Energy Transition Strategy 1.5 Degree Update

Technological Solutions for Negative Emissions

Prepared by City of Edmonton

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Edmonton's Community Energy Transition Strategy (CETS) was approved by City Council in 2015, which identified strategies to reduce greenhouse gas (GHG) emissions, and increase energy efficiency and adoption of renewable energy in all sectors represented across the community. The CETS was developed and approved with emissions reduction targets of 35% below 2005 levels by 2035. This strategy went into effect prior to the signing in 2016 of the Paris Agreement in which the UN Intergovernmental Panel on Climate Change (IPCC) set a globally-agreed limit of 2 degrees Celsius global average temperature increase above pre-industrial levels.

In the intervening years the scientific understanding of the global climate system has increased, and the IPCC published the "Special Report on Global Warming of 1.5 °C (SR15)"[1] which compared and contrasted the dangers faced by people, natural systems and infrastructure around the world by allowing the climate to warm beyond 1.5 °C versus the official 2 °C limit. The differences were stark, and the report issued a call for signatories to the Paris Agreement to work hard to limit GHG emissions to hold warming to less than 1.5 °C. Edmonton hosted the "Cities IPCC Science and Climate Change Conference" in March of 2018, at which the "Edmonton Declaration" was issued which calls on cities to work towards the same 1.5 °C goal. The declaration has been adopted by over 4,500 cities worldwide.

On August 27, 2019, the City of Edmonton Council declared a "Climate Emergency" as a signal to citizens and other levels of government that the Edmonton municipal government is taking climate change seriously and is committed to work towards the 1.5 °C limit to global temperature rise. Edmonton City Council requested Administration to investigate GHG reduction levels required to align with the IPCC 1.5 °C target, and to revise the Community Energy Transition Strategy to reflect these more aggressive limits.

It was found that to achieve alignment with this international target, the community would have to adhere to a local carbon budget of 155 Megatonnes of carbon dioxide equivalent (Mt CO2e). This is the total amount

[1] "Special Report on Global Warming of 1.5 °C"; UN IPCC; October 8, 2018.

of greenhouse gas emissions permitted cumulatively between the current year (2019) and 2050, after which emissions from the community must be net zero. Unfortunately, with high per-capita emissions and a growing population, the 155 Mt CO2e carbon budget will be exhausted in the year 2028.

Modeling of possible GHG reduction strategies out to 2050 indicates that there are no combinations of activities that allow the community-wide GHG emission in Edmonton to drop to zero. Edmonton is always left with a “residual” level of emissions that is very hard to address. Edmonton published the “Getting to 1.5 °C” discussion paper in July of 2019, which presented the following Wedge Stabilization Assessment over time to 2050. The grey area represents GHG emissions that remain, and even if all actions are taken then in 2050, when net emissions should be zero, there is a “residual” of about 2.5 MtonnesCO2e.

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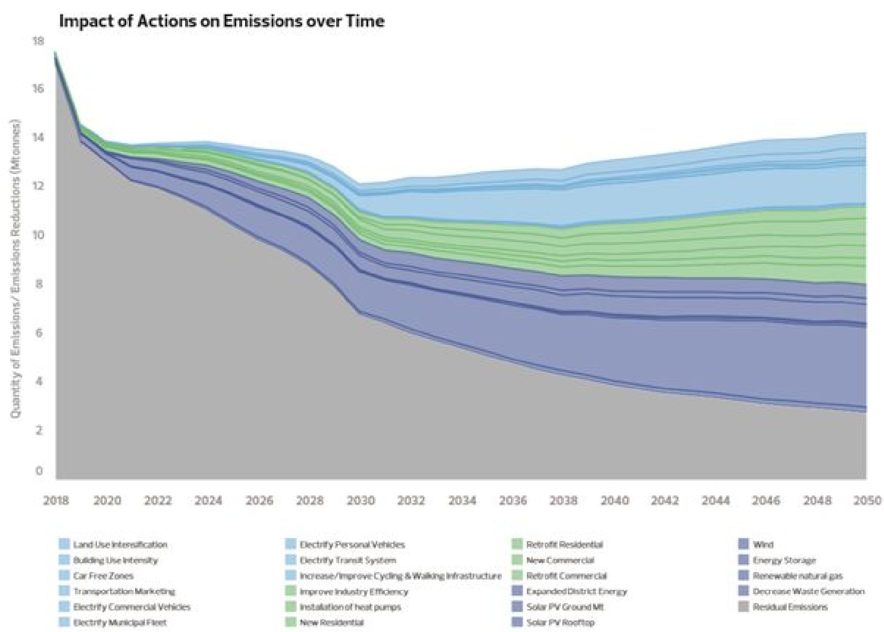

