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TRANSITION PATHWAYS FOR CANADA'S OIL AND GAS SECTOR

How the sector can decarbonize operations and develop new net zero products

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Introduction

The global low-carbon transition raises big questions about the future of Canada's oil and gas sector. As a whole, the sector represented $105 billion of Canada's gross domestic product (approximately 6.5 per cent) and $105 billion in exports in 2020 (approximately 16 per cent). However, it also represented about 27 per cent of Canada's greenhouse gas emissions in 2020 (ECCC 2022a) and was one of the main drivers behind the increase in Canada's total greenhouse gas emissions in the past three decades.

There is no doubt that the sector needs to transition and find ways to dramatically reduce its greenhouse gas emissions: the question is *how*. Part of the solution in the short term is decarbonizing production—continuing to meet crude oil and gas demand on the journey to net zero emissions, while reducing the risk of stranded assets. In the long term, however, the industry will need to pivot to new ultra-low emissions business and product lines to stay profitable. Fortunately, there are both short and long-term opportunities for major oil and gas players poised to make this transition.

The Paris Agreement goals of limiting the global temperature increase from pre-industrial levels to "below 2° C and towards 1.5° C" require net zero carbon dioxide emissions by mid-century and net zero greenhouse gases by 2070.[1] The recent report by the International Panel on Climate Change (IPCC) further indicates that global greenhouse gases must fall 27-43 per cent and carbon dioxide emissions 27–48 per cent by 2030 from 2019 levels to keep 1.5–2° C in sight (IPCC 2022).

1 Carbon dioxide from fossil fuel combustion and industrial processes represents 64 per cent of greenhouse gases in 2019 (IPCC 2022). Carbon dioxide from deforestation and land use changes is another 11 per cent. Methane from fugitive oil and gas, agriculture, and land use represents 18 per cent. Nitrous oxides from various sources are four per cent, and fluorinated gases, mainly from industry, are two per cent.

The *Canadian Net-Zero Emissions Accountability Act* commits the country to reaching net zero greenhouse gases by 2050. No sector is exempt, including oil and gas production serving both domestic and international markets (Government of Canada 2021). To this end, in its recent *Emissions Reduction Plan*, the federal government commits to reducing oil and gas emissions by 30 per cent from 2005 levels by 2030, or 42 per cent from current levels as overall emissions from the sector have risen since 2005 (ECCC 2022b).

So what are oil and gas companies to make of this? Both their means of production (Scope 1 and 2) and products (Scope 3) are emissions intensive. How do they stay competitive and profitable as global demand plateaus and eventually falls, with what will likely be wild gyrations in price? How do they manage their existing assets, with sunk capital and difficult-to-change greenhouse gas profiles? What retrofits are worthwhile, and why? What new products will be viable? What is the government's role in helping support oil and gas companies and workers to succeed while ensuring the necessary transition?

The purpose of this paper is to initiate discussions on these questions in the policy-making context and demonstrate that while the global low-carbon transition is often seen as a threat to the oil and gas sector, it could also present a major opportunity.

Canada's oil and gas sector and its greenhouse gas emissions

The gasoline, diesel, and jet fuel that goes in our vehicles and the natural gas that heats our homes, buildings, and industry is processed in several steps from various grades of crude oil and gas. Crude oil production results in different variations including: offshore light oil, conventional light and heavy oil, and integrated and in-situ oil sands.

Offshore light is typically the least emissions intensive because the coproduced natural gas must be carefully managed for explosion and fire risk, particularly at sea. This means that very few fugitive emissions (unintentional emissions, leakage, or discharge of gases or vapours) are allowed. Natural gas is also coproduced with conventional light oil production (mainly methane) and gets piped separately for processing; however, with laxer standards than offshore production, it can result in significant fugitive emissions depending how the field and transport are operated.

