Resource Industry of the Future: Pathways Framework

Alberta Chamber of Resources

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This White Paper ("guideline") was developed through a consensus development process approved by the Alberta Chamber of Resources (“ACR”). This process brings together volunteers representing varied viewpoints and interests to achieve a reasonable consensus to develop a general guideline for industry use. The content of this guideline does not represent the views of any particular committee member. This document is a general guideline and ACR strongly recommends third party advice being obtained to complement and clarify this guideline – and moreover, to implement any recommendations.

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Executive Summary

Our purpose is to build on the Alberta Chamber of Resources' (ACR) ongoing mission of providing cross-sector leadership for strategic and responsible development of Alberta's natural resources, with specific focus on envisioning sustainable advancement for the Resource Industries of the Future (RIF).

The intent of our RIF initiative is to outline opportunities to leverage enabling conditions and overcome limiting conditions for the purpose of identifying conceptual practical pathways, over the next 30 years, in support of a low carbon sustainable resource economy in Alberta.

Our white paper, herein, outlines conditions for promoting success in a low carbon economy including economic, technical, policy, and collaboration aspects. We have composed a vision of practical conceptual pathways for Alberta future focused economic diversification for consideration.

Alberta is home to an abundance of natural resource industries. We have a mature ecosystem for energy innovation and collaboration to build on and leverage for further successes.

We, as a global community, have a significant challenge ahead of us as we accelerate and implement our energy transition solutions. Alberta and Canada have a critical role to play to meeting transition pathway demand. There is an incredible economic opportunity associated with meeting transition pathway demand with competitive, low emission production. An orderly transition will require practical approaches and significant investment on the part of government and industry.

A conceptual pathway shows promise for significant reductions in GHG across Alberta's industry sectors. Ongoing energy efficiency and operational improvements, together with available and developing technologies, require accelerated implementation by industry. These improvements and innovations will need continuously more staunch support and enabling by government policy.

High level actions to support reaching successful outcomes across industry sectors should include:

- Accelerate the deployment of energy efficiency and process improvement technologies
- Identify electrification and fuel substitution opportunities and start to implement
- Build CO2 trunk line and storage hubs as enabling infrastructure
- Develop, demonstrate, and deploy CCUS technologies
- Accelerate development, demonstration, and deployment of new net zero technologies
- Fund and support hydrogen enriched natural gas (or hythane)
- Continue to allocate funding towards continued irrigation infrastructure modernization.
- Broaden access to funding for research and development on advanced irrigation technologies
- Appropriate upgrades to the electric distribution system to support solar installations
- Focus on waste mitigation and diversion solutions that consider the full waste hierarchy
- Focus on solutions to improve energy efficiency, reduce carbon footprint, and reduce impacts on water supply and water quality associated with circular economy processes
- Data-based and digital solutions to measure ESG benefits and outcomes.
- Attention as well to potential new wastes from emerging advanced and composite materials.
- Benchmarking programs to quantify the performance of industry relative to global standards and highlight the untapped potential to reduce energy demand and GHG emissions levels.
- Incentivize energy management, fuel switching and bioenergy with CCUS programs.

Continued and expanded collaborations will be a vital component to enabling pathways for industry GHG reductions. We, as members of the ACR; represent industry, academia, and professional service leaders in Alberta. As vested stakeholders, we are keenly interested in the future of our industries. Next steps in follow-up to our RIF initiative could include focused, solution-oriented dialogues between government and ACR members to high-grade the opportunities for government to action.

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1. MISSION STATEMENT

Our purpose is to build on the Alberta Chamber of Resources' (ACR) ongoing mission of providing cross-sector leadership for strategic and responsible development of Alberta's natural resources, with specific focus on envisioning sustainable advancement for the Resource Industries of the Future (RIF).

2. INTRODUCTION

The intent of our RIF initiative is to outline opportunities to leverage enabling conditions and overcome limiting conditions for the purpose of identifying conceptual practical pathways, over the next 30 years, in support of a low carbon sustainable resource economy in Alberta. We, as members of the ACR representing industry, academia, and professional service leaders in Alberta, have prepared this Pathway Framework guidance message for communication to the Government of Alberta, as well as the Government of Canada.

Pertinent information from available publications has been reviewed to assess conceptual pathways and associated considerations (strengths, opportunities, and risks) for sustainable development of the natural resource industry sectors.

Our framework, herein, outlines conditions to promote success in a low carbon economy including economic, technical, policy, and collaboration aspects. We have composed a vision of practical conceptual pathways for Alberta future focused economic diversification, for consideration.

Introductory Remarks

Alberta is home to an abundance of natural resource industries including forestry, oil & gas, oil sands, mining, agriculture, and have among the best wind and solar resources in Canada.

We have a mature ecosystem for energy innovation and collaboration, which the government could build upon and leverage for further successes. Our industry associations include PTAC, CRIN, and COSIA which offer world-leading examples of industry collaboration. Alberta Innovates and Emission Reduction Alberta are well-structured to partner with industry for the acceleration of innovation. Technology Innovation and Emissions Reduction (TIER) funding supports re-investment in emission reductions. Alberta is also a world leader in environmental regulation.

Environmental, Social and Governance

It is well understood that environmental performance is critical to social acceptance and business success. Climate change is both a serious and real issue and Alberta's resource industries are well positioned with expertise in both science and technology to reduce emissions. We have high standards for transparency, environmental performance, social responsibility, and governance. Alberta has also demonstrated commitment to Indigenous engagement, economic participation, and reconciliation.

It is understood that the Government of Alberta has undertaken an ESG Challenge to address the governance, environmental and societal challenges to strengthen Alberta's image and reputation, aimed at building a more resilient economy. It is our aim that initiatives such as RIF will help support the Challenge.

The Energy Transition

We, as a global community, have a significant challenge ahead of us as we accelerate and implement our energy transition solutions. This global transition will evolve to an energy mix of lower and net-zero energy alternatives. Within this energy mix, most forecasts indicate oil and natural gas will continue to be needed for decades, even in the most aggressive transition scenarios.

Alberta and Canada have a critical role to play to meeting transition pathway demand. There is an incredible economic opportunity associated with meeting transition pathway demand with competitive, low emission production. An orderly transition will require practical approaches and significant investment on the part of government and industry.

3. CURRENT STATE AND INITATIVES FOR INDUSTRY SECTORS

Alberta GHG overall emissions are summarized in -Figure 3-1. In 2019, the total Alberta emissions were 276.8 Mt CO_2eq based on the latest data from Environment Canada and Climate change.

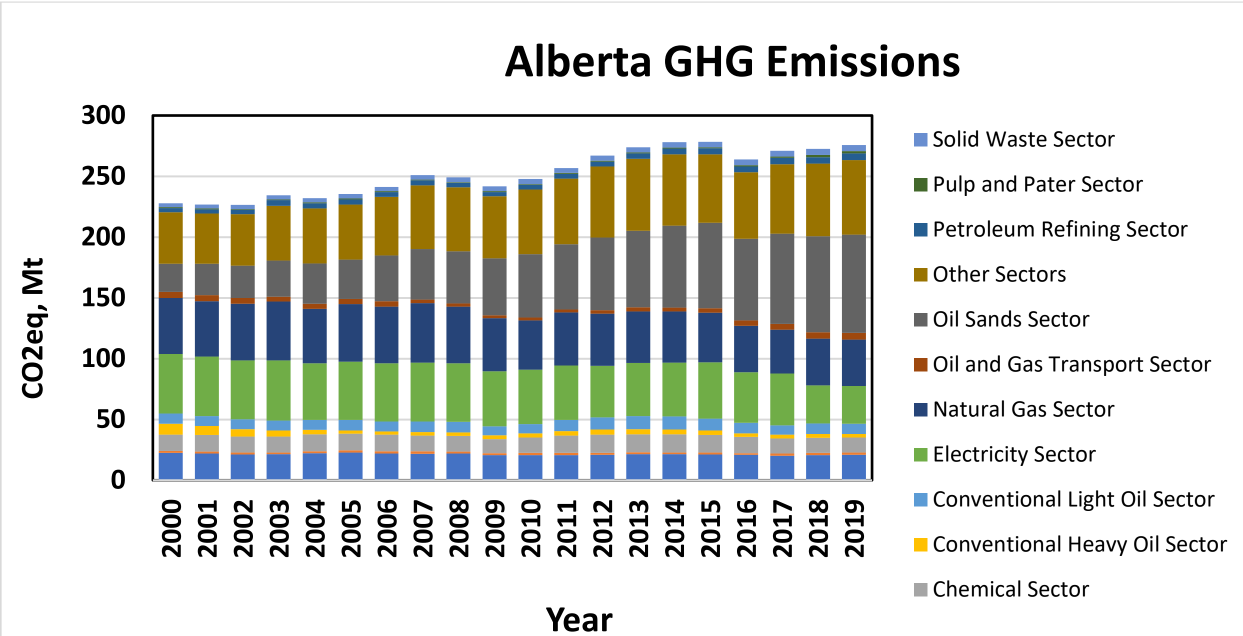

FIGURE 3-1: Business-as-usual Alberta Electricity Sector Projections [1]

Alberta's major emissions in our ACR industry sector categories total 215 CO2eqMt and are summarized below in Figure 3-2 (highest to lowest). The emissions excluded from the review are other sectors including passenger transport, municipal heating, and other non-industrial categories.

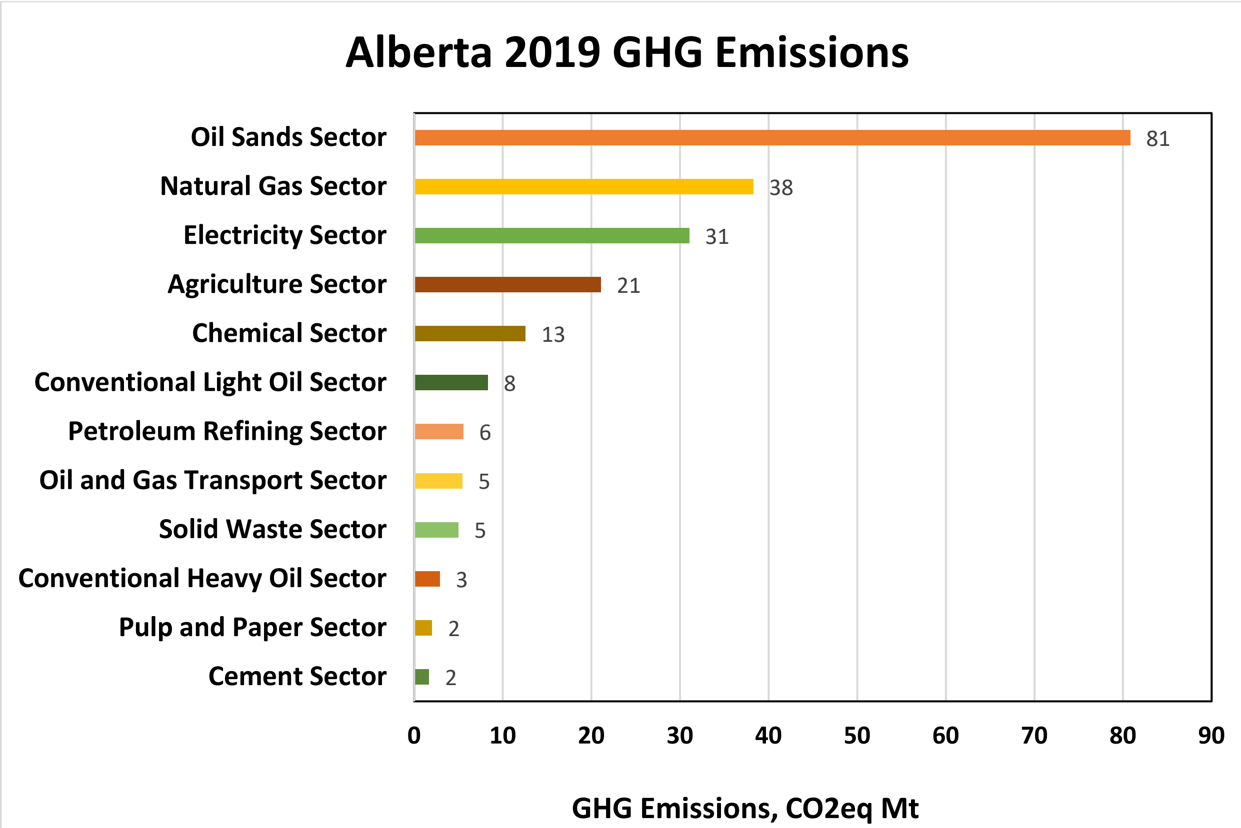

FIGURE 3-2 Alberta GHG Emissions by March 2022

The majority of the ACR reviewed emissions are currently in the oil and gas, agriculture, and chemicals sectors, accounting for 63% of the industrial emissions that we have tracked.

The current situations and emission reduction initiatives in the industry sectors are summarized in the following section.

Oil Sands Sector

Oil sands continue to be a significant contributor to the economy with

- 217,000 direct and indirect jobs across Canada
- $1.0 trillion to Canadian economy between 2009-2019
- $17 billion provincial and federal taxes in the same period [2]

Production from oil sands was 1,130 MMb or 3.095 MMb/d in 2019 [3] with industry growth continuing, driven by global energy demand. CAPP has estimated oil sands growth from 3.1 to 3.5 MMb/d in Q4 2021. It is expected that growth will be on the order of 1% per year in Alberta over the years.

The Canadian oil sands hold vast unconventional crude oil resources, and exploitation has grown quickly. Canada's oil reserves ranked third globally in 2020 by BP for 9% of total proved reserves and 97% of these are Alberta's oil sands. GHG emission intensity of the oil sands extraction processes is significantly more than from conventional oil production. Thus, oil sands is a key sector for both GHG emission concerns and clean technology development.

Industry average emission intensity has been 0.0715 tCO_2e/bbl. or 71.5 $kgCO_2$/bbl. Upstream component GHG emission intensities consist of

- Surface mining SCO: 93.3 (70.6) kg CO_2e/bbl. (total(direct))
- Surface mining PFT dilbit: 54.7 (25.7) kg CO_2e/bbl. (total(direct))
- SAGD dilbit: 66.1 (37.9) kg CO_2e/bbl. (total(direct))

Direct emission is then 47% - 76% of total upstream emission (which sets the limit for on-site mitigation measures for electrification, fuel substitution, and CCUS) [4]

Emissions from current conditions and growth will increasingly need to be mitigated by applying GHG intensity reduction pathways.

It is recognized, by many, that the ESG performance of oil sands industry is among the best in the world [4+]. Alberta's oil sands include significant and growing stakeholder and Indigenous community participation.

Most oil sands companies have committed to the aspiration for net-zero emissions by 2050 (The Oil Sands Pathways to Net Zero Alliance) represents 95% of existing production), demonstrating alignment with Canada's current ambition for net zero emissions by 2050. This represents a unique opportunity for Canada to continue to be a preferred supplier of low carbon production to competitively meet global energy demand in a responsible way.

Natural Gas Sector

Globally, Canada is the fourth-largest producer and the sixth-largest exporter of natural gas, and Alberta produces about 66% of Canada's natural gas.

Investor and stakeholder pressure for ESG actions to combat climate change has intensified focus on GHG emission reduction. Companies in the sector are actively lowering operating Scope 1+2 emissions intensity with a weighted average reduction of 2% in 2020. [5]

LNG continues to be a significant global opportunity. For low-cost natural gas transport from Western Canada to non-inland destinations (especially to Europe to Asia), liquified natural gas (LNG) is preferred. The natural gas costs from Western Canada are significantly lower than in the Asia-Pacific region, providing opportunity for Canadian natural gas businesses investing in LNG facility development in Western Canada. Asia's regional share of global natural gas demand has risen from 13 to 19% in the last decade, with overall consumption nearly doubling, making the Asia-Pacific the most important region in worldwide LNG commerce [5+].

Blue Hydrogen from natural gas has experienced dramatically increasing attention as low carbon energy. Alberta recently released its hydrogen roadmap with active plans to use its natural gas resource base to fuel a growing hydrogen economy, building on our hydrogen economy and carbon capture experience [6]. As the energy transition across different end-use demand sectors of the economy ramps up, the role of natural gas as a bridge fuel for heating and the production of low-carbon hydrogen increases. There is also a potential to export low-carbon hydrogen from Alberta to Asia-Pacific and Europe. Expectations are that the global demand for hydrogen could reach $12 trillion by 2050.

