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Towards Hydrogen

A HYDROGEN HUB FEASIBILITY STUDY FOR SOUTHEAST ALBERTA

Randy O. Litun, P.Eng.

The Transition Accelerator
L'Accélérateur de transition

Towards Hydrogen

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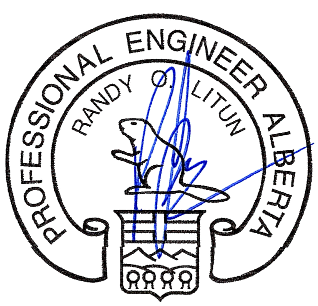

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ABOUT THE TRANSITION ACCELERATOR

The Transition Accelerator (The Accelerator) exists to support Canada's transition to a net zero future while solving societal challenges. Using our four-step methodology, The Accelerator works with innovative groups to create visions of what a socially and economically desirable net zero future will look like and build out transition pathways that will enable Canada to get there. The Accelerator's role is that of an enabler, facilitator, and force multiplier that forms coalitions to take steps down these pathways and get change moving on the ground.

Our four-step approach is to understand, codevelop, analyze and advance credible and compelling transition pathways capable of achieving societal and economic objectives, including driving the country towards net zero greenhouse gas emissions by 2050.

1. UNDERSTAND the system that is being transformed, including its strengths and weaknesses, and the technology, business model, and social innovations that are poised to disrupt the existing system by addressing one or more of its shortcomings.

2. CODEVELOP transformative visions and pathways in concert with key stakeholders and innovators drawn from industry, government, indigenous communities, academia, and other groups. This engagement process is informed by the insights gained in Stage 1.

3. ANALYZE and model the candidate pathways from Stage 2 to assess costs, benefits, trade-offs, public acceptability, barriers and bottlenecks. With these insights, the process then re-engages key players to revise the vision and pathway(s), so they are more credible, compelling and capable of achieving societal objectives that include major GHG emission reductions.

4. ADVANCE the most credible, compelling and capable transition pathways by informing innovation strategies, engaging partners and helping to launch consortia to take tangible steps along defined transition pathways.

ABOUT THE AUTHOR

Randy O. Litun, P.Eng.

SKY POINT RESOURCES LTD.

Randy Litun is the President of Sky Point Resources Ltd., an engineering consulting company offering evaluation and advisory services to the energy sector. With greater than 30 years of energy industry experience, Litun has deployed his broad expertise in energy and energy systems for various projects focused on corporate strategy and visualizing new technology implementation for the commercial development and value optimization of energy assets, which includes upstream, midstream, and downstream oil and gas projects, electrical generation, CCUS, and energy transition.

In addition to being a former co-founding member of a private oil and gas company, Litun has held a variety of operational and management positions with various oil and gas organizations, with both domestic and international exposure, in multi-disciplinary roles combining technical and executive leadership to drive commercial and business development. As an advocate for optimization, efficiency, and creative innovation, he has worked on the responsible development of primary and secondary recovery of oil, gas, heavy oil, and unconventional resources, and is currently focusing on the role of hydrogen and hydrocarbons in a sustainable low-carbon energy transition economy. Litun is a Professional Engineer with APEGA and a member of the SPE.

Litun was engaged by The Transition Accelerator as an independent HUB Facilitator consultant to work in conjunction with the Southeast Alberta Hydrogen Task Force for the purpose of generating this Hydrogen Foundation Report to support the launch of a Hydrogen HUB in Southeast Alberta.

The author would like to acknowledge the support and contributions from the **Transition Accelerator** and specifically **David B. Layzell**, Ph.D., FRSC, **Dinara Millington**, **Lydia Lam**, and **Chris Bayley**, in the compilation of this report.

FIGURES, TABLES, BOXES

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LIST OF ABBREVIATIONS

ABBREVIATION	DEFINITION
AADT	Annual Average Daily Traffic
ACCTC	Alberta Carbon Conversion Technology Centre
Acid Gas	Gas mixture containing significant quantities of H_2S, CO_2 and other acidic gases
AECO	Alberta Energy Company natural gas hub situated at Suffield, Alberta
AEOR	Alberta Emissions Offset Registry
AER	Alberta Energy Regulators
AESO	Alberta Electricity System Operator
AIH	Alberta Industrial Heartland, a region in Alberta which includes Edmonton, Strathcona, Fort Saskatchewan, Sturgeon, and Lamont counties
AIL	Alberta Internal Load
AMTA	Alberta Motor Transport Association
APEC	Asia-Pacific Economic Cooperation
APEGA	Association of Profession Engineers and Geoscientists of Alberta
APIP	Alberta Petrochemical Incentive Program
ATR	Autothermal Reforming
AUC	Alberta Utilities Commission
AZETEC	Alberta Zero-Emission Truck Electrification Collaboration Project
BATUS	British Army Training Unit Suffield

ABBREVIATION	DEFINITION
BEB	Battery Electric Bus
BEV	Battery Electric Vehicle
Blue Hydrogen	Hydrogen produced from natural gas utilizing carbon capture and storage
BTF	Behind the Fence
BSP	Business Scale-up and Productivity
BU	Bus
C	Carbon
CAD	Canadian Dollar
CAF	Canadian Armed Forces
CaMI	Containment and Monitoring Institute
CC	Combined Cycle natural gas electrical generation
CCUS	Carbon Capture, Utilization, and Storage
CEDD	Community Economic Development and Diversification
CER	Canadian Energy Regulators
CESAR	Canadian Energy Systems Analysis Research
CETO	Central East Transfer-out project
CFB	Canadian Forces Base
CH4	Methane
CIB	Canada Infrastructure Bank
CMC	Carbon Management Canada
CMH	City of Medicine Hat

ABBREVIATION	DEFINITION
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Coalition of the Committed	Group of diverse stakeholders with the common beliefs, interests, and goals of establishing low-carbon energy transition in SE Alberta
Cogen	Cogeneration natural gas and thermal electrical generation
CSA	Canadian Standards Association
CV	Commercial Vehicles (BU, SU, & TT combined)
DAS	Data Acoustic Sensing
DMFC	Direct Methanol Fuel Cell
DND	Department of National Defence
Domestic Exporter	Reference to shipping from SE Alberta to other regions of Canada
DRDC	Defence Research and Development Canada
DSST	Defence and Security Science and Technology
DTE Ratio	Drivetrain Efficiency Ratio (GJ H_2/GJ diesel or gasoline for same distance)
DTS	Distributed Temperature Sensing
EATL	Eastern Alberta Transmission Line
ECCC	Environment and Climate Change Canada
EDI	Economic Development Initiative
EID	Eastern Irrigation District
EOR	Enhanced Oil Recovery
ERA	Emissions Reduction Alberta

ABBREVIATION	DEFINITION
ERT	Electrical Resistivity Tomography
EU	European Union
FCEB	Fuel Cell Electric Bus
FCEV	Fuel Cell Electric Vehicle
FF	Fossil Fuel
FRC	Field Research Centre
GHG	Greenhouse Gas
GHGRP	Greenhouse Gas Reporting Program
GJ	Gigajoule (10^9 joules)
Green Hydrogen	Hydrogen produced by water electrolysis using intermittent zero-carbon electricity generated from wind and solar facilities
Grid	Alberta's power transmission network
H_2	Hydrogen gas
H_2O	Water
H_2S	Hydrogen Sulphide
HDV	Heavy-Duty Vehicle: Vehicles with a gross vehicle weight rating > 15 tonne
HFCE	Hydrogen Fuel Cell Electric
HHV	Higher Heating Value
HGV	Hydrogen Gas Vehicle
HPIT	Hydrogen Powered Industrial Truck
HRSG	Heat Recovery Steam Generator
HUB	Formal Hydrogen HUB as defined within the report

ABBREVIATION	DEFINITION
IBR	Inverter-Based Resources
ICE	Internal Combustion Engine
iDEaS	Innovation for Defence Excellence and Security
IEA	International Energy Association
IEPS	Integrated Energy & Power Solutions
iMHZEV	Incentives for Medium- and Heavy-Duty Zero Emission Vehicles program
IPL	Inter Pipeline Ltd.
IRAP	Industrial Research Assistance Program
ISO	International Organization of Standards
kJ	Kilojoule (103 Joules)
Last Mile	Final step between a distribution centre and the end user
LDV	Light-Duty Vehicle
LH_2	Liquid Hydrogen
LHV	Lower Heating Value
LOHC	Liquid Organic Hydrogen Carrier
LTP	AESO Long Term Plan for electrical generation and transmission
MDV	Medium-Duty Vehicle
MHC	Medicine Hat College
MHIC	Medicine Hat Industrial Complex
MHZEV	Medium- and Heavy-Duty Zero Emission Vehicles
MJ	Megajoule (10^6 joules)

ABBREVIATION	DEFINITION
MOU	Moratorium of Understanding
Mt	Megaton (10^6 metric tonnes)
NG	Natural Gas
NGTL	Nova Gas Transmission Line
NGX	Natural Gas Exchange Inc. (Canada)
NH_3	Ammonia
NIMBY	Not In My Back Yard
NIT	Nova Inventory Transfer
NRCan	Nature Resources Canada
NWR	Northwest Redwater Partnership
O_2	Oxygen
OCH	Organic Chemical Hydride
OEM	Original Equipment Manufacturer
OGIP	Original Gas in Place
OOIP	Original Oil in Place
PCOR	The Plains CO_2 Reduction Partnership
PEM	Proton Exchange Membrane
PEP	Palliser Economic Partnership
PFR	Primary Frequency Response
PHEV	Plug-in Hybrid Electric Vehicle
PJ	Petajoule (10^{15} joules)

ABBREVIATION	DEFINITION
Pool Price	Hourly settlement of average wholesale price paid by AESO to Alberta generators
Power Pool	Balance of electric load and generation and the market for buying and selling electricity
PPA	Power Purchase Agreement
PSAC	Petroleum Services Association of Canada
PV	Passenger Vehicle
RCID	Ross Creek Irrigation District
REA	Rural Electrification Association
REP	Renewable Electricity Program
RFP	Request for Proposals
RIE	Regional Innovation Ecosystems
RNG	Renewable Natural Gas
Rural	All areas with fewer than 1,000 inhabitants and a population density below 400 persons per square kilometer
RV	Recreational Vehicle
SA	Special Areas
SAAEP	Southern Alberta Alternative Energy Partnership
SAEWA	Southern Alberta Energy from Waste Association
SC	Simple Cycle natural gas electrical generation
SDTC	Sustainable Development Technology Canada
SE Alberta	Southeast Alberta
SETR	Southeast Transmission Reinforcement Project
SIF	Strategic Innovation Fund

ABBREVIATION	DEFINITION
SMP	System Marginal Price for electricity, highest-priced offer block in each minute
SMR	Steam Methane Reforming
SMRID	St. Mary River Irrigation District
SOEC	Solid Oxide Electrolyzer
SR&ED	Scientific Research and Experimental Development tax incentive
SRC	Suffield Research Centre
StatsCan	Statistic Canada
SU	Single Unit Truck
SUT	Single Unit Truck
TIER	Technology Innovation and Emissions Reduction
TJ	Terajoule (10^{12} joules)
TT	Truck and Trailer
TTC	Tractor Trailer Combination
Urban	A continuously built-up area having a population concentration of 1,000 or more and a population density of 400 persons or more per square kilometer
US	United States of America
WCB	Western Canadian Basin
ZEB	Zero Emission Bus
ZETP	Zero Emission Truck Program
ZEV	Zero Emission Vehicle
ZEVIP	Zero Emission Vehicles Infrastructure Program

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CITY OF MEDICINE HAT

Medicine Hat is a thriving community of approximately 63,000+ residents and is alive with vibrancy and spirit few communities witness. Located in the beautiful South Saskatchewan River Valley, the community enjoys the values that are intrinsically tied to our history and quality of life. Medicine Hat strives to achieve City Council's vision of being "a community of choice" where people come to live, work, and play. We boast an excellent climate, a safe and healthy community, vibrant arts and entertainment, and ample recreation and leisure opportunities.

INVEST MEDICINE HAT

Invest Medicine Hat (IMH) is the Economic Development department of the City of Medicine Hat. IMH, is responsible for connecting entrepreneurs and investors to land development and real estate, incentives, local business resources and investment opportunities in the area.

BROOKS NEWELL REGION

The Brooks Newell Region includes four urban municipalities within the County of Newell: City of Brooks, Town of Bassano and Villages of Duchess and Rosemary. It is well positioned to access markets across Canada and beyond, as it is central to Calgary, Medicine Hat, and Lethbridge and is a growing transportation hub provided by the TransCanada Highway, Highway 36, and the CP Rail mainline running down the spine of the county. The Region continues to benefit from the economic driver of the oil and gas industry, as Brooks and area is home to many major oil and gas production and service companies. The Brooks Newell Region is also a leader in the Agricultural sector, having significant farming operations, research and development facilities, and a world scale food processing industry. Additionally, local businesses have consistently diversified and have found innovative ways to operate and grow.

Business costs are low. Quality of life is high. Better. Realized.

PALLISER ECONOMIC PARTNERSHIP

Palliser Economic Partnership is a collaborative regional economic development initiative that includes 19 southeast Alberta communities, and one post-secondary educational institution. It is the only economic development organization in southeast Alberta to receive ongoing operational funding from the Government of Alberta.

Palliser Economic Partnership's mission is to facilitate regional cooperation to position southeast Alberta as an ideal location for business investment, and to assist communities in regional projects and economic development activities that cannot be completed by communities on their own.

APEX ALBERTA

APEX Alberta is a Regional Innovation Network supporting the growth of innovation-driven and technology-oriented businesses in southeast Alberta. APEX is a collaborative partnership between three core service providers: Medicine Hat College, Community Futures Entre-Corp and Alberta Innovates.

CAMPUS ENERGY

Campus Energy is an Alberta-based energy infrastructure company, headquartered in Calgary and owned by Birch Hill Equity Partners. Our energy infrastructure assets include natural gas transmission pipeline systems in Alberta and Saskatchewan; natural gas gathering and processing facilities in Alberta and Saskatchewan; a Liquified Natural Gas (LNG) processing facility in British Columbia; and power peaking units in Southern Alberta. Our energy supply business provides natural gas to commercial and industrial customers in British Columbia, Alberta, Saskatchewan, Manitoba and Ontario, and electricity to customers in Alberta. Campus actively pursues the development, construction, acquisition, and operation of additional energy infrastructure businesses and assets within our footprint, that supports Canada's net-zero Goals.

CF INDUSTRIES

At CF Industries, our mission is to provide clean energy to feed and fuel the world sustainably. With our employees focused on safe and reliable operations, environmental stewardship, and disciplined capital and corporate management, we are on a path to decarbonize our ammonia production network – the world's largest – to enable green and blue hydrogen and nitrogen products for energy, fertilizer, emissions abatement, and other industrial activities. Our 9 manufacturing complexes in the United States, Canada, and the United Kingdom, an unparalleled storage, transportation and distribution network in North America, and logistics capabilities enabling a global reach to underpin our strategy to leverage our unique capabilities to accelerate the world's transition to clean energy.

COMTECH ENERGY / 4REFUEL INDUSTRIAL SERVICE

4Refuel + Comtech offers diverse energy refueling and infrastructure design-build solutions. Together we partner in sustainable fuel management operations— now and for the innovation ahead.

Our diverse renewable and regenerative fuel delivery services, including CNG, RNG and Hydrogen, optimize emission control, save companies time, and reduce inflating labor costs. We make fuel handling a safe, standardized, and measurable part of your project. 4Refuel is a wholly owned subsidiary of Finning International.

METHANEX CORPORATION

Methanex is a Canadian company headquartered in Vancouver, BC, with a manufacturing facility in Medicine Hat, Alberta. Methanex is the world's largest producer and supplier of methanol to international markets in North America, Asia Pacific, Europe, and South America. In addition to Medicine Hat, our production facilities are in New Zealand, Egypt, Trinidad, the United States, and Chile. We have more than 1,400 employees globally, with approximately 300 in Canada. Methanex is a leading proponent of Responsible Care®, the chemistry industry's commitment to sustainability. Founded by the Chemistry Industry Association of Canada (CIAC), the Responsible Care® ethic has been adopted in over 60 countries. Methanex was the first Canadian company to verify all our global production facilities to Responsible Care®.

ROCKPOINT GAS STORAGE

Rockpoint Gas Storage began commercial operation of its assets over 20 years ago and has grown to become the largest independent owner and operator of natural gas storage in North America. Rockpoint Gas Storage is owned by Brookfield Infrastructure Partners, L.P. (Brookfield). In Alberta, Rockpoint owns and operates the AECO Hub™ (154 Bcf) and Warwick Gas Storage (21 Bcf). Rockpoint owns and operates both Wild Goose Storage (75 Bcf) and Lodi Gas Storage (31 Bcf) located in California and Salt Plains Gas Storage (13 Bcf) in Oklahoma. Rockpoint also has a 49.99% membership interest in the Tres Palacios facility in Texas (34 Bcf). In addition to its gas storage assets, Rockpoint, through its subsidiary, Access Gas Services, provides gas management services to commercial, residential, industrial, and institutional customers throughout Canada.

Natural gas storage plays a vital role in maintaining the reliability of supply to meet the demands of consumers. Rockpoint Gas Storage is committed to leveraging its existing storage assets to enable to the energy transition and contribute to a functional and successful hydrogen economy.

PRAIRIES ECONOMIC DEVELOPMENT CANADA

PrairiesCan is the federal department that supports economic growth in Alberta, Saskatchewan, and Manitoba. Its programs and services help businesses, not-for-profits and communities grow stronger. The mandate of PrairiesCan is to support economic growth and diversification in the Prairie provinces and advance the interests of the region in national economic policy, programs, and projects.