In conventional heavy production, less gas is coproduced. It typically does not get its own pipe and is normally flared, usually incompletely and therefore partially as methane, a potent greenhouse gas. Oil sands production requires lots of heat produced mainly from combustion of natural gas to extract the bitumen from sand. Then, either synthetic crude or light hydrocarbons (e.g. natural gas liquids) are needed as diluent to allow bitumen to flow in pipelines. Gas is also needed to supply heat and add hydrogen in the process that upgrades bitumen to full synthetic crude oil. These processes all result in a high level of greenhouse gas emissions.

Canada also has a dedicated natural gas production industry, with both conventional and hydraulic fracking methods of extraction. This industry produces most of Canada's gas and the larger part of its process produces carbon dioxide emissions and fugitive methane emissions. The raw formation gas that is extracted is a varying mixture of methane, ethane, natural gas liquids, water, hydrogen sulfide, and carbon dioxide. Formation gas cleaning plants are used to separate out the water, hydrogen sulfide (which is reinjected), and carbon dioxide (which is released into the atmosphere). Straddle plants remove the ethane and natural gas liquids for use as chemical feedstock, diluent, or fuel. Because of the value of the ethane and natural gas liquids as ready-made feedstocks for the chemicals industry, that industry operates closely with the gas industry.

Not only is a lot of heat and electricity needed for the oil and gas sectors, but a significant amount of methane emissions leak from various parts of these industries. Methane leaks are estimated to be equivalent to at least 7 per cent of Canada's total greenhouse gas emissions from energy supply and demand and possibly 13 per cent or higher according to recent research into Canada's fugitive emissions (Chan et al. 2020; Tyner and Johnson 2021; MacKay et al. 2021). The International Energy Agency (IEA) recently raised its estimates of Canada's methane fugitives by 43 per cent (IEA 2022), and has recommended that all producers aim to reduce their fugitives by at least 75 per cent (IEA 2021a). The IPCC indicates that 50-80 per cent of current fugitives can be reduced for less than $50 per tonne of carbon dioxide equivalent and more than half of current fugitives at a negative cost, due to extra methane becoming available for sale (IPCC 2022).

Forecast global demand for crude oil and gas on the way to a 1.5° C world

In the IEA net zero scenario (IEA 2021b), global crude oil demand falls steadily to about 20 per cent of current consumption by 2050. In this scenario there is limited use of carbon dioxide removal and natural gas demand peaks in the mid 2020s, falling to about a third of today's consumption by 2050. In 2050, about one quarter of oil and gas continues to be produced in North America, with most of it used for chemical feedstocks (currently 14 per cent of global crude oil use and eight per cent of gas)[2] and abated with carbon capture and storage (CCS). How much will continue to be produced in Canada and by which companies will depend on the cost and greenhouse gas intensity of production, inclusive of any net carbon pricing and other climate and trade policies of Canada and its trading partners.

To engage this massive, generational transformation, high-level political direction and policy certainty that greenhouse gas emissions from oil and gas will be capped and drop to net zero by 2050 is required from both the federal and provincial governments. This must be associated with recognition by all levels of government and stakeholders that global crude oil production, as indicated by the IEA and others, could fall by roughly 80 per cent by 2050. Existing Canadian crude oil producers with established reserves, and especially those with built oil sands projects, will likely be competitive down to their operating cost of roughly $15-$25 per barrel. Fulsome CCS and other aggressive measures to reduce greenhouse gas intensity may add only $5-$6 per barrel (Bataille et al. 2015). This assumes Canada's fugitive methane emissions levels have been reduced at least 75 per cent by 2030, as recommended by the IEA and promised by Canada's current government. Below $15-$25 per barrel, other lower-cost regions (e.g. most of the Middle East) will have more of the market share, assuming they have also reduced their fugitive emissions.

[2] https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2019/Feedstocks_for_the_chemical_industry.pdf

Short-term opportunities to improve the oil and gas sector's carbon competitiveness

Canada's oil and gas sector has several opportunities to improve its survivability and competitiveness in a world where the greenhouse gas intensity of production and consumption of crude oil and gas products is strongly controlled and overall demand is falling. Many of these options are based on technologies that are already readily available and, in some cases, are highly cost effective.