Electricity Sector

The Alberta Electric System Operator (AESO) administers the wholesale electricity market in Alberta in a manner that supports fair, efficient and open competition. In 2020, 208 market participants were active in the wholesale electricity market in the province transacting $5.7 billion of energy (AESO 2020 Annual Market Statistics). This economic activity supports industry in Alberta and is the backbone of significant economic activity across Alberta's resources industries.

Alberta's market has grown significantly over the past decades as population growth, general economic activity, and resource development, particularly in the oil sands, has spurred direct and indirect growth in electricity consumption. In 2020, Alberta's peak demand stood at 11,729 MW and total Alberta Internal Load was 83,115 GWh.

To meet the demands of the electricity system, Alberta consumers rely on a mix of supply that includes coal, natural gas, cogeneration, wind, solar, hydro, and other forms of generation. In 2020, installed capacity in the province averaged 16,362 MW.

Over the past decade, Alberta's supply mix has undergone a significant transition as a policy-directed phase of coal generation has retired significant portions of installed capacity. In 2017, installed capacity of coal-fired generation exceeded 6 GW. By 2023, this capacity will be retired in its entirety, accounting for the largest emissions reductions achieved in the province.

Concurrently, Alberta has realized significant growth in renewable generation as developers have looked to exploit some of the best solar and wind resources in the country. Wind capacity in 2020 was approaching 2 GW, while installed capacity of solar was approximately 500 MW.

The combined impact of these changes in fundamentals has been a significant reduction in electricity sector emissions. Between 2017 and 2019, electricity sector emissions dropped from 44.3 MT to 31 MT, with a further 11 MT expected in the coming years. As coal capacity continues to retire and renewables expand, the electricity sector in Alberta will have made significant contributions to Canada's overall objective of achieving net zero carbon emissions. [7]

Alberta contributes nearly 60% of Canada's electricity sector GHG emissions. Alberta currently generates 46% of its electricity from coal and 10% from renewables. Wind capacity is expected to expand 5000 megawatts by 2040, from 1475 megawatts in 2019 and generation from wind increases to 18 terawatt-hours by 2050, making up 18% of the generation mix. Relatively limited growth is seen for other renewables. As coal generation is reduced, 32% of GHG emissions are eliminated by 2030. Natural gas cogeneration and natural gas combined cycle emissions make up the majority of emissions between 2030 and 2050; total GHG emissions only decrease by 8% during that time, also reflected by the emission factor remaining relatively stable after 2040. Figure 8 below shows projections for Alberta's business-as-usual electricity sector.

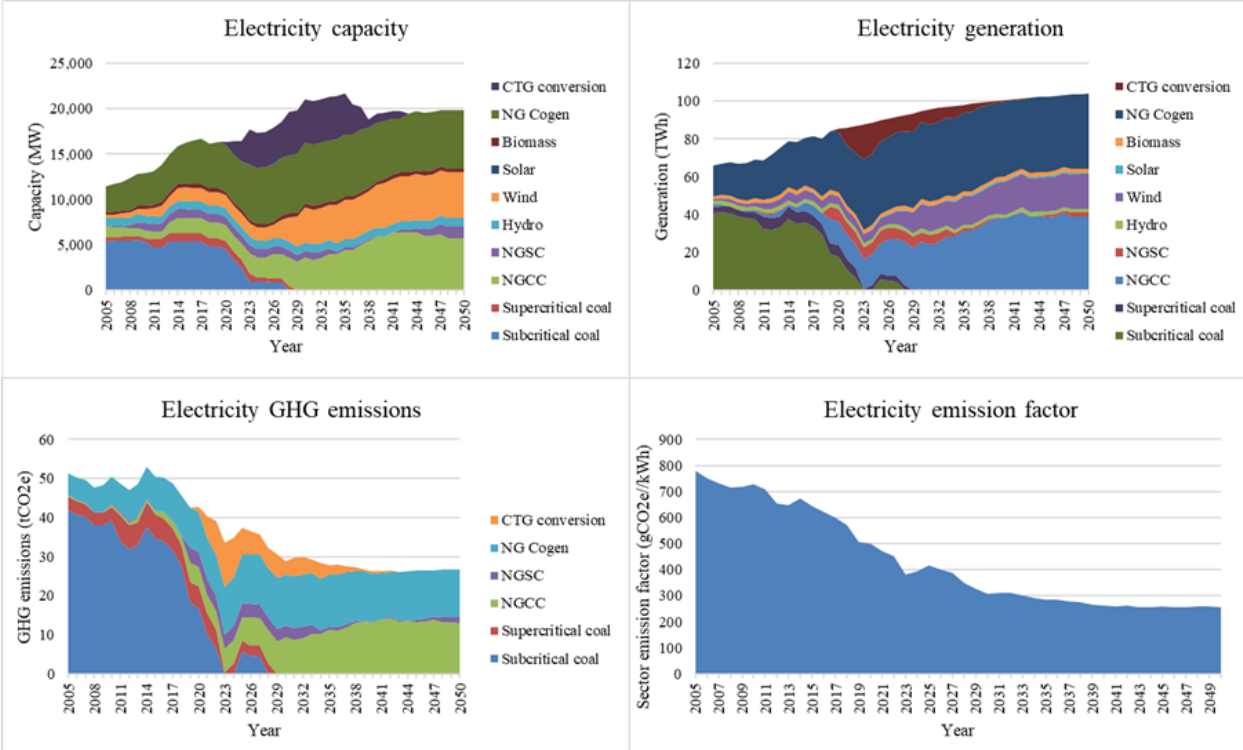

FIGURE 3-3 Business-as-usual Alberta Electricity Sector Projects [8]

Chemical Sector

Alberta's chemical industry relies on oil and gas products for both fuel and feedstock. As such, activity in the sector will be strongly affected by investment in new oil and gas production capacity and regulatory instruments designed to decarbonize the oil and gas sector.

Alberta's chemical sector accounts for 17% of total sales value for manufacturing sectors in the province [9]. Ammonia and ethylene production are together responsible for 12% of industrial energy consumption and 10% of industrial GHG emissions. Dow's recent announcement to build a net-zero emission ethylene production facility shows promise for decarbonization in Alberta's petrochemical subsector [10]. Canadian ammonia producers are among the most efficient worldwide, but opportunities for energy demand and GHG emissions reduction remain unrealized [11].

Agricultural Sector

In 2017, 8% of Alberta's total GHGs were from agricultural sources; about half were from livestock production and half from cropping operations, with on-farm fuel use at 13% of agricultural GHGs.

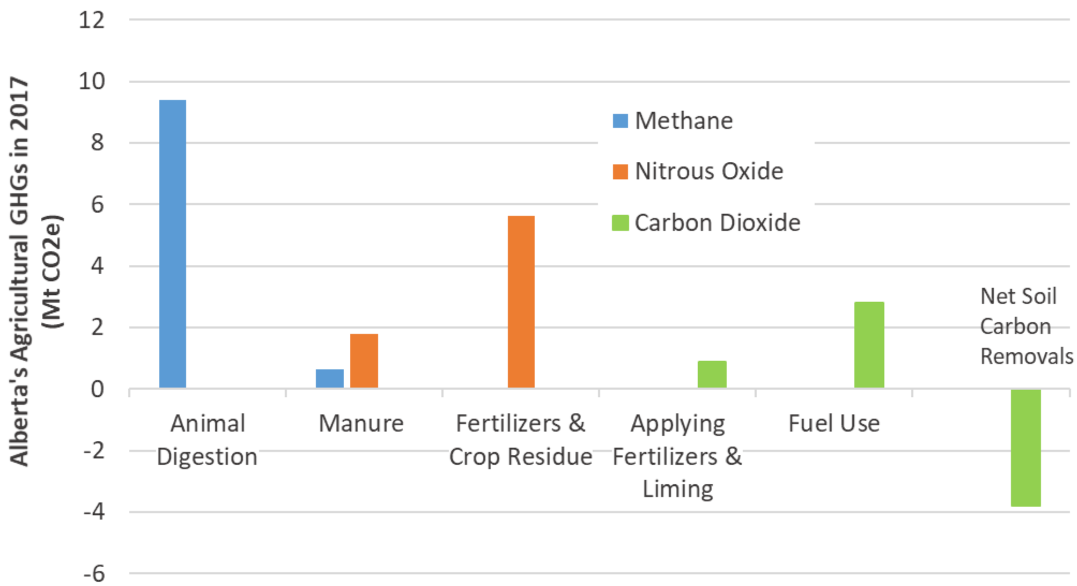

FIGURE 3-4 Alberta's Agricultural GHG's in 2017 [12]

Key agricultural sector GHG trends are notable. Methane from animal production in Alberta has decreased since 2005, due to efficiency improvements and lower cattle numbers. Higher yielding crops that use more fertilizer and manure have increased N_2O. More land area in annual crops has increased CO_2 from fuel use. Rates of soil carbon storage in 2009 reported removing close to one-fifth of agricultural GHGs. However, this is decreasing as conservation cropping becomes more widely practiced and areas of perennial crops decline according to Environment Canada.

At current adoption rates of carbon sequestering agricultural practices in Canada, it is reported that soil carbon accumulation can continue for at least until 2040. After this period, the continuance of sound farming practices that conserve the soil will maintain this sink rather than increase it.

Water conveyed through irrigation infrastructure provides water access to:

- 50,000 people in 50 towns and villages and the rural area of southern Alberta,
- Commercial and industrial purposes, oil and gas production, value-added processing facilities
- Other agricultural purposes such as livestock watering
- Recreational opportunities on over 52 irrigation reservoir storage reservoirs.

The presence of irrigation conveyance infrastructure provides regional climate change adaptation by mitigating drought and flood events.

Rehabilitation/modernization of irrigation infrastructure has created a highly efficient water delivery system in southern Alberta and supports on-farm conversion to more efficient application systems. Water efficiency gains, largely achieved through rehabilitation and on-farm conversions, allow the sector to irrigate more land while diverting less water from source rivers.

Delivery of water through district infrastructure is achieved primarily through gravity conveyance. The remaining area that cannot be fed by gravity requires on-farm electricity, natural gas- or diesel-powered pumping units to facilitate water application where 60% utilizes electricity, 23% natural gas and 2.2% diesel, and a negligible amount of solar.

The total capacity of eight hydroelectric stations located on the Government of Alberta and irrigation district infrastructure is 92MW.

Genome Alberta plays an integral role in technology, research, and innovation in the province by supporting the development and deployment of genomics enabled solutions for health, agriculture, energy, forestry, and the environment - Alberta's Bioconversion Ecosystem. This initiative aims to establish Alberta as a national bioconversion hub that will enable ecosystem growth across Canada and expand biorefining capacity towards economic growth and diversification.

Economic Value of Irrigation Districts

- $5.4 B annual contribution to GDP; 80% accrues to the region and province and 20% to the irrigation producers.
- $3.2 B annual contribution to labour income
- 46,000 FTEs annually
- $1,096.97 M in fiscal revenues generated for GOC by irrigation related activities with no direct irrigation-related expenditures by the GOC.
- Every $1.00 invested in irrigation related activities returns $3.56 revenue to the Province of Alberta. [13]

Petroleum Refining Sector

The petroleum refining sector accounts for more than 30% of global greenhouse gas (GHG) emissions. Within the sector, the oil and gas industry accounts for 39% and 37% of the energy consumption and GHG emissions, respectively. In the petroleum refining industry, fossil fuels are used as both feedstock and a source of process energy. In addition to its environmental footprint, energy makes up almost 50% of the operating cost in the petroleum refining industry.

With a crude distillation capacity of 1.98 million barrels per day, Canada hosted more than 2% of the global petroleum refining capacity in 2015. Almost 25% of Canada's refining capacity is in Alberta, which then is the largest refining capacity in the country. Considering the anticipated increasing trend in GHG emissions from the petroleum refining sector (as a result of capacity expansion) and Alberta's ambitious targets for emissions reduction and energy efficiency improvement, it is crucial to understand energy efficiency improvement and GHG emissions mitigation potential in the petroleum refining sector.

Pipelines and Midstream Sector

Pipelines in Alberta consist of natural gas, oil, hydrogen, and CO_2 pipelines. Interprovincial natural gas pipelines total 407 million cubic metres per day of capacity. Capacities for oil pipelines moving Alberta crude to outside markets total 727.6 thousand cubic metres per day and interprovincial oil pipelines total 1219 thousand cubic metres per day [14]. The Alberta Carbon Trunk Line (CO_2 pipeline) has a transportation capacity of 14.6 Mt of CO_2 per year [15].

The growth in bitumen and synthetic crude oil (SCO) production in Canada has superseded pipeline capacity growth in recent years, leading to the possibility to transport the crude oil from Alberta by rail to desired markets. The transportation potential of SCO by rail or newly built pipelines is highly sensitive to market distance, transportation scale, and crude grade being transported. The use of insulated rail carriages for the transport of raw bitumen may have a cost competitiveness advantage over pipelines.

The economic consequences of a pipeline capacity shortfall are prohibitive for the oil and gas sector and can result in a rise in pipeline tolls due to producers' increased sense of urgency to prevent production shutdowns and deliver their goods to market or where investment in rail loading infrastructure for takeaway capacity is justified.

To reduce the emission intensity of natural gas and increase short-term demand for hydrogen, hythane (a blend of natural gas and hydrogen) can be used. The potential for hydrogen blends to reduce emissions from using hythane is limited by safe blend limits. Overall, hydrogen blends of 5%-15% in natural gas pipelines would require only minor adaptions to natural gas infrastructure [16]. End-use limitations need to be considered. While properly serviced appliances could handle blends up to 28%, poorly serviced ones cannot handle any hydrogen. Also note that if existing natural gas pipelines are repurposed for transporting hydrogen, the pipeline capacity will be reduced since hydrogen has a reduced heating value and energy density compared to natural gas. At a 15% blend of hydrogen, the capacity of a pipeline would be decreased by approximately 11%.

Solid Waste Sector

Municipal solid waste (MSW) management has become one of the most challenging tasks for policymakers and regulatory authorities worldwide. Canada's MSW generation increased by 31 million tonnes in 2019 from 2009 and Alberta's MSW generation increased by 1.37 million tonnes from 2002 to 2018. Alarmingly, more than 70% of this MSW is disposed of on land [17].

Since land disposal has environmental and public health issues, there is increased emphasis on diverting MSW from landfills to material and energy recovery facilities by waste management authorities and local communities. The disposal of MSW in landfills is one of the key factors contributing to human health and surrounding environment [18]. In Canada, greenhouse gas (GHG) emissions from landfills account for about 20% of methane emissions of the country [19]. Given increased regulations to reduce fossil fuel use and to ultimately discontinue using fossil fuels, the concept of waste-to-value-added (W2VA) facilities is receiving increased attention. Recovering material and energy from solid waste is considered environmentally preferable. This helps in MSW management and can help offset GHG emissions [20]. Selecting a site for a W2VA facility without proper assessment may adversely affect its operational efficiency. To minimize adverse environmental, economic, and social impacts and ensure the sustainability of W2VA facilities, carefully identifying optimal locations is essential.

Quantifying the availability of various feedstocks are key for sustainable decision-making process. Canada currently generating nearly 30, 28, 24, 21 and 7 million tonnes of dry manure, agricultural residue, MSW, forest residue, and biosolids, respectively, per year (Figure 28). Patel et al. [21] developed a GIS-based framework to locate biomass and municipal solid waste collection points for an optimal waste conversion facility in Alberta, Canada. They estimated of the annual availability of feedstock using the most recent data shows MSW, agricultural residue, and forest residue potentials of 4,330,000 wet megagrams (Mg), 4,060,000 dry Mg, and 2,070,000 dry Mg, respectively, in Alberta.