The objective of this policy brief is to investigate “Negative Emission” technologies and understand if these are appropriate for The City of Edmonton to use in the Energy Transition Strategy. Such direct interventions could allow for the removal and sequestration of greenhouse gases from the atmosphere in quantities which are equivalent to the amount of “residual” emissions that can't be addressed through other means. The deployment of Negative Emissions technologies would allow Edmonton to have "Net Zero" emissions.

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Negative Emissions using technological (as opposed to biological) approaches can be divided into two broad categories:

ŏ Carbon Capture and Utilization, and
ŏ Carbon Capture and Sequestration.

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In Carbon Capture and Utilization, CO2 emissions are intercepted before they enter the atmosphere and are converted into products that keep the greenhouse gas locked up.

Reducing GHG emissions through carbon capture can be economic in many cases since the captured CO2 can be made into value-added products. Alberta is home to several start-up companies working in the Carbon Capture and Utilization space, and has facilities like the Alberta Carbon Conversion Technology Centre (ACCTC) at the Shepard Energy Centre in Calgary where companies can set up pilot plants to develop new processes for carbon capture.

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Companies developing Carbon Capture and Utilization capitalize on waste streams of CO2 to manufacture revenue-generating products for a wide variety of industries. Each solution is typically tailored to the waste stream available, and to the end products that are desired. Four Carbon Capture and Utilization companies that include CleanO2, Carbon Upcycling Technologies, C2CNT and Carbon Cure are described in Appendix A.

It is important to understand that the emerging Carbon Capture and Utilization companies like CleanO2, Carbon Upcycling Technologies, C2CNTand Carbon Cure are commercial businesses that have developed value-added products that generate revenues from customers. This pathway of removing GHG emissions does not depend on financial support from the government, nor the enacting of climate-related regulations (although these two things would help the CCUS industry). Using waste streams of CO2 that would otherwise be emitted from a chimney or exhaust pipe as a feedstock for manufacturing other goods simply makes good business sense in many cases.

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In contrast to intercepting high-concentration CO2 streams at exhaust stacks, the Direct Air Capture (DAC) technique filters CO2 from the ambient air. DAC uses fans to draw air from the atmosphere through a machine where the CO2 is chemically bound with an absorber compound.

Key advantages of using Direct Air Capture are: the machines can be set up in any location, and emissions from any source can be addressed.

These characteristics are very useful for sectors such as air travel which are currently highly dependent upon fossil fuels. Two pioneering companies in DAC technology, Carbon Engineering and Climaworks are described in Appendix A.

In some DAC processes, the absorber compound is further processed to release a pure stream of CO2 which can be used in other industries, or pumped underground into geological reservoirs. The latter method of CO2 disposal is called Geological Sequestration.

Alberta has favorable geology for CO2 sequestration, and expertise in piping, gas processing, and drilling of wells.

Direct Air Capture is a technology that would allow municipal governments to fully achieve GHG reduction targets. The City of Edmonton could own and operate the equipment within their geographical boundaries, capturing and disposing of emissions making up the gap to the target that is not achieved through other strategies such as energy efficiency and renewable energy.

