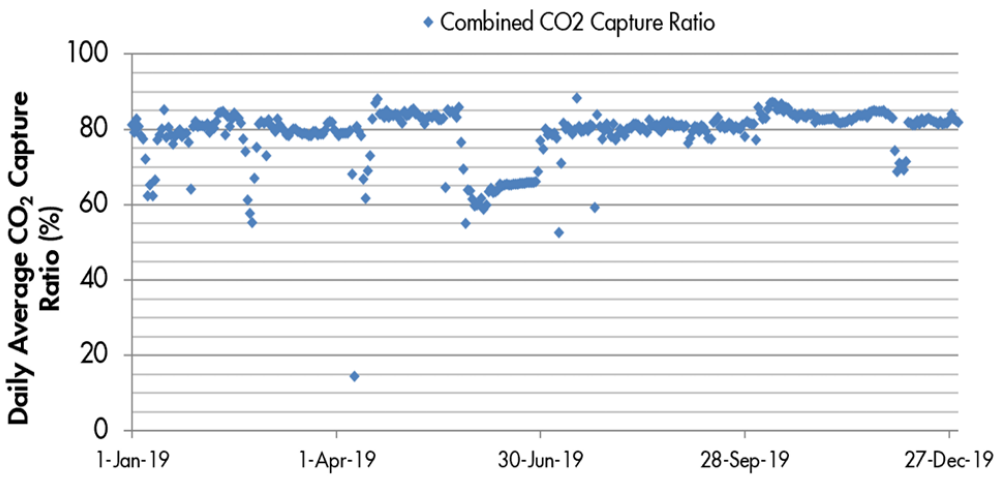
Figure 13: Operational performance of key CCUS projects in Canada



Source: Author calculations based on captured emissions at various facilities.

The Boundary Dam project has only captured about 65 per cent of recoverable CO_2 since its 2014 commissioning, compared to a target of 90 per cent. SaskPower, the operator, has put this down to equipment reliability and larger than expected downtimes rather than the technology. Recent operational improvements appear to have resulted in higher capture rates, closer to target. The other two facilities appear to be performing in line with their design, Figure 14 highlighting the relatively high degree of carbon capture consistency at the Quest facility.

Figure 14: Quest CCUS project performance (2019)



Source: Shell Canada.

[50] Morton, Adam (2021). '"A shocking failure": Chevron criticised for missing carbon capture target at WA gas project', *The Guardian*, 19 July, https://www.theguardian.com/environment/2021/jul/20/a-shocking-failure-chevron-criticised-for-missing-carbon-capture-target-at-wa-gas-project (accessed 25 July 2021).

The performance of Quest and the ACTL, the two heavy industry and/or oilsands-based projects, demonstrates that operational execution is unlikely to be an issue if the major CCUS projects currently under development in Canada are sanctioned.

For firms, CCUS adoption in heavy industry will enable two energy transition pathways – one focused on emissions reduction and the other focused on profitability. To reduce emissions, firms will utilize carbon capture to reduce total Scope 1 and 2 emissions by up to 50 per cent, with further reductions from carbon credits associated with variable renewable energy projects. Scope 3 emissions for oil and gas firms are likely to be reduced by introducing a higher share of biofuels, but also through lower combustible fuel sales as the government's ban on new gasoline- and diesel-powered vehicles comes into effect in the middle of the next decade. To sustain and grow current profitability levels, firms will need to identify new business opportunities and markets. This is increasingly challenging in an environment where Canadian firms, already unsure of the government's commitment level, are struggling to secure international funding and will need to be innovative with project finance. In that sense, it is worth pointing out that CO_2 storage has economic value, especially when tied to the regulatory framework under which the project operates. Shell Canada has reported that the cost of carbon avoided at the Quest project is higher than the cost of capturing and storing the carbon. In 2017 that differential was C$13/t$CO_2$e.[51] With the carbon price in Canada increasing from $40/t$CO_2$e in 2021 to C$170/tCO_2e by 2030, capturing and storing carbon could become an unlikely source of profitability for heavy emitters. Lower fuel sales can be offset by an increase in electricity sales, the creation of CO_2-based products, and an increase in non-combustible uses for bitumen and crude oil, such as lubricants and petrochemicals. The biggest opportunity is likely to lie in the development of a hydrogen-based economy in Canada, but it also carries a lot of risk and uncertainty. Despite the hype surrounding hydrogen, it is a long way from displacing natural gas as a primary fuel. Its lower energy content mean that it can only be blended into natural gas in small amounts, while the high pressures at which it operates at mean that its use in residential applications is limited. That said, there is a strong focus on developing and unlocking new hydrogen markets, particularly for power production and hydrogen fuel cell vehicles. For natural gas-rich countries like Canada, a future in which every major power utility has a hydrogen plant, and where hydrogen fuel cell vehicles compete with electric vehicles in the transport sector, may be far away, but political and corporate will is marshalling action in that direction.