TABLE 3-1: CO2e Emissions from Waste in Alberta (2019) [22]

WASTE	**2019** CO2e	Notes
a. Solid Waste Disposal (Landfills)	4,500	Includes municipal landfills; may not include large commercial landfills (e.g., WM landfill, Thorhild)
b. Biological Treatment of Solid Waste	20	Mainly composting

c. Wastewater Treatment and Discharge	120	Largely municipal facilities
d. Incineration and Opening Burning of Waste	40	Common in small/rural landfills
e. Industrial Wood Waste Landfills	400	Mainly forest industry mills
TOTAL	5,200	

A number of strategic initiatives and programs target diverting waste from landfill and other disposal mechanisms, targeting diversion of specific waste streams, and mitigating environmental impacts of landfills to achieve ESG outcomes. Highlighted initiatives include:

- Recycling (Landfill diversion) - As in many jurisdictions, Alberta has established markets for regulated recyclable ("designated") material collected under recycling programs
- Plastics Circular Economy - The Government of Alberta, Alberta Plastics Recycling Association, Plastics Alliance of Alberta, and Recycling Council of Alberta are collaborating with industry in developing a plastics circular economy for Alberta that leverages Alberta's petrochemical/polymer industry strengths and are also pursing implementation of extended producer responsibility (EPR) under Alberta's recent legislative amendments. [23]
- Organic Waste (including Wood Waste)
    - A long standing common key objective in municipal, provincial [24] and federal waste strategies has been mitigation of methane emissions from landfilled organic wastes as well as organic wastes from wastewater treatment, and creation of value-added products from organics. These areas of interest have activated numerous collaborations amongst Alberta's R&D institutions, industry, entrepreneurs, and municipalities.
    - Active research and demonstration projects focus on enhancing production and economics for biogas and other gas products, liquid biofuels, advanced materials, and chemicals from diverted organics (including wood waste).

Pulp and Paper Sector

The pulp and paper sector is characterized by high bioenergy consumption and high levels of process-integrated electricity cogeneration [25], but cost-effective energy demand and GHG emissions reduction opportunities remain unrealized or under-utilized. The development of novel bioenergy production processes and its integration with carbon capture and storage (CCS) may accelerate decarbonization in the sector, although many facilities are virtually carbon neutral already due to biogenic energy production.

The sector has relatively high energy demand but lower relative GHG emissions across industry sectors [26]. Alberta is home to 5% of Canada's pulp mills [27], which together accounted for 2.0 $MtCO_2e$ in direct GHG emissions in 2019 [28].

Four pulp mills in Alberta rely on the kraft pulping process (a chemical process that enables self-contained energy production), while 3 thermo-chemical or 'high yield' pulp mills have large energy demands. Those three latter mills have invested in alternative energy approaches to offset their reliance on external power, while the former four have made significant investments to expand generation and transmission capacity. In all cases, further opportunities related to heat recovery, carbon capture and emissions' reduction exist, awaiting feasible economics and appropriate technologies.

Cement Sector

Alberta's cement industry relies on three major energy sources: natural gas, coal, and electricity. Therefore, cement sector activities will be affected by growth in carbon price and policies on net zero emission targets in the future. New investment in the cement sector needs to consider decarbonization tools and measures. The cement, gypsum and lime sectors are very integrated.

Total energy use in Alberta's cement sector was increasing with an annual growth rate of 0.05% from 2000 to 2018. However, due to implementing energy efficiency measures, GHG intensity in terms of (tonne/TJ) was decreasing with a rate of -0.32% in the same period.

4. ENABILING OR LIMITING CONSIDERATIONS

An assessment of considerations that enable or limit the advancement of GHG reductions in identified resource sectors is summarized in the following sections.

Funding, investment, incentives, taxation, and credits – available and needed

Oil Sands Sector

The oil sands have attributes that represent both opportunities and challenges. Attractive aspects include large proven reserves, low production decline rates, requiring low sustaining capital, and a refining market that prefers heavy oil with a resilient long term demand outlook. Oil sands must remain competitive on cost and improve emissions performance to attract continued investment. Any material additions to the tax burden above that of other jurisdictions globally (e.g., carbon taxes) risks contributing to shifting global investment leakage outside the province. Significant co-investment by governments in emissions reduction are needed to unlock the significant long term economic opportunity to meet transition pathway demand.

Funding sources are available to support continued sustainable growth and ESG performance of oil sands. Alberta Innovates (AI), Emissions Reduction Alberta (ERA), and Alberta Environment and Parks (AEP) provide significant funds for technology innovation and emission reduction in the sector.

Further leveraging and additional funds are needed to support the industry transition.

ERA offers an important vehicle that could be further leveraged. A 5X or 10X multiple investment in innovation for emission reduction should be considered. Consideration for directing funding towards net zero production of energy and lowering emissions from consumers

For technologies that are proven but not economic, investment will occur where incentives sufficiently close the gap. As a waste stream, emissions management is just a cost for which operators merely seek to break even. Any consideration of offset credits needs to reflect certainty of value for the long term. Direct support for capital costs in the form of grants is preferred over tax credits.

Natural Gas Sector

The enabling and limiting considerations for the natural gas sector are similar those outlined in the Oil Sands sector. Currently the only other area that is significant is the Government of Canada Emission Reduction fund (ERF) that was announced in 2020 and the new Methane targets issued in December 2020. Focus on methane emission reduction technology development is required to meet these new aggressive targets.

Electricity Sector

Key to further decarbonization in the power sector is the application of carbon capture and sequestration to existing gas-fired generation facilities. To support overall viability of these technologies, targeted government support is needed to reduce risk and encourage deployment. Support that is currently being considered in the form of tax credits, concessionary lending through the Canadian Infrastructure Bank, and other forms of direct and indirect support are essential to the development of projects and sequestration hubs across the province.

A significant transition is required for Alberta to decarbonize its electricity sector, somewhat mirroring the current global predicament. It is not clear what clean production pathways or combinations of technologies would be best suited for the transition, given the wide range of low-carbon options, fast changing costs of renewables, and the sensitivity of their cost-effectiveness. In-depth analysis of long-term renewable electricity generation transitions can shed light on this issue considering resource availability, energy prices, economic development, and government policy, and can also help to inform developing countries to transition away for coal.

The Alberta government Carbon Competitiveness Incentive Regulation (CCIR) incentivizes electricity generation with lower carbon emissions than efficient natural gas-based generation.

Chemical Sector

Currently to decarbonize the chemical sector will utilize hydrogen and CCS as a method to decarbonize the manufacture of chemicals and plastics. Enabling is the Carbon tax, Clean Fuel Standard and the new proposed Investment Credit for Carbon Capture, Utilization, and storage.

Agricultural Sector

ERA funding has been identified through the Food, Farming and Forestry Challenge which is committing $33 million for 17 projects with a combined value of $107 million in public and private investment. Funding will advance technological innovations in Alberta's agriculture, agri-food, and forestry sectors. It will create jobs, attract investment, open new markets, and deliver it all with improved environmental performance.

Long-standing (Irrigation Rehabilitation Program) and new (Alberta Modernization Program) funding assist in maintaining and strengthening the efficiency of irrigation infrastructure and should be maintained.

Incentive programs offered to producers through the Canadian Agricultural Partnership continue to support upgrades to on-farm irrigation application systems.

Consumers are driving conversations on sustainability through the entire agricultural value chain. In the future irrigators may be expected to prove water sustainability and undertake further on-farm actions in order to market their product. Market prices may not necessarily rise enough to allow the producer to recapture additional costs placed on them due to final consumer demands.

Expected changes to precipitation patterns increasing temperatures may modify the timing of river flows. Consideration, approval, and construction of additional reservoir storage facilities will provide further adaptation to the region. Improved and increased levels of climate and river supply forecasting will assist the southern region in a better plan for and respond to extreme weather events and strengthen southern Alberta water management.

The anticipated increase in electricity demand driven by the global desire to reduce carbon emissions could increase risk to the irrigation sector. To date, the sector has been relatively immune from large scale electricity outages. However, future high demands driven by the global desire to reduce carbon emissions could increase risk to irrigation infrastructure and therefore to crop and livestock production.

Aquatic invasive species, particularly invasive Dressenid mussel species, are a risk to irrigation infrastructure and the ecological health of irrigation storage reservoirs. Prevention, inspection and enforcement actions across the country are patchy, somewhat misaligned, and drastically underfunded.

Conventional Light Oil Sector

The enabling and limiting considerations for the conventional light oil sector are similar those outlined in the Natural gas sector. Currently the only other area that is significant is the Government of Canada Emission Reduction fund (ERF) that was announced in 2020 and the new Methane targets issued in December 2020. Focus on methane emission reduction technology development is required to meet these new aggressive targets.

Petroleum Refining Sector

Currently to decarbonize the refining sector, similar to the chemical sector, industry will utilize hydrogen and CCS as a method to decarbonize the manufacture of chemicals and plastics. Enabling is the Carbon tax, Clean Fuel Standard and the new proposed Investment Credit for Carbon Capture, Utilization, and storage. The Clean Fuel standard should provide a mechanism to allow credit access for this sector and more work is required to understand the ability to fund and utilize these credits to decarbonize this sector.

Solid Waste Sector

Alberta Innovates (AI), Emissions Reduction Alberta (ERA), and Alberta Environment and Parks (AEP) have a history of investing in knowledge generation and technology innovation projects to support waste reduction, value-added opportunities from waste reuse and recycling, and direct/indirection emissions benefits in the solid waste sector. Additional sources of funding include:

- First Nations Waste Management Initiative [29]
- Federation of Canadian Municipalities Programs [30]
- Collaboration between Federal and Provincial/ Provincial, Municipal and Indigenous in economic development around waste diversion

Similar to oil sands, financial supports and considerations from ERA could be further leveraged for directing funding towards:

- net zero production of energy,
- lowering emissions from consumers
- enabling emissions reductions (and other environmental impacts) in upstream production of consumer goods by displacing virgin materials with recycled materials.
- consideration of offset credits needs to reflect certainty of value for the long term.
- direct support for capital costs in the form of grants is preferred over tax credits.
- while not all solid waste is managed by municipalities, waste management is an overhead for municipalities, financed through capital funding (federal/provincial), municipal taxation or utility charges, tipping fees and deposit programs for regulated “designated” materials.
- solid waste management – including diversion and recycling – are potential additional revenue generating opportunities for municipalities and business opportunities for the private and non-profit sector, depending on the waste management business model.
- Examples of investment in support for waste management and diversion:
    - Innovation: AB Innovates priorities – Circular Economy [31], Bioenergy, Waste Diversion

- Scale-Up to Commercialization: ERA, Prairies Canada
- Recycling: Alberta deposit programs for "designated" materials
- Government of Alberta Extended Producer Responsibility engagement [32]
- Development and adoption of material "fit for use" quality standards and operating standards and best practices (e.g., CCEM federal/provincial/territorial collaborations; Biomass Quality Network; SWANA (Solid Waste Association of North America)

Pulp and Paper Sector

Energy efficiency improvements may lead to significant levels of GHG emissions reduction in the sector. In many cases, these measures may be realized at net cost benefits excluding avoided carbon tax. Alberta pulp producers are far from reaching the practical minimum energy intensities for end-products, as over half of forecasted emissions from the sector can be mitigated through economic measures by 2050 [33]. Bio-based fuel production and use represents a significant opportunity for the sector as well due to the availability of feedstock and waste. The use of fuels like black liquor, biomass, and biogas for process heat generation can reduce energy demand, GHG emissions, and fuel costs for pulp and paper producers.

An estimated 97% of the cumulative GHG mitigation potential represented by commercially ready measures can be achieved at negative marginal abatement cost, and 98% at a cost lower than \$170/tCO2e. Measures with marginal abatement costs above \$170/tCO2e are unlikely to become cost-effective through carbon pricing increase alone and may require specific subsidization to become economical for Canadian pulp and paper producers.

ERA funding has been identified through the Food, Farming and Forestry Challenge which is committing \$33 million for 17 projects with a combined value of \$107 million in public and private investment. Funding will advance technology innovations in Alberta's agriculture, agri-food, and forestry sectors. It will create jobs, attract investment, open new markets, and deliver it all with improved environmental performance.

Cement Sector

Cement sector is one of the major energy intensive industries globally, and there are different efforts to reduce the energy demand and mitigate GHG emission in this sector. Using the waste of other sectors such as waste tires and agriculture wastes in the cement sector as a fuel can be considered as tools to reduce energy demand in this sector. Using green hydrogen instead of natural gas and employing energy efficiency opportunities in this sector can reduce total energy use and GHG emissions. Energy efficiency improvements in iron and steel sector can lead to significant levels of GHG mitigation. Some of these measures are at net cost benefits excluding avoided carbon tax.

<u>Technology readiness and adoption - practical/achievable/economic in time frames</u>

Oil Sands Sector

Scenario analysis have indicated that assessed energy efficiency measures are achievable at negative cost and are thus expected to be adopted and implemented fully. These measures are of high technical readiness level (TRL) and face low adoption barriers. Carbon capture and storage technologies have been demonstrated in Alberta but are of varied TRL (medium to high). Renewable and nuclear energy sources may be integrated with oil sands production facilities to reduce emissions intensity. Many of these technologies are mature but face implementation barriers in high capital costs of electrified end-use equipment. Additionally, the development of nuclear energy is not feasible in the short term due to required regulatory approval. Market penetration modelling shows that carbon capture technologies are expected to achieve higher relative adoption than renewable and nuclear energy integration by 2050.

Several pathways for emissions reductions are being pursued in parallel:

- Efficiency and Process improvements:
    - In-situ: steam additives, non-condensable gas co-injection, well design, water treatment, co-generation
    - Mining: alternative ore handling, mine truck fuel switching, trolley-assist
    - Natural gas decarbonization, hydrogen
    - Geothermal
- New recovery technologies: solvents, electro-magnetic heating
- CCUS with current extraction technologies; new CCUS technology development, molten carbonate fuel cells
- Other net zero emission technology including small modular nuclear reactors

The range of technology readiness needs to be addressed with several that are near commercial:

- Efficiency and process improvement (cogeneration, water treatment, digital oilfield, steam additive, non-condensable gas cap, etc.):
    - TRL 7 – 10
    - low adoption barrier
    - either in or near commercial deployment,
    - a single tech may lead to less than 10% upstream GHG emission reduction.
- Electrification and fuel substitution:
    - TRL 6 – 9
    - medium deployment barrier
    - near commercial deployment, deployment commences within 5 years (?)
    - may lead to less than 5% upstream GHG emission reduction.
- CCUS and Blue Hydrogen:
    - TRL 5 – 9 (TRL 9 in upgrading hydrogen production facility, TRL 5-8 in OTSG facility, and TRL 5 – 6 in NGCC and Cogen facilities)
    - medium to high deployment barrier
    - deployed in upgrading facility already, demonstration in OTSG facility in 5 years and commercial deployment before 2030
    - may lead up to 50% upstream GHG emission reduction
    - Alberta has among the best opportunities globally for geologic storage of CO2
    - Oil Sands emissions are geographically concentrated making them better suited to capture
    - Current CCUS technology proven but struggle with economics
    - Alberta has considerable existing resources, infrastructure and talent that can be leveraged
- New recovery technologies (NAE, IPEP, ES-SAGD, Steam-Solvent hybrid, Pure Solvent, RF, etc.)
    - TRL 5 – 8, mainly in technology development and demonstration stage
    - medium to high deployment barrier
    - A few technologies will likely be deployed before 2030
    - may lead up to 50% upstream GHG emission reduction
- Net Zero emission technologies (SMR, Renewable, BE-CCUS, DAC, etc.)
    - TRL 5 – 8, mainly in technology development and demonstration stage
    - high deployment barrier

- SMR may be deployed post 2035; renewable energy powered extraction or RF process may be deployed post 2040; negative emission technologies (BE-CCUS and DAC) will need to be in place before 2050 to make up the difference.
- in combination, may lead up to 100% upstream GHG emission reduction.

As the world transitions, net zero emissions oil sands production also offers compelling opportunities for non-combustion uses, particularly carbon fibre as an incredible next-gen economic growth opportunity. SMNR for oil sands in a post-oil sands operation period could then provide base load power to the grid.

Industry has positioned itself for the opportunity to collaborate with government with organizations including Oil Sands Pathways to Net Zero Alliance, Alberta Carbon Grid (Pembina & TC Energy), and COSIA. By partnering with industry, government can unlock ESG excellence while maintaining jobs and long-term economic prosperity, with considerable resource rents that can be put to work decarbonizing other parts of the economy and ultimately reducing demand for fossil fuels.