DATA PROVIDERS

Additional acknowledgement to the dozens of public, private, municipal, and regulatory organizations which have provided their proprietary energy and infrastructure information to the author via telephone, video, and written communications during the period of October 2021 to June 2022, to allow for the bottom-up evaluation and extrapolation used within the report. This information, provided in confidence and further referenced as [137] within the report, was the basis of and vital to estimating the energy supply and demand specific for the Southeast Alberta region in the areas of transportation, electrical generation, natural gas utilities, industrial, and agricultural.

EXECUTIVE SUMMARY

There is a growing recognition that the cumulative effect of utilizing fossil carbon-based energy carriers commonly used today (gasoline, diesel, jet fuel, coal, natural gas) are contributing to the climatic changes that are impacting the quality of life and economy of communities across Canada and around the world. To mitigate these impacts, Canada and dozens of other nations have committed to net zero greenhouse gas (GHG) emissions by 2050. Canada has reaffirmed its commitment to cut GHG by 40-45 percent below 2005 levels by 2030 and has further identified key industrial sectors for emission reductions, such as transportation, oil and gas, electric generation, and agriculture. This requires the immediate pursuit of zero emission alternatives such as hydrogen, across all regions of the country.

> Canada has reaffirmed its commitment to cut GHG by 40-45 percent below 2005 levels by 2030 and … requires the immediate pursuit of zero emission alternatives such as hydrogen, across all regions of the country.

To that end, this report explores the feasibility of creating a geographic centric Hydrogen HUB centered on Southeast Alberta. The region has a history of being a **change agent** for energy transition, of being **innovative and adaptable** to new energy sources, of **producing and supplying cost effective and reliable energy**, and establishing itself as a **critical node** in the trans-Canadian transport and transmission corridor for both regional distribution as well as access to export markets.

Regional strengths and recommendations for Southeast Alberta, areally defined by the Palliser Economic Partnership area **(Figure E.1)**, that have been identified and expanded upon within the report include:

1. **Availability of abundant and economical primary resources.** Hydrogen does not naturally occur in a pure stable state and thus must be

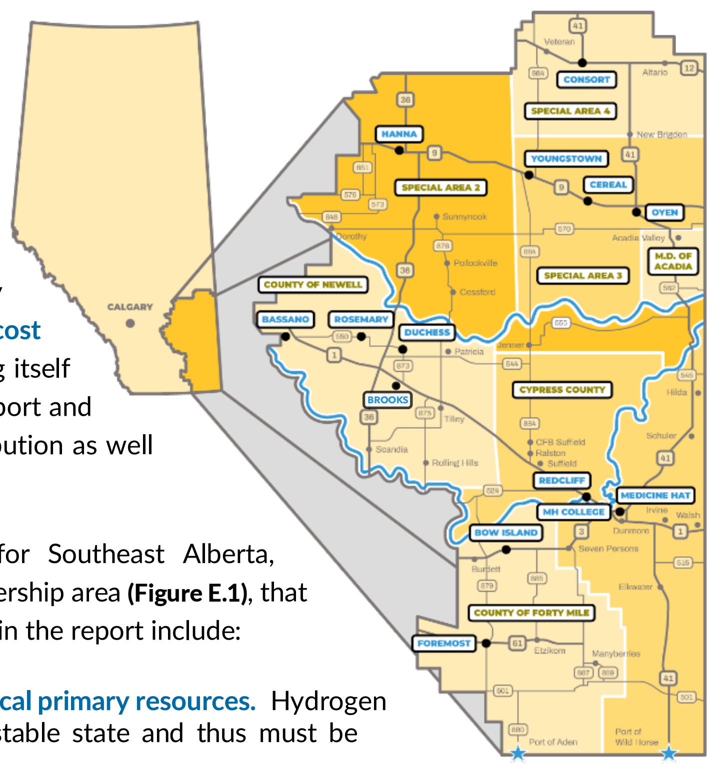


Figure E.1 SE Alberta Region

generated from other primary energy feedstocks. Though not for merchant sales, Southeast Alberta currently produces 20% of the hydrogen in Alberta, only behind the Alberta Industrial Heartland and Fort McMurray **(Figure E.2)**. The region has access to large quantities of natural gas and renewable power, at costs favourable to almost all jurisdictions across Canada and world-wide. This attractive access to large quantities of the energy feedstock allows for the large-scale generation of hydrogen through various technologies: electrolysis, steam reformation, pyrolysis, or other commercially developed processes of the future, with the potential to be one of the lowest cost hydrogen generation regions. This, combined with the region's location and access to both existing rail, road and pipeline infrastructure and potential new purpose-built infrastructure, opens the opportunity to increase hydrogen generation in the region by multiples of existing production, to remain amongst the highest hydrogen generation regions of Alberta if not North America.

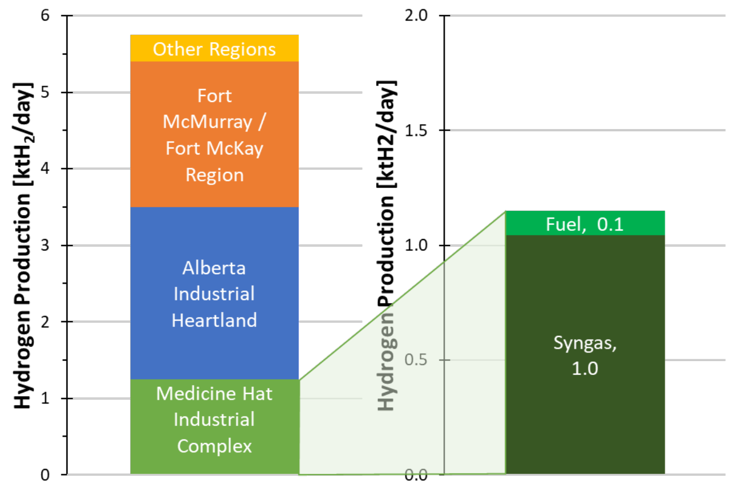


Figure E.2 Existing Hydrogen Generation in Alberta by Region

2. **Critical node within the trans-Canadian transportation and transmission corridor.** As indicated, delivery of hydrogen on an economical basis will be critical for its acceptance as a long-term energy source. Southeast Alberta has a history of being a transportation and distribution hub **(Figure E.3)**, with efficient transport logistics from and through the region being achieved by utilizing two interprovincial highways, four designated core provincial highways, CP Rail mainline, 240 and 500 MV power transmission lines, and numerous interprovincial and international pipeline transmission systems. Hydrogen will play a critical role in fueling and optimizing the operation of this infrastructure within the region. Additionally, effective utilization of this infrastructure for purposes of hydrogen transport could result in Southeast Alberta being the hydrogen supplier of choice for regions of high hydrogen demand.

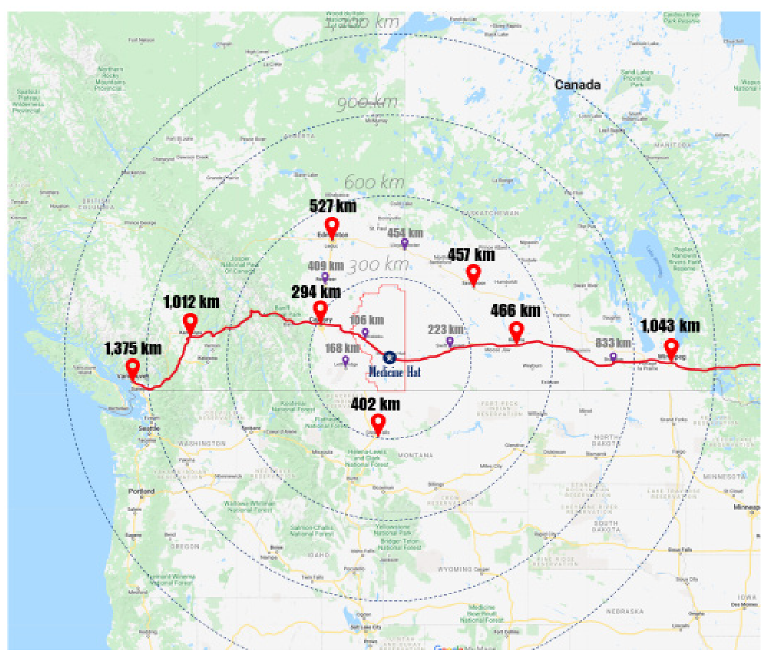


Figure E.3 TransCanada Highway Fueling Corridor
Travel distance from Medicine Hat to major fueling nodes.

3. **Diverse energy intensive industrial activity throughout region.** There is significant existing petroleum, petrochemical, food processing, agriculture, electric generation, and industrial operations throughout the region capitalizing on the abundance of resource, the ease of transportation, favourable environmental factors, and the positive business environment prevalent throughout the region. These industries will require low carbon alternatives to continue to thrive and will create significant local demand for hydrogen and will be complementary in the build out of incremental hydrogen supply.

4. **Continued growth in renewable power generation and need to optimize and stabilize electrical grid.** Southeast Alberta is currently a leader in integrating renewable energy into its power generation network, being at 35% currently and anticipated to continue to grow to more than 60% with energizing of projects under construction **(Figure E.4)**. The high percentage of renewable energy will put a strain on existing transmission systems. Without being able to control when renewable generation occurs (i.e., when the sun is shining or the wind is blowing), frequency instability occurs when renewable generation stops, and other generation sources are not available to satisfy the instantaneous load. Additionally, overall system transmission efficiency will drop with increasing percentage of renewable, with the regions generation capacity factor potentially dropping to 40% or less. Hydrogen will play a critical role in both stabilizing the grid as an instantaneous on demand generation source, whether by hydrogen combustion or hydrogen fuel cell peaking, and optimizing the capital efficiency of the existing transmission system by increasing the overall system capacity factor.

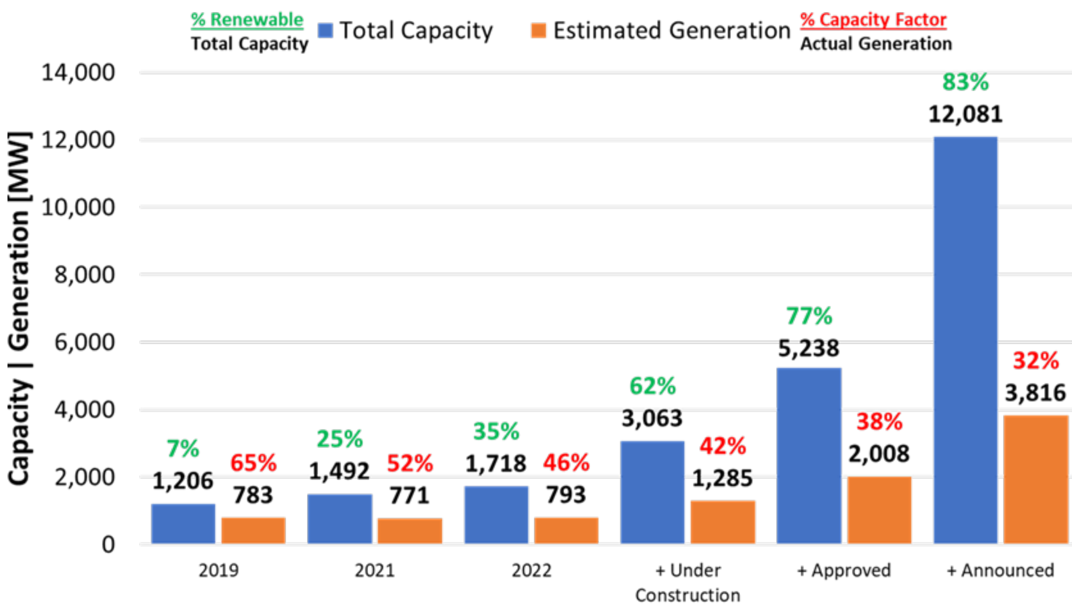


Figure E.4 SE Alberta Power Generation Growth via Renewable Solar and Wind

Comparison of historical and future potential power generation capacity in SE Alberta denoted by percentage of capacity as renewable and total regional capacity factor of actual / forecast generation.

5. **Advantageous Carbon Capture, Utilization, and Storage (CCUS) potential.** Active oil and gas industrial activity and natural depositional setting provides advantageous conditions for the establishment of commercial CCUS for the mitigation of existing and future CO_2 emissions. Regional knowledge and technical expertise will facilitate development of CO_2 capture and pipeline infrastructure, to facilitate utilization of CO_2 for industrial or enhanced petroleum recovery, or sequestration within the high-quality saline aquifers, such as the Basal Cambrian, or other depleted reservoirs that are present throughout the region.

6. **Existing Medicine Hat Industrial Complex and existing hydrogen carrier export industry.** Though not of the scale of the Alberta Industrial Heartland, the Medicine Hat Industrial Complex is populated with various industries that currently produce approximately 20% of the hydrogen within Alberta. The majority of the hydrogen is further processed as a syngas to create hydrogen carriers such as ammonia and methanol which are exported to US markets via rail. Serendipitous to the industrial complex is the proximity of the transport sector (TransCanada Highway, CP Rail mainline and the various transport companies and fueling stations), electrical generation (City of Medicine Hat combined cycle natural gas generation), natural gas utilities (City of Medicine Hat distribution system), agricultural sector (Redcliff greenhouses), and municipal fleets (City of Medicine Hat and Town of Redcliff) **(Figure E.5)**. Through a combination of initially accessing non-reactive and by-product hydrogen generation or utilizing the readily available hydrogen carriers for conversion, multiple diverse opportunities exist for potential hydrogen piloting.

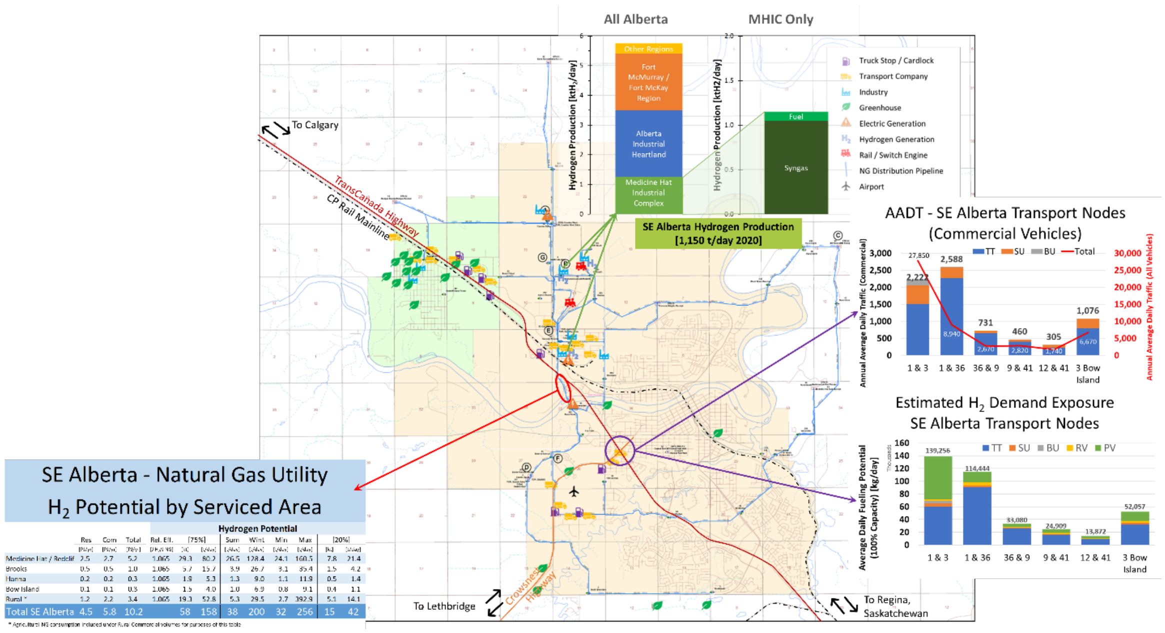


Figure E.5 Medicine Hat Industrial Complex with Hydrogen Potential

Location of existing 1,150 t/day of hydrogen generation in NW Medicine Hat industrial park and proximity to potential hydrogen transition opportunities – TransCanada Highway truck stops for transport, natural gas fired power generation, natural gas distribution utility, municipal fleets, and greenhouse operations.

7. **Large scale, concentrated, high energy demand rural agricultural sector.** Southeast Alberta is characterized by having larger than provincial average agricultural operations including the largest concentration of greenhouse operations, both by number and by area. Additionally, the nature of a rural population is of a higher per capita energy demand for both utility and transportation. Development of "Last Mile" fueling depots in conjunction with the hydrogen development of existing conventional fueling nodes along secondary highways that cover the entire region, would allow for the access and distribution of hydrogen or hydrogen carriers for both regional access as well as the "at location" on-demand requirements.

8. **Strong institutional support.** Existing industry has benefited from the presence of Medicine Hat College, CFB Suffield and the Defense Research and Development Canada – Suffield laboratory, as well as a group of diverse private research entities such as Carbon Management Canada. These institutions bring the ability to provide technical research, certification, and academic support directly to the region and are well positioned to continue to provide ongoing technical support to both hydrogen and carbon capture initiatives and pilots.

Supply and demand must grow in equivalent broad steps to support the build out of the necessary infrastructure to allow for generation, transportation, distribution, and consumption of hydrogen at scale to realize commercially viable and economically sustainable conditions.

> Supply and demand must grow in equivalent broad steps … to realize commercially viable and economically sustainable conditions.

Southeast Alberta is already moving forward with proposals for hydrogen and low-carbon related projects and has immediate opportunities to leverage the region's location and capabilities to establish itself as a critical hub within the hydrogen transportation fueling node corridor. With heavy transport identified as an early adopter, the estimated **regional hydrogen demand potential of 1,250 t/day** represents approximately 10% of the estimated provincial demand and would result in **1.5 MT CO_2e of emission reductions for the region** (14% of the total current emissions in the region).