7. Conclusion

It is widely acknowledged that no single option or technology can cut industrial emissions on its own. In the climate strategies released by industrial firms, energy efficiency, fuel switching, and carbon capture feature prominently. Carbon capture is viewed as having breakthrough potential because of how deeply it can cut emissions – up to 90 per cent or more – once installed in a process. CCUS technologies are also very broad, with a potential pathway for significant emissions reduction in a variety of heavy industrial applications – from boilers to reformers and stacks – and for CO_2 streams with varying levels of purity.

Canada is considered a world leader in CCUS, with three world-class projects built since 2014 and several more at various stages of development. As of 2020 the country hosts about 17 per cent of global CCUS projects in operation or under construction, most of them focused on decarbonizing the natural gas used to convert oilsands to crude oil and other refined petroleum products. These projects had significant financial backing from the provincial and federal governments, evidence of the importance attached to demonstrating and deploying CCUS in Canada. However, there are few clearly defined policies to support the commercial scaling up of carbon capture from the federal and provincial governments. This has led to concerns that investment will suffer on two fronts – insufficient funding for CCUS projects and continued divestment from the resource extraction sector. The plethora of new

[51] Maas, Wilfried (2017). Quest CCS Project Costs, 13-14 September, https://ukccsrc.ac.uk (accessed 10 July 2021).

projects proposed by Pathways to Net Zero consortium, TC Energy, ATCO, Air Products and others face several other challenges before they can become reality. The roadblocks encountered by pipelines in recent years suggest that support – or at least neutrality – from environmental groups and Indigenous populations will be critical. While the latter appear to be open-minded, especially for those firms that approach them in the spirit of Canada's Truth and Reconciliation Commission's findings, the former appear convinced that CCUS is the latest attempt to greenwash the oil and gas industry. Highlighting the value of industrial CCUS as an enabler of DACCS and BECCS will be important in securing this support.

Collaboration between firms will also be important in piloting various CCUS technologies as their application to industrial processes grows. This would be akin to the way many of these same firms combined efforts to not only prove oilsands extraction technology, but to drive down operating costs to the point where their netbacks are competitive with light tight oil in the United States. Even the collaboration – local and global – since Quest was commissioned has already resulted in CCUS capital costs decreasing to as low as C$40/t$CO_2$e for the relatively pure CO_2 streams in upgrading and refining. This can help offset the higher costs of carbon capture from the chemical, steel, and cement industries. Such collaborations could also provide more assurance on project viability to investors, while minimizing the financial outlay required from each firm and accelerating project delivery.

Carbon capture may not be a cure-all for the global climate challenge, but it has a major role to play in decarbonizing heavy industry. In Canada, where industrial emissions make up over a third of total emissions, it can play an even greater role than in other countries. For firms in the oilsands and natural gas sectors, already buffeted by volatile prices, lack of takeaway space for new production, and increased asset divestment, it is likely to be essential for survival. This all-in effort will require the significant transformation of oil and gas firms, resource-rich provinces like Alberta and Saskatchewan, and even more disruptively, Canada's economic structure. A stable regulatory climate will provide clarity to investors, while collaboration between firms will support alignment and cost learning in the various CCUS technologies. Early signs on both fronts are positive, but certainty in the form of legislation and sanctioned projects is required if carbon capture is to achieve its promise of becoming a core part of Canada's energy transition.