Natural Gas Sector

Hydrogen produced from natural gas with carbon capture and sequestration (CCS) has the potential to help reduce emissions in the transportation and home heating sectors. Hydrogen from steam methane reforming (SMR), autothermal reforming (ATR), and Natural Gas Decomposition (NGD). Steam methane reforming (SMR) is a mature technology that has been used for hydrogen production for decades. This technology uses natural gas and steam to produce grey hydrogen and is responsible for 48% of the hydrogen produced globally. Interest in autothermal reforming (ATR) and natural gas decarbonization (NGD) for blue hydrogen production is also growing. The concept behind these technologies is not new as applications are incorporated in some industrial processes. For ATR, the most notable commercial applications are oxygen-blown units for methanol production and air-blown units for ammonia production using natural gas.

Projected water needs for the implementation of increasing hydrogen production could be significant compared to current industrial and consumptions, as illustrated in Figure 4-1. Actual water needs will depend on the extent of specific conversions within industry for a hydrogen-based economy.

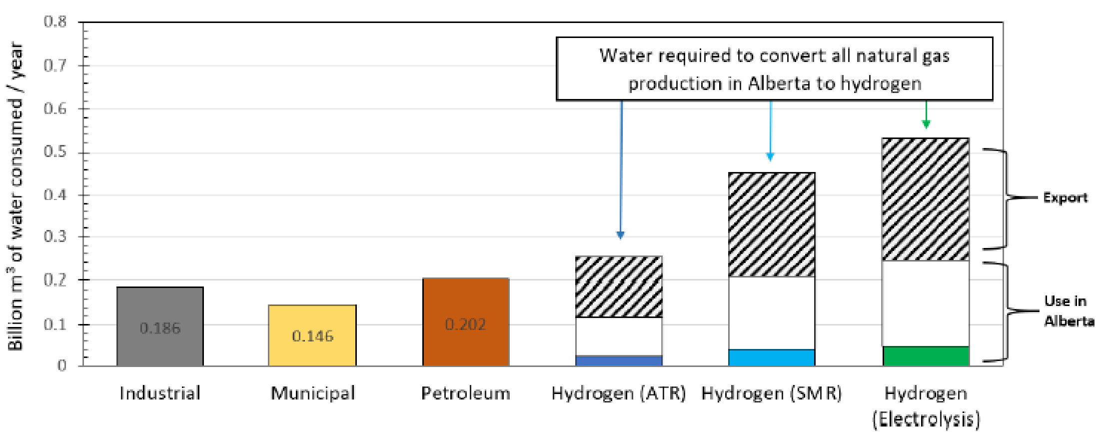

Figure 4 - Annual water consumption in Alberta, including projected demands for hydrogen production.

FIGURE 4-1: Annual water consumption in Alberta, including projected demands for hydrogen production [34]

Water availability is an important constraint, especially in the South Saskatchewan River Basin which is no longer open to applications for new water licences. The technologies currently under consideration for hydrogen production such as SMR and ATR are highly water intensive. The opportunities for producing hydrogen are more realistic in the Athabasca River and Peace River basins, as well as some limited additional development in the North Saskatchewan basin.

Thus, water is often a constraining factor in conventional hydrogen production methods. In addition, the regulatory framework for hydrogen use in Alberta remains unclear.

There are a number of new hydrogen technologies that have indicated publicly that their production from stranded resources with carbon sequestration may provide low carbon intensity options for Alberta (Proton and Cvictus). These technologies may have a material impact on the use of hydrogen.

NGD has also been used in syngas applications and to produce carbon black.

Electricity Sector

Alberta operates a competitive wholesale electricity system that allows generation to be developed based on supply and demand fundamentals and the cost of generation. Mechanisms that impact the level playing field between generation types should be avoided.

Cost competitiveness of renewables continues to improve and will continue to drive additional capacity expansion of low-carbon sources of power in Alberta. There is high technology readiness for renewable energy technologies in Alberta and commercial viability will continue to drive capacity additions and emissions reductions across the electricity sector.

Other key decarbonization technologies applicable to the power sector include

- Carbon capture and sequestration applied to combined cycle natural gas generation
- Negative emissions technologies, including direct air capture. Applied where physical decarbonization is not possible for economic or technical reasons (peaking units).

In many scenarios, wind power reached its annual capacity additions of 600 megawatts throughout recent study period. The highest wind capacity generated across all scenarios was 15 gigawatts, which generated 55 terawatt-hours in 2050. These figures are significantly higher than current (2019) levels of wind-based power, but feasible Alberta wind power potential reported in the literature ranges from 64 to 150 gigawatts and 169 to 410 terawatt-hours/year, indicating that the wind power projected is feasible, provided the required transmission infrastructure and grid integration is completed.

Chemical Sector

The chemical sector is focused on hydrogen and CCS adoption as the technology solutions to abate emissions.

Agricultural Sector

The agricultural sector is working on incremental improvements for GHG reduction as shown in Figure 4-2. The largest GHG impact is from animal digestion and nitrogen fertilizer management. Total GHG emissions from production of one kilogram of Canadian beef has been reduced by 15% from 1981 to 2011. RNG from waste streams is being introduced. There has been progress on reduced fuel use and fuel switching.

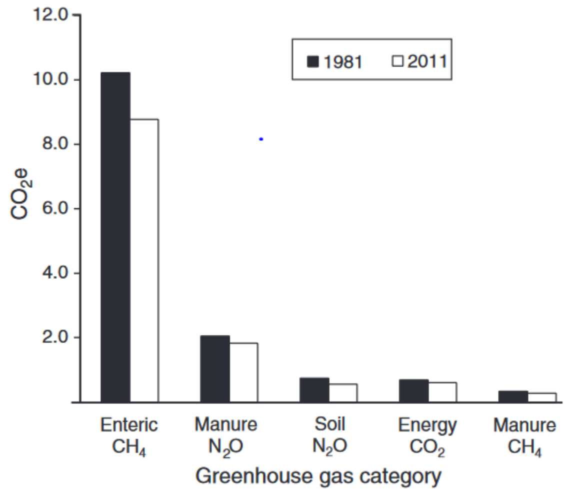

FIGURE 4-2 The contribution of different sources of greenhouse gases to the total emissions associated with production of a kilogram of Canadian beef in 1981 versus 2011. [35]

There may be opportunity to consider installing solar PV over or in association with larger conveyance canals or smaller storage reservoirs/balancing pools to reduce evaporation and algal growth. This technology has not yet been proven. Incentives are required to initiate pilot projects to determine the economic viability of investing in solar PV over conveyance canals.

Several producers have installed solar PV systems to energize their irrigation application systems, and some have the ability to sell excess energy into the distribution system. There is potential for this action to gain prevalence as traditional electrical costs increase. Currently the provincial electrical distribution system does not always easily accept excess power that may be generated at the farm level. Without the ability to easily sell back to the grid, the timeline to receive a return on investment is long.

Agriculture has a long history in the province and will continue to have a long future. Solutions need to be easily applied at farm level and must be cost effective at farm level to succeed.

Petroleum Refining Sector

Refining sector emissions technology is similar to the Chemical sector and potentially electrification.

Solid Waste Sector

An assessment of technologies applied to the solid waste sector is summarized below:

- Waste reduction through product design and material quality
    - TRL 3-10
    - commercialization stage depends on process and targeted material
- Waste collection, sorting/separating/cleaning
    - TRL 7-10
    - Innovation is required to improve the efficiency i.e., robotics
- Organic waste diversion
    - Composting
    - Energy or fuel
- Inorganic waste diversion (plastics, others)

        - Mechanical recycling of plastics
            - TRL 7-10
            - Commercial technologies
            - Challenges: limited feedstock types, sensitive to contamination, more expensive compared to virgin materials
            - Recycling is GHG intensive, the reduction comes from replacement of virgin materials
        - Chemical recycling of plastics
            - TRL 3-8
            - Majority of technologies are at lower TRL with limited applicability
            - Suitable for mix plastics, easy to replace virgin plastics
            - Expensive and high level of feedstock is required to benefit from economy of scale
            - Same for GHG
- Processing waste with lower environmental footprints
    - Biopolymers
        - TRL 3-10
        - Commercial technology
        - Niche application such as food and agriculture, suitable for composting and ADs
        - Feedstock limitation, challenging economy of scale, expensive
    - Metal, glass, reusable
- Replace virgin materials by recycled content
    - TRL 3-10
    - Chemistry and costs are prohibitive
    - Main source of GHG reduction
- Improve monitoring and tracking of environmental impacts of waste collection, sorting, recycling, replacing virgin materials with recycled materials: Traceability, data collection and data management, digital and AI solutions
    - TRL 3-8
    - Cross-market deployment and integration may be costly and logistically challenging
    - Will enable transparent reporting and accountability on GHG and other ESG metrics.

Pulp and Paper Sector

Achieving net-zero GHG emissions in this sector will likely require the implementation of carbon capture or DAC technologies (TRL 4-7) or the development of cross-sector carbon offset accounting frameworks. Use of biomass in low carbon-intensity biofuels, or the use of other biogenic pulp waste / by-products to contribute to reducing carbon intensity of hydrocarbons is becoming increasingly attractive and feasible.

Growth and diversification – long term production and impact on industry

Oil Sands Sector

As the dominant source of GHG emissions and economic activity in the province, Alberta's oil sands represent both challenges and opportunities in the ongoing energy transition. Enhanced oil recovery can play a key role as a transition pathway towards a CO2 utilization economy due to its present cost-effectiveness [36]. Demand for oil products in the petrochemical industry has surged in recent years and is expected to drive global oil demand to 2030 and 2050 [37].

Bitumen has a unique opportunity for diversification in the production of non-combustible materials. The Bitumen Beyond Combustion (BBC) initiatives provide the oil sands industry an opportunity to grow and diversify with value-added carbon contained products, including carbon fibre and asphalt [38].

Trade considerations are critical for trade exposed industries. Carbon leakage is real and will become increasingly important. Since investment will flow to jurisdictions with the lowest cost, carbon tax protection for emission intensive, trade-exposed industries are critical to maintaining investment.

Natural Gas Sector

The natural gas sector primary sources of emissions originate from either fugitive sources (very small leaks of methane) or from energy use within the processing facilities themselves. Significant progress has been made with newer technologies (flanges and connections) and through the replacement of natural gas based recompression with electrical recompression.

Electricity Sector

In general, it was found that many scenarios produced net system cost savings with significant GHG abatement giving negative marginal GHG abatement costs compared to the business-as-usual scenario. This indicates that there are many future renewable technology mixes that would both lower system costs and be more environmentally beneficial compared to a mostly natural gas-based business-as-usual scenario. The technology mix which a negative marginal abatement cost and the largest abatement potential was a combination of increased wind, hydro, and solar power which resulted in over a 90% reduction from 2005 emission levels. This was found to be possible considering system reserve margin requirements, variable output and low firm capacity rating of wind and solar, renewable resource availability, and low natural gas costs.

Chemical Sector

Alberta's chemical sector uses 38% of hydrogen produced in the province, meaning that continued investment in developing Alberta's clean hydrogen economy may lead to environmental and economic benefits for the province's ammonia producers [39].

Agricultural Sector

Agriculture has a long history in the province and will continue to have a long future. Solutions need to be easily applied at farm level and must be cost effective at farm level to succeed.

Petroleum Refining Sector

The continuation of historical capacity expansion together with confirmed governmental plans for new refineries were considered to forecast future sectoral capacity. No refineries have been built in Alberta since the 1970s. However, since the 1950s the refining capacity has increased steadily, and it stabilized after 2000. The Sturgeon Refinery capacity expansion plans are accounted for in developing the baseline scenario. The first phase of the Sturgeon Refinery plant become operational in 2017 and full capacity of 50,000 bbl./day is expected by 2022.

Solid Waste Sector

In consideration of the opportunity for plastics circular economy, for example

- The plastics circular economy represents a $7.8 billion opportunity for Canada [40], and

- Alberta has an opportunity to create 4,500 direct full-time equivalent jobs in the province as a result of existing recycling activities with a further 1,600 indirect and 1,400 induced jobs, for a total of 7,500 jobs [41].
- Alberta's robust petrochemical/plastic polymer sector provides a local market to offtake recycled plastics, on a scale that could not only divert post-consumer plastics from Alberta landfills, but also potentially accept post-consumer from other jurisdictions.

Similar benefits could be realized for building circular economy systems around other targeted waste streams. This may include diverting existing recycled materials away from export markets to local manufacturing opportunities in Canada.

Pulp and Paper Sector

Implementing all identified economical GHG mitigation measures would significantly reduce or virtually eliminate natural gas demand and significantly reduce electricity grid demand for all mill types across the sector by 2050. Conversely, these measures would increase biomass demand for most mill types. Since additional biomass energy demand would be met through onsite waste streams, emissions reductions measures in this sector are not expected to lead to increased emissions elsewhere.

Infrastructure utilization, repurpose or new build

Oil Sands

Full decarbonization will require extensive retrofitting of existing crude oil production capacity. The use of nuclear energy for SAGD steam generation represents an effective pathway towards decarbonization but may not be cost-effective or feasible due to the large capital investment requirements and long approval processes required for new plant commissioning. Conversely, carbon capture technologies may integrate with existing production capacity and offer economic benefits if captured carbon dioxide is used for enhanced oil recovery.

Natural Gas Sector

Existing natural gas pipelines may be repurposed for transporting renewable natural gas or low-carbon hydrogen produced from the oil and gas sector.

Electricity Sector

There has been significant utilization of existing infrastructure in the electricity sector. Repowering of coal-fired facilities has allowed generators to repurpose existing infrastructure to cost-effectively expand natural-gas fired generation with best-in-class technologies that will support further decarbonization through hydrogen blending and carbon capture and sequestration.

Early coal retirement (ECR) scenarios make up 5 of the 6 least costly GHG emission mitigation scenarios. The scenarios that involve ECR resulted in 15-19% GHG mitigation and marginal costs between -25.1 and -$11.6/t. ECR-cogeneration scenarios have the lowest marginal GHG emission abatement costs, and ECR-wind the most GHG emission mitigation across the ECR scenarios. Wind and early coal retirement and conversion to natural gas were shown to produce negative marginal abatement costs with 14-25% GHG emission abatement. The details on the scenarios and results can be found in published article [42].

Pipelines and Midstream

Canada currently has 147 km of hydrogen pipelines [43]. Growth of new pipeline infrastructure or repurposing of pipelines will become increasingly important as energy transitions to cleaner sources, such as hydrogen and integration of carbon capture and storage with CO2 pipelines.

Solid Waste Sector

Alberta has fairly mature waste management infrastructure and upstream supply chains for collection and aggregation of wastes at waste management centres. Regulated, designated materials also have relatively mature downstream supply chains and markets, many of which are out of province.

Alberta has a robust and growing petrochemical and plastic polymer sector that has strong potential to integrate polymers derived from recycled materials.

Many existing landfill sites have potential to accommodate additional physical infrastructure. However, additional recycling infrastructure and supply chains will likely be required to build new circular economy systems. Waste volume, relative to jurisdictions with higher populations and higher population densities, may be a limitation in commercializing and deployment of recycling technologies in Alberta. Importing wastes from other jurisdictions may help offset low, in-province volumes.

Pulp and Paper Sector

The assessed measures may all be applied to existing processes and do not include radical structural changes. Achieving net-zero emissions in this sector by 2050 will not require the development of entirely new production facilities since the level of GHG emissions unmitigated by assessed measures may feasibly be offset through carbon-negative solutions, such as process-tied carbon capture and storage, DAC, or the development of forestry-based offset programs.

ESG performance and competition for investment

Oil Sands Sector

Continued and accelerated ESG efforts for demonstrated GHG emission reduction will be required to reposition the oil sands sector as a chosen industry for investment.

Natural Gas Sector

As a sector that is critical for the reduction of emissions from coal, a key fundamental requirement is the understanding of Canadian and Alberta gas being a low carbon fuel source for LNG and international coal displacement. With the emergence of sustainability linked loans it is critical for the Natural Gas Sector to have a ESG ready product.