Additional domestic and international export potential could add multiples more in volume of hydrogen demand. When combined with existing hydrogen production in the region and the opportunity of being a low-cost supplier of choice for other domestic and international markets, Southeast Alberta could realize a **total future hydrogen generation potential of greater than 10,000 t/day** by 2050 **(Table E.1)**.

Table E.1 SE Alberta Current Hydrogen Production Plus Potential Regional Demand and Export Volumes

	t H_2 / day
Existing Hydrogen Production	**1,150**
Transportation	168
Natural Gas Utilities	123
Power Generation	872
Construction - Heavy Equipment	30
Agriculture	57
SUBTOTAL - Regional Hydrogen Demand Potential	**1,250**
Domestic and International Hydrogen Export Potential	**7,600+**
TOTAL SE Alberta Hydrogen Production Potential	**10,000+**

At a realized value of $2.00/kg for hydrogen, this generation potential would represent an annual economic impact of greater than **$7 billion for the region**.

Longer term opportunities exist for Southeast Alberta to be a leader in the hydrogen utilization and transition in the natural gas utilities, electrical generation, industrial and agricultural sectors and to establish a substantial export economy.

CALL TO ACTION:

A. **Install Southeast Alberta Hydrogen HUB Governance** to **establish engagement** between all levels of public and private stakeholders and **pursue available funding** from public, private, municipal, provincial, and federal funds, initiatives, incentives, and programs.

B. It is **critical to move forward with CCUS** development as soon as possible to address existing CO_2e emissions, to establish low-cost blue hydrogen generation, and begin to address regional demand and attract synergistic industry,

C. Initiate discussions with regulatory and renewable power proponents to **include green hydrogen as part of long-term electric generation strategy** as both a product and for use as a generation fuel to provide transmission frequency stability, optimize existing transmission capacity, maximize regional generation capacity factor, and capture of excess non-peak renewable generation,

D. **Establish regional hydrogen demand** by building fueling stations and return-to-base operations along the TransCanada transport corridor. Assemble a **"Coalition of the Committed"** – industry, associations, transport fleets, municipal fleets, and rail operations – to create supply and demand partnerships, and

E. **Build external demand** from other domestic (Calgary, Lethbridge, Swift Current) and US (Montana, California, Mid-West) supply deficient locations. Utilize existing road and rail transport infrastructure to build demand with at scale supply of hydrogen and hydrogen carriers, to position the region for larger long term pipeline infrastructure and expanded export opportunities.

BOX E.1 INTENDED REPORT AUDIENCE

This is a technical report that is intended to document regional 'assets' that could be harnessed in a transition to a low carbon hydrogen economy and engage key players in the concept. Its objective is to inform and motivate a broad suite of actors that have key roles in accelerating the implementation of the low carbon hydrogen-as-fuel economy in Canada. They include:

- **Policy Makers:** This report, and earlier reports in this series published by the Transition Accelerator are intended to inform and encourage policy makers, but not usurp their role in developing and implementing economic and environmental policy that is critical to the attainment of a self-sustaining hydrogen economy in Canada.
- **Academics and Students:** The Transition Accelerator feels academia can play a much larger role in making practical, tangible progress to help society attain societal objectives, in additional to the traditional roles of analyses, research and technology development. Society has invested massively in technology innovation, yet comparatively, there has been extremely limited societal investment and focus on innovating commercial deployment of existing technologies so society can benefit from R&D. To this end, the Accelerator has launched a Fellow Program to attract like-minded professionals, including academics, to grow capacity and focus combined efforts on innovating new energy systems and commercial deployment of existing technologies.
- **Environmental Groups:** This report presents very practical steps to help realize the environmental and economic benefits of hydrogen, especially as a step in a transition pathway to a net-zero emissions society. The Transition Accelerator is convinced that the production and use of both blue and green hydrogen are critical in a transition pathway to net-zero and would like to engage environmental groups in this discussion.
- **Industry:** Attaining an economically self-sustaining hydrogen economy is a complicated endeavour, requiring new public and private sector roles and outcomes along a full, new hydrogen value chain. Industry is essential in this venture. The Transition Accelerator is eager to work with a 'Coalition of the Committed', typically led by industries who wish to start on the journey along a transition pathway to a net-zero energy future fueled, in part by hydrogen.

1 INTRODUCTION

Energy transition is not a novel idea or concept. Humanity has always had a thirst for energy and the ingenuity and creativity to discover new and more efficient means to satisfy an ever-increasing thirst. The desire to do more, to be faster, and be more efficient has led to innovations in technologies and transformation of energy systems to achieve those goals without prescribed mandates or timelines.

Today is different.

There is a growing recognition that the cumulative effect of utilizing fossil carbon-based energy carriers commonly used today (gasoline, diesel, jet fuel, coal, natural gas) are contributing to the climatic changes that are impacting the quality of life and economy of communities across Canada and around the world. To mitigate these impacts, Canada and dozens of other nations have committed to net zero greenhouse gas (GHG) emissions by 2050. Canada has reaffirmed its commitment to cut GHG by 40-45 percent below 2005 levels by 2030 and has further identified key industrial sectors for emission reductions, such as transportation, oil and gas, electric generation, and agriculture. [1][2][3] This requires the immediate pursuit of zero emission alternatives such as hydrogen, across all regions of the country, including Southeast Alberta.

Hydrogen is not a newly discovered element or energy supply, as it is the most abundant element in the universe. When two hydrogen atoms are brought together, the resulting H_2 gas (also called 'hydrogen') is one of the cleanest and purest sources of energy available to humanity. It can be combusted in air to provide heat or thrust, or it can be converted to electricity in a fuel cell with heat and water vapour as the only by-product.

> Supply and demand must grow in equivalent broad steps to support the build out of the necessary infrastructure to allow for generation, transportation, distribution, and consumption of hydrogen at scale to realize commercially viable and economically sustainable conditions.

Hydrogen's potential has been known for centuries and has been used around the globe for decades, whether as a fuel to power space exploration, a buoyant gas, or for its chemically reactive properties for fuel cells or as a syngas for various industrial and refining processes. The challenges of safely utilizing and economically generating hydrogen for mass consumption are continually being advanced in conjunction with the reduction in carbon intensity. Today, the focus has turned to making hydrogen readily available to broader society at a cost that is competitive to existing fuel sources to compel the transition to the lower carbon alternative in a variety of high energy demand sectors.

Supply and demand must grow in equivalent broad steps to support the build out of the necessary infrastructure to allow for generation, transportation, distribution, and consumption of hydrogen at scale to realize commercially viable and economically sustainable conditions.

The viability of hydrogen as a replacement fuel source will be directly dependent upon:

1. the cost on an energy service basis – to supply the hydrogen, create the efficiencies, to lower the cost of operation, and to deliver greater value on a comparable energy unit basis as compared to our current fuels,
2. the access to the conversion technologies that can use the fuel and deliver the services required – mobility, transport, heating, power generation, etc., and
3. the convenience and quality of the zero-emission fuel and technology, both in access and operation, to deliver the desired service compared to the incumbent fuels and technology.

Current public sentiment and demand for environmentally positive alternatives coupled with government incentives, whether in the form of punitive carbon tax or direct compensation, will provide a window of opportunity to build demand during a period of cost volatility associated with early-stage hydrogen piloting and development. However, this will not prove to be sustainable and must become commercially viable under its own economic merits within a relative short time frame to achieve long term acceptance and use.

As such, the cost of blue hydrogen production in Alberta is now cost competitive with the wholesale cost of diesel fuel. However, challenges exist as hydrogen is more difficult and expensive to transport and deliver to vehicles than liquid diesel. The only way to make the overall retail cost comparable for existing diesel vehicles is to scale-up rapidly and bring the per kilogram cost down.

The hydrogen using devices and infrastructure (vehicles, furnaces, etc.) are also currently more expensive than existing technologies since they are made in small quantities and do not benefit from the efficiencies of scale. Increasing demand for these technologies should bring these costs down as manufacturers can realize economies of scale.

To create the necessary magnitude of hydrogen supply, transport, and demand to strive towards economic viability without ongoing public investment, Hydrogen HUBs are needed throughout the country. Ideally, the number of HUBs will grow to create a national interconnected network, supporting a variety of supply and demand corridors.

Each HUB may vary in size, possess its own unique characteristics of supply, transport, and demand, and reflect the region's specific strengths and weaknesses. However, when connected with other HUBs in a cohesive and complimentary network, there is a magnification of the overall strengths of the network that will enable Canada to move towards the goal of a sustainable transition to a net zero energy future.

1.1 Hydrogen – Roadmaps to HUBS

The Transition Accelerator has published a series of reports evaluating the macro-economic benefits of the transition to Hydrogen:

- In September 2020, the "*Towards Net-Zero Energy Systems in Canada: A Key Role for Hydrogen*" report was published presenting a pan-Canadian perspective to assess the potential for hydrogen to be part of Canada's transition to a net-zero emission energy system. [4]
- In November 2020, the "*Building a Transition Pathway to a Vibrant Hydrogen Economy in the Alberta Industrial Heartland*" report was published presenting an Alberta focused techno-economic assessment of implementing hydrogen transition in Alberta focused on the initiation of that transition from the Alberta Industrial Heartland. [5]

These reports have been followed up by Federal and Provincial Roadmaps as a call to action to highlight the potential within Canada to embrace utilization of hydrogen for low-carbon transition and an opportunity for economic diversity in this emerging global sector.

- In December 2020, the Government of Canada released the "*Hydrogen Strategy for Canada, Seizing the Opportunities for Hydrogen*", which was a call to action laying out the opportunities and requirements for Canada to be a leader in energy transition to achieve the zero emissions by 2050 goal that has been committed to. [6]
- In July 2021, British Columbia government published "*B.C. Hydrogen Strategy*" to outline the plan for a sustainable pathway for B.C.'s energy transition. [7]
- In November 2021, the Government of Alberta published the "*Alberta Hydrogen Roadmap*" which continued the theme of establishing Canada, and more specifically the province of Alberta as a leader in low-carbon energy transition and hydrogen utilization and export. [8]
- In April 2022, Ontario released "*Ontario's Low-Carbon Hydrogen Strategy*", which set the vision for the province's low-carbon economy. [9]

Other provincial governments have previously released preliminary reports or have indicated they too will be releasing hydrogen strategy documents with Quebec anticipated to be released mid 2022 and Newfoundland and Labrador in late 2022 or early 2023. [10][11][12][13]

This all follows or has been in conjunction with hydrogen strategy documents by France, Japan, South Korea, Australia, New Zealand, Norway, Germany, Portugal, Spain, Chile, Finland, United Kingdom, China, as well as the European Union with the United States pending. [14][15][16][17][18][19]

This highlights both the Canadian and global momentum that has been gathering steam since Canada and 135 other nations committed to achieve net-zero greenhouse gas (GHG) emissions by 2050. The desire to see the reduction in end use combustion of carbon-based energy carriers and the realization of the limitations of utilizing zero-emission electricity has pushed the focus onto the commercial utilization of hydrogen as a primary fuel source.

Initial concentration on the major industrial complexes resulted in the formation of the Edmonton Hydrogen HUB due to its proximity to the Alberta Industrial Heartland. However, transition is not defined as a partial change but a **complete transformation from one state to another**. Thus, there remains a tremendous amount of work to facilitate the complete transformation of Alberta's energy systems to zero-carbon and that cannot be accomplished without evaluating the potential low-carbon and hydrogen pathways that are required throughout the province and ultimately throughout the country. [20][21]

This report is intended to be the first of many regional analyses, both undertaken by the Transition Accelerator as well as other entities, to create a network of interconnected HUBs across the country with the mandate to support the timely transition to hydrogen from the major industrial centers through to the vast rural countryside and every unique region in-between. The strength and resilience to move towards hydrogen as a country to achieve net-zero will only be achieved through the magnification of each individual region's strengths and overcoming inherent gaps and weaknesses by achieving a cohesive and complimentary trans-Canadian hydrogen network.

> The strength and resilience to move **Towards Hydrogen** as a country to achieve net-zero will only be achieved through the magnification of each individual region's strengths and overcoming inherent gaps and weaknesses by achieving a cohesive and complementary trans-Canadian hydrogen network.

1.2 Southeast Alberta Hydrogen HUB Initiative

In August of 2021, several municipal and industrial interests in southeast Alberta reached agreement with the Transition Accelerator to fund this foundation report with the intent to move forward the determination of whether the region could support the creation of a Hydrogen HUB.

It is believed that Southeast Alberta offers the opportunity to successfully demonstrate the transitional pathway bridges that are required to move the low-carbon economy between major industrial centers to small urban and sparsely populated rural regions and overcome perceived potential limitations.

As established in the "*Building a Transition Pathway to a Vibrant Hydrogen Economy in the Alberta Industrial Heartland*", the principles of the "hydrogen nodes" shall still apply as the potential for Southeast Alberta is evaluated. This includes:

- The ability to make low-cost low-carbon intensity hydrogen, regardless of color,
- Substantial nearby markets for the hydrogen,
- The ability to connect hydrogen supply to demand,
- An ability to achieve a scale of supply and demand where the economics work without sustained public investment, and
- Engaged industry, municipalities, and academic institutions.

To fully realize the potential of the Southeast Alberta region, it is imperative to understand the characteristics of the region, to determine the appropriate scale of the supply, distribution, and demand systems as they apply specifically to the region, and how this new energy system, once established, can remain economically viable and not dependent on continuous government subsidies.

The NRCan definition of a HUB is:

> A **coordinated, synergistic, regional** initiative for economic development to create an **economically viable** hydrogen **value chain** where **low or zero emission hydrogen** is **used as a novel fuel or industrial feedstock**, thereby achieving **substantial reductions** in greenhouse gas emissions.

- In addition to the Funding Partners, this report will look to identify key stakeholders within the region that could become the 'Coalition of the Committed' and provide the **coordinated and synergistic** principles for a HUB.
- The southeast region will be characterized to understand the **regional** geographical constraints.
- **Economic viability** will be considered through a detailed bottom-up evaluation to determine the specific scale of supply, transport and demand and ability to achieve economy of scale.

- The full **value chain** will be identified from production to supply and the supporting parties and enablers within the region.
- The ability to produce and utilize **low or zero-emission hydrogen** in the region will be evaluated.
- How hydrogen can be deployed as a **novel fuel or industrial feedstock** will be identified.
- The report will address green house gas emissions and how hydrogen can achieve **substantial reductions**.

Within this report you will find:

- a high-level discussion of hydrogen and potential hydrogen pathways and a top-down analysis of the hydrogen potential of the Southeast Alberta region based on simple extrapolation of provincial estimates **(Sections 2 & 3)**,
- a detailed characterization of the region to gain insight into strengths and weaknesses specific to Southeast Alberta and a detailed bottom-up analysis to address the economic viability and area specific value chains along with the enabling features of the region **(Sections 4 to 6)**,
- a **Call to Action** to address current initiatives within the region **(Section 7),** and
- a summary of key partners, programs, associations, and stakeholders **(Section 8)**.

It is hoped that this report will achieve the goals set out by the Transition Accelerator and Funding Partners and led to the establishment of a Hydrogen HUB in the Southeast Alberta region.

Intent is to move from critical analysis to practical action. That the presented evidence-based analysis and qualitative perspectives can be combined with imaginative thinking, ingenuity, and entrepreneurship, to create social, economic, and regulatory alignment to drive sustainable and meaningful progress on transformative pathways for southeast Alberta.

2 HYDROGEN AS AN ENERGY CARRIER

Hydrogen is the most abundant element in the universe and is a tremendous energy carrier which, unlike other energy carriers, when converted to energy it only produces water. It is a gas in its natural state, with no color or odor, the lowest mass of any element, and the lowest density of any gas. Hydrogen's energy potential is extracted via chemical reaction; either by creating an electric current when oxidized through a fuel cell or by combustion. By mass, hydrogen has the highest energy content of any fuel, though due to its low volumetric density as a gas, and thus low energy content in gas form, distribution and storage of hydrogen pose economic challenges.

2.1 Energy Systems and Net-Zero 2050

As indicated previously, Canada and numerous countries around the globe have committed to reducing carbon emissions by 2030 and achieving net-zero carbon emissions by 2050. This will require significant and comprehensive shifts in existing energy systems to achieve these ambitious goals **(Figure 2.1).** [22]

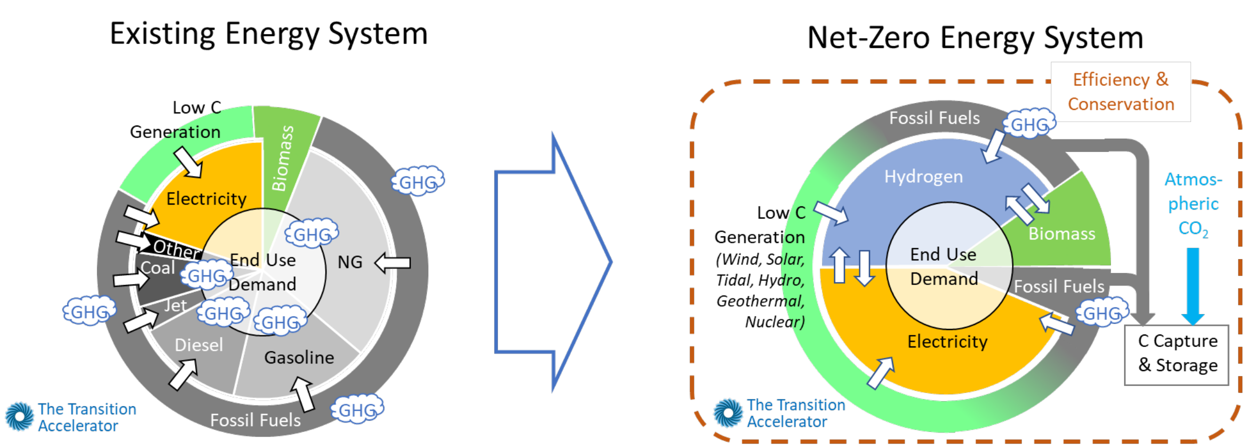


Figure 2.1 Existing Energy Systems Transition to Net-Zero Energy System

Existing Energy Systems utilizing numerous different energy sources with significant GHG emissions transitioning to a potential net-zero system based on renewable energy, hydrogen, biofuels, and CCUS associated fossil fuels.