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Currently existing gasoline and diesel-fueled vehicles are likely to continue operating throughout their serviceable lives of 15 to 20 years. A vehicle sold today could continue to burn fossil fuels until 2040. The current fleet of vehicles contributes approximately 29% of the total GHG emissions in Edmonton, and the distributed emissions from this sector are very hard to address without Direct Air Capture. This method could even address emissions from air travel, a sector that is growing worldwide and is dependent on high-energy-density liquid fossil fuels.

Heating systems for buildings are also difficult to address. Almost every home and commercial/institutional building in Edmonton burns natural gas for heating, and buildings are extremely long-lived assets. A standard building that is designed around a heating plant delivering 80 °C water is hard to retrofit to use the most efficient condensing boilers since the return water temperature is too high to condense moisture from the flue gases. Without intervention, existing buildings will likely continue to burn natural gas and emit GHGs long past the 2050 target date for Edmonton to achieve zero emissions. Calgary-based CleanO2 has developed a carbon capture and utilization system that is sized specifically for the building heating industry. Building owners can keep their existing heating boilers, while the CleanO2 system scrubs carbon dioxide out of the flue gases. The system also recovers heat from the flue gases, and this heat is sent back to the domestic hot water system, further reducing fuel consumption and operating costs for the facility owner.

Deploying Negative Emissions technologies now will buy time for owners of existing buildings to take other measure such as energy efficiency upgrades and switching to renewable fuels. It also buys time for the Alberta Building Code to be changed to set zero-emissions standards for new buildings.

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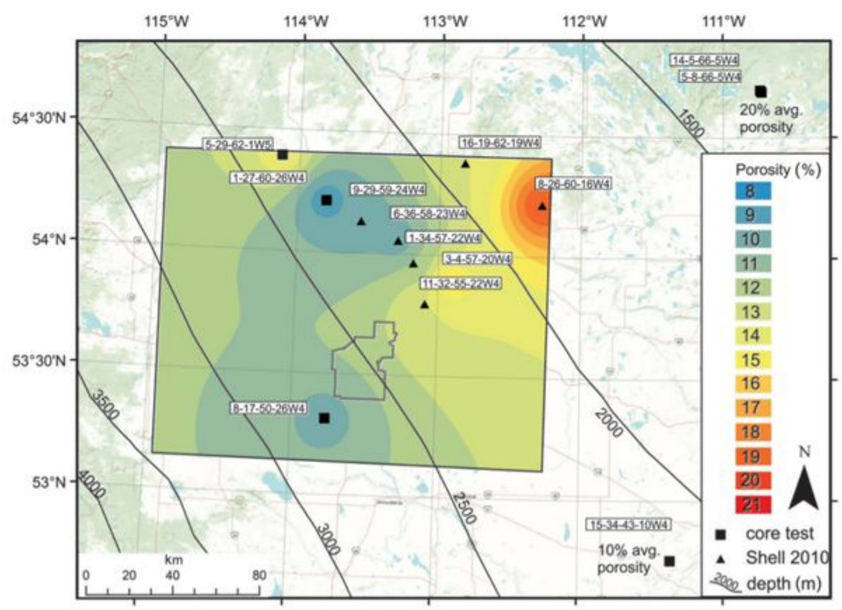
Geological sequestration is very appropriate in the Canadian Prairies. Alberta is home to one large industrial sample of carbon capture and geological sequestration at the Shell Scotford upgrader facility in Ft. Saskatchewan. The Shell Quest plant has been operating since 2015, injecting high pressure CO2 into the Basal Sandstone Unit (BSU) formation at a rate of 1 million metric tonnes of CO2 per year. Shell plans to operate the Quest CO2 sequestration plant for the lifetime of the Scotford Upgrader which is more than 25 years.