Electricity Sector

As Canada's only fully competitive wholesale electricity market, it has attracted significant activity among corporate entities looking to procure energy and associated environmental attributes from renewables. Corporate power purchase agreements established between corporate entities and project proponents have been a primary driver of expanded renewable development in the province in the past several years. Total capacity of deals signed through 2021 total over 1,700 MW of renewables. [44].

Solid Waste Sector

Mitigation of waste generation and disposal (landfill, incineration, etc.) align strongly with Environmental and Social objectives. Environmental benefits are GHG, land and biodiversity, water quality and human health. The main GHG benefits of waste diversion will likely be in the manufacturing processes that utilize diverted waste.

Increase in cost of living as a result if landfill mitigation measures that increase municipal taxes/utility charges and consumer goods would have a negative social impact. The role of municipalities in waste management can create both opportunities and barriers for investment.

Resources and skills

Oil Sands Sector

The oil sands sector has the advantage of a large proven reserve. The industry has demonstrated skills in bitumen production, processing, and CCUS. The expertise of additional value-added products and manufacturing (i.e., BBC products) needs to be developed.

Natural Gas Sector

Similarly, to the oil sands sector, the natural gas sector has demonstrated skills and resources to abate emissions significantly including methane emissions.

Electricity Sector

Alberta has wind and solar resources that are among the best suited to renewable energy development in Canada.

Alberta has a workforce that is well suited to continue to the development of energy infrastructure and pursuit of decarbonization technologies applied in the electricity sector.

Solid Waste Sector

Alberta has existing skilled and unskilled workers operation in waste management and recycling employed in the private sector. There are several research facilities, collaborations, and accelerators (e.g., Alberta Clean Energy Technology Accelerator [45]; All West Bio-Industrial Park [46], which focus on diversion, conversion, and emissions reductions for solid (or other) waste. These enabler services are already connected with Alberta’s waste management sector.

Alberta has the advantage and challenge of waste management systems operating under a variety of public/private business models as well as wholly private systems.

Alberta waste management professionals and workers in need of retraining have access to a wide range of resources for training, knowledge and skills development in post-secondary institutions, in-house training, and North American waste management associations such as SWANA.

Regulatory/policy

Oil Sands Sector

Alberta's oilsands producers have benefited from the Job Creation Tax Cut, accelerated capital cost allowances, reductions in red tape regulations. However, while these policies have supported the sector, federal and foreign policy and regulatory uncertainty has made it challenging attracting new capital to the industry. With commodity prices improving, many companies are forgoing new investments in favor of returning capital to shareholders through dividends and share purchase buybacks.

Reducing regulatory burden has had an appreciable impact in areas such as streamlining approvals for oil sands projects. Further regulatory and policy direction from the province regarding CCUS on the issuance of subterranean tenure through a competitive bid process and support on advancing a favorable federal tax treatment that is agnostic towards sector and technology, would be beneficial in accelerating project development for large-scale emission reduction applications. Clarity on how CCS/CCUS projects will be regulated is required.

Natural Gas Sector

The Alberta Petrochemicals Incentive Program (APIP) policy advanced value-added and upstream investment in the sector and exploring opportunities where the Crown can support enhanced egress through liquified natural gas development and hydrogen. These incentives, post COD, will need to be enhanced in order to offset the significantly increased costs of hydrogen for industrial conversion from natural gas.

Electricity Sector

Alberta's provincial regulatory systems have supported the evolution and success of the wholesale electricity system. The regulatory frameworks applied by the province have respected the competitive nature of the market, while supporting continued development of energy infrastructure in a fair, efficient and competitive manner.

The TIER program applied to large emitters has been successful in reducing emissions in the electricity sector and incenting the development of reliable and cost-effective sources of generation.

Alberta's offset system has also been critical in the development of wind and solar generation. Policy-directed coal retirements have also significantly reduced emissions in Alberta.

Renewable generation targets raised GHG mitigation by an average of 17% and 19% for the 30% and 50% renewable generation targets. Only two scenarios had notable increases in marginal costs due to the 30% renewable target, the wind-cogeneration I and II scenarios, indicating that in most cases, the 30% target increased GHG mitigation without a corresponding increase in marginal abatement costs. The wind-cogeneration scenarios had increased marginal abatement costs from the 30% target because additional wind capacity was added earlier in the time period to meet the target. This increased cost compared to the scenarios with no target, where more wind capacity was added later rather than earlier in the time period. The 50% renewable target increased marginal abatement costs by an average of 27% compared to the baseline scenarios.

Chemical Sector

The APIP policy has and will continue to, through further enhancement, help advance value-added and investment in the sector.

Conventional Light Oil Sector

Liability Management Framework has established expectations for the conventional sector for the lifecycle of projects. This has enabled more certainty for investors and owners to address site closure obligations. An Inventory reduction program that includes mandatory spend targets, a landowner opt-in mechanism and Area Based Closure Program, and a subject matter expert panel from industry and the financial community for post-closure liabilities will assist in addressing well-site remediation and improve the financial health of producers by lowering their Asset Retirement Obligations (ARO).

The Site Rehabilitation Program (SRP) through targeted grant funding phases has enabled abandonment and environmental reclamation work on sites across Alberta that has significantly reduced the growing inventory of inactive and abandoned sites.

Solid Waste Sector

Alberta Environmental Protection and Enhancement Act (EPEA) Legislative/regulatory frameworks that enable revenue generation from diversion of waste include:

- Extended Producer Responsibility (EPR): Dec 2, 2021 -- Alberta Legislature amends Sections 170, 173, and 175 of the EPEA to legislate provisions for EPR. These amendments set out provisions for deposit programs under an EPR waste management model.
- Designated Materials (Recycling): EPEA has an existing regulatory framework to incentivize collection and diversion of "designated" waste materials and hazardous materials, as well as management authorities to oversee programs established under these regulations [47].

Regulations and policies in Alberta that further enable or align with waste diversion, utilization and emissions mitigations include Alberta's Carbon Offset System, the Renewable Fuels Standard Regulation (both under EPEA), and the Land Use Framework under the Land Stewardship Act.

Federal initiatives include:

- Waste Plastics: Canada has recently implemented or proposed several regulations to address single use plastics and plastics in the environment [48]:
- Canada Clean Fuels Regulations: Regulations focus on low carbon fuels and alternative energy sources (e.g., electricity) to reduce GHG emissions in Canada's ground transportation sector. Regulations are at the stage of initial implementation.
- Canadian Council of Environment Ministers [49]: provides an avenue for collaborative F/P/T development of national standards, guidelines and best practices that do not fall under direct federal jurisdiction. (See Collaborations section).

Pulp and Paper Sector

The pulp and paper sector will require comparatively low regulatory intervention to reduce emissions levels over the next decade. There are abundant emissions reduction opportunities through energy efficiency improvement and waste-fuel utilization and most measures are already economically attractive even without consideration of avoided carbon taxes. Residual GHG emissions unmitigated by these measures may be offset through activity in the forestry sector. Due to the close relationship of these two sectors, achieving carbon neutrality in the pulp and paper sector through cross-sector carbon offsets may be more cost-effective and regulatorily simple than reliance on developing carbon removal technologies.

Market conditions including access

Oil Sands Sector

Trade considerations – trade exposed industries

Carbon leakage is real. Investment will flow to jurisdictions with the lowest cost. Carbon tax protection for emission intensive, trade-exposed industries is critical to maintaining investment

Natural Gas Sector

The cost of hydrogen delivered from Alberta is cost-competitive with primary domestic hydrogen production pathways in Japan and South Korea with wind- or solar-based electrolysis [50]. In China and Europe, the domestic supply of hydrogen through steam methane reforming with carbon capture and sequestration, coal gasification with carbon capture and sequestration, and electrolysis were found to be cheaper than the total supply chain cost of delivering gaseous hydrogen from Alberta; thus, exports to these destinations are not cost-competitive in the immediate term.

To justify the export of low-carbon hydrogen to the Asia-Pacific, the delivered hydrogen from Alberta needs to be cheaper than or be cost-competitive with alternative delivery options from other countries such as Australia. Low-carbon gaseous hydrogen from Alberta can offer a lower-cost alternative source of hydrogen for Japan and South Korea at a time when policymakers in both countries are trying to diversify their hydrogen supply mix, minimize energy security risks, and meet their emissions reduction obligations.

Leveraging the existing export supply chain for ammonia and/or methanol commodity trade, especially to Japan, can create an economic prospect for the province. Low-carbon hydrogen delivered from Alberta to Europe is presently uncompetitive with the domestic production cost of blue hydrogen and electrolytic hydrogen. However, there may be an opportunity for export in the short term as electrolysis technology is still developing and the demand for low-carbon hydrogen could exceed the domestic supply in Germany and the United Kingdom.

Chemical Sector

Production and export of ammonia to Asian markets also represents an important economic opportunity for a world pursuing net zero emission energy.

Solid Waste Sector

Alberta has the highest per capita output of waste over any other province (Table 4-1), and the highest per capita spending on waste diversion of any province [51].

Provincial and national composition and volume estimates provided in many recent studies, such as the 2021 Fraser Institute Study [52] (Table 4-1), rely on data collected in 2018 or earlier, including a key Alberta (2005) [53] and a national (2016) [54] report.

Alberta’s Natural Gas Vision and Strategy identifies plastics circular economy as a priority, in order to integrate plastics recycling with Alberta’s robust petrochemical/polymer industry.

TABLE 4-1 Fraser Institute 2021 Estimates [51]

The Numbers	Alberta		Canada
	Solid Waste Generation 2018 (non-hazardous)		
Million Tonnes	5.05[55] M Tonnes		35.5 M Tonnes
Kg per Capita	1,175 Kg[56]		959 Kg
T per $1MM GDP	25		22.04
% residential/non-res (2016)	32% residential 68% non-residential		44% residential 56% non-residential
	Solid Waste Disposal		
Million Tonnes	4.18 M Tonnes[57]		25.7 M Tonnes
Kg Per Capita	958 Kg		694 Kg
T per $1 M GDP	12		15.96
	Waste Diversion		
Million Tonnes	0.94 M Tonnes		9.8 M Tonnes
% (2018)	18%		28%
Kg Per capita	217 Kg		265 Kg

Pulp and Paper Sector

The largest market access issue facing the sector is reliable and sufficient rail and truck capacity to deliver product to market. Interruptions in the supply chain have greatly impacted the sector's ability to reach its customers over the last number of years.

5. CONCEPTUAL PATHWAYS AND TIMELINE FOR REDUCTIONS IN 2030, 2040 AND 2050

The conceptual pathway for reductions is discussed in this section. The process followed was to review potential mitigations and technology readiness and reduction factors were applied by ACR sector.

Efficiency Measures Across Sectors

Assessments have been made for applying efficiency improvements for GHG mitigation scenarios across Alberta industry sectors. Findings indicate that cumulative GHG emissions can be significantly reduced between 2021 and 2050 compared to a baseline scenario where existing technologies and associated energy intensity values are assumed to be constant, excluding technologies under existing regulatory control. The baseline represents a case where no further action is taken by government or consumers to reduce energy use or emissions. The analysis only includes commercially available technologies and measures are assumed to be implemented over 2021 to 2030.

Energy efficiency improvements across all economic sectors represent 26 MtCO2e in annual GHG mitigation by 2050. 88% of the total cumulative emissions reduction potential over 2021-2050 is achievable at negative cost (5% discount rate). Figure 1 shows the mitigation potential associated with energy efficiency improvements across all sectors relative to the baseline/reference scenario. “Economic GHG mitigation potential” includes measures that lead to net cost benefits, whereas “additional GHG mitigation potential” includes only measures with positive social costs. High efficiency (HE) technologies and processes can mitigate 630 million tonnes CO2e between 2021 and 2050 at an average cost benefit of $59/t, or $40 billion (2021 CAD). Implementing all energy efficiency measures before 2030 may limit the growth of provincial emissions to 2% by 2050 relative to 2020 levels as illustrated in Figure 5-1 below.

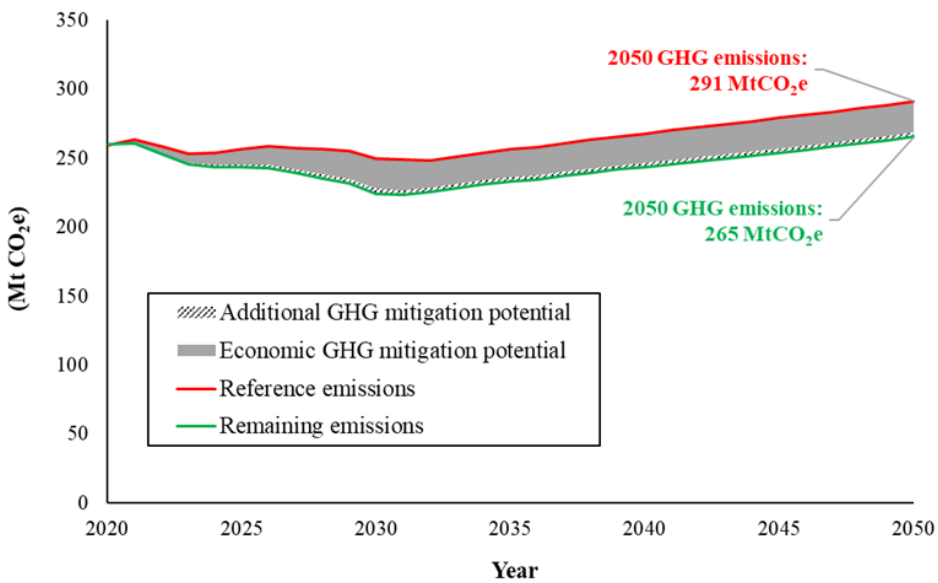

FIGURE 5-1 Annual GHG mitigation potential of 81 energy efficiency measures applied in Alberta between 2021 and 2050 [58]

Oil Sands Sector

Assessments of promising technology applications are continuing and increasing.

Energy-use reduction scenarios (operational improvements) have been evaluated for in situ extraction, surface mining, and bitumen upgrading [59]. All strategies resulted in a negative $/tCO_2e$ cost, indicating a net benefit for investing in the strategies. If the strategies are implemented together, there is an ultimate potential to reduce both sector-wide cumulative energy consumption and direct GHG emissions in the oil sands by 12% by 2050.

Technologies with integrated carbon capture including steam methane reforming, underground coal gasification, and oxyfuel boilers, either fueled by natural gas or bituminous fuels, were investigated under three different carbon pricing policies and two different carbon end use options, resulting in the analysis of 24 scenarios from years 2021 to 2050 [60]. Scenarios incorporating carbon capture into in situ bitumen production using oxyfuel boilers fueled by bituminous fuels outperformed other technology options, providing both the top abatement potential and lowest marginal costs. Under the current federal carbon price reaching $170/tonne by 2030, up to 83 $MtCO_2e$ may be mitigated relative to the baseline scenario through the capture and utilization of CO_2 from oxyfuel boilers for SAGD steam generation, underground coal gasification, and steam methane reformers. This mitigation potential may be achieved at an average net cost benefit of $44/$tCO_2e$.

Feasible technology scenarios were developed under three different carbon pricing policy options for the period of 2019-2050 for a total of 30 scenarios across oil sands extraction (cyclic steam stimulation, steam-assisted gravity drainage, and surface mining), upgrading, and electricity generation [61]. In general, technology market penetration was found to more than double when a $30/t carbon pricing was applied. Scenarios with no carbon price resulted in 50 Mt less emissions abatement. Small modular nuclear reactors applied for steam-assisted gravity drainage provided the most GHG abatement potential of any single technology. Geothermal energy, biomass feedstocks, and hydropower scenarios had limited emission reduction potential. Wind and solar technologies failed to displace existing processes in the scenarios considered. Under Canada's current carbon pricing plan, renewable energy penetration in the oil sands may mitigate a cumulative total of 59 $MtCO_2e$ between 2021 – 2050.