SOURCE: The Transition Accelerator

Though innovation and technology advancement will be critical to realizing success in the transformation of the energy systems, it is believed that incorporation of renewable power and other low-carbon energy in conjunction with fossil fuels and carbon capture, utilization, and storage (CCUS) will have success in achieving the net-zero goal. User demand will require the primary energy to be converted to both hydrogen and electricity, as some sectors will continue to need chemical energy carriers, such as transport, heavy industry and space heating, and will not be satisfied by electrical energy carriers alone. Additionally, the energy system must recognize the realities of a region's energy economy and be flexible to incorporate it into the net-zero system to achieve economic sustainability. This is true with Alberta and the ability to utilize the tremendous oil and gas resources in conjunction with CCUS as well as renewable energy potential to establish a global leading position in the generation of both methane derived low-carbon hydrogen and green hydrogen.

2.2 Color of Hydrogen and Carbon Intensity

Hydrogen in its purest form is a colorless gas but is rarely encountered in a natural state due to its reactive potential with other elements and its properties (small molecular size and buoyancy) which make it difficult to contain. Due to the various processes that can be utilized to generate hydrogen, various colors have been applied to signify the technique utilized and the implied carbon intensity of that process. [23][24]

The processes utilized to generate the hydrogen dictate the carbon intensity of hydrogen. However, the purity of the feedstock, the input energy source and the physical variation of the primary process can result in a variation of calculated carbon intensity as does the addition of secondary processes such as CCUS.

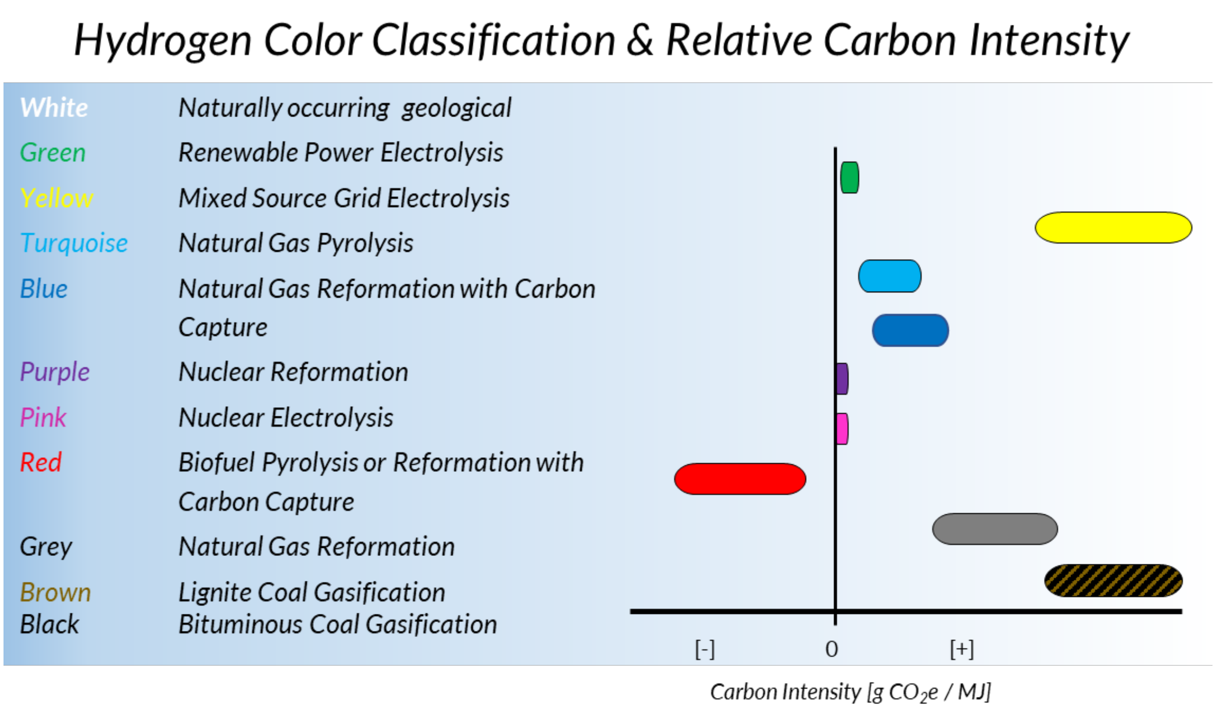


Figure 2.2 Relative Carbon Intensity as Associated by Hydrogen Color Designation

When utilized as a fuel, hydrogen, regardless of color classification, has no associated carbon emissions. When compared to other fuels and hydrogen carriers (**Figure 2.3**) it is clear that hydrogen is a desirable net-zero energy alternative due to its high energy density and zero carbon emissions associated with combustion [25][26]. Thus, the carbon intensity of generating hydrogen becomes critical in determining the net life-cycle carbon emissions and comparative CO_2 emission offsets, just as it is for other conventional fuels and energy carriers.

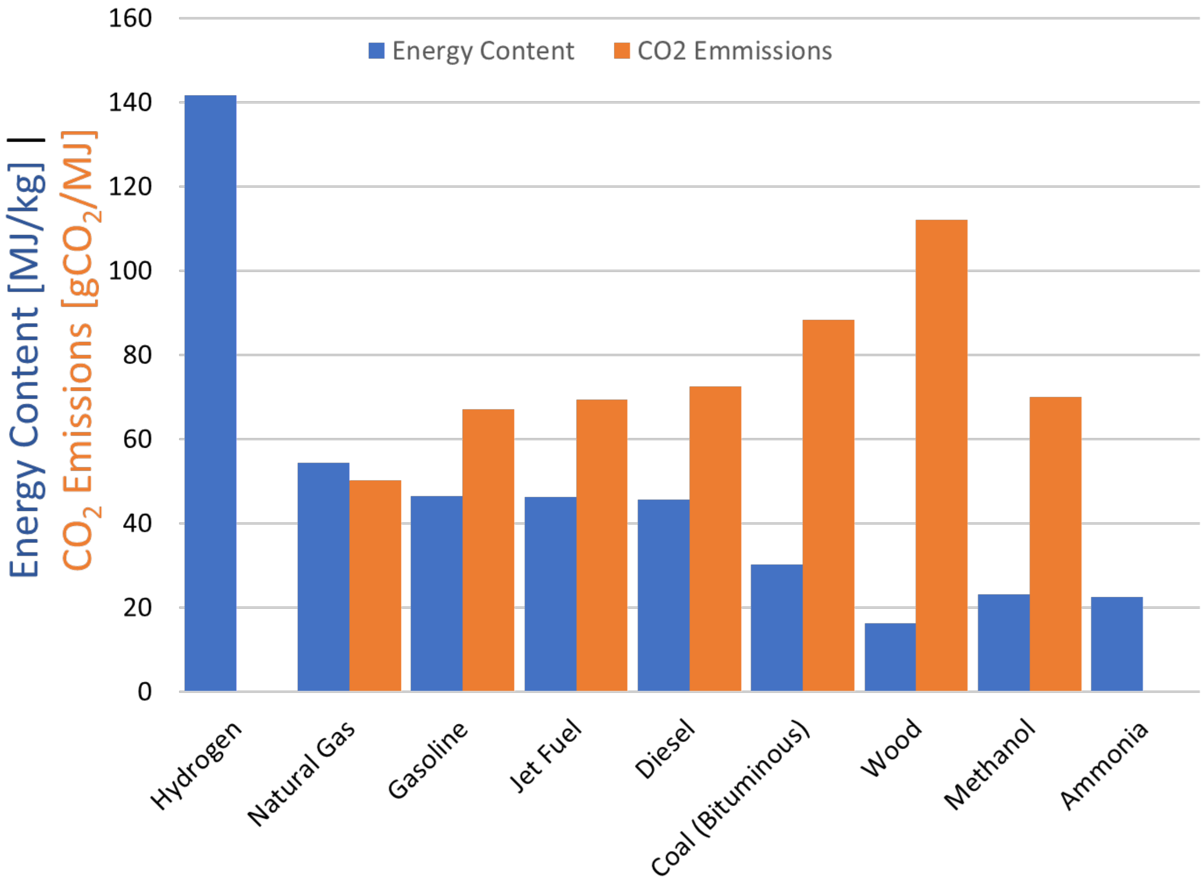


Figure 2.3 Energy Density Compared to Associated CO_2 Emissions from Combustion of Various Fuels

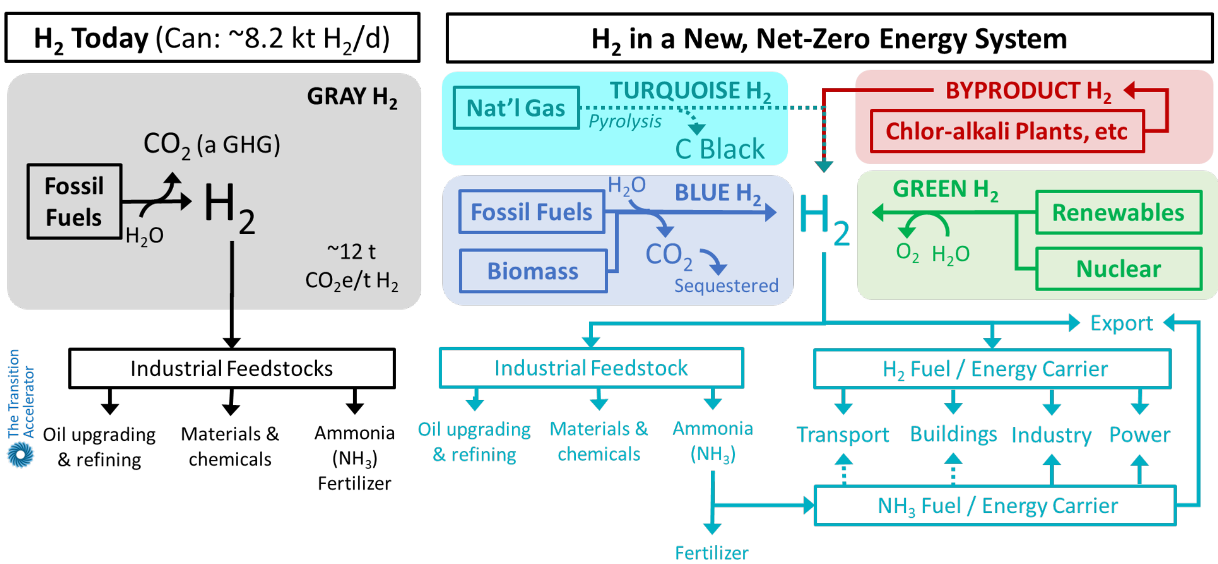
Comparison of hydrogen's high energy density in comparison to other conventional fuels and hydrogen carriers. Also shown are the CO_2 emissions of each fuel during combustion. As hydrogen does not emit CO_2 upon combustion, no emissions are indicated, however this graph does not account for full lifecycle CO_2 emissions, such as those incurred during various hydrogen generation processes or those associated with generation of other secondary fuels or energy carriers.

Canada is currently looking to develop and adopt a national definition and standard for 'clean' hydrogen where carbon intensity thresholds can be established and independently certified. If successful in gaining international acceptance, this method would allow for low-carbon intensity hydrogen to come from a range of generation pathways. This initiative corresponds with the EU pilot program CertifHy [27] that attempts to provide an EU-wide Guarantee of Origin for green and low-carbon hydrogen that considers both origin and GHG intensity of the hydrogen. The recommended threshold for GHG intensity is set at 36.4 gCO_2e/MJ, which is approximately 60% below grey hydrogen carbon intensity.

Though colors are often used to indicate acceptable low-carbon hydrogen sources, successful hydrogen transition and achieving the goals of zero carbon will require all forms of low-carbon hydrogen regardless of color or generation process. Due to the large quantities of hydrogen that will be required, and the diverse geographic locations, available feedstock and energy sources will likely dictate the most economical generation process for the specific location. Alberta, and specifically Southeast Alberta, is fortunate to have access to a variety of feedstocks and energy sources and will be able to deploy various processes for future hydrogen generation.

2.3 Towards a Hydrogen Economy

Hydrogen already plays a significant role in the energy systems of Canada **(Figure 2.4)**. It is primarily used as an industrial feedstock in the upgrading and refining of hydrocarbons, generation of chemicals and fertilizers (such as ammonia and methanol), and steel manufacturing. In Canada hydrogen production is estimated at 8,200 t/day (3.0 Mt/year). Alberta is the largest producer of hydrogen with an estimated 5,800 t/day (2.1 Mt/year). The majority of the hydrogen generated today is derived from natural gas, where the CO_2 by-product of the process is released into the atmosphere which has an associated GHG of approximately 28 Mt CO_2e/year.



From
Layzell et al. 2020

Figure 2.4 Role of Hydrogen Today Compared to Potential Role in the Net-Zero Energy System

Comparison of the role hydrogen currently plays in the energy systems of Canada (H_2 Today), and its possible role in a future New, Net-Zero Energy System, as a fuel.

SOURCE: The Transition Accelerator

Canada is well situated to create an enviable hydrogen economy based on the abundance of natural resources and primary energy sources and the ability to utilize various hydrogen generation processes to become a global leader in low-carbon, low-cost hydrogen, with Alberta playing a pivotal role. Utilizing CCUS allows for the reduction of greater than 90% of the CO_2e emissions associated with grey hydrogen. Increased hydrogen generation allows for the expanded use as an industrial feedstock with less associated emissions as well as creating new fuel applications in transport, heating, and power generation. As Alberta will be well situated to generate low-cost blue hydrogen, it will allow for the establishment and growth of hydrogen demand while economics for the generation of green hydrogen are advanced, and other processes are commercialized. Ultimately this should position Canada to lead in establishing itself as a dominant leader in hydrogen technology and in the global hydrogen export markets.

2.4 New Hydrogen Value Chain

To create a new hydrogen value chain, it is necessary to first define where to start, where it can lead, and how will it get there. Each step in a value chain helps enable the subsequent step and further strengthens the preceding step, increasing the overall economic viability of the entire chain **(Figure 2.5)**.

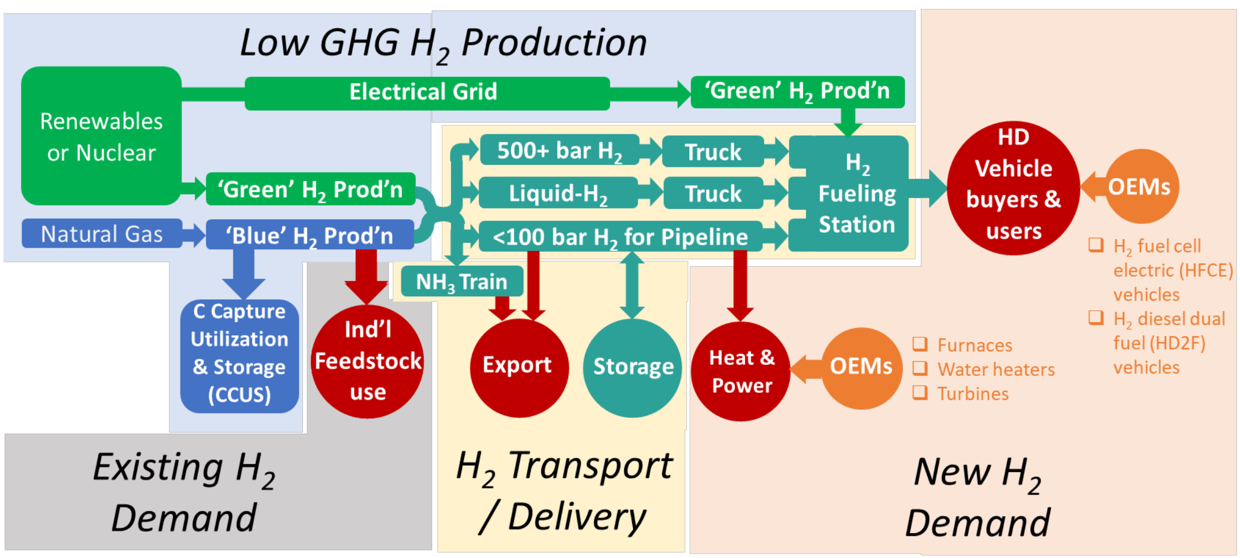


Figure 2.5 New Hydrogen Value Chain

Moving past simple industrial feedstock to a value chain that includes blue and green generation and transportation infrastructure to meet new demands in transportation, heating, power generation, as well as expanded industrial use and exports.

SOURCE: The Transition Accelerator

Currently, the main demand for hydrogen is as an industrial feedstock. However, as grey hydrogen is a secondary energy source (must be generated utilizing a primary energy source such as natural gas) its usage as a wide-spread fuel is limited due to its associated GHG emissions and the comparative economics and efficiency of directly using the primary energy source. Reducing the associated GHG emissions by utilizing CCUS or producing the hydrogen through green processes, allows for the expanded use of low-carbon hydrogen for transport, heating and electrical generation, all sectors that are under pressure due to the GHG emissions resulting from the incumbent fuel in these sectors and associated carbon costs.