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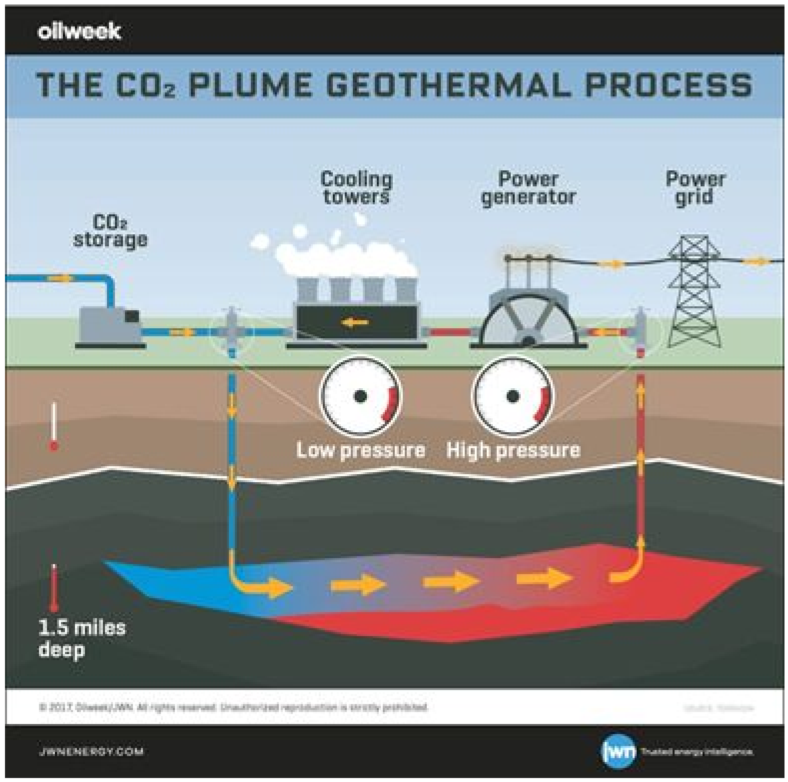
Due to the pressure underground, CO2 in the geological reservoir exists in the “supercritical” phase. Supercritical CO2 has unique properties; it has the high density of the liquid phase but the low viscosity of the gas. This combination of properties makes supercritical a good medium for transferring geothermal heat to the surface. The BSU reservoir has been surveyed for its geothermal potential and has been found to have temperatures ranging from 65 °C to 120 °C, which are attractive. Edmonton could capitalize on the subsurface CO2 storage as a heat transfer medium for a low-temperature (50 °C) District Heating system, or even Geothermal electricity generation if the temperature achievable is 80 °C or higher.



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A supercritical CO2 geothermal plant could operate even while additional CO2 from Direct Air Capture is added to the reservoir. Since it is a closed-loop system, the hot CO2 from the production well is re-injected into the reservoir, and not released to the atmosphere.

[2] R.P. Stastny; "How geothermal could transform Alberta's suspended and uneconomic oil and gas wells for power generation"; IV Emdqfx(October 16, 2017. (https://www.jwnenergy.com/article/2017/10/how-geothermal-could-transform-albertas-abandoned-oil-and-gas-wells-power-generation/)

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In theory, carbon capture and utilization or sequestration could address Edmonton's full community-wide GHG Inventory. In many stationary applications such as buildings and industrial plants, Carbon Capture and Utilization companies could sequester Mega-tonnes of CO2 emissions while manufacturing value-added products. Due to the wide variety of applications, and new start-ups finding their niche it is difficult to predict quantities of emission reductions with any accuracy.

For Direct Air Capture and geological storage, the question of deployment comes down to the budget available. Edmonton sits above a favorable reservoir for geological storage of CO2 in the Basal Sandstone Unit. This stratum could absorb Edmonton's entire 18 Mt CO2 emissions given the right injection well infrastructure. However, in 2050 Edmonton's residual emissions are forecast to be on the order of 2.5 Mt CO2. This is only about twice the size of Shell's Quest CO2 sequestration project, which injects about 1 Mt CO2 per year.