Feasible scenarios for incorporating cogeneration into in situ, and surface mining and upgrading, subsectors, as well as additional scenarios incorporating electricity-based technologies to improve in situ plant efficiencies, were developed [62]. These scenarios were evaluated under three different carbon pricing policies. Incorporating higher levels of cogeneration into oil sands processes provided 8 Mt of GHG abatement potential. The incorporation of electrical equipment, including well pad boilers, well pad compressors, additional steam compressors, and steam superheaters all resulted in additional costs that outweighed the benefits to plant efficiency. Under a 2030 carbon price of $170/t, the analyzed cogeneration scenarios do not offer any GHG emissions reduction potential due to the projected rapid decarbonization of Alberta's electricity grid included in our baseline scenario.

Scenarios were also developed to determine the GHG mitigation potential of novel extraction processes for SAGD bitumen extraction. The use of hydrocarbon solvents, solvent-steam hybrid technology, and solvents with electromagnetic heating instead of standard SAGD extraction processes were represented under three carbon pricing scenarios. Of the three novel techniques assessed, solvent-steam hybrid extraction achieved the highest market penetration by 2050. Together, all three measures are estimated to represent 47 $MtCO_2e$ of GHG abatement potential under projected market penetration and may be implemented at a negative marginal abatement cost.

The combined anticipated GHG reductions in the oil sands sector are illustrated in Figure 5-2 below.

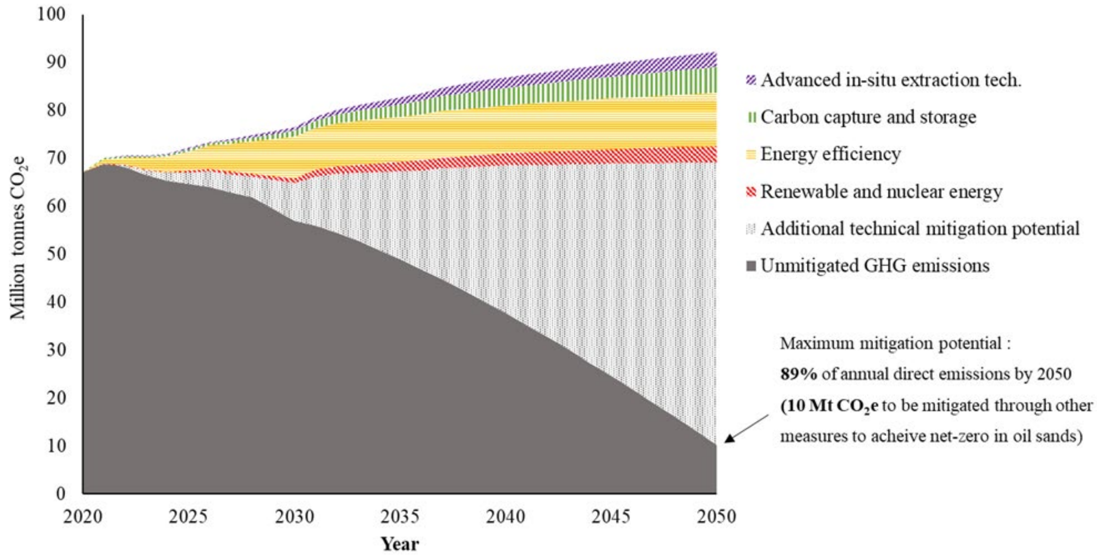

FIGURE 5-2 GHG mitigation potential of energy efficiency, renewable and nuclear energy, CCUS, cogeneration, and advanced extraction technologies in the oil sands considering alternative technologies for newly added capacity (colors) and all capacity (additional technical mitigation potential) [63]

The wide range of sustainable technology demonstration, development, commercialization, and broad deployment in the oil sands sector is accelerating. Projected timeline for implementation of commercial and developing technologies is illustrated in Figure 5-3 below.

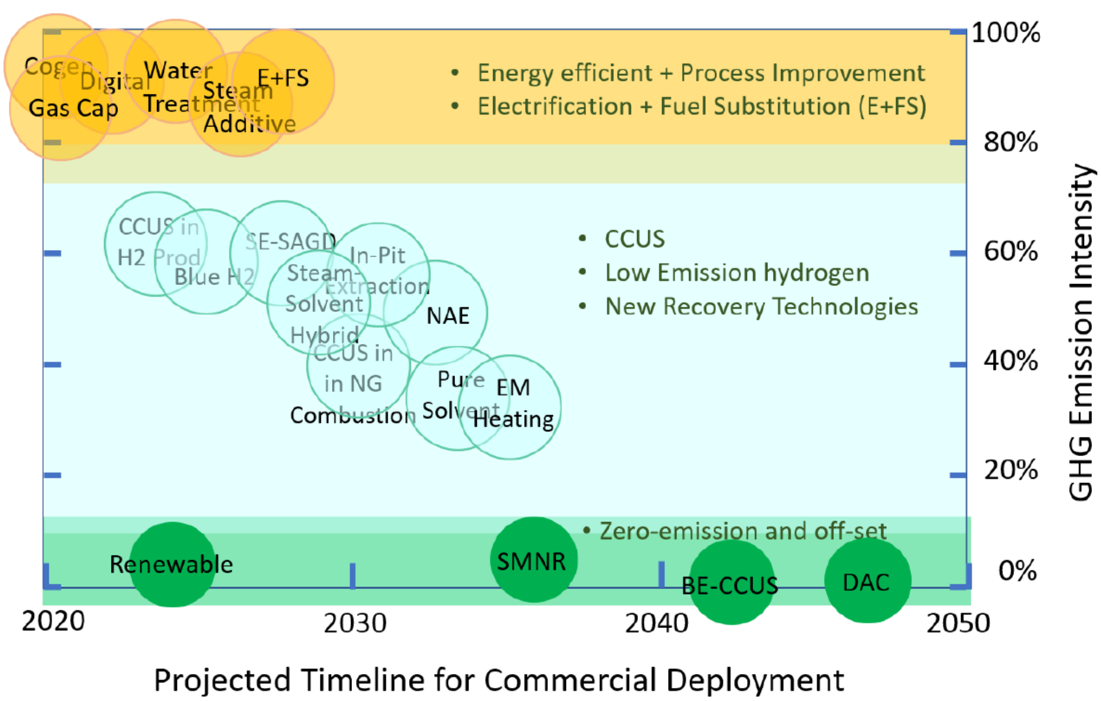

FIGURE 5-3 Projected Timeline for Commercial Deployment [64]

The Oil Sands Pathways to Net Zero narrative is a key alignment initiative for the future of the sector. This initiative is largely consistent with the technology analysis above.

In emerging technologies, it should be noted that SMR has a role to play in the long term, and DAC may have a role in emission reduction, but its scale will be limited.

Specifically for oil sands, the near-term pursuit of incremental and transformational technologies will continue to be important. It is important for Government to continue to partner in the investment of these significant pathways. This also recognizes that the deployment of existing CCUS technology can be pursued in parallel and given the scale will take longer. Yet this near-term technology investment window is important as it could also make CCUS more affordable. As an example – for in-situ projects – it is possible that a combination of technologies could result in a 50% reduction in steam requirements – potentially translating to only having to install CCUS on half of the steam generators.

Natural Gas Sector

Providing near term incentives, beyond APIP, for hydrogen production could accelerate the life cycle emission reductions of natural gas. Although hydrogen production costs may be competitive with costs in other markets, they are still much greater than the combustion of natural gas on its own, particularly in jurisdictions where there are no penalties, like carbon tax, to discourage the use of natural gas.

The highest new near-term impact would be through incentives of LNG exports.

Electricity Sector

The Electricity sector emission metrics are summarized as follows:

- 2019 electricity sector (excluding cogeneration) emissions – 31 MT
- Expected emissions reductions achieved through remaining coal retirements – 11 MT
- Repowering and natural gas conversions at Genesee generating station – 3.4 MT
- CCUS projects being pursued by Capital Power in collaboration with Enbridge – 3 MT

Alberta has a renewable energy generation target of 30% by 2030. Analysis shows that 35% renewable generation is possible at a negative abatement cost with an addition of about 3.5 GW of hydro and 4.5 GW of wind, given that the hydro sites can be developed at the modelled costs. Even with 20% higher hydro capital costs, sensitivity analysis shows that the marginal abatement cost by 2050 remains negative.

Canada is beginning work towards achieving net zero emissions by 2050, as well as fulfilling commitments to meet and exceed the 2030 mitigation target. A combination of Alberta wind and hydro expansion can provide negative marginal abatement costs in the 2030- and 2050-time frames as well as contribute about 31 million tonnes, or 10%, to Canada’s 2030 emission reduction target. Thus, both provincial and federal benefits exist in the short and long term in the form of both economic benefit in Alberta and progress towards climate goals for Canada.

Figure 5-4 shows the Electricity generation mix in year 2030 and 2050 for alternative scenarios.

FIGURE 5-4 Electricity generation mix in year 2030 and 2050 for alternative scenarios [65]

Chemical Sector

Energy efficiency improvement scenarios in the petrochemical (ethylene) and fertilizer (ammonia) industries spanning low to high levels of technological readiness were developed for analysis [66]. The assessed measures may reduce cumulative GHG emissions by 7.1 $MtCO_2e$ between 2018 and 2030, and by 29.7 $MtCO_2e$ between 2018 and 2050. Under a carbon price plan that increases to \$170/tCO_2e by 2030, it is estimated that cumulative mitigation potential from the chemical industry would be 35.2 $MtCO_2e$ between 2021 and 2050. Under this policy, all emissions reduction measures are achievable with negative cost.

Petroleum Refining Sector

Detailed process simulations were done for eleven energy efficiency improvement measures in the refining sector [67]. The results show that integrating the energy efficiency options in the refining sector will result in cumulative emissions reduction of 12%, an annual emissions reduction of 1 $MtCO_2e$ by 2050 (14%). Results shows that measures accounting for 47% of the total cumulative mitigation potential may be achieved at negative cost when considered individually, but when interaction effects are accounted for, cost-effective measures achieve 88% of the maximum mitigation potential represented by all measures.

Solid Waste Sector

The opportunities for reductions in the solid waste sector is summarized in Table 5-1.

STRATEGY		
	2030	2040
CCME (2014) – Canada-wide waste disposal goals [68]	490 kg per capita (30% reduction by 2030) relative to 2014 Baseline	350 kg per capita (50% reduction by 2040) relative to 2014 Baseline
	2030	2040
Canada Plastics Pact [69]	By 2025: 1) Measures to identify and eliminate problematic plastic packaging. 2) 100% of plastic packaging designed to be reusable, recyclable, or compostable. 3) at least 50% of plastic packaging is effectively recycled or composted. 4) All plastic packaging contains at least 30% content by wt.	By 2035, collection of >90% percent plastic packaging from residential and IC&I sectors. 1.5 million tonnes of the plastic packaging or 75% of the total put on the market – is being returned to manufacture as recycled resin or chemical carriers to produce new plastics in North America.
Natural Gas Vision and Strategy (Alberta, 2020) [70]	Alberta is established as the Western North America centre of excellence for plastics diversion and recycling by 2030.	

TABLE 5-1 Opportunity Metrics for Solid Waste

Pulp and Paper Sector

GHG-reduction scenarios were developed for Canada's pulp and paper sector [71]. Figure 5-5 shows that GHG emissions from the pulp and paper sector may be mitigated by over 50% relative to 2019 levels by 2030 through the adoption of economic measures alone. Over the medium to long term, the economic GHG mitigation potential of the assessed measures diminishes but remains significant (1.3 $MtCO_2e$). Considering both economic and uneconomic measures, it is estimated that GHG emissions from Canada's pulp and paper sector may be reduced by 87% by 2050 relative to 2019 levels.

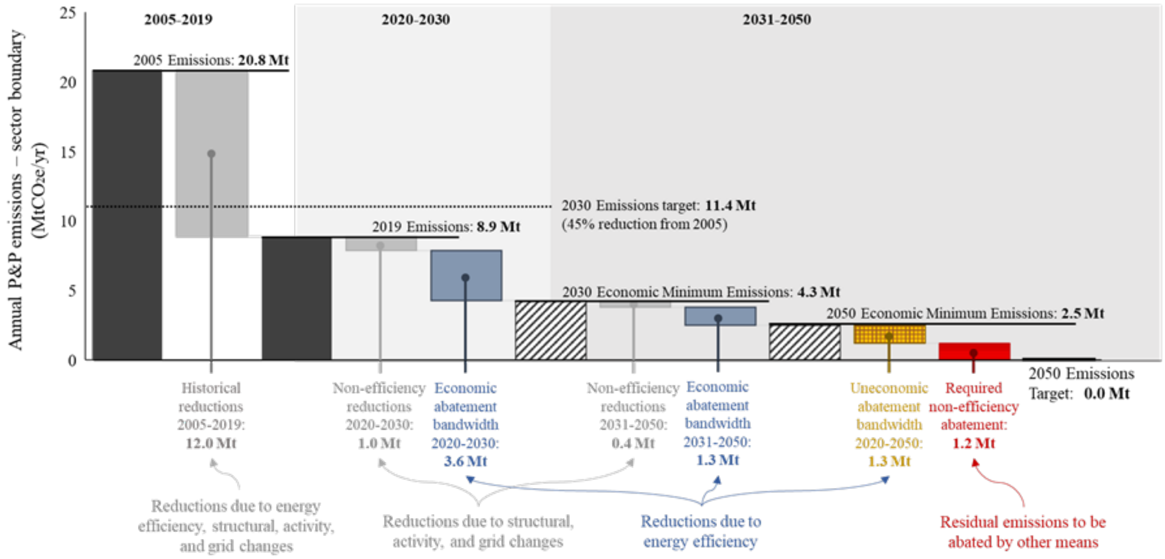

FIGURE 5-5 Contributions of energy efficiency, structural, activity, and electricity grid changes towards achieving net-zero emissions in Canada's pulp and paper sector [72]

Cement Sector

Scenarios were evaluated for the cement sector which focused on energy efficiency improvement measures within conventional production processes [73]. 100% of the cumulative emissions' reduction potential was found to be achievable with negative cost. Together, the assessed measures may mitigate a cumulative total of 2 $MtCO_2e$ or 10% of projected emissions between 2021-2050.

<u>Forecast of Aggregated Alberta Emissions Reduction Across All Sectors</u>

GHG emission reduction pathways, applying existing and developing solutions over time, are forecast to provide progressive reductions as illustrated below in Figure 5-6.

These percentage reductions were identified from each sector above as a percentage reduction over the expected timeframe. In the near term the expectation is that most reductions will be focused on energy efficiency, fugitive emissions reduction and implementation of regional CCS by industries. We expect this trend to continue until 2030 where the impact of new technologies and regional infrastructure for either hydrogen or CCS can be implemented.

After 2040 we will see the broad impact of innovative technologies, broad scale implementation of new unproven technologies such as SMNRs, electrification and wide regional infrastructure for carbon management.

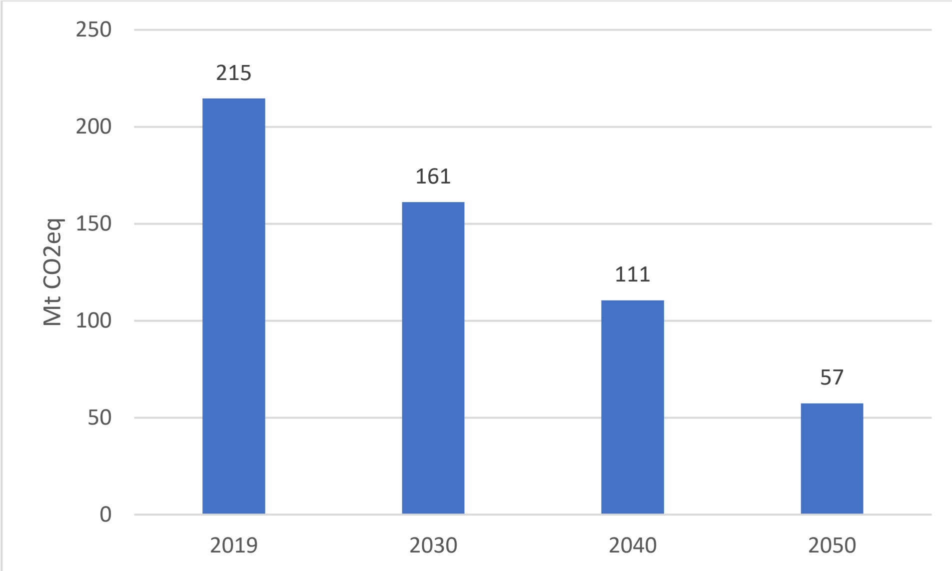

FIGURE 5-6 Forecasted Alberta emissions aggregated across ACR sector groups (2019, 2030, 2040, 2050)

Forecasted emissions reductions by sector are then summarized below in Figure 5-7.