The path for hydrogen to realize these new markets is dictated by the ability to economically transport and deliver the hydrogen from generation to demand. This requires the use of electrical transmission infrastructure, pipelines, road and rail transport, and the ability to store it. A coordinated effort by a 'Coalition of the Committed' is necessary to establish initial supply and demand as well as to begin the build out of the initial components of this transportation and distribution network to enable the demand for hydrogen to become established and provide for viable growth. Once the chain is established, technology advancements and economies of scale can be achieved through the increased demand for hydrogen generation and expanded economical transportation and distribution network **(Figure 2.6)**.

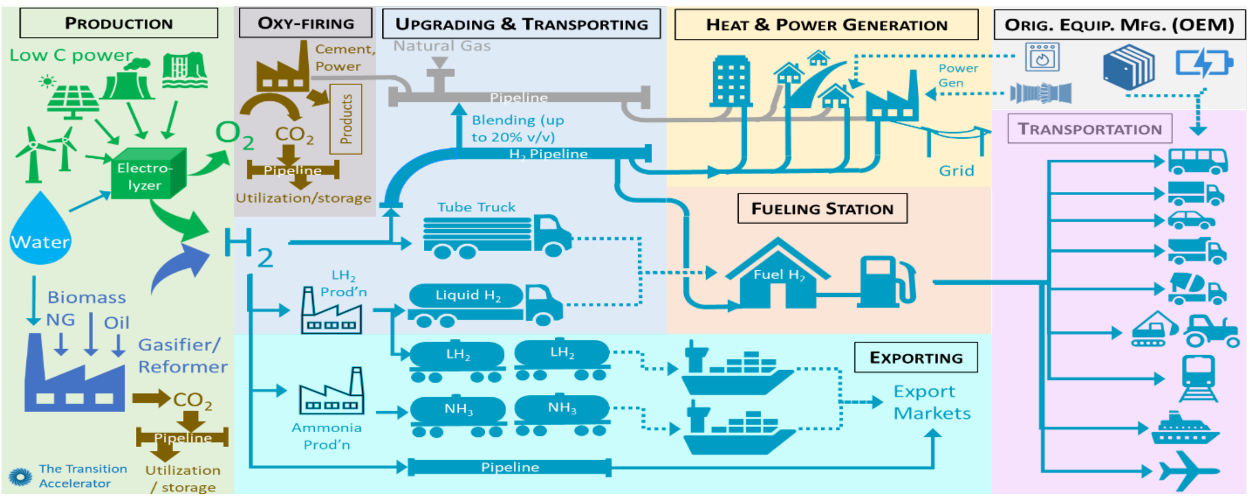


Figure 2.6 Envisioned Hydrogen Energy Chain

Representation of expanded hydrogen energy chain, from various forms of generation to transport and utilization in the transport, heating, power generation, and industrial sectors, along with capture of growing export markets.

SOURCE: The Transition Accelerator

2.5 Challenges of Hydrogen as an Energy Carrier

Some of the characteristics that make hydrogen a favourable fuel for a low-carbon energy system also pose challenges for widespread use and acceptance.

Hydrogen does not generally exist in a pure state and must be generated from other primary energy sources [28][29][30]. This introduces energy inefficiencies as energy is consumed to generate the pure hydrogen. The most common process of producing hydrogen is steam reformation from natural gas or other fossil fuels and results in the by-product of CO_2, which must be captured and sequestered. Generation of hydrogen by electrolysis requires the application of electricity to water, which eliminates the creation of CO_2. However, the majority of the electricity that is generated today is derived from fossil fuels and thus introduces both energy inefficiencies and CO_2 emissions at the generation source. Renewable power generation can be used to overcome these issues but introduces economic inefficiencies due to low-capacity factor (time generating power during a period of time) which in turn introduces capital investment inefficiencies.

Being a gas at standard conditions, having a small molecular size, and being highly buoyant makes storing and transporting hydrogen challenging. Transport and storage of hydrogen in traditional natural gas reservoirs and pipelines can result in hydrogen migration and seepage, thus introducing greater volumetric loses. Hydrogen's chemically reactive nature also poses an issue with reaction to high carbon content steel and can cause hydrogen embrittlement and ultimately failure. This is caused by hydrogen atoms diffusing into the metal and then recombining to form a hydrogen molecule in minuscule voids within the metal. This increases the pressure in the cavity that they are trapped in and induces stress in the metal leading to cracks.

Hydrogen has a high energy content but a low volumetric density. In a gas phase the energy content is approximately a third of natural gas. In a liquid state it is 3 times higher than gasoline or diesel. Thus, transport in a compressed gas phase is less efficient than current transport of natural gas. Hydrogen can be stored and transported as a liquid but must be kept in a cryogenic state once liquified. Hydrogen liquefies at a temperature below -250°C. The liquefaction of hydrogen and subsequent transport is a very costly process, especially over great distances. To address this issue, transporting and storing hydrogen as hydrogen carriers, such as ammonia and methanol, or in a liquid organic hydrogen carrier, such as methylcyclohexane and other hydrides, are being evaluated. These products are already widely transported and would be suitable for expanded transportation infrastructure due to their high energy densities and similarities to traditional liquid fuels.

2.6 Macro Economics for Hydrogen Value Chain

Canada is among the world's lowest cost producers of both blue and green hydrogen. In the 2018 Asia Pacific Research Centre paper "*Perspectives on H_2 in the APEC Region*" **(Figure 2.7) [31]**, both Canadian electrolysis and steam reformation projects were shown to be equal to or lower than wholesale diesel costs. This has become even more pronounced with current diesel prices being nearly double the prices utilized in the comparison.

Per unit of energy, Canadians pay more for transportation fuels than for heating fuels **(Figure 2.8)**. Thus, in the short to medium term, the economics for transition of diesel to hydrogen is the most promising sector to be satisfied with current hydrogen generation. Hydrogen transition for peak power generation, space/water heating, and industrial heating will be more challenging and will require advancements in lowering green hydrogen production costs to be a net-zero fuel of choice for these sectors.

Production costs are only one component of the hydrogen value chain. Transportation and delivery costs need to be considered when comparing current fuel costs to those estimated for hydrogen. [32][33][34][35][36][37][38][39] For hydrogen, this includes 1) the initial production cost of hydrogen, 2) the processing and transport cost of moving the hydrogen to the location required, and 3) the fueling station cost to deliver the hydrogen to the end user. **Figure 2.9** illustrates various scenarios as it relates to options for each component of the total delivered cost. To determine the specific total delivered cost, one generation process would be selected, along with the primary deliver method and the size of the fueling station.

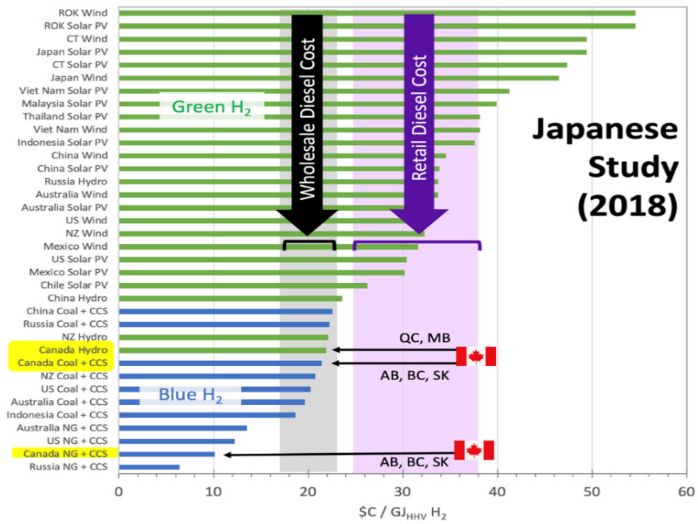


Figure 2.7 Global Hydrogen Generation Cost Comparison

Comparison of 2018 hydrogen generation around the world compared to wholesale ($0.50 to $0.80/L) and retail diesel costs.

SOURCE: APERC Perspectives on Hydrogen in the APEC Region

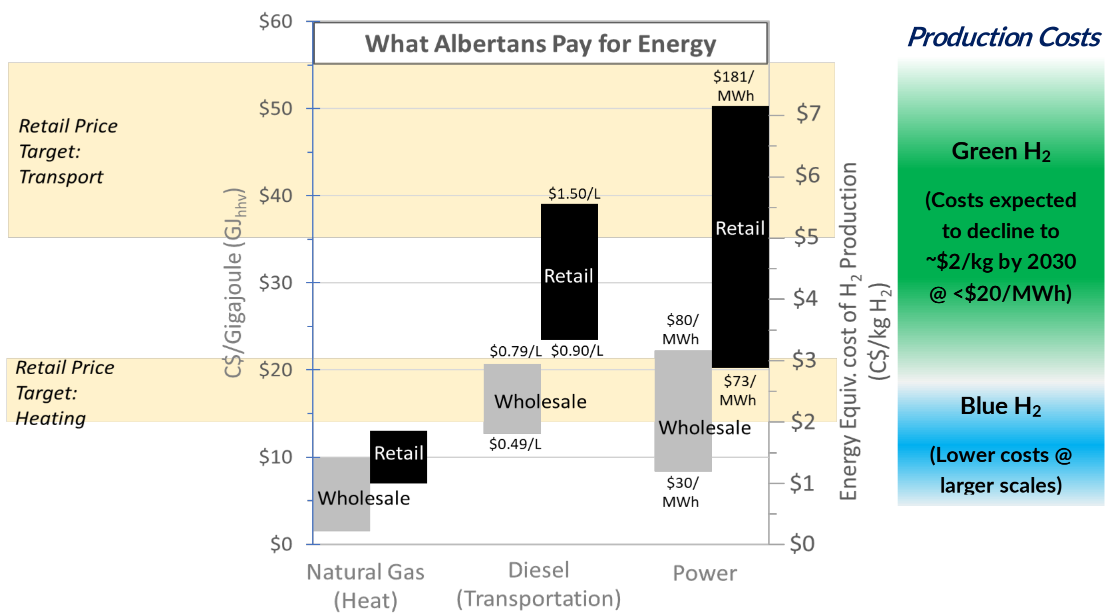


Figure 2.8 Various Fuel Source Pricing per Gigajoule

Comparison of fuel cost for heating, transport, and power generation on an energy basis with the energy equivalent value for hydrogen, to demonstrate the range of hydrogen cost required to maintain retail cost parity. Current production cost range for blue and green are indicated with blue having the lowest production cost.

SOURCE: The Transition Accelerator

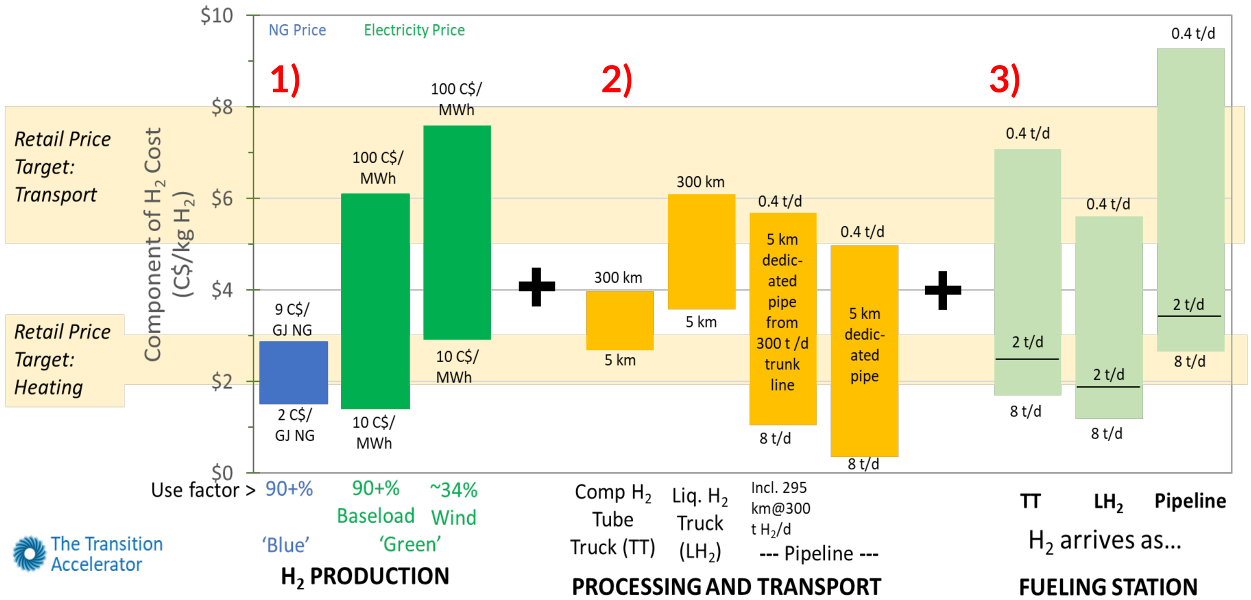


Figure 2.9 Total Retail Cost Matrix of Hydrogen for Transport Section

Total cost for hydrogen delivery to end-use user for transportation is composed of 1) how hydrogen is produced, 2) the processing and transportation expense and impact of scale and distance, and 3) the fueling station and impact of form of hydrogen delivery and scale

. SOURCE: The Transition Accelerator

How hydrogen is delivered and the scale of the fueling stations has significant impact on the economic viability. Smaller demand and short haul distances are best served by truck delivery of compressed or liquified hydrogen. However, processing for liquified hydrogen adds significant incremental costs to the total delivered cost. Long distance and large-scale delivery of hydrogen is most economically serviced by pipeline. The Transition Accelerator has determined a rule of thumb for economic pipeline use of 1 t/day/km.

For fueling stations, scale has the most dramatic impact on cost, but delivery mechanism also plays a role due to the degree that compression is required on site. It is assumed that liquified hydrogen will have the least compression requirement and pipeline delivered hydrogen would have the most. It should be noted that this is not a linear scale and, as shown for fueling stations, a change from 8 t/day to 2 t/day in fueling station capacity has a relatively minor change in cost as compared to 2 t/day to 0.4 t/day.

When calculating the cost of each of these components a range has been indicated dependent on the volume of hydrogen. As indicated above, the range is not linear to the change in scale and needs to be considered. Thus, scale of project is the most significant factor that drives cost. Another rule of thumb developed by the Transition Accelerator suggests that a 2 t/day hydrogen fueling station is currently required to meet minimum economic viability. This would represent daily fueling of 80 buses, 40 large trucks, 20 to 30 trains, or 100+ cars per day.

In context of the need for a margin between existing energy costs and the cost to replace it with hydrogen (cost to generate it, transport it, distribute it and the capital cost for the required infrastructure, facilities, and end use equipment), the current and forecast prices of natural gas, diesel, and electricity can be used to derive the equivalent hydrogen energy value with assumed hydrogen energy efficiency. To ensure a valid comparison, additional components (carbon tax, delivery charges, etc.) need to be included where those are not incorporated in the listed commodity price, such as with natural gas.

Delivered retail pricing of diesel is currently greater than $2.00/L with this price including the cost of refining, transporting and profit margin in addition to taxation (i.e., sales tax, carbon tax, federal and provincial taxes) included **(Figure 2.10)**. Though it is forecast to drop in price in the next two to three years, the long-term forecast predicts increasing to greater than $2.00. This would imply an equivalent hydrogen retail price of $8.00 to $10.00/kg (based on energy efficiency of 0.86 GJ_{H2}/GJ_{Diesel}) **(Figure 2.11)**. Utilizing the forecast hydrogen value of $0.85/kg and adding CCUS expense, the produced value of hydrogen can be estimated at +/- $1.50/kg. This would create a margin of $6.50 to $8.50/kg of hydrogen if sold at diesel equivalent prices, to cover the cost of transport and infrastructure.

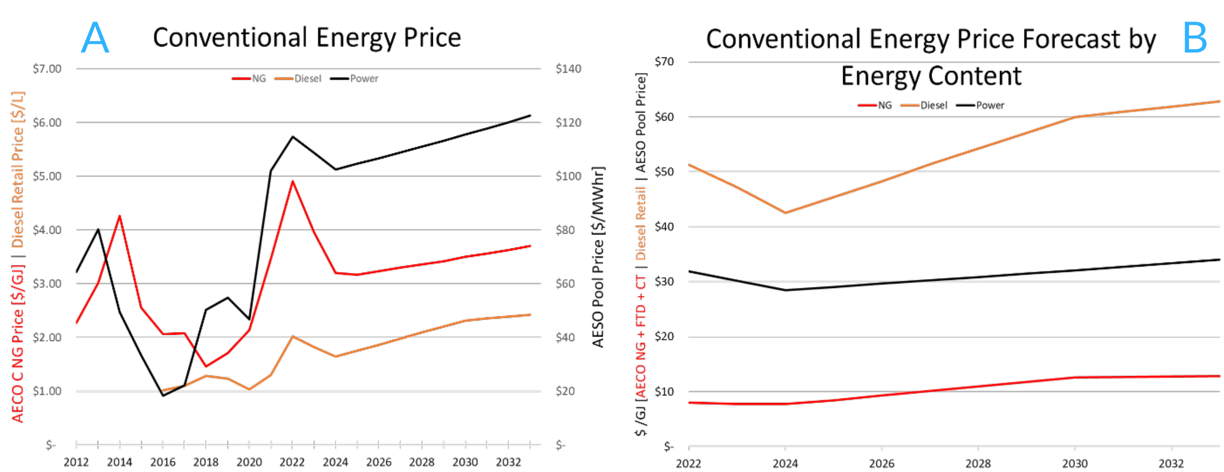


Figure 2.10 Historic and Forecast Conventional Fuel Prices

As sourced from April 2022 Price Forecast by GLJ Ltd. [40] the historical and forecast pricing of natural gas, diesel, and power by traditional units [A]. These forecast prices can be converted to a price by energy content and represented on a comparative retail basis to hydrogen [B].