Dramatically reducing fugitive methane emissions

The cornerstone for responsible greenhouse gas management by the oil and gas sector is to dramatically reduce its fugitive greenhouse gas emissions as soon as possible using existing technologies and practices. The government reviewed its methane regulations in late 2021, with the goal of reducing fugitive emissions by 39 per cent by 2025 and by 75 per cent by 2030. The sector has evolved a regulatory regime and associated management culture for worker safety, hydrogen sulfide control, and fire prevention. Fugitive greenhouse gas minimization must be added to this list. Several measures are available to reduce fugitive methane and carbon dioxide: relatively cheap repair activities focused on pipeline leaks, moderately capital intense additions of wellhead hoods and gas collection lines to all wells, and more capital intense application of CCS to formation gas cleaners to capture and dispose of carbon dioxide. Using all these strategies, a new ultra-tight regime for gas should be imposed as soon as feasible, perhaps over the next three to five years for larger producers with greater management capacity, and before the end of the decade for smaller producers.

Technological advances can help make compliance easier and cheaper. Multiple monitoring systems (e.g. satellite services provided by companies like Québec-based GHG Sat), airborne lasers, and pipeline inspections could be used to confirm whether fugitive emissions reduction goals are being met. Because of the monitoring challenges that make carbon pricing difficult, "speeding ticket" penalties may be required that escalate for repeat violations based on multiples of the current carbon levy.

There are other more expensive and involved actions that could help the oil and gas sector with fugitive methane management, but they come with a cost and governments and industry would need to be careful about how ratepayers are impacted. For example, all formation gas cleaners releasing significant amounts of carbon dioxide could have CCS applied within five years, and the cost would be tolled back to users in the rate base. All retired wells could be sealed to 1,000-year permanence levels. As part of this, the federal Orphan Wells program could be expanded, but to prevent it from becoming a subsidy to producers, the costs should be tolled back to oil and gas producers and, if this proves difficult, to all users. The added cost could incentivize efficiency improvements, but low-income households would need support through provincial utilities commission regulatory regimes, for example, through reduced utility bills.

It should be noted there are large differences in methane fugitive emissions rates in Canada. Part of this difference relates to product structure (i.e. pure gas plays, light oil, heavy oil and unconventional, offshore), but a large component relates to governance. British Columbia's gas sector, for example, has an official leakage rate of 0.22 per cent (ECCC 2022a) and perhaps 1.6-2.2 times that in reality (Simmons 2021; Tyner and Johnson 2021). Alberta's official fugitive emissions rate is 1.15 per cent (ECCC 2022a), but will likely rise by 1.5-2.0 times this with improved monitoring (Chan et al. 2020; MacKay et al. 2021). Saskatchewan has historically flared over 20 per cent of its produced methane due to the preponderance of heavy oil, and currently sits at 11.9 per cent, but overall fugitive emissions have fallen approximately 50 per cent with the application of recent regulations (Government of Saskatchewan 2021). These values give an overall rating of 1.13 per cent official leakage rate across the Western Canadian Sedimentary Basin, which could rise to 1.7-2.3 per cent. If recent updates to the B.C. gas production regulation are followed (e.g. no routine non-emergency flaring, with modifications as necessary for light and heavy conventional production, and shutting down or choosing not to develop wells as necessary (BC Oil and Gas Commission 2021)), it is possible to achieve a leakage rate less than 0.5 per cent across Canada by the late 2020s to early 2030s. The latest inventory indicates that fugitive emissions are already 25 per cent lower than 2019 levels as a result of the 2016 federal commitment to a 45 per cent reduction from 2012 levels by 2025. At COP26 the Canadian government committed to the IEA's recommended 75 per cent reduction in oil and gas fugitive emissions by 2030 compared to 2019. Recent progress indicates this may possible; it would contribute significant direct emissions reductions and improve the business case for blue hydrogen and derivatives, which are discussed in more detail below (ECCC 2022a).