Carbon Engineering is developing commercial-scale Direct Air Capture plants with a standard size of 1 Mt of CO2 capture per year. With three of these plants, Edmonton could reduce their 2050 residual emissions to zero.

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[3] Jeff Tollefson, "Sucking carbon dioxide from the air is cheaper than scientists thought"; ***M`stqd,*** issue 558, page 173, 2018; (https://www.nature.com/articles/d41586-018-05357-w)

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It is important to understand that the emerging Carbon Capture and Utilization companies like CleanO2, Carbon Upcycling Technologies, C2CNT and Carbon Cure are commercial businesses that have developed value-added products that generate revenues from value-added products. This pathway of removing GHG emissions does not depend on financial support from the government, nor the enacting of climate-related regulations (although these two things would help the CCUS industry). Using waste streams of CO2 that would otherwise be emitted to the atmosphere as a feedstock for manufacturing other goods simply makes good business sense in many cases.

For the Capital region, the development of novel industries surrounding the CO2 capture phase of projects, and the processing and end use of the resulting products represents economic diversification.

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For Direct Air Capture, a new cost evaluation[4] published by Prof. David Keith of Carbon Engineering indicates the levelized cost of capture is in the range of $94 – $232 USD per short ton of CO2 (roughly $138 - $340 CAD per metric tonne CO2). The range of costs is sensitive to the local costs of electricity and natural gas. With the range given by Keith ***ds `k.*** Edmonton could capture and sequester the residual 2.5 Mtonnes of CO2 emissions in 2050 for between $345 - $850 million Canadian dollars per year.

The energy balance published by Dr. Keith indicates much of the energy input required to operate the system is dedicated to regenerating the absorber chemical. In this step, high heat is needed to drive the CO2 gas off the absorber, and this heat typically comes from burning fossil fuels. However, the Edmonton region is home to much of Alberta's heavy industry and an

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[4] Keith ***ds `k***, "A Process for Capturing CO2 from the Atmosphere"; ***Intkd 2***, pages1573-1594; Aug. 15, 2018; Elsevier Inc.; (https://doi.org/10.1016/j.joule.2018.05.006)

industrial waste heat survey [5] conducted by Natural Resources Canada found there is at least 300 MW of waste heat available in the Industrial Heartland region between north-east Edmonton and Ft. Saskatchewan. A Direct Air Capture system may be able to drive down the energy penalty of calcining if it could tap into the heat currently being vented to the atmosphere in the region. This is speculative at this stage, and more discussion with Carbon Engineering, or other DAC companies, are necessary.

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Climate change disproportionately affects the poorest and most vulnerable of the world. In that sense, Edmonton is protected from the worst impacts of climate change simply due to the relative wealth of citizens and of the Province of Alberta. However, Edmonton has suffered catastrophic weather in the past (the 1988 tornado for example), and Alberta has seen the insured losses due to extreme weather events increase over time. From mountain pine beetles, and devastating forest fires, to floods and droughts, Alberta is seeing the effects of climate change in the present, and with a rich history of being good neighbours and pitching in, Edmonton should do our part to reduce our contributions to the global problem of greenhouse gas emissions.

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There are currently no regulatory requirements in Canada or Alberta for the removal of CO2 from the atmosphere. However, given the public risk of allowing the climate to change unabated due to anthropogenic GHG emissions, there is a case to be made for governmental action to protect citizens, and one direct action government could take is active removals of CO2 from the atmosphere.

Due to the upfront capital cost and ongoing operational costs involved, there is likely to be considerable debate about what level of government would be the most appropriate to finance and deliver services of Direct Air Capture and

[5] Natural Resources Canada; "Community Integrated Energy Mapping Feasibility Study: Gateway to Alberta's Energy Demand and Supply"; Lead Proponent: C3 and CMC Research Institutes, 2015; (https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/community-integrated-energy-mapping-feasibility-study-gateway-albertas-energy-demand-supply/16067)

sequestration of greenhouse gases. However, Edmonton could demonstrate worldwide leadership by taking this on itself and engaging in Direct Air Capture at a city level.