The same analysis can be done with natural gas and power. Natural Gas is currently at $5.00/GJ with a long term forecast to fall and average approximately $3.50 over the next 10 years. However, this does not reflect the true retail price of natural gas as compared to diesel. To be equivalent we would need to add in the carbon tax which is not included in the commodity price. Delivery cost would also need to be added to represent the point of possession of the fuel. This nearly doubles the total energy cost for purposes of comparing it to hydrogen at $10/GJ, which implies an equivalent hydrogen price of $1.00 to $1.80/kg (based on energy efficiency of 1.065 GJ_{H2}/GJ_{NG}). This represents a very small margin to generation costs and thus would present a challenge for purposes of capital investment return, though transition may ultimately be driven by consumer demand for a net-zero fuel option. An additional consideration is that to truly represent retail pricing, other distribution expense would need to be compared, however these would likely be equivalent whether it was distribution of natural gas or hydrogen.

For power, the analysis can be done by comparing the values at the generation level rather than consumer retail level. The incremental transmission and distribution costs incorporated into retail power prices would not change regardless of whether the power was provided by convention means or via hydrogen generation. The equivalent price for hydrogen based on the power forecast would be in a range of $1.50 to $2.20/kg (an efficiency range of 2 to 3 utilized, with 2 corresponding to fuel cell and 3 to combustion). As with natural gas, the value margin is limited though use of fuel cell efficiencies provides for favourable economics. Secondary transition support will also exist for power transition, as hydrogen provides incremental benefit of providing frequency stability and transmission line optimization and capital efficiency (reducing incremental capital expenditures for transmission expansion). Additionally, if hydrogen is generated from renewal power that would otherwise not be captured and distributed within the power grid due to excess generation during off-peak periods, the economics could be supported by lost opportunity value.

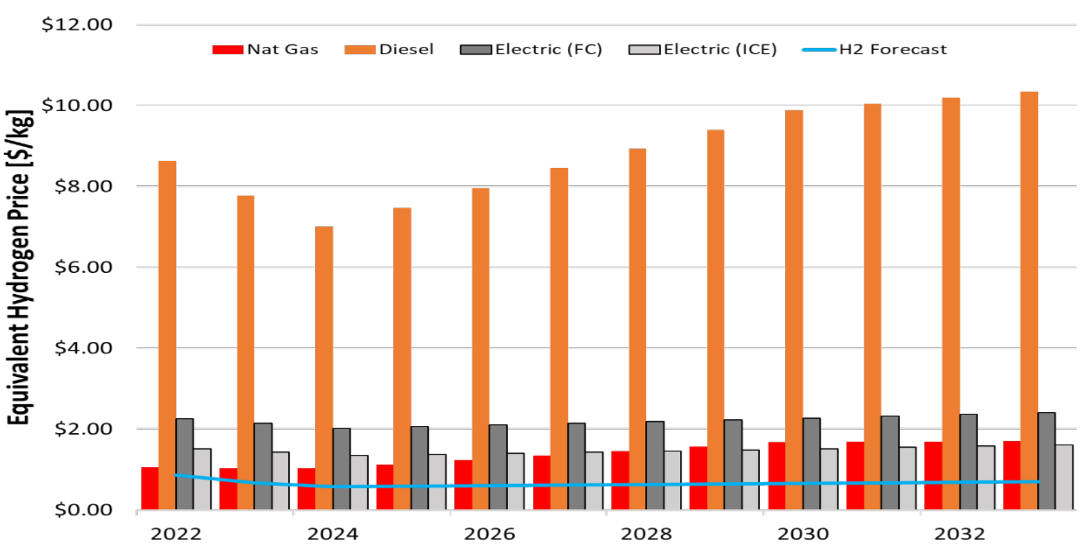


Figure 2.11 Equivalent Hydrogen Prices of Forecast Conventional Fuel Prices

Utilizing hydrogen efficiency and inclusion of full retail expenses and taxes in addition to commodity price, the equivalent hydrogen price per kg can be determined. Current forecast hydrogen pricing (grey H_2) is shown to indicate the value margin between the conventional fuel and hydrogen which would be utilized to establish hydrogen transition. Hydrogen / Natural gas efficiency determined by heating value and incorporates delivery expense and carbon tax. Hydrogen / Diesel efficiency determined by heavy transport efficiency. Hydrogen / Power efficiency shown for both hydrogen combustion and fuel cell applications.

2.7 Hydrogen Production

Though hydrogen accounts for about 75% of all mass, free molecules are seldom found in a natural state due to its buoyancy, small molecular size, and its high reactive potential. Thus, hydrogen requires to be generated from other primary materials. Methane and water are the two primary feedstocks utilized in generating hydrogen. Hydrogen can also be generated from biomass and extracted from hydrogen carriers [41][42][43][44].

Three main processes are utilized for generating hydrogen and all are either in current use or have high potential for use within Alberta and by extension in southeast Alberta. These are **Reforming**, **Electrolysis**, and **Pyrolysis**. The majority of hydrogen generated in Alberta is for syngas use in refining and other industrial chemical processes or as a by-product. These same processes could be expanded and utilized for generation of merchant hydrogen.

2.7.1 Reforming

Chemical reformation is the process of altering a hydrocarbon-based molecule to generate free hydrogen through the use of heat and water. The most common feedstock for reformation is natural gas but other hydrocarbons such as coal, oil and biomass can be utilized.

The most common reformation process utilized is steam methane reformation (SMR) with an added water-gas shift applied to maximize the hydrogen generation efficiency **(Box 2.1)**. SMR is viewed as the most economical means of generating hydrogen today, though most processes currently do not capture the generated CO_2 from the process stream and thus results in the classification of the hydrogen as grey, which is not considered a low-carbon fuel. However, carbon intensity can be reduced significantly by capturing the generated CO_2 from the process stream. With the sequestration of the CO_2, the generated hydrogen is classified as blue hydrogen and is the most economical process of generating low carbon intensity hydrogen currently.

BOX 2.1 HYDROGEN GENERATION PROCESS – STEAM METHANE REFORMING (SMR)

Methane reacts with high temperature steam (700°C – 1,000°C) at atmospheric pressure in the presence of a catalyst to produce hydrogen, carbon monoxide, and small amounts of carbon dioxide. A subsequent process, "water-gas shift" further reacts the carbon monoxide and steam to produce additional hydrogen and carbon dioxide. "Pressure-swing adsorption", removes the carbon dioxide and other impurities from the gas stream leaving pure hydrogen. When combined with carbon capture, utilization, and storage (CCUS), the generated hydrogen is referred to as "Blue" hydrogen.

Steam – Methane Reforming

$$CH_4 + H_2O\ (+heat) \xrightarrow{Catalyst} CO + 3H_2$$

Water – Gas Shift

$$CO + H_2O \xrightarrow{Catalyst} CO_2 + H_2\ (+small\ amount\ of\ heat)$$

Other variations of the reformation process are the partial oxidation reformation process and auto thermal reformation.

Partial oxidation **(Box 2.2)** is a quicker reaction than steam reformation but can be less efficient as the reaction results in less hydrogen produced for each molecule of methane.

BOX 2.2 HYDROGEN GENERATION PROCESS – PARTIAL OXIDATION

Methane reacts with a limited amount of oxygen that is insufficient to completely drive oxidation to carbon dioxide and water. The primary products realized with this reaction is hydrogen and carbon monoxide. The "water-gas shift" process further reacts the carbon monoxide and steam to produce additional hydrogen and carbon dioxide. "Pressure-swing adsorption", removes the carbon dioxide and other impurities from the gas stream leaving pure hydrogen. When combined with carbon capture, utilization, and storage (CCUS), the generated hydrogen is referred to as "Blue" hydrogen. Partial oxidation is typically a faster reaction as compared to steam reforming but does produce less hydrogen per unit of methane.

Partial Oxidation

$$CH_4 + {}^{1}/{}_{2}\, O_2 \xrightarrow{Catalyst} CO + 2H_2\ (+heat)$$

Water – Gas Shift

$$CO + H_2O \xrightarrow{Catalyst} CO_2 + H_2\ (+small\ amount\ of\ heat)$$

Auto thermal reformation (ATR) **(Box 2.3)** is often utilized for production of syngas which is then converted to other hydrogen carriers such as ammonia and methanol. The process is viewed as being more efficient than SMR as it has a greater hydrogen production efficiency and generates a high-purity stream of carbon dioxide which allows for greater capture and further reduced carbon intensity.

BOX 2.3 HYDROGEN GENERATION PROCESS – AUTO THERMAL REFORMING (ATR)

ATR combines SMR with Partial Oxidation resulting in increased energy efficiency and greater hydrogen production efficiency. The combined process is comprised of a reformer, where methane and steam are mixed with oxygen, and a reactor, where partial oxidation occurs. Heat generated in the reactor is utilized in the reformer resulting in a heat balance in an ideal case. "Water-gas shift" further reacts the carbon monoxide and steam to produce additional hydrogen and carbon dioxide. "Pressure-swing adsorption", removes the carbon dioxide and other impurities from the gas stream leaving pure hydrogen. When combined with carbon capture, utilization, and storage (CCUS), the generated hydrogen is referred to as "Blue" hydrogen. ATR is advantageous due to the smaller compact design, lower capital investment and economy of scale, higher hydrogen generation efficiency, and higher CO_2 capture efficiency.

Auto Thermal Reforming

$$4CH_4 + O_2 + 2H_2O \xrightarrow{Catalyst} 4CO + 10H_2$$

Water – Gas Shift

$$CO + H_2O \xrightarrow{Catalyst} CO_2 + H_2\ (+small\ amount\ of\ heat)$$

2.7.2 Electrolysis

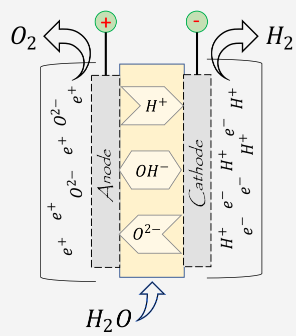
Electrolysis is the process of inducing a chemical reaction to split water into hydrogen and oxygen by applying an electric current **(Box 2.4)**. The process is composed of an anode and an electrode to induce an electric current through an electrolyte or membrane. As hydrogen and oxygen are generally the only products of the reaction, the quality of the hydrogen that is generated is of high purity and does not require further processing. Approximately 9 L of water is required to produce 1 kg of H_2 and 8 kg of O_2. The oxygen by product stream is often vented but due to the high purity of the oxygen stream, further application of oxygen in medical and industrial applications are being pursued.

Proton Exchange Membrane (PEM) electrolyzers are the main technology currently being used, however other electrolyzer compositions and components are rapidly being developed so as to increase the scale and reduce the cost of the electrolyzers, resulting in reduced hydrogen generation expense.

The source of the electric current ultimately determines the carbon intensity of the hydrogen generated. Electrolysis from power generated via renewable generation (solar, hydro, wind) or nuclear is designated as low-carbon intensity hydrogen. Fossil fuel power generation or utilization of a mixed power grid has the carbon intensity associated with the generation source, thus would be considered higher carbon intensity unless carbon capture is a component in the electrical generation.

BOX 2.4 HYDROGEN GENERATION PROCESS – ELECTROLYSIS

Electricity is used to split water into hydrogen and oxygen. An electrolyzer is used to conduct the reaction. An electrolyzer consists of an anode and a cathode separated by various types of electrolyte membranes. If the electrical source is derived from renewable resources (Wind, Solar, Hydro, etc), the generated hydrogen is referred to as "Green" hydrogen. If the electrical source is derived from nuclear resources, the generated hydrogen is referred to as "Pink" hydrogen. "Yellow" hydrogen is used to signify hydrogen derived from grid electricity that is composed of mixed generation sources, thus having a range of carbon intensity.



Proton Exchange Membrane / Polymer Electrolyte Membrane (PEM) Electrolyzer is a solid specialty polymer material that creates oxygen gas and positively charged hydrogen ions at the anode, with the hydrogen ions migrating to the cathode to form hydrogen gas.

Alkaline Electrolyzer is a liquid electrolytic solution such as potassium hydroxide (KOH) or sodium hydroxide (NAOH) and water to which a current is applied creating hydroxide ions (OH-). Oxygen gas is formed at the anode and hydrogen gas is formed at the cathode.

Chlor-Alkali Electrolyzer utilizes a salt solution (NACl or KCl) at the anode and water at the cathode to which a current is applied creating sodium (Na+) or potassium (K+) ions. Chlorine gas (Cl_2) is formed at the anode with caustic soda (NaOH) or caustic potash (KOH_2) and hydrogen gas formed at the cathode.

Solid Oxide (SOEC) Electrolyzer is a solid ceramic material which operates at higher temperatures (> 500°C) and creates hydrogen gas and negatively charged oxygen ions at the cathode, with the oxygen ions migrating to the anode to form oxygen gas.

2.7.3 Pyrolysis

Pyrolysis is a hydrogen generation process that is currently being utilized in Alberta and specifically in southeast Alberta but is generally regarded as a developing process for purposes of large-scale hydrogen production.

Pyrolysis utilizes high temperatures to thermally decompose methane, resulting in the splitting of the molecule into pure hydrogen and solid carbon **(Box 2.5)**. Pyrolysis is the process that is utilized for the generation of carbon black. The purity of the hydrogen stream and the carbon that is generated is dependent on the composition of the input natural gas stream and the degree to which that stream is contaminated with other elements.

The heat for the pyrolysis process can be derived in various forms. [45][46][47][48][49] Thermal pyrolysis is achieved using heat derived from the combustion of natural gas. Plasma pyrolysis utilizes an electric arc to generate a high temperature plasma. Other systems are based on the utilization of microwaves and photo catalysts for purposes of heat generation. Numerous research initiatives are focused on developing pyrolysis as a 'point of delivery' alternative where existing natural gas distribution systems can be utilized to provide the methane feedstock at the location where hydrogen is required, and pyrolysis can be utilized to generate the hydrogen without CO_2 needing to be captured or sequestered.

BOX 2.5 HYDROGEN GENERATION PROCESS – PYROLYSIS

Pyrolysis is the thermal decomposition of methane at high temperatures (800°C – 2,000°C) dependent upon the catalytic, thermal, or plasma process utilized. The produced large particle, high density carbon product, often referred to as carbon black, can be further processed to create graphene, carbon fibre, or carbon nanotubes for further use; as a high strength physical material in steel and concrete, as a high conductivity material for electricity and heat in batteries and electronics, as a thin high tensile strength additive for polymer composite materials and coatings, as a lubricant in the chemical sector, and other developing areas such as medical, aeronautics, and high performance sensors. The generated hydrogen from pyrolysis is referred to as "Turquoise" hydrogen. The purity of the carbon product produced as well as any additional by-products is a function of the composition of hydrocarbon / natural gas feedstock utilized and results in the need of additional clean up processes. The advantage of little or no CO_2 generation is offset by lower hydrogen generation efficiencies as compared to SMR and ATR processes.

Methane Pyrolysis

$$CH_4\ (+heat) \xrightarrow{Catalyst} C + 2H_2$$

2.8 Hydrogen Carriers & Liquid Organic Hydrogen Carriers

2.8.1 Ammonia

Ammonia is one of the most common and abundant chemicals produced globally for the use in producing fertilizers. It is produced by combining nitrogen and hydrogen, with hydrogen generally being derived as a syngas from the stream reformation process.

Ammonia can serve as both a hydrogen carrier and a fuel and is widely exported around the globe, [50][51][52][53] Hydrogen can be extracted from ammonia via an endothermic reaction as shown in **Box 2.6**. Further processing is required for purification of the hydrogen stream to ensure all ammonia has been reacted or removed from the end product stream.

BOX 2.6 HYDROGEN CARRIER – AMMONIA

Potential processes for utilizing ammonia as a hydrogen carrier and generating hydrogen on site are being pursued, due to its high energy density and ability to be easily stored and transported in a liquid state. Due to ammonia's instability at elevated temperatures, hydrogen can be extracted via thermal catalytic decomposition or electro-oxidation processes.

$$2NH_3\ (+heat) \xrightarrow{Catalyst} N_2 + 3H_2$$

1) Plasma Membrane Reactor. Ammonia is passed through a high temperature plasma within a high-voltage device, which allows for the decomposition into hydrogen radicals that are drawn through a hydrogen separation membrane allowing for the formation of hydrogen gas.
2) Catalytic decomposition of ammonia. Various oxidized metal catalysts have been investigated with ruthenium (Ru) being regarded as having the highest conversion rate of ammonia to hydrogen. However, due to the cost and scarcity of ruthenium, nickel (Ni) is likely to be utilized at higher temperatures to generate comparable results.

Ammonia can also be utilized as a fuel and is being widely touted for maritime use. Investigation is underway to utilize ammonia directly within fuel cells.

2.8.2 Methanol

Methanol is another common chemical that is widely used around the world. It is a stable liquid with a high energy content that makes it attractive for purposes of shipping. Due to methanol's non-toxicity to marine life, it is being pursued as both a marine fuel for direct consumption and for shipping and extracting of hydrogen at the end-use destination. [54][55][56] However, as methanol is a carbon-based fluid, extraction of hydrogen does release CO_2 and thus poses challenges for use as a zero-carbon based fuel source. Production of green methanol is being pursued (utilizing atmospheric extracted CO_2 or biofuel sources for purposes of producing methanol rather than methane) to address the generation of incremental emissions, and to maintain a net-zero status. [57]

Box 2.7 illustrates the reformation process required for release of the hydrogen. To satisfy the requirements of a zero-emission fuel source, the CO_2 would need to be captured and sequestered. This, in addition to the greater energy requirements to extract the hydrogen, further reduces the hydrogen efficiency of this carrier.