A sector-specific oil and gas emissions cap falling to net zero greenhouse gas emissions by 2050

Given the critical need to reign in rising oil and gas emissions against the backdrop of falling emissions in the rest of the economy, and provide firm direction to reach net zero, all oil and gas combustion and possibly fugitive greenhouse gas emissions should be under a sector-specific and declining cap ending at net zero emissions by 2050. This system, rooted in the federal government's 2022 *Emissions Reduction Plan* (ERP), would be negotiated as a successor to the Output-Based Pricing System or Alberta's Technology Innovation and Emission Reduction Regulation. It would provide the sector with its own cap-and-trade system or regulatory framework. These would be under the governance of provinces with federal oversight within its jurisdiction over total emissions. The explicit goal would be net zero by 2050 with only additive, verifiable, and geologically permanent offsets allowed, like bioenergy with CCS or direct air capture plus CCS. Interprovincial trading could be allowed but just within the oil and gas sector. Within the hard and declining cap, means would be investigated for existing oil sands projects to run out their lives at ever lower greenhouse gas intensities (e.g. solvent extraction; direct contact steam generation; CCS, blue and green hydrogen for heat and upgrading; and other as yet unknown possibilities).

It is debatable whether fugitive emissions should continue to be governed separately under the existing methane regulations or co-governed with combustion emissions. If all combustion and fugitive emissions were put under one cap, a logical outcome could be the oil and gas sector rapidly eliminating lower cost fugitive emissions by 2030. The sector could have some cost offsetting from increased methane revenues, while eliminating higher cost and more uncertain combustion emissions starting in the late 2020s and early 2030s. In either case, a 75 per cent reduction in fugitive emissions by 2030 (equivalent to about 0.5 per cent or less of total production after recent advances in monitoring), should be maintained given their importance for future oil and gas sector actions to reduce greenhouse gases (Bauer et al. 2022), and a 90 per cent or better reduction should be encouraged.

Finally, given the world will likely require some permanent, additive, and verifiable negative carbon dioxide removal emissions to maintain the Paris targets while allowing developing countries to meet core needs, some form of incentive will be needed. In the short run this could include allowing offsets under the emissions cap for the oil and gas sector, providing they meet the established criteria. In the long run, the cap could become negative or a "bounty" could be offered (Bataille and Lee 2021).

Long-term opportunities to transform Canada's oil and gas sector

So far, this paper has explored the emissions constraints on the oil and gas sector in a low-carbon economy and the opportunities to reduce these emissions in the short term. Now we can consider the fun part: the long-term opportunities to transform the sector so it can take advantage of new global markets and succeed in the low-carbon future. Canada's oil and gas companies are masters of the chemical engineering arts of mixing and matching carbon, hydrogen, and oxygen atoms to transform feedstocks into fuels and materials. This is currently a highly greenhouse-gas-intense activity both because of the high process heat used and the greenhouse gas intensity of current feedstocks for sourcing these atoms. If we can incentivize oil and gas companies to find and use ever lower greenhouse gas intensity processes and feedstock sources (e.g. from carbon capture and use, biomass gasification, direct air capture of carbon dioxide, or electrolysis of water), these cornerstone commodities could be produced in Canada at much lower intensities. This is where Canada's access to secure CCS geology (e.g. the Western Canadian Sedimentary Basin), biomass, and clean electricity from several sources, becomes a strong competitive advantage in a global low-carbon world. With these advantages, Canada can secure a strong position as a supplier of choice for aviation fuels, high-value chemical feedstocks, and replacement net zero fuels for buildings and industries that have challenges converting to electricity and hydrogen (Bataille 2020). We will consider first hydrogen and its derivatives, then oxygen, and ultimately carbon.