A CBC survey[6] conducted in the summer of 2019 indicated that public opinion is quite strong in terms of desire for action to be taken on climate change, but less so when asked how much money they are willing to put towards such action. On average, the survey indicated people are willing to spend about $100 per year to reduce climate change. That is roughly on par with an annual subscription to an internet-streaming service like Netflix.

For meeting such a large problem as global climate change, $100 seems to miss the mark. But spread out over a large population like metro Edmonton's (1,430,000 in 2019), the publicly tolerable $100 would give Edmonton $143-million each year to operate a Direct Air Capture system.

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Alberta enjoys high wages and good lifestyles largely as the result of the development of the Province's oil and gas reserves. Approximately 30% of Alberta's gross domestic product is directly linked to activity in the oil and gas sector, and significantly more is indirectly linked. For a transition to a low-carbon economy to be successful, those workers within and closely-tied to the fossil fuel industries must be able to see a place for themselves in the new system.

Negative Emissions technologies are an excellent bridge that capitalizes on infrastructure that exists for the production, distribution and consumption of fossil fuels, while employing the immense knowledge and skill sets of oil and gas workers. Furthermore, these technologies can exist beside a thriving oil and gas sector, while promoting economic diversification. Edmonton would certainly become a hub of high-tech research and development of novel solutions to climate change, and also new industries linked to materials like carbon nanotubes.

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[6] Eric Grenier; "Canadians are worried about Climate Change, but many don't want to pay taxes to fight it: poll", CBC News, July 18, 2019; (https://www.cbc.ca/news/politics/election-poll-climate-change-1.5178514)

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Carbon capture, utilization, and sequestration has typically been the exclusive domain of large industrial facilities like power plants. However, more and more companies like CleanO2, Carbon Upcycling Technologies, C2CNT and Carbon Cure are developing innovative CCUS solutions applicable to a wide variety of sectors and for emission sources ranging from small to large. Edmonton could promote the success of the fledgling carbon capture and utilization industry simply by issuing statements of support and using The City's various communications platforms to inform citizens and businesses that carbon capture exists and can be an attractive method of reducing GHG emissions. The City could also act as facilitator to host workshops for stakeholders in the buildings and industrial sectors to discuss strategies for reducing GHG emissions, including carbon capture.

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The City of Edmonton has a loud voice when working with higher levels of government, and quasi-governmental organizations like the Alberta Electric System Operator (AESO). For carbon capture to be successful, the project proponents must be able to claim the environmental benefits of reducing GHG emissions.

The current GHG accounting systems simply apply emission factors to the electricity and fuels purchased and consumed in different activities (e.g. heating of buildings, vehicle fuels). The underlying assumption is that the CO2 produced in burning the fuel will end up in the atmosphere, and financial records from fuel purchases can be used as a proxy of GHG emissions. However, with carbon capture this assumption is not valid since while the fossil fuels are still purchased, the resulting CO2 is prevented from reaching the atmosphere.

This is especially true of carbon taxes, which tend to be applied at the point of purchase of fossil fuels, rather than the point of emission. Companies that use fossil fuels and choose to reduce GHG emissions through post-combustion carbon capture should be exempt from the carbon levy at the point of purchase of the fuels. Alternatively, if the carbon tax is paid there should be an easy and transparent tax refund mechanism that companies employing carbon capture can apply for.

The City of Edmonton should work with the Government of Alberta, the Federal Government and other regulating agencies who develop emission factors to ensure there is a consistent and transparent measurement and verification system, and carbon tax relief mechanism, that can be used for carbon capture projects.

Procurement Policy

Edmonton has ownership and operational control of large civil works. The City could include a clause in the procurement policy indicating concrete used in municipal projects must contain a minimum percentage of captured CO2.