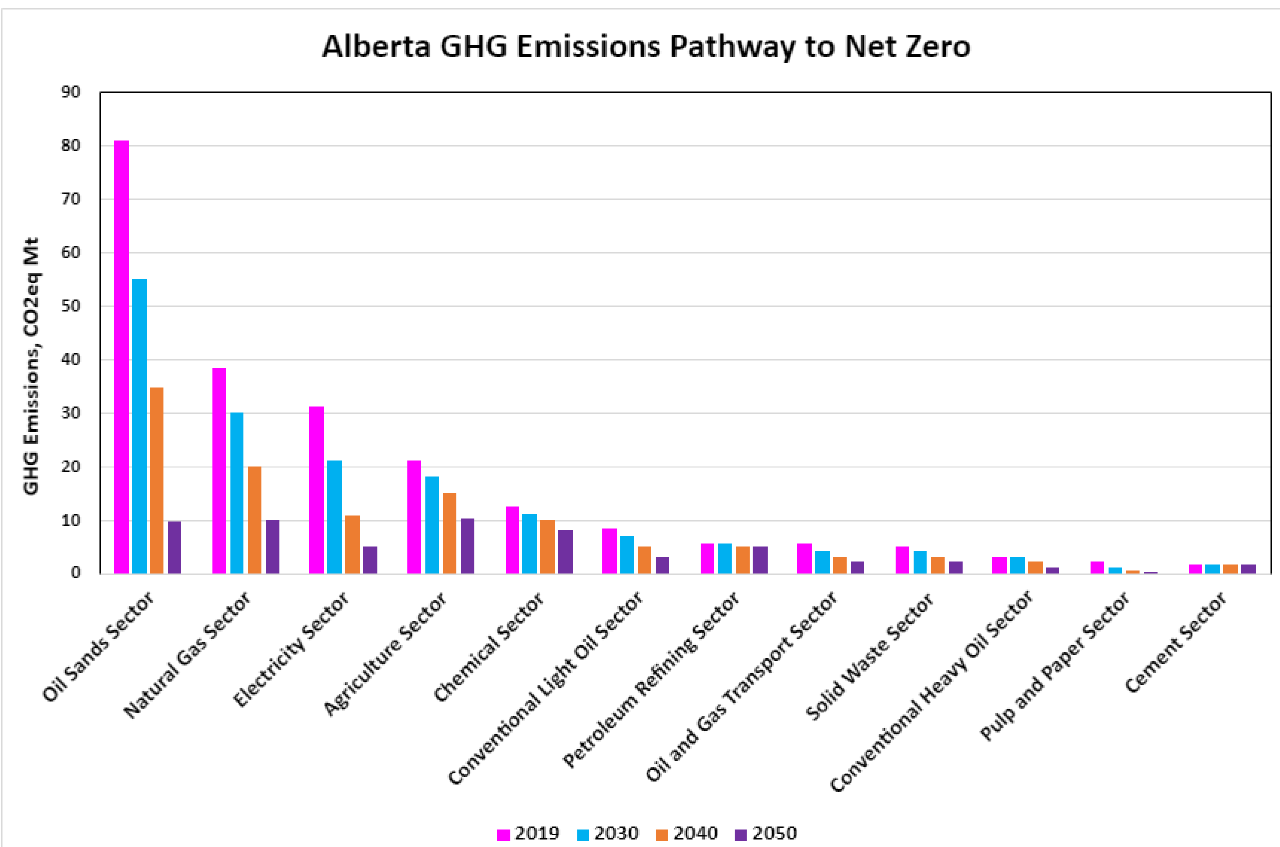

Figure 5-7 ACR Emission reduction targets by ACR Sector groups.

The potential reduction targets above are based on our review of relevant documentation, studies, and industry knowledge. It is assumed that there would be limited growth in overall emissions in this timeframe in a business-as-usual scenario for Alberta, and that credits are key for achieving lower net emissions in all timeframes.

The anticipated pathway components for forecast reductions over time include:

Short-term (to 2030)	Mid-term (2030 to 2040)	Long-term (2040 to 2050)
Pathways for GHG Reductions		
Energy efficiencies Process improvements Electrification and grid modernizations Geothermal heating and power Wind and solar generation Fuel substitutions Recovery and enhanced technologies Credits and trading		
CCUS limited scale	CCUS broad scale	Integrated CCUS
Flue decarbonization	Inlet decarbonization	Direct air capture
Blue hydrogen	Blue & Green hydrogen	Green hydrogen
Hydrogen-enriched gas	Hydrogen distribution	Hydrogen industry
Bio Industrial	Bio industrial next gen	Bio industrial networks
	BBC products	New products
	SMNR	Nuclear

Table 5-2 Anticipated GHG Reduction Pathway Components

6. HIGH LEVEL ACTIONS TO REACH FORECASTED OUTCOMES

High level actions are suggested to help better position Albert Resource Industry for GHG reductions and sustainable future.

Oil Sands Sector

Energy efficiency measures may reduce GHG emissions in the short term while offering economic benefit to oil sands producers, but together, these measures represent only a fraction of the total GHG mitigation required to achieve net-zero in the sector by 2050. Measures involving carbon capture, renewables, and nuclear energy integration hold significant technical GHG mitigation potential but do not show high enough market penetration under current carbon price forecasts to reduce emissions from 2020 levels by 2050. Decarbonization in the oil sands will require stringent regulation and massive levels of supportive economic investment.

High level actions to reach a successful outcome should include:

- Accelerate the deployment of energy efficiency and process improvement technologies
- Identify electrification and fuel substitution opportunities and start to implement
- Build CO2 trunk line and storage hubs as enabling infrastructure
- Deploy CCUS technologies in H2 plants of upgrading facilities
- Develop, demonstrate, and deploy CCUS technologies for
  - Once through steam generation (OTSG)
  - Cogeneration (COGEN)
  - Natural gas combined cycle (NGCC) facilities
- Accelerate the development and deployment of new recovery technologies
  - Non aqueous extraction (NAE)
  - In pit extraction process (IPEP)
  - Expanding Solvent Steam Assisted Gravity Drainage (ES-SAGD)
  - Steam-Solvent hybrid
  - Pure Solvent
  - Radio Frequency (RF)
- Develop, demonstrate, and deploy net zero technologies
  - Small modular nuclear reactors (SMR)
  - Renewables
  - bio energy carbon capture utilization and storage (BE-CCUS)
  - Direct air capture (DAC)
- Invest in Bitumen Beyond Combustion (BBC) pathways to diversify the industry and strengthen long-term sustainability

Natural Gas Sector

To take advantage of the benefits the hydrogen enriched natural gas (or hythane) provides for the energy transition in the country, there needs to be clarity and legislation to support maximum blending limits for household applications. There also needs to be funding made available to support the industry during pilot tests to determine the acceptable and safe blending limit. Creating inland hydrogen export markets (such as Alberta to Ontario, Manitoba, and California) will establish an economic justification for hydrogen blending in natural pipeline infrastructure in the long term.

Electricity Sector

Government programs to incentivise/accelerate renewable electricity deployment, especially wind. Figure 6-1 shows the marginal abatement costs of Alberta low-carbon electricity scenarios

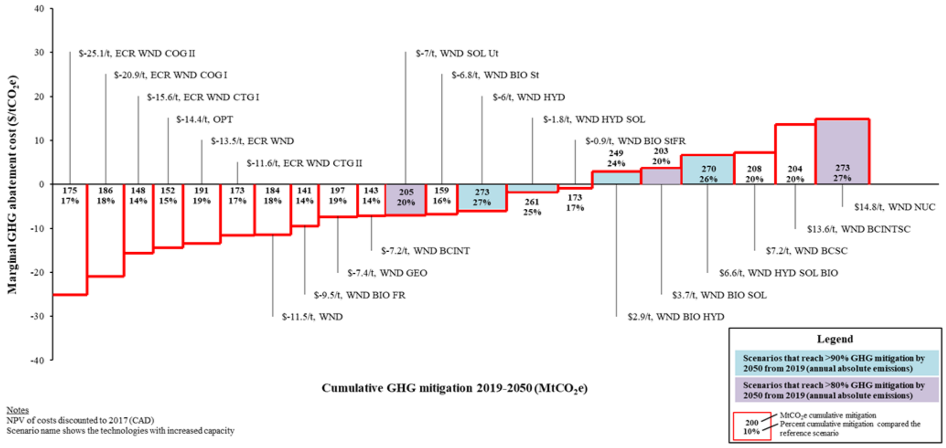

FIGURE 6-1 Marginal abatement costs of Alberta low-carbon electricity scenarios [74]

Chemical Sector

Similar to oilsands and natural gas sectors a combination of energy efficiency, hydrogen and CCS are envisioned to reduce these emissions over the time period.

Agricultural Sector

In order to further enhance climate resiliency and climate change adaptation in the agricultural sector, provincial and federal governments should continue to allocate funding towards continued irrigation infrastructure modernization. Investments in processes to optimize water management within the major river basins will build the capacity to adapt to climate change and enhance resiliency utilizing the modernized irrigation infrastructure to support more industrial growth and water supply for communities.

Canada should broaden access to funding for research and development on advanced irrigation technologies that will contribute to future water management efficiencies. The Canadian Agri-Food Automation and Intelligence Network (CAAIN) based in Alberta is an excellent starting point.

Appropriate upgrades to the electric distribution system should be considered to support on-farm solar PV installations to electrify pivot irrigation systems and allow producers to facilitate the movement of excess energy from these developments into the system.

Solid Waste Sector

The Canada Plastics Pact (CPP) Route to 2035 recommends the following high-level actions [75]:

- Priority 1: Reduce, Reuse, Collect
- Priority 2: Optimize the Recycling System (including Energy demand and supply)
- Priority 3: Use Data to Improve the Whole System
- Supportive activities identified in CPP include Regulatory, Data/Digital/AI Solutions, Material Standards, Energy supply (GHG emissions), Process Efficiency, and Partnerships to drive regulatory change, technology innovation and deployment, and alignment with ESG targets.

These same key recommendations can be generally applied to non-plastic wastes, such as organics, although the systems and solutions may be different.

For optimal ESG, focus on waste mitigation and diversion solutions that consider the full waste hierarchy, including Reduce and Reuse, not just Recycle and Recover (Energy).

Solutions to improve energy efficiency, reduce carbon footprint, and reduce impacts on water supply and water quality associated with circular economy processes will be an important aspect of both large-scale industrial facilities and micro-businesses.

Data-based and digital solutions to measure ESG benefits will be important to measure outcomes. Digital/data-based solutions will need to recognize and accommodate digitally impoverished communities and enterprises (e.g., rural, and remote locations; marginalized communities) to enable full participation and earning of available ESG credits.

Attention should be given not only to existing wastes, but potential for new wastes from emerging advanced and composite materials.

Other opportunities include right sizing (scale up/down) technologies; Repair businesses (supporting Reduce and Reuse); improving efficiency of Collection, Sorting and Pre-Processing; social enterprise opportunities in the circular/recycling system.

Pulp and Paper Sector

Institute sector-wide benchmarking programs to quantify the performance of Canadian/Albertan pulp and paper relative to global standards and highlight the untapped potential to reduce energy demand and GHG emissions levels. Incentivize energy management, fuel switching and bioenergy with carbon capture and storage programs across sector.

7. POTENTIAL COLLABORATIONS

Collaborations continue to be an essential part of communicating, promoting, and enabling progress.

Collaborations including federal-provincial governments, oil sands industry-government, researchers and cleantech providers with the industry, and oil sands industry with materials manufacturers and end users should continue to be strengthened.

Continued collaboration is encouraged between industry and agencies, including Emissions Reduction Alberta; among industry and Alberta's research universities; with the Federal Government on policies and programs that support the application of decarbonization technologies, while respecting the competitive nature of the wholesale electricity market.

Irrigation collaborations with the provincial and federal governments, and researchers should be continued.

The collaborative opportunity represented by the Canadian Council of Environment Ministers (CCEM) [76], "the primary minister-led intergovernmental forum for collective action on environmental issues of national and international concern", can be leveraged.

Continued collaboration and support of technology innovation and knowledge generation involving post-secondary/research, different levels of government and the private sector is needed.

Ongoing and new collaborations should be built on across industries/sectors such as manufacturing, waste and environmental management, retail, supply chain management, research and development, information technology and finance/investment.

There are good opportunities for synergies and collaborations with end-use industries such as fuel refiners and utilities companies. Leveraged access to biomass and logistics expertise can help contribute to reduce carbon emissions and intensities in other sectors. Additionally, there is opportunity to collaborate on CCUS projects to assist others in reducing emissions through the monetization of offsets.

Continued and expanded collaborations will be a vital component to enabling pathways for industry GHG reductions.

We, as members of the ACR; represent industry, academia, and professional service leaders in Alberta. As vested stakeholders, we are keenly interested in the future of our industries. Next steps in follow-up to our RIF initiative could include focused, solution-oriented dialogues between government and ACR members to high-grade the opportunities for government to action.

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Appendices

APPPENDIX A

Key Messages Table – Present State, Opportunities and Recommendations by Sector

<table>
<tr><th>Present State</th><th>Opportunities</th><th>Recommendations</th></tr>
<tr><td colspan="3">Our purpose is to build on the Alberta Chamber of Resources’ (ACR) ongoing mission of providing cross-sector leadership for strategic and responsible development of Alberta’s natural resources, with specific focus on envisioning sustainable advancement for the Resource Industries of the Future (RIF).

The following is a Key Message Summary of our RIF Pathway Framework whitepaper.</td></tr>
<tr><td><u>General / Cross-Sector</u>

Alberta has abundance of natural resource industries including forestry, oil & gas, oil sands, mining, agriculture, and has among the best wind and solar resources in Canada.

Government of Alberta has undertaken an ESG Challenge.</td><td><u>General / Cross-Sector</u>

Alberta has a mature ecosystem for energy innovation and collaboration to build on and leverage for further successes.

A critical role to play to meeting transition pathway demand.

An incredible economic opportunity associated with transition pathway with competitive, low emission production.

An orderly transition will require practical approaches and significant government and industry investment.</td><td><u>General / Cross-Sector</u>

Technologies that are proven but not economic, investment will occur where incentives sufficiently close gap.

As a waste stream, emissions management is just a cost for which operators merely seek to break even.

Any consideration of offset credits to reflect certainty of value for the long term.

Direct support for capital costs in the form of grants is preferred over tax credits.</td></tr>
<tr><td><u>Oil Sands</u>

Canada's oil reserves globally 9% of total proved reserves and 97% are Alberta's oil sands.

GHG emission intensity of the oil sands is significantly more than conventional oil.

Most companies have intended commitments to net-zero 2050.</td><td><u>Oil Sands</u>

Funding sources including AI, ERA, AEP, and federal sources are available to support sustainable development.

Opportunity to continue to be supplier of low carbon production to competitively meet energy demand in a responsible way.

Increasing industry commitments to ESG advancements are better positioning for the future.</td><td><u>Oil Sands</u>

Canada’s should be a supplier of choice. Need to promote more international support.