Blue hydrogen production

Hydrogen is currently used in large quantities for integrated synthetic crude oil production and merchant upgraders, as well as for ammonia and other chemical production. It is made by reforming methane in two steps into hydrogen and carbon dioxide. The carbon dioxide is currently released to the atmosphere and could have CCS applied to it, creating "blue" hydrogen (Bataille et al. 2021). For blue hydrogen to be sustainable, the fugitive methane emissions levels would need to be less than or equal to 0.5 per cent, and at least a 90 per cent capture rate of carbon dioxide would be required (Bauer et al. 2022). This is difficult to do technically and economically with modern steam methane reformers because they separate the process carbon dioxide waste stream, on which CCS is cheap and easy because the carbon dioxide is concentrated, and the heat waste stream, on which CCS is hard and expensive because it is diluted in nitrogen. However, there is another option in autothermal reformers. This option should be encouraged because the heat and carbon dioxide are produced together, making the waste stream carbon dioxide more concentrated and easier to capture. Carbon dioxide from early blue hydrogen production, like that from Air Products' project, could be moved via the Alberta Trunk Line for permanent disposal or enhanced oil recovery projects in older wells. Enhanced oil recovery can count as permanent disposal if all the carbon dioxide is reinjected, if the process is managed to maximize sequestration instead of minimizing carbon dioxide costs, and if the wells are sealed properly afterward. While there is significant debate about how much project support should be provided to kickstart a blue hydrogen industry (e.g. through the CCUS tax credit), there is a legitimate role for government to help build key carbon dioxide transport and disposal infrastructure and tolling it back on use.

Transitioning to green hydrogen

While the oil and gas sector will have a head start in blue hydrogen, based on falling solar, wind, and electrolyzer costs, it is anticipated that green hydrogen made via water electrolysis will supersede blue hydrogen globally by 2035-2040 for almost all new production. Green hydrogen is critically dependent on low-cost clean electricity to be competitive without subsidies (e.g. less than $0.01-0.02/kWh in regions where there is competition with blue hydrogen), and regions most likely to kickstart production of green hydrogen are those with access to cheap hydro-electricity and poor CCS geology, e.g. Québec (Bataille et al. 2021; Neff et al. 2021). Small modular reactors are another pathway to supply heat and electricity for electrolysis and may be a key primary energy source in regions with poor wind and solar. However, too little is known at this time about their eventual costs. Finally, water electrolysis during green hydrogen production produces oxygen as a valuable byproduct. Where the oil and gas sector has long-term skills to contribute is in the handling, storing, transport, and especially use of blue then green hydrogen to make higher value products with low greenhouse gas intensity carbon and oxygen.

Low greenhouse gas carbon-based fuels and feedstocks

In the short run, it is expected oxygen for chemicals, hydrocarbon, and alcohol fuels will come from air separation units powered by ever cleaner electricity; in the long run, oxygen could come as a byproduct from electrolysis for making green hydrogen. Once a steady surplus of relatively low greenhouse gas oxygen is available, it can be used as a chemical feedstock or for oxycombustion, such as in NET Power's CO_2 methane driven electricity generation system. Because of the ample geology for CCS in northeast British Columbia, Alberta, and Saskatchewan as well as inexpensive methane, the NET Power system could be a key supplier of clean electricity to support variable wind and solar in these regions. The oil and gas sector's geological reinjection skills could be a key complement, given the necessity to dispose of the excess carbon dioxide. In a related way, the oil and gas sector's skills with drilling and geological management could be used for deep geothermal generation (Roberts 2020).

In the long run, most useful chemicals (e.g. carbon monoxide, methane, methanol, ethanol, and ethylene) for fuels, plastics, and other end uses require carbon, which currently comes from fossil fuels. It could instead come from using waste carbon dioxide streams, biogenic carbon sources (e.g. anaerobic digestion, fermentation, or woody biomass gasification), or be directly captured from the air. Canada's oil and gas sector is ideally suited to conduct the molecular "Lego" necessary to make chemicals and fuels from low greenhouse gas carbon, hydrogen, and oxygen. There will likely be large global market opportunities associated with this carbon management business. First, it will take long past 2050 to replace the buildings and industrial facilities that run on fossil methane, and companies that can make a zero greenhouse gas methane replacement will have many opportunities. Second, methanol, ethanol, and ethylene are cornerstone commodities of the plastics and other chemicals industry. Companies that can master physical carbon management—replacement of fossil carbon sources with lower or zero greenhouse gas intensity sources—will have a significant role to play in creating fuels and feedstocks for industries such as high-value legacy buildings, aviation, and chemicals. The functional limits to this business opportunity will be how fast we can substitute direct use of electricity and hydrogen in the transport, buildings, and industry sectors, and the eventual cost of carbon dioxide removal, for example via biomass combustion or direct air capture of carbon dioxide followed by its permanent geological disposal. Implementing large scale carbon dioxide removal will be an enormous institutional challenge, however, and is still projected to cost at least $200-300 per tonne of carbon dioxide, with enormous clean energy requirements.