Setting CO2 Emissions Performance Standards

Edmonton could enact CO2 emissions standards for new and existing buildings. Using a performance metric like CO2/m2/year would allow the buildings industry to innovate to find the most cost-effective methods to meet the standard. Micro-scale carbon capture to reduce Scope 1 emissions from burning fuels for heating onsite could be an attractive method for building owners to achieve the targets, alongside existing solutions like energy efficiency upgrades and renewable energy adoption.

Direct Ownership and Operation

The City could simply build and operate Direct Air Capture plants to achieve the GHG reduction targets. City Council has broad support for government action on climate change, and the declaration of a Climate Emergency on August 27, 2019, provides urgency for bold action. The City could offer CO2 management services as a utility much like the municipal water and wastewater system, or the landfill for solid waste.

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For geological sequestration of CO_2 to be effective, there has to be good integrity of an impermeable cap rock layer. Fractures and faults are not typical of rock layers at depth, and the Basal Sandstone Unit which is the target reservoir has good cap rock layers composed of non-porous evaporites. The risks to the integrity of the cap rock include:

- induced hydraulic fracturing of the cap from injecting the CO_2 plume too quickly,
- fracturing from other oil and gas operations in the region,
- naturally occurring seismic events.

The risk of induced hydraulic fracturing can be reduced through proper sizing, design and operation of the injection system. The Shell Quest CO_2 sequestration system has been in operation since late 2015, and to date has safely stored over 4 million tonnes of CO_2 in the BSU strata without problems. Emulation of this successful project is advised.

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Alberta has quite robust Provincial regulations around geological sequestration of carbon dioxide. The “Mines and Minerals Act” was modified in 2011 to address the use of geological reservoirs for CCS, with the inclusion of Part 9: “Sequestration of Carbon Dioxide”. Upon the cessation of operating the injection well, the regulation makes it clear that responsibility and liability for the CO_2 sequestered underground would be transferred to the Government of Alberta post closure of the CCS project. Responsibility would fall on The City of Edmonton to prove the safe and secure containment of the CO_2 plume underground before the Government of Alberta would issue a certificate of closure and take on responsibility.

The greater risk from a municipal policy perspective is the continuation of operation of a City-owned carbon capture and sequestration plant through successive municipal elections. Future Edmonton City Councils may have less enthusiasm for climate action and GHG emission reductions than the current

Council, and may decide to switch off the Direct Air Capture plant, instantly returning Edmonton's net zero emissions status to Business-As-Usual.

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Alberta has expertise with respect to geological disposal of gases, and is home to innovative start-up companies such as CleanO2, Carbon Upcycling Technologies, C2CNT and Carbon Engineering working to commercialize carbon capture and utilization strategies. With the right municipal policy, Edmonton could become a global hub of research and development focused on Negative Emissions, and attract jobs in new industries that are complimentary to the existing petrochemicals industries. Even with full adoption of the identified "stabilization wedges", Edmonton is not able to achieve the zero emissions target by 2050. This invites contemplation of deploying Negative Emission technologies which can close the gap.

There are commercially viable opportunities in many sectors to reduce CO2 emissions using carbon capture and utilization. These are new products and services which require education and outreach to be adopted by industry. However, being market-driven and cash-flow positive, these emission reduction strategies should be picked up for economic reasons once potential clients become aware.

For emissions that are not addressed through other programs, Direct Air Capture and geological sequestration offers Edmonton the tools necessary to eliminate "residual" GHG emissions and get to net zero emissions by 2050.

Based on the information presented in this brief, the following policy statements are proposed for The City of Edmonton's consideration:

1. Negative Emissions should be considered as one part of a portfolio of greenhouse gas mitigation activities. Carbon capture and utilization or sequestration should not be considered a "silver bullet" which allows society to otherwise continue on a Business-as-Usual emissions trajectory.