BOX 2.7 HYDROGEN CARRIER – METHANOL

Methanol reformation can be used to generate hydrogen on site when utilizing methanol as a hydrogen carrier, due to its high energy density and ability to be easily stored and transported in a liquid state. Hydrogen is released from methanol in a three-step catalytic reformation process.

[A] $$CH_3OH\ (+heat) \xrightarrow{Catalyst} HCHO + H_2$$

[B] $$HCHO + H_2O \xrightarrow{Catalyst} HCOOH + H_2\ (+heat)$$

[C] $$HCOOH \xrightarrow{Catalyst} CO_2 + H_2\ (+heat)$$

Methanol can also be utilized as a fuel and is being widely touted for maritime use as it meets the reduced sulphur requirements, as well as for its miscibility in water and quick biodegradation properties. Direct Methanol Fuel Cells (DMFC) are available but requires further advancement in improving catalytic activity to overcome inefficient electrode performance. CO_2 generation in using methanol can be mitigated by utilizing bio-methanol or "Green" methanol that is generated with renewable electricity and carbon capture.

2.8.3 Liquid Organic Hydrogen Carriers

Liquid Organic Hydrogen Carriers (LOHC) are a class of liquid molecules consisting of homocyclic and heterocyclic aromatic rings that have the ability to be reversibly hydrogenated and dehydrogenated at elevated temperature in the presence of a catalyst. The hydrogen is stored in aromatic C-C double bonds resulting in a volumetric storage density comparable to liquid hydrogen but is in the form of a stable liquid at standard conditions.

LOHC's can be recycled and continually ladened with hydrogen. Though energy is required to dehydrogenate the carrier, it is less than the requirements for other carriers such as methanol and can be combined with waste heat from other processes to increase the overall efficiency.

Existing liquid fuel infrastructure can also be used for storage and transport of LOHCs. However, double transport capacity is required to account for the return of the dehydrogenated LOHC (toluene), to become re-hydrogenated. As marine shipping requires ballast on the return voyage from a delivery, LOHC's are being evaluated as a viable option for ocean transport of hydrogen, with the toluene replacing water as the ships ballast for return, thus incurring no incremental cost for the deliver process.

Various compounds are currently being evaluated with methylcyclohexane (MCH) being commercialized by Chiyonda Corporation under the trade name SPERA Hydrogen **(Box 2.8) [58]**. MCH and toluene are both classified under the same category as gasoline and thus can be handled and transported in the same way as liquid petroleum products. This process does pose some issues as small aromatic molecules are classified as being a carcinogen and its low flashpoint implies a fire hazard. Additionally, the process is energy intensive for hydrogenation and dehydrogenation.

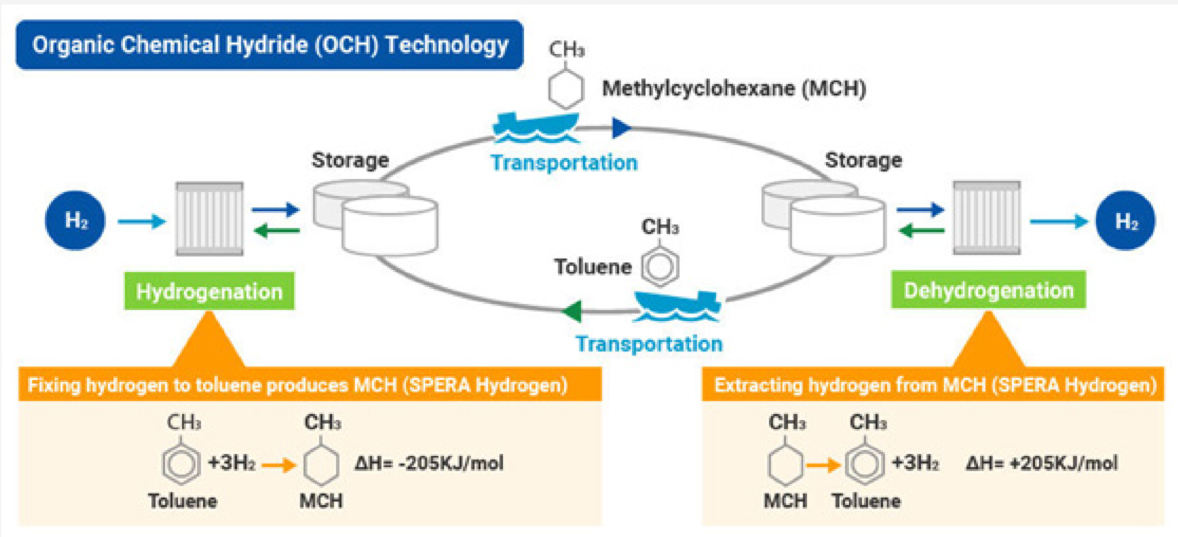
Other LOHC's that are currently being evaluated include:

- N-ethyl carbazole (NEC), which is a larger aromatic with an added nitrogen atom. NEC does not store as much hydrogen as MCH but has a lower enthalpy and thus allows for the dehydrogenation at lower temperatures. NEC, is a solid at ambient conditions and can only be held in a liquid state if hydrogenated to 90%. Another disadvantage is the lack of availability of the chemical as it is only currently obtained as a distillate from coal tar.
- Dibenzyltoluene (DBT) is a more complex toluene structure that has a higher boiling point and flashpoint as compared to MCH thus providing for a purer hydrogen stream upon dehydrogenation and is less of a fire hazard. It is also considered to be less toxic than MCH. However, DBT is less common than toluene and is considerably more expensive.

BOX 2.8 LIQUID ORGANIC HYDROGEN CARRIER – SPERA HYDROGEN

Chiyonda Corporation of Japan has registered a Liquid Organic Hydrogen Carrier (LOHC) by the trade name SPERA Hydrogen [58]. The process utilizes Organic Chemical Hydride (OCH) Technology to hydrogenate toluene to form methylcyclohexane (MCH – SPERA Hydrogen). MCH is then transported via ship as a liquid at ambient conditions, similar to liquid petroleum products, to the end-use destination. Hydrogen is then catalytically extracted from MCH leaving toluene as the process's by-product. The toluene can then be returned and re-hydrogenated to repeat the cycle. MCH energy content represents a compressed volume of approximately 1/500th of hydrogen at ambient conditions.

Chiyonda has successfully demonstrated the process in conjunction with Mitsubishi Corporation, Mitsui & Co. Ltd., and NYK Line in December 2020, with transport and storage of 100 t of hydrogen over a 20-month period, from a hydrogenation facility in Brunei to a dehydrogenation facility in Kawasaki, Japan, a round trip distance of 5,000 km



SOURCE: Chiyonda Corp (www.chiyodacorp.com)

2.9 Transitional Pathways

From the new Net-Zero Energy System, we can envision the transitional pathways that will be created to deliver the hydrogen or hydrogen derived fuel source for use within the various sectors **(Figure 2.12) [59]**.

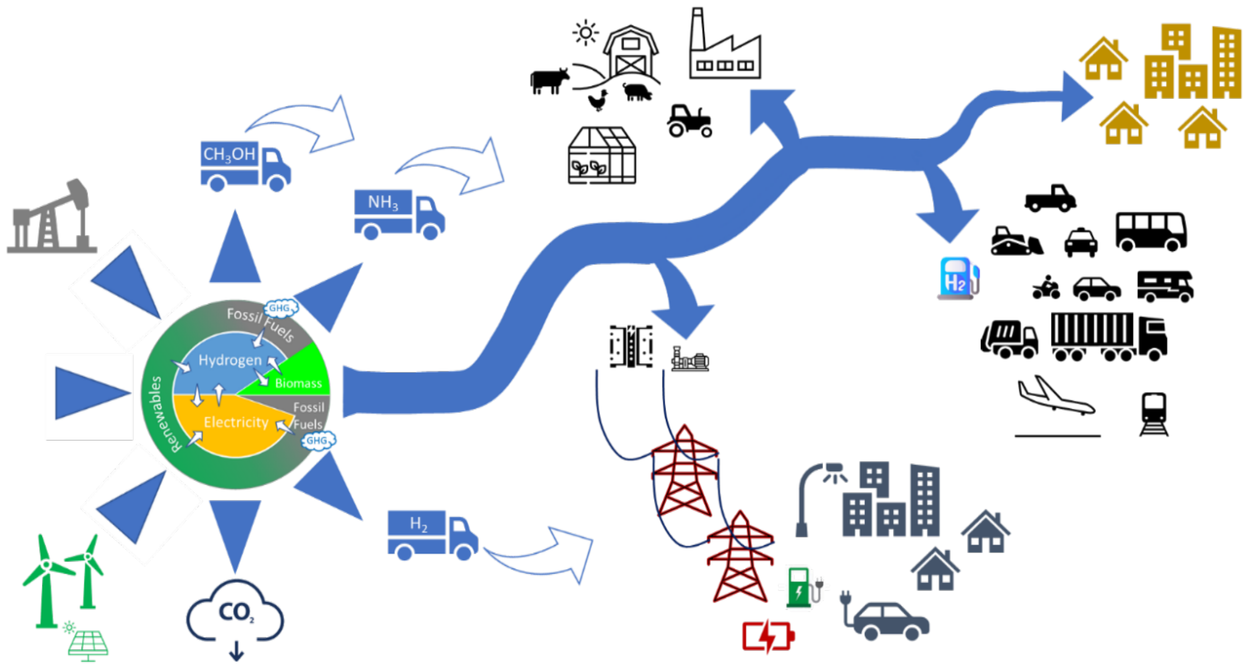


Figure 2.12 Transitional Pathway for the Delivery of Net-Zero Energy to End Use Demand Sector
Once a Net-Zero Energy System has been established, the pathways to deliver hydrogen, hydrogen carriers, or electricity can be put in place via trucking, pipeline, or electrical distribution.

2.9.1 Transportation

Hydrogen can be utilized as a low carbon displacement for diesel and gasoline, with application in both fuel cell electric vehicles (FCEVs) and hybrid internal combustion vehicles (hybrid ICE). Both reduce tail pipe emissions with FCEVs having zero emissions. FCEVs have added benefits by being upwards of twice as energy efficient as internal combustion vehicles. Light duty passenger vehicles and transit buses are commercially available in FCEVs with heavy duty truck and rail currently being manufactured and becoming close to commercial release. Conversion capability of existing diesel combustion engines to hybrid hydrogen/diesel internal combustion currently exists.

FCEVs are viewed as offering advantages over battery electric vehicles (BEVs) where high energy demand is required, whether due to heavy load requirements, long distance travel, or operation in cold remote locations. FCEVs do not suffer the same inherent battery degradation in cold weather and generate waste heat for purposes of cabin heating in contrast to BEVs. FCEVs are lighter than BEVs and currently offer the capability for greater mileage and reduced time to refill/recharge. [60][61][62][63]

2.9.2 Space Heating

Hydrogen provides the benefit of removing CO_2 generation at the burner tip. There is general consensus that introduction of hydrogen into the existing natural gas stream at concentrations of less than 20% will have no material operational impact.

Some challenges remain as higher volume percentages of hydrogen are contemplated. As hydrogen has approximately $^{1}/_{3}$ of the energy content in gas form, increased system velocities and/or system pressures will be required to maintain the equivalent energy delivery. Material compatibility of pipelines and other equipment will need to be assessed to ensure hydrogen embrittlement does not occur. Existing gas metering may be insufficient to measure hydrogen blends correctly at high hydrogen concentrations and will need to be evaluated to ensure no hydrogen leakage occurs through mechanism or at joints that could be compatible for natural gas but not for a smaller hydrogen molecule. Engineering evaluation is required from source to burner tip to understand the suitability of burning hydrogen in each specific application due to the hydrogen providing less radiant heat as compared to natural gas (specifically for appliances that are intended for heating purposes). Increased water condensation related to burning hydrogen needs to be considered as well.

Introduction of hydrogen into the utility stream will require updates and modification of regulations, policies, and CSA standards.

2.9.3 Electrical Generation

Hydrogen can be utilized for both combustible and fuel cell power generation. Hydrogen has the capability to displace natural gas in existing operations, which have varying capabilities with regards to hydrogen concentration levels. New generation equipment is being designed to combust 100% hydrogen. Fuel cell generation is also possible and can act as peaking and stabilizing generation in support of renewable power generation. [64]

Hydrogen use for power generation is also a possibility for remote areas where CCUS for natural gas fired generation is not feasible. Hydrogen can also be utilized as an energy storage vector to capture excess renewable generation during off-peak hours as well as being available on demand during peak hours or when renewable generation drops. Hydrogen as a “storage battery” would have the benefit of a longer storage lifespan than currently developed industrial batteries.

2.9.4 Industrial

Hydrogen use in high fuel consumption areas that rely on diesel, gasoline, or natural gas as an energizer / heat source can result in significant CO_2 emission reductions. Heavy equipment could be retrofit with hybrid hydrogen/diesel engines or replaced with FCEV equipment to reduce diesel consumption. Direct generation of hydrogen at large scale industrial sites could have added benefits of waste heat and/or oxygen generation, which can enhance combustion and heating efficiencies.

2.9.5 Agriculture

Hydrogen can provide a low carbon alternative to an energy intensive operation that are usually seasonally time demanding (i.e. need sustained energy supply when they need it over relatively short periods of time). It is unlikely that electric battery operations can satisfy most of the high season operation demands. FCEV tractors are currently being developed but will require Last Mile delivery capability to fuel on location. Due to its current fertilizer application and ease of storage and transport, the opportunity exists to develop ammonia as a direct fuel source or to utilize it as a hydrogen carrier and generate hydrogen on demand at site.

3 TOP-DOWN ANALYSIS – PROVINCIAL FUEL USE AND H_2 MARKET ESTIMATES PRORATED TO SOUTHEAST ALBERTA

3.1 Overview

For the province, **4,242 PJ** of total primary and secondary energy demand was recorded in 2020.[65][66][67][68] Breaking this demand into five main sectors, Industrial demand accounted for 60% (2,564 PJ) of the total energy **(Figure 3.1)**. Electrical Generation was the next most intensive sector at 17% (701 PJ) followed by Transportation and Utilities at 11% (469 PJ and 451 PJ) each and finally Agriculture at 1% (57

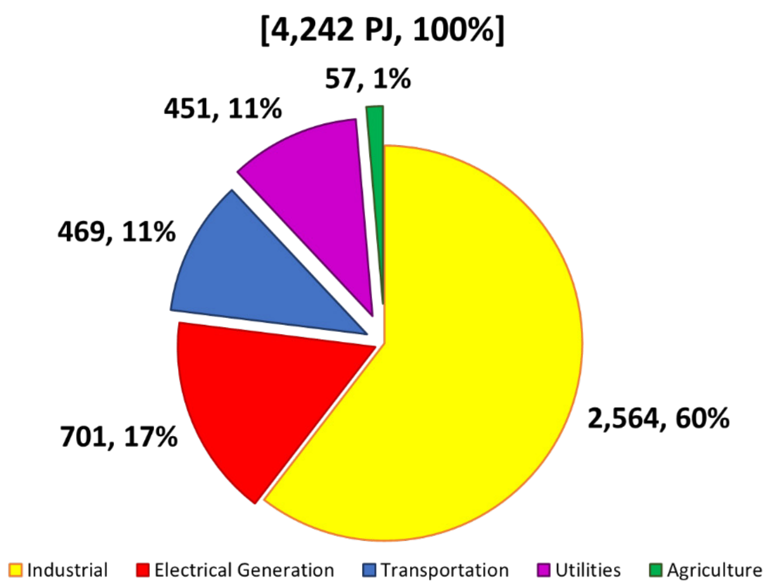


Figure 3.1 Total 2020 Alberta Energy Demand by Sector – Stats-Can
As sourced from Stats-Can, the 2020 energy demand in Alberta was dominated by the industrial sector, nearly four times that of the next highest demand sector, electrical generation.

PJ). Energy demand in the province dropped by 5% in 2020 reflecting the reduced energy consumption caused by the COVID pandemic.

As has been discussed in detail in previous reports, three main areas for hydrogen transition have been identified: i) road, rail, and air transportation, ii) space heating natural gas utilities, and iii) electrical generation. Utilizing detailed fuel information at a provincial level, an estimate of potential hydrogen transition can be determined and subsequently prorated to generate an estimate for hydrogen demand potential to a specific geographic region. If the assumption is made that population drives consumption of energy for vehicular transportation, residential and commercial natural gas use, and electrical generation, a region's population could be an appropriate proration factor. In 2020, Southeast Alberta (SE Alberta) had a population of 120,373 compared to the total population of Alberta of 4,421,876, which would represent a percentage of 2.72%. [69]

3.2 Transport

In 2018, energy use by all vehicular transportation in Alberta was **462 PJ**. NRCan consumption data is categorized by various size and function of vehicle. With the Canadian mandate to stop all new internal combustion sales by 2035, all new vehicles within Canada are assumed to transition to electric, hydrogen fuel cell, or other zero carbon alternatives such as biofuels by 2050. To generate an estimated potential for hydrogen transition, assumptions are required for the percentage of each vehicular class as well as the expected energy efficiency that would be realized in the transition of fuel source. Based on the organization's experience, the Transition Accelerator has generated assumptions for each class of vehicle summarized in **Table 3.1**. Using these assumptions, **Figure 3.2** demonstrates the split between hydrogen and other energy source vehicles by major category; light-duty vehicles, medium duty trucks, heavy duty trucks, rail, air, and off-road. Utilizing these transition assumptions and the detailed transport fuel demand in 2018, it can be estimated that 40% of energy used for transportation in Alberta will be satisfied by hydrogen, with the total potential demand for hydrogen being an average of **2,797 t/day (1,021 kt/year)**. **Table 3.2** illustrates the amount of energy transition from current fuel sources to hydrogen by vehicle classification, with the most demand being for medium and heavy-duty trucks used for freight transport.