Industry hubs for hydrogen, oxygen, and carbon management

Coordination of the supply, storage, and demand for hydrogen, oxygen, and carbon compounds will be easier and the per tonne costs lower if they are collocated in industrial clusters near existing oil and gas hydrogen, upgrading, and chemical production facilities. This would ideally be near geology suitable for bulk storage of hydrogen (i.e. salt caverns) and carbon dioxide (i.e. depleted oil and gas fields and deep saline aquifers). An open provincial and federal invitation could be offered to chemical companies to develop net zero synthetic chemical clusters (e.g. Fort Saskatchewan, Medicine Hat, Lloydminster), with preapproved industrial zoning, CCS collection and disposal, high voltage transmission, blue then green hydrogen production and storage, and potentially district heat sharing from which small and medium enterprises could "farm" heat using industrial scale heat pumps. Finance could be made available for elements such as planning and infrastructure, and the federal and provincial governments could even build the core infrastructure and toll its costs back to participants.

Conclusion

This paper offers a vision for how Canada's oil and gas companies can decarbonize their production, maintain market share as demand for crude oil and gas falls, and simultaneously pivot to new net zero products. Fulfilling this vision means oil and gas companies could evolve into "carbon management" companies using low greenhouse gas carbon, hydrogen, and oxygen to make useful fuels and materials feedstocks at ever lower greenhouse gas intensities. Looking deeper into the future, the sector could eventually become carbon negative via biomass and direct air capture of carbon dioxide use followed by CCS, their profitable "mantra" being ever less carbon dioxide in the air, ever more recycled, and ever more back into the ground.

Implementation of this vision, however, requires several interlinked policy interventions that need further research to develop properly. The following is a list of potential policy actions that could help move the technological pathways talked about in this paper forward:

- Implement strict fugitive methane emissions regulations, with at least a 75 per cent reduction by 2030 or earlier. Several companies have demonstrated this can be rapidly achieved, so a credit system could also be implemented for companies that reduce their emissions early and/or go above and beyond the targets.
- Reduce and eventually eliminate fossil fuel production subsidies (GSI 2022, Samson et al. 2022).
- Establish an oil and gas emissions cap falling to net zero (and possibly negative) by 2050, inside or outside the existing provincial or federal output-based pricing system (OBPS) systems. Whether it is based on carbon dioxide or greenhouse gases will depend on how the policy is designed to interact with the prior fugitive methane emissions policy.
- Develop instruments to improve policy certainty for capital intensive, long-lived projects, e.g. contracts for differences indexed to a prespecified product price or climate policy (Sartor and Bataille 2019; Beugin and Schaffer 2022).
- Develop policy, such as the *Clean Electricity Standard*, to make sufficient low cost and reliable clean electricity available for green hydrogen and process heat, for example, through industrial heat pumps or directly for heat.

- Support research, development, and commercialization of technologies that can enable the use of Canada's woody biomass resources as a carbon source, and make this more of a priority and possibly attract more global investment.
- Develop a low-carbon fuel standard (LCFS) compatible with net zero emissions. This could be a key policy for helping low carbon fuels reach markets. A Canada-wide LCFS is expected to emerge in Fall 2022. Given the challenges and five years it has taken to negotiate the existing policy, further tightening may work best if it's done with partners in the United States, modelled on California and British Columbia's policies, and with careful tracking of "well-to-combustion" life-cycle emissions.
- Preplan, zone, and establish infrastructure for industrial clusters. This could include hydrogen production and storage; CCS collection and disposal; high voltage transmission; waste heat collection and reuse with heat pumps; and recyclable material collection and processing. This would require cooperation between the federal and provincial governments, and could include prebuilding of infrastructure by government and tolling back on use, or tax credits to establish the infrastructure.
- Create long term signals to trigger negative emissions, which could come by strengthening the OBPS and equivalent benchmarks while allowing inclusion of permanent, additive, and verifiable offsets, or perhaps via a "bounty" on negative emissions (Bataille and Lee 2021).