Accelerate the deployment of energy efficiency and process improvement technologies

Identify electrification and fuel substitution opportunities and start to implement</td></tr>
</table>

Investment in the oil sands is being impacted by divestment from the industry. With commodity prices improving, many companies are forgoing new investments in favor of returning capital to shareholders through dividends and share purchase buybacks. Challenge to change "dirty" Canadian oil sands narrative and relaying truth of our stringent ESG standard.	Reducing regulatory burden has helped streamline approvals for oilsands projects. Producers have benefited from Job Creation Tax Cut, accelerated capital cost allowances, reductions in red tape regulations, however federal and foreign policy and regulatory uncertainty have made it challenging to attract new capital to the industry. Further regulatory and policy direction CCUS on subterranean tenure and support for favorable federal tax treatment agnostic towards sector and technology would be beneficial.	Build CO2 trunk line and storage hubs as enabling infrastructure Deploy CCUS technologies in H2 plants of upgrading facilities Develop, demonstrate, and deploy CCUS technologies for OTSG, COGEN, and NGCC. Accelerate the development and deployment of new recovery technologies (NAE, IPEP, ES-SAGD, Steam-Solvent hybrid, Pure Solvent, RF) Develop, demonstrate, and deploy net zero emission technologies (SMNR, Renewable, BE-CCUS, DAC) Invest in Bitumen Beyond Combustion (BBC) pathways to diversify and strengthen long-term sustainability
Natural Gas Sector Globally, Canada is the 4th-largest producer and 6th-largest exporter of natural gas. Alberta produces 66% of Canada's natural gas. Global demand for gas and LNG is significant, however, Canada has not full capitalized on the international export opportunity.	**Natural Gas Sector** Critical energy source for transitioning energy systems from fossil fuels to more sustainable systems for balancing energy security, affordability, and accessibility. Canada is behind other top producing countries in the natural gas and LNG opportunity and faces international competition. Growth in global LNG demand. Costs advantage from Western Canada to Asia-Pacific. Significant opportunity to use natural gas to fuel a growing hydrogen economy at globally competitive costs. Global hydrogen demand could reach $12 trillion by 2050. APIP policy has advanced value-added and upstream investment,	**Natural Gas Sector** Funding and reducing red tape to developing Canada's natural gas reserves. Investment and incentives required for LNG infrastructure and export. Funding for the development of industrial scale blue hydrogen is required, particularly for industrial hubs in Calgary, Red Deer, Edmonton, and Grande Prairie Water availability is an important constraint, especially in the South Saskatchewan River Basin. The technologies under consideration for hydrogen production (SMR and ATR) are highly water intensive. Alternative tehnologies (Cvictus process and

	however, more is needed, particularly for Hydrogen production Exploring opportunities where the Crown can support enhanced egress through liquified natural gas development.	pyrolysis) are still in development. Opportunities for producing hydrogen are more realistic in the Athabasca River and Peace River basins, and some limited additional development in the North Saskatchewan basin.
Electricity Sector AESO administers the wholesale electricity market in a manner that supports fair, efficient and open competition. Wholesale electricity market transacting $5.7 billion of energy with installed capacity of 16,362 MW, peak demand of 11,729 MW and total internal load of 83,115 GWh. Carbon emissions regulation and pricing have driven emissions reduction in sector over 15 years. Generation (AESO, 2020): Coal ~ 5,050 MW Cogen ~5,150 MW CC ~ 1,800 MW Wind ~1,800 MW SC ~1,050 MW Hydro ~ 900 MW Solar ~200 MW Other ~400 MW Coal generation capital costs increased while renewable costs decreased, creating environment where economics of new coal generation were subordinated by natural gas and renewables.	**Electricity Sector** Alberta has transitioned from coal-based to largely natural gas-fired over last 2 decades. Coal-to-gas conversions enable producers to make meaningful near-term emissions reduction. Continue growth in wind and solar, and high-efficiency natural gas-fired generation expected to be a significant portion of the future generation capacity. Reduction of emissions in electrical sector is critical to reducing emissions across other high emitting sectors. With changing economics, driven by government policy and technological advancements, emissions from Alberta's electricity generation to decline in the future. Natural gas cogeneration and natural gas combined cycle emissions make up most emissions (2030-2050); GHG emissions decrease by 8%.	**Electricity Sector** Coal generation reduction will eliminate 32% of GHG emissions by 2030. Remaining emissions reduction more challenging and rely on new infrastructure and technology. Maintaining baseload and affordability as increased renewables are added to grid. Need more certainty in forward-looking policy and regulation. Other potential paths for carbon emissions reductions include CCUS, introducing hydrogen as a component of the natural gas fuel supply, and the introduction of SMRs into the supply mix. Green Hydrogen from electrolysis will develop increasingly over the mid and long term
Chemical Sector Relies on oil and gas products for both fuel and feedstock, thus, strongly affected by new	**Chemical Sector** Dow's net-zero emissions ethylene production facility	**Chemical Sector** Continued investment in developing Alberta's clean hydrogen economy may lead to

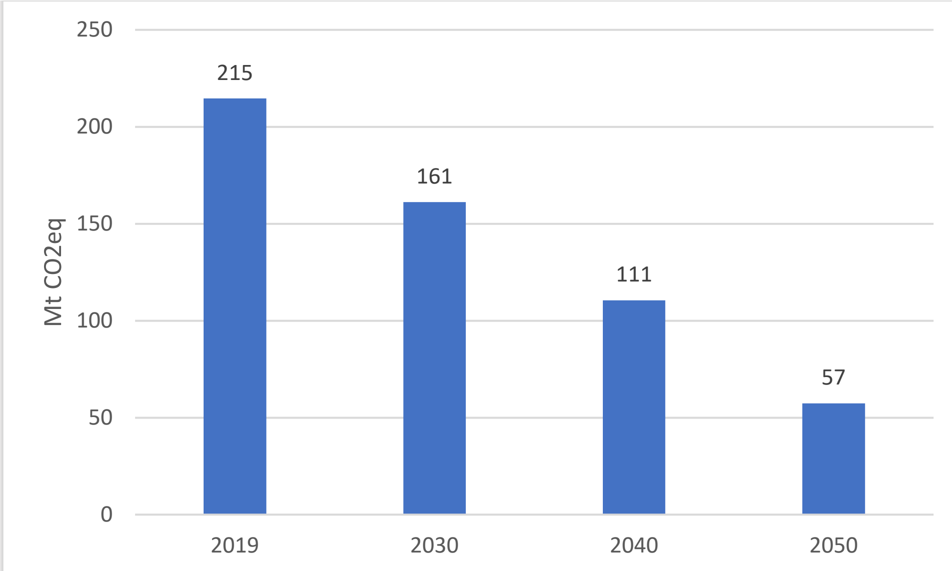
oil and gas production capacity and regulatory designed to decarbonize oil and gas. Accounts for 17% of total sales value for all manufacturing sectors in the province. Ammonia and ethylene production are 12% of industrial energy consumption and 10% of industrial GHG emissions. Uses 38% of hydrogen produced in the province.	promising decarbonization in petrochemical sector. Canadian ammonia producers are among most efficient worldwide. Energy efficiency improvement scenarios indicate potential reduced emissions of 7.1 $MtCO_2e$ (2018-2030), and 29.7 $MtCO_2e$ (2018-2050). Under a carbon price plan that increases to $170/$tCO_2e$ by 2030, mitigation potential from chemical industry could be 35.2 $MtCO_2e$ (2021-2050). Unconventional clean hydrogen opportunities from stranded resources with carbon sequestration	environmental and economic benefits for the producers
Agricultural Sector 8% of Alberta's GHGs from agricultural; half livestock and half cropping, with on-farm fuel use 13% of agricultural GHGs. Irrigation infrastructure is primarily gravity with some on-farm electricity, natural gas- or diesel-powered pumping units. 8 hydroelectric stations on Government of Alberta and irrigation district total 92MW. Irrigation infrastructure provides water access to: • 50,000 people in southern Alberta • Commercial and industrial purposes, oil and gas and processing facilities	**Agricultural Sector** ERA funding through Food, Farming and Forestry Challenge committing $33 million for 17 projects with a combined value of $107 million in public and private investment. Irrigation conveyance infrastructure provides regional climate change adaptation by mitigating drought and floods. Rehabilitation/modernization of irrigation infrastructure has created a highly efficient water delivery system in southern Alberta and supports on-farm conversion to more efficient application systems. Genome Alberta is integral in technology, research, and innovation supporting development and deployment of genomics enabled solutions for	**Agricultural Sector** Irrigation Rehabilitation Program and new Alberta Modernization Program funding should be maintained. Carbon sequestering through soil carbon accumulation can continue until 2040. After which, continuance of farming practices maintains this sink. Irrigators may be expected to prove water sustainability and undertake further actions. Market prices may not rise enough to allow producers to recapture additional costs. Aquatic invasive species are a risk. Prevention, inspection, and enforcement actions across the country require improvement on

• Livestock watering • Recreational opportunities on irrigation reservoirs.	health, agriculture, energy, forestry, and the environment.	consistency, alignment, and funding. Alberta's Bioconversion Ecosystem
Conventional Light Oil Sector	**Conventional Light Oil Sector** Liability Management Framework has established expectations for lifecycle and enabled more certainty to address site closure obligations. The Site Rehabilitation Program (SRP) has enabled abandonment and environmental reclamation work to significantly reduce inactive and abandoned sites.	**Conventional Light Oil Sector** An Inventory reduction program with spend targets, a landowner opt-in mechanism and Area Based Closure Program, and a subject matter expert panel from industry and the financial community for post-closure liabilities will assist in addressing well-site remediation and improve the financial health of producers by lowering their Asset Retirement Obligations (ARO).
Petroleum Refining Sector Within sector, the oil and gas is 39% of energy consumption and 37% of GHG emissions where fossil fuels are both feedstock and source of energy. Energy is 50% of operating cost. Crude distillation capacity of 1.98 Mbbl./day in Canada. 25% of Canada's refining is in Alberta. No refineries built since 1970s. Since 1950s refining capacity increased steadily and stabilized in 2000. Sturgeon Refinery expansion add recent capacity.	**Petroleum Refining Sector** Energy efficiency in the refining could result in cumulative emissions reduction of 12%, or 1 $MtCO_2e$/year by 2050 (14%).	**Petroleum Refining Sector**
Pipelines and Midstream Sector Pipelines in Alberta consist of natural gas, oil, hydrogen, and CO_2. Total capacities: - Interprovincial natural gas 407 Mm3/day.	**Pipelines and Midstream Sector** Bitumen and synthetic crude oil (SCO) production has superseded pipeline capacity. SCO by rail or new pipelines is sensitive to distance, scale, and crude grade.	**Pipelines and Midstream Sector** Hydrogen blends end-use limitations need to be considered.

- Oil pipelines to outside markets 728 Km3/day and interprovincial 1219 Km3/day. - Alberta Carbon Trunk Line (CO_2) 14.6 Mt CO_2 per year.	The economic consequences of a pipeline capacity shortfall can result in a rise in pipeline tolls. Reduce emission intensity of natural gas and increase use of hydrogen, as hythane (HENG). Hydrogen blends of 5%-15% require minor adaptions to natural gas infrastructure. For repurposed natural gas pipelines, capacity will be reduced (for 15% hydrogen, capacity would decrease 11%).	
Solid Waste Sector Alberta's MSW generation increased 1.37 million tonnes (2002-2018). 70% of MSW is disposed of on land. Alberta has the highest per capita output of waste, and the highest per capita spending on waste diversion of any province. The disposal of MSW in landfills is a key factor contributing to impacts on human health and surrounding environment. Waste management is overhead for municipalities, financed through capital funding (federal/provincial), municipal taxation or utility charges, tipping fees and deposit programs for regulated "designated" materials. EPEA legislative/regulatory frameworks that enable revenue generation from diversion of waste include:	**Solid Waste Sector** Increase on diverting MSW from landfills to material and energy recovery facilities Concept of W2VA facilities is receiving increased attention. Alberta has strong potential to integrate polymers derived from recycled materials. Alberta's Natural Gas Vision and Strategy identifies plastics circular economy as a priority. Plastics Circular Economy - The Government of Alberta, Alberta Plastics Recycling Association, Plastics Alliance of Alberta, and Recycling Council of Alberta collaborating with industry for plastics circular economy and are also pursing implementation of extended producer responsibility (EPR). Research and demonstration projects enhancing production and economics for biogas and gas products, biofuels, advanced	**Solid Waste Sector** Careful selection of optimal locations for W2VA is essential. Quantifying the availability of feedstocks are key for sustainable decision-making. The role of municipalities in waste management can create both opportunities and barriers for investment. Mitigation of methane from organic landfill and wastewater treatment, and creation of value-added products collaborations should have increased importance. For optimal ESG, focus on waste mitigation and diversion solutions that consider the full waste hierarchy, including Reduce and Reuse, not just Recycle and Recover (Energy). Canada Clean Fuels Regulations for low carbon fuels and alternative energy for ground transportation. Further enactment

• Extended Producer Responsibility (EPR) • Designated Materials Regulations and policies that further enable waste diversion, utilization and emissions mitigations include Alberta's Carbon Offset System, the Renewable Fuels Standard Regulation, and the Land Use Framework.	materials, and chemicals from organics. Funding sources to support waste reduction and value-added opportunities include: AI, ERA, Alberta Environment & Parks, First Nations Waste Management Initiative, and Federation of Canadian Municipalities High variance of technology TRL's, most near commercial.	of regulations that are at initial implementation. The Canada Plastics Pact (CPP) Route to 2035 recommends • Reduce, Reuse, Collect • Optimize Recycling System • Data to Improve System • Supportive activities include Regulatory, Data Solutions, Material Standards, Energy supply, Process Efficiency, and Partnerships. Same recommendations can generally apply to organics.
<u>Pulp and Paper Sector</u> Sector is characterized by high bioenergy consumption and high levels of process-integrated electricity cogeneration, but cost-effective energy demand and GHG emissions reduction opportunities remain unrealized or under-utilized. Alberta has 5% of Canada's pulp mills, which accounts for 2.0 $MtCO_2e$ in direct GHG emissions.	**<u>Pulp and Paper Sector</u>** Development of novel bioenergy production processes and integration with CCS may accelerate decarbonization. Many facilities are virtually carbon neutral already due to biogenic energy production. Implementing economical GHG mitigation measures would significantly reduce natural gas and electricity grid demand for all mill types by 2050. 50% of emissions can be mitigated through commercially ready, economic measures by 2050 considering a carbon cost of up to $170/tCO_2e. Bio-based fuel production and use is a significant opportunity. ERA funding through Food, Farming and Forestry Challenge is committing $33 million for 17	**<u>Pulp and Paper Sector</u>** Largest market access issue is reliable and sufficient rail and truck capacity. Further opportunities related to heat recovery, carbon capture and emissions' reduction exist for both Alberta's self-contained and external power reliant mills, awaiting feasible economics and appropriate technologies. Additional uneconomic mitigations will require specific subsidization to become economical for producers. Considering both economic and uneconomic measures, GHG emissions from Canada's pulp and paper sector may be reduced by 87% by 2050.

	projects with a combined value of $107 million in public and private investment. Achieving net-zero emissions by 2050 will not require development of entirely new production facilities as the GHG emissions may be offset through carbon-negative solutions, such as process-tied CCUS, DAC, or forestry-based offset programs.	
Cement Sector Industry relies on natural gas, coal, and electricity. The cement, gypsum and lime sectors are very integrated. Energy use in cement sector increasing 0.05%/year (2000-2018). By implementing energy efficiency measures, GHG intensity decreasing -0.32%.	**Cement Sector** Waste of other sectors such as tires and agriculture waste as a fuel can be considered to reduce energy demand. Using green hydrogen instead of natural gas and employing energy efficiency opportunities in this sector can reduce total energy use and GHG emissions.	**Cement Sector** Scenarios have been evaluated for energy efficiency improvement measures within conventional production processes. Together, the assessed measures may mitigate a total of 2 $MtCO_2e$ or 10% of projected sectoral emissions between 2021-2050.
Overall Industry Sectors Roadmap for Alberta We have composed a vision of practical GHG emission reduction pathways for Alberta future focused economic diversification for consideration:		



Short-term (to 2030)	Mid-term (2030 to 2040)	Long-term (2040 to 2050)
Pathways for GHG Reductions		
Energy efficiencies Process improvements Electrification and grid modernizations Geothermal heating and power Wind and solar generation Fuel substitutions Recovery and enhanced technologies Credits and trading		
CCUS limited scale	CCUS broad scale	Integrated CCUS
Flue decarbonization	Inlet decarbonization	Direct air capture
Blue hydrogen	Blue & Green hydrogen	Green hydrogen
Hydrogen-enriched gas	Hydrogen distribution	Hydrogen industry
Bio Industrial	Bio industrial next gen	Bio industrial networks
	BBC products	New products
	SMNR	Nuclear