2. Alberta is home to several Carbon Capture and Utilization companies that are developing for-profit businesses around captured CO2 converted into value-added products. The City of Edmonton should promote commercially-viable Carbon Capture and Utilization strategies through their communications and outreach platforms. One factor necessary for the successful deployment of commercial CCUS technologies is simply making businesses aware that these technologies exist and are appropriate for their sectors.

3. The City of Edmonton should work with higher levels of government to develop policy mechanisms that allow companies who deploy Negative Emissions technologies to avoid paying carbon taxes on fuel purchases, or to recoup those taxes collected on emissions that are captured and prevented from entering the atmosphere.

4. The City of Edmonton should amend their procurement policy to indicate concrete used in municipal projects must contain a minimum percentage of captured CO2.

5. The City should work with the buildings industry to establish minimum emissions performance standards such as tonnesCO2 per square meter per year. A performance standard would allow building owners to choose the portfolio of emission reduction strategies that work best in their operations. Negative Emissions technologies could be an attractive option for building heating systems.

6. Edmonton’s policy for Negative Emissions should be written broadly enough to be inclusive of technologies that are still in the basic research phase. The Negative Emissions field is quite young, so innovation and breakthroughs are likely prior to 2050 when Edmonton must have net zero emissions.

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Calgary-based CleanO2 is focused on reducing emissions from the building heating industry. Across Canada, heating systems for commercial and institutional buildings are dominated by natural gas. CleanO2 has developed a post-combustion CO2 scrubber that can be attached to the flue duct of any building. Among other end products, CleanO2 converts the captured CO2 into soap product

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Carbon Upcycling Technologies (CUT) is an Alberta corporation with headquarters and operating facilities in Calgary. The company has devised a process to produce advanced solid material additives from CO2 emissions and cheap solid feedstock. Through a proprietary, patented technology, CUT can chemically adsorb CO2 emissions into exfoliated solid feedstock to create a portfolio of fine nanoparticles (1000x finer than a strand of hair) such as

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[7] https://www.cleano2.ca/
[8] https://www.carbonupcycling.com/

graphitic nanoplatelets (GNPs), graphene oxide (GO), graphene quantum dots (GQDs), and enhanced fly ash (EFA). Enhanced fly ash offers a 60% reduction in embodied CO2 compared to Portland cement and increases the compressive strength of concrete by 32%.

CUT pilot plant at Shepard Energy Centre

CUT's enhanced fly ash product made with captured CO2

C2CMS[9]

A Calgary-based start-up company has developed a novel electrolysis process which treats flue gases from power plants to split CO2 and generate carbon nanotubes and oxygen. Capital Power has expressed interest in the process, and has announced it will work with the C2CNT team to build a "commercial-scale carbon nanotube production facility"[10] at the Genesee Generating Station. Carbon nanotubes have unique physical and electrical properties that make them attractive materials for many sectors.

[9] https://www.c2cnt.com/

[10] "From CO2 to super material: Edmonton power company gets into the nanotube business"; CBC News, December 6, 2019;https://www.cbc.ca/news/canada/edmonton/capital-power-carbon-nanotubes-carbon-dioxide-1.5387333

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The initial carbon nanotube plant at Genesee will reduce GHG emissions from the power plant by 10,000 tonnes of CO2 per year while producing 2,500 tonnes of nanotubes, with scale-up opportunities of producing 7,500 tonnes of nanotubes per year (presumably reducing CO2 emissions by 30,000 tonnes per year).

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CarbonCure manufactures a technology for concrete producers that introduces recycled CO2 into fresh concrete. In a process known as CO2 mineralization, the CO2 is converted to a mineral and becomes permanently captured. This enables production efficiencies as well as carbon footprint reduction.

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Carbon Engineering is a pioneering DAC company that was started at the University of Calgary by Dr. David Keith. They have set up a demonstration DAC plant in Squamish, BC, as shown in the following image.

[11] https://www.carboncure.com/