In order for this package of policies to be implemented and politically accepted, a fast but effective process is required to engage stakeholders and produce adaptable federal and provincial plans to take the oil and gas sector to net zero emissions, supported with new technology and compatible with global developments. The Alberta provincial government accomplished a similar process in the early months of 2015 leading up to the Paris Agreement, with full buy-in from all significant stakeholders, including large oil and gas firms, but the plan was later abandoned (Leach et al. 2015).

Given their jurisdiction over natural resources, the provinces will likely remain in the driver seat, but the federal government can play a crucial planning, coordination, and funding role. Establishing a national, independent arm's length agency could help in this regard. It could be mandated with evaluating federal and provincial plans, monitoring progress, and suggesting modifications to provincial and federal governments, following the example of the UK Climate Change Committee.

While the journey from producing some of the most greenhouse gas intense barrels on the planet to profitable greenhouse gas negative carbon management may seem long and improbable, and the laundry list of necessary policies lengthy, it is not only necessary if Canada is going to meet its net zero goals, it is feasible with vision and effort on the part of all stakeholders.

References

Bataille, Chris, and Caroline Lee. 2021. "Going Negative: Why Canada and the World Need Carbon Dioxide Removal, and How to Make It Happen." Canadian Climate Institute. https://climateinstitute.ca/going-negative/

Bataille, Chris, Noel Melton, and Mark Jaccard. 2015. "Policy Uncertainty and Diffusion of Carbon Capture and Storage in an Optimal Region." *Climate Policy* 15 (5): 565–582. https://doi.org/10.1080/14693062.2014.953905

Bataille, Chris, Jordan Neff, and Blake Shaffer. 2021. "The Role of Hydrogen in Canada's Transition to Net-Zero Emissions." *The School of Public Policy Publications: SPP Research Paper* 14 (30). https://www.policyschool.ca/wp-content/uploads/2021/11/EFL49_Net-Zero-Emissions_Bataille-et-al.pdf

Bataille, Christopher G.F. 2020. "Physical and Policy Pathways to Net-Zero Emissions Industry." *Wiley Interdisciplinary Reviews: Climate Change* 11 (2): e633. https://doi.org/10.1002/WCC.633

Bauer, Christian, Karin Treyer, Cristina Antonini, Joule Bergerson, Matteo Gazzani, Emre Gencer, Jon Gibbins, et al. 2022. "On the Climate Impacts of Blue Hydrogen Production." *Sustainable Energy Fuels*, 66–75. https://doi.org/10.1039/d1se01508g

BC Oil and Gas Commission. 2021. *Flaring and Venting Reduction Guideline*. https://www.bcogc.ca/files/operations-documentation/Oil-and-Gas-Operations-Manual/Supporting-Documents/flaring-and-venting-reduction-guideline.pdf

Beugin, Dale, and Blake Shaffer. 2022. "Removing Policy Uncertainty Can Position Canada for a Decarbonizing World." Canadian Climate Institute. https://climateinstitute.ca/removing-policy-uncertainty-can-position-canada-for-a-decarbonizing-world/

Chan, Elton, Douglas E.J. Worthy, Douglas Chan, Misa Ishizawa, Michael D. Moran, Andy Delcloo, and Felix Vogel. 2020. "Eight-Year Estimates of Methane Emissions from Oil and Gas Operations in Western Canada Are Nearly Twice Those Reported in Inventories." *Environmental Science and Technology* 54 (23): 14899–14909. https://doi.org/10.1021/acs.est.0c04117

ECCC (Environment and Climate Change Canada). 2022a. *National Inventory Report – 2022 Edition Part 1 (NIR)*. https://unfccc.int/documents/461919