Table 3.1 H_2 Transport Transition Assumptions (TA 2020)

Transport H_2 Transition Assumptions

Transportation sector	Percentage Transition to H_2	Relative Efficiency (J H_2/J petrol prod)
Cars	10	0.40
Passenger Trucks	10	0.40
School Buses	20	0.59
Urban Transit	60	0.59
Intercity Buses	80	0.59
Motorcycles	0	n/a
LD Trucks	10	0.40
MD Trucks	20	0.86
HD Trucks	80	0.86
Rail - freight	100	0.55
Rail - passenger	50	0.55
Air - freight	50	1.00
Air - passenger	50	1.00
Off road	50	0.86

As developed by the Transition Accelerator, various classes of vehicles have been assigned both a percentage of transition to hydrogen (vs other low carbon alternative such as electric) and the subsequent relative efficiency of the hydrogen FCEV to current ICE.

Prorating to a population base of 2.72% this would equate to **76 t/day (28 kt/year)** specific to the SE Alberta region.

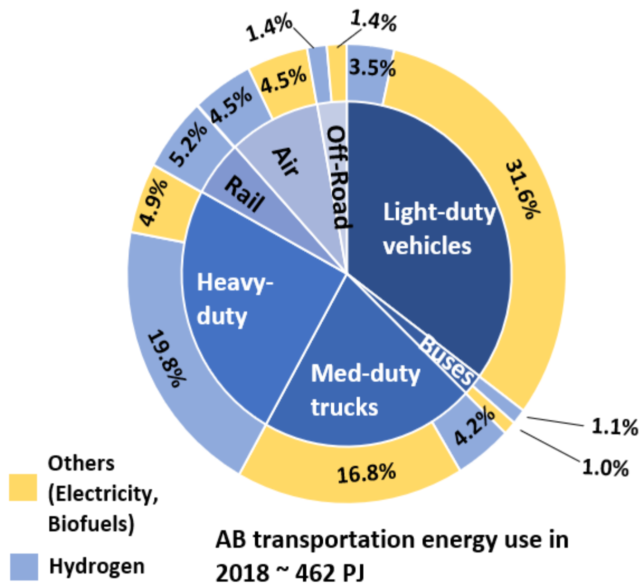


Figure 3.2 Alberta Transportation Hydrogen Transition

Utilizing the 2018 NRCan data for Alberta Transportation, divided by vehicle class in combination with the Transition Accelerator's assumptions, Heavy Duty transport represents the largest potential transition segment. Most Light-duty vehicles and Med-duty trucks are assumed to transition to electric battery vehicles.

Table 3.2 Hydrogen Transition – Potential Transportation Market

Transportation sector	All Alberta				SE AB @ 2.72%	
	Total A PJ/yr	Trans B PJ/yr	ktH_2/yr C	tH_2/d	ktH_2/yr D	tH_2/d
LD vehicles	163	16	46	125	1.2	3.4
Buses	9	5	21	57	0.6	1.6
MD trucks	97	19	118	323	3.2	8.8
HD trucks	115	92	556	1,523	15.1	41.4
Rail	24	24	93	256	2.5	7.0
Airplanes	42	21	146	401	4.0	10.9
Off road	13	7	41	111	1.1	3.0
Total	**463**	**184**	**1,021**	**2,797**	**27.8**	**76.1**

Table with Total Energy use for Transportation in Alberta (2018) divided by vehicle class [A]. Utilizing the Transition Accelerator's assumption for transition, the portion of total energy that is subject to transition is calculated [B]. Applying relative efficiency assumptions results in the equivalent amount of hydrogen required on an annual and per day basis [C] to satisfy this energy requirement. Using a population proration for SE Alberta (2.72%) an estimated potential for the region can be calculated [D].

3.3 Natural Gas Utility – Building Heat

Alberta utilized **352 PJ** of energy in 2018 for the purpose of residential and commercial building heat, both for space and water heating. Of that amount, 330 PJ was fueled by natural gas. It is assumed by the Transition Accelerator, based on accumulated information, that 75% of the natural gas used for these utilities can be transitioned to hydrogen with the remainder transitioning to electricity or other non-carbon-based fuel sources. As illustrated in **Figure 3.3**, residential demand accounts for just slightly more than commercial demand, at 53% (177 PJ) of the combined consumption. To further estimate the total hydrogen potential, the differences in natural gas' and hydrogen's higher and lower heating values need to be accounted for, which creates a relative efficiency of transitioning from natural gas to hydrogen. The relative efficiency factor for hydrogen from natural gas is assumed to be 1.065 J H_2 per J NG.

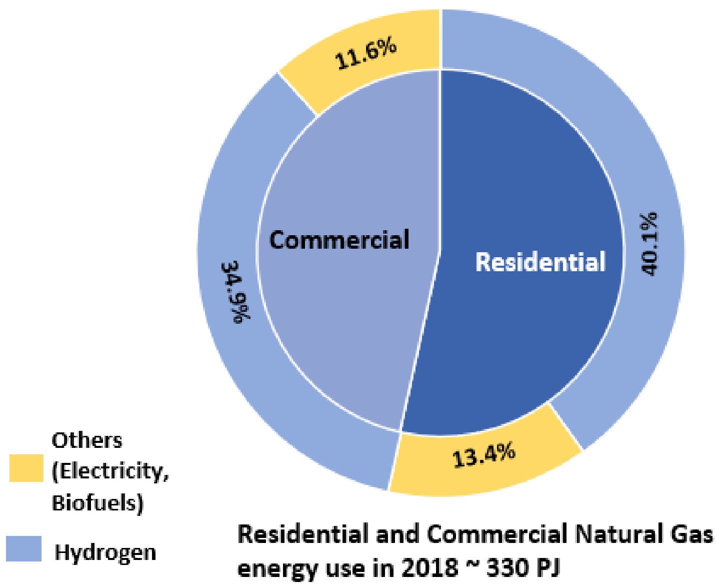


Figure 3.3 Alberta Natural Gas Utility Hydrogen Transition

Representation of 2018 natural gas use for residential and commercial utilities, and resultant transition to hydrogen utilizing the Transition Accelerator's 75% transition assumption.

As shown in **Table 3.3**, transitioning **247 PJ** of natural gas on an annual basis would result in a hydrogen demand of **4,782 t/day (1,746 kt/year)**. However, this average daily number does not account for the typical seasonal demand fluctuations that occur in Alberta. Typical variances between summer demand and winter demand can be by a factor of 8, thus implying an approximate hydrogen demand in August of 1,000 t/day and in January of 8,000 t/day. With these dramatic average seasonal variabilities and the understanding that further variabilities occur within the timeframe of a given day, a realization can be made that full electrification of buildings for purposes of heating is not a feasible solution for Alberta without dramatic overbuilding of heating systems as well as the electrical generation, transmission, and distribution supply infrastructure to meet peak requirements. Thus, a combination of energy sources with reasonable amounts of delivery variance will be required.

For SE Alberta, utilizing the proration by population, the potential for hydrogen in this region can be estimated at **130 t/day (47 kt/year)** with similar degree of seasonal fluctuations.

Table 3.3 Hydrogen Transition – Potential Natural Gas Utility Market

Building sector	All Alberta				SE AB @ 2.72%	
	A Total NG PJ/yr	B Trans PJ/yr	ktH2/yr	C tH2/d	ktH2/yr	D tH2/d
Residential	176	132	933	2,557	25	70
Commercial	154	115	812	2,226	22	61
Total	**330**	**247**	**1,746**	**4,782**	**47**	**130**

Table with Total Natural Gas Energy for Residential and Commercial use in Alberta (2018) [A]. Utilizing the Transition Accelerator's assumption of 75% transition, the portion of total energy that is subject to transition is calculated [B]. Applying relative efficiency assumptions based on heating values the equivalent amount of hydrogen required on an annual and per day basis [C] to satisfy this energy requirement can be determined. Using a population proration for SE Alberta (2.72%) an estimated potential for the region can be calculated [D].

3.4 Electrical Generation

Alberta used **86,158 GWh** of electrical generation in 2021, which represents **310 PJ** of energy consumption. Seventy seven percent of that generation was derived from natural gas fired generation, with cogeneration being the most significant of the various types of natural gas generation **(Figure 3.4)**. Renewable energy: wind, hydro and solar, represented fifteen percent of the generation. Seventy percent of 'Other' generation is from power imports through interties with British Columbia, Saskatchewan, and Montana.

Hydrogen transition for electrical generation is envisioned to have two main roles: 1) as a displacement for nature gas use within nature gas fired cogeneration systems for the continued purpose of heat generation [70], and 2) as a peaking source to stabilize and offset intermittent renewable energy generation. This peaking could be in the form of purpose-built hydrogen combustion peaker units or with the installation of hydrogen fuel cell generation sites.

Most current natural gas fired generation is not capable of a full transition to hydrogen. As such only a portion of the natural gas consumed in these generators can be displaced with hydrogen combustion. On a provincial average basis, the assumption is that combustible hydrogen can be utilized for the equivalent of 20% of total actual generation, primarily for purposes of supply heat for operations reliant on cogeneration. Additionally, it is assumed that an incremental 10% of total actual generation will be required in the form of hydrogen combustible peaking plants or hydrogen fuel cells, to firm up renewable generation by introducing peaking generation to compensate for the intermittent downtime and grid frequency instability associated with renewable generation. These assumptions by the Transition Accelerator are based on industry observations and accumulated information.

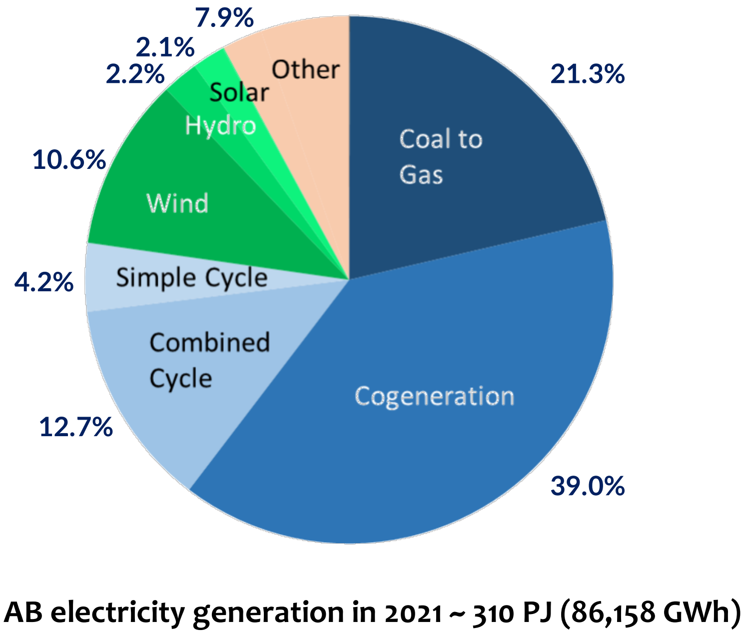


Figure 3.4 Alberta 2021 Electrical Generation by Generation Source

Natural gas fired generation accounted for 66,509 GWh of generation in 2021 (77%). Renewable generation accounted for 12,747 GWh (15%). Net Imports represented 4,666 GWh and is 70% of 'Other' category.

Due to the lower heat value of hydrogen as compared to natural gas and the inefficiencies related to the energy requirements to first generate hydrogen and then to convert hydrogen to electricity by either direct combustion or fuel cell electrical generation, a relative efficiency is required. For purposes of this report, a relative efficiency of hydrogen for electrical generation, by internal combustion, is assumed to be 3 J H_2 per J e-. This results in a total provincial potential hydrogen demand of 5,397 t/day (1,970 kt/year) **(Table 3.4)**. This generation would displace 31 PJ of natural gas consumption and provide 62 PJ of incremental peaking consumption that ultimately would assist in renewable energy displacement of high carbon base generation if not providing incremental generation capacity for demand growth. Utilizing the population proration factor of 2.72% for SE Alberta, a potential hydrogen demand of 147 t/day (54 kt/year) can be estimated for the region.

Table 3.4 Hydrogen Transition – Potential Electrical Generation Market

Power generation sector	Gen Pje /yr A	Rel. Effic. J H_2/ J e B	All Alberta		SE AB	
			ktH_2/yr	C tH_2/d	ktH_2/yr	D tH_2/d
Peaking to firm intermittent renewables (est. at 10% of Generation)	31	3	657	1,799	17.9	48.9
Cogeneration (estimated at 20% of generation)	62	3	1,313	3,598	35.7	97.9
Total			**1,970**	**5,397**	**53.6**	**146.8**

Hydrogen potential to support electrical generation. Total 2021 energy equivalent for actual generation indicated [A], with assumption of a relative efficiency of 3 that would represent hydrogen combustion generation [B]. Transition Accelerator's assumption of having 20% of all generation transitioned to hydrogen for co-generation and 10% of all generation to act as peaking for renewable energy generation, determines an annual and daily potential for hydrogen for the province [C]. Potential for SE Alberta prorated by population (2.72%) [D].

3.5 Top-Down Summary

Total Hydrogen demand for energy transition in Alberta is estimated at **12,977 t/day (4,737 kt/year)** **(Table 3.5)**. Utilizing regional population as a proxy for estimating hydrogen demand for a geographic area, SE Alberta estimated potential demand would be **353 t/day (129 kt/year)**.

Natural Gas utility and power generation represent the largest potential sectors for hydrogen transition **(Figure 3.5)**, with each being approximately 40% of the demand. This total potential demand is likely a conservative estimate as it does not account for the use of hydrogen within the industrial sector, (such as in Oil and Gas, Cement, Steel, and other high energy / high emission sectors), does not account for future population or economic growth of the province, and does not account for the potential of generation of hydrogen for export to other markets, whether to the other Canadian provinces, United States or overseas.

This estimate of hydrogen demand represents transition of **524 PJ** of total energy consumption for the province, or 12.5% of the energy consumed in 2018. The CO_2e reduction this transition would result in is **29.6 Mt CO_2e**, which represents a reduction of 41% of emissions associated with Transport, Building Heat and Electrical Generation, or 11% on total provincial CO_2 emissions of 272.8 Mt. [71]

As both the hydrogen transition demand and emission estimates have been derived based purely on regional population, a means of verifying the regional estimate is required to ensure the region's prorated hydrogen potential is reasonable and reliable. As large emitter data is available through the Greenhouse Gas Reporting Program (GHGRP), a comparison between provincially and regional emissions can be made. If a correlation can be assumed that GHG emissions of a region is dependent on energy use, then hydrogen transition potential would be a function of GHG emissions. From the Environment and Climate Change Canada 2020 GHGRP report [72], total large emitter emissions in Alberta were 156.6 Mt CO_2e. For SE Alberta the

Table 3.5 Total Hydrogen Transition Potential

Sector	End use	% share to hydrogen	Relative efficiency	All Alberta			SE Alberta @ 2.72%	
				A Trans PJ	ktH_2/yr	B tH_2/day	ktH_2/yr	C tH_2/day
Transport	LD vehicles	10% cars; 10% light trucks; 0% motorcycles	0.40	16	46	125	1	3
	Buses	20% school ; 60% transit and 80% inter-city	0.59	5	21	57	1	2
	MD trucks	20% of medium duty trucks	0.86	19	118	323	3	9
	HD trucks	80% of heavy duty trucks	0.86	92	556	1,523	15	41
	Rail	50% passenger rail; 100% freight rail	0.55	24	93	256	3	7
	Airplanes	50% passenger air; 50% freight air	1.00	21	146	401	4	11
	Off road	50% of off-road vehicles	0.86	7	41	111	1	3
Total for transport				**184**	**1,021**	**2,797**	**28**	**76**
Heat	Residential space and	75% of natural gas use	1.07	132	933	2,557	25	70
	Commercial space and	75% of natural gas use	1.07	115	812	2,226	22	61
Total for heat				**247**	**1,746**	**4,782**	**47**	**130**
Power	Peaking to firm intermittent renewables	10% of all generation	3.00	31	657	1,799	18	49
	Co-generation	20% of all generation	3.00	62	1,313	3,598	36	98
Total for electric generation				**93**	**1,970**	**5,397**	**54**	**147**
Total hydrogen demand				**524**	**4,737**	**12,977**	**129**	**353**

Summary of hydrogen potential for Alberta for Transport, Heat (natural gas utility), and Power Generation with description of the end use and the transition assumption and relative efficiency of transitioning to hydrogen. Total transitioned energy [A] indicated with corresponding hydrogen volume on an annual and daily basis [B]. SE Alberta estimated is shown as a proration by regional population [C].

reported emissions were 9.5 Mt CO_2e, which represents 6.1% of the provincial GHG emissions. Further, as shown in **Figure 3.6**, the most significant emission source in SE Alberta is from Electrical Generation as compared to upstream and midstream Oil & Gas for Alberta. Generation emissions in SE Alberta in 2018 represented 13.6% of the provincial generation emissions. As Electrical Generation has been identified as one of the most significant sectors for hydrogen transition, the estimate for hydrogen potential in SE Alberta is likely significantly higher than the 2.72% population estimate.

This comparison of emission data and the realization of the disproportionate demands by sector suggests that utilizing population as a means to prorate hydrogen demand to specific geographic regions may be oversimplified. To better estimate the hydrogen potential of SE Alberta, a bottom-up evaluation and characterization of the region has been conducted to provide a comprehensive understanding of its' unique energy character and to attempt to quantify the full energy chain for each sector within the region: consumption, generation, and distribution.