ECCC (Environment and Climate Change Canada). 2022b. "Canada's 2030 Emissions Reduction Plan." Government of Canada. https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/plan.html

GSI (Global Subsidies Initiative). 2022. "Unpacking Canada's Fossil Fuel Subsidies." International Institute for Sustainable Development. https://www.iisd.org/gsi/faqs/canada

Government of Canada. 2021. "Canadian Net-Zero Emissions Accountability Act." https://laws-lois.justice.gc.ca/eng/acts/c-19.3/FullText.html

Government of Saskatchewan. 2021. *Oil and Gas Emissions Management Regulations 2020 Annual Emissions Report*. https://publications.saskatchewan.ca/#/products/115699

IEA (International Energy Agency). 2021a. *Driving Down Methane Leaks from the Oil and Gas Industry*. OECD. https://doi.org/10.1787/003A5A4C-EN

IEA (International Energy Agency). 2021b. *Net Zero by 2050*. OECD. Paris. https://doi.org/10.1787/C8328405-EN

IEA (International Energy Agency). 2022. "Global Methane Tracker 2022." https://www.iea.org/reports/global-methane-tracker-2022

IPCC (Intergovernmental Panel on Climate Change). 2022. *Climate Change 2022: Mitigation of Climate Change Summary for Policymakers*. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf

Leach, Andrew, Angela Adams, Stephanie Cairns, Linda Coady, and Gordon Lambert. 2015. *Climate Leadership Report to Minister*. https://open.alberta.ca/dataset/212a6266-b8d3-4822-b208-9221da2a0966/resource/9f52c-d8e-5477-45a6-a337-f2d64d091cf9/download/2015-climate-leadership-report-to-minister.pdf

MacKay, Katlyn, Martin Lavoie, Evelise Bourlon, Emmaline Atherton, Elizabeth O'Connell, Jennifer Baillie, Chelsea Fougère, and David Risk. 2021. "Methane Emissions from Upstream Oil and Gas Production in Canada Are Underestimated." *Scientific Reports* 11: 8041. https://doi.org/10.1038/s41598-021-87610-3

Neff, Jordan, Chris Bataille, and Blake Shaffer. 2021. "The Role of Hydrogen in Decarbonizing Alberta's Electricity System." *The School of Public Policy Publications* 14 (31). https://ssrn.com/abstract=4045872

Roberts, David. 2020. "Geothermal Energy Is Poised for a Breakout." Vox. https://www.vox.com/energy-and-environment/2020/10/21/21515461/renewable-energy-geothermal-egs-ags-supercritical

Samson, Rachel, Don Drummond, and Peter WB Phillips. 2022. “Cutting to the Chase on Fossil Fuel Subsidies.” Canadian Climate Institute. https://climateinstitute.ca/publications/fossil-fuel-subsidies/

Sartor, Oliver, and Chris Bataille. 2019. “Decarbonising Basic Materials in Europe: How Carbon Contracts-for-Difference Could Help Bring Breakthrough Technologies to Market.” IDDRI. https://www.iddri.org/en/publications-and-events/study/decarbonising-basic-materials-europe

Simmons, Matt. 2021. “Methane Emissions from B.C. Oil, Gas Up to 2.2 Times More than Estimates: Study.” The Narwhal. https://thenarwhal.ca/bc-oil-gas-methane-emissions-study-2021/

Tampier, Martin, Matt Dickson, Len Bykowski, Warren Mabee, Geoff Budd, and Thomas Cheney. 2022. *B.C. Renewable and Low-Carbon Gas Supply Potential Study*. https://www.cdn.fortisbc.com/libraries/docs/default-source/about-us-documents/renewable-gas-study-final-report-2022-01-28.pdf?sfvrsn=cb5ca1fd_0

Tyner, David R., and Matthew R. Johnson. 2021. “Where the Methane Is - Insights from Novel Airborne LiDAR Measurements Combined with Ground Survey Data.” *Environmental Science and Technology* 55 (14): 9773–9783. https://doi.org/10.1021/ACS.EST.1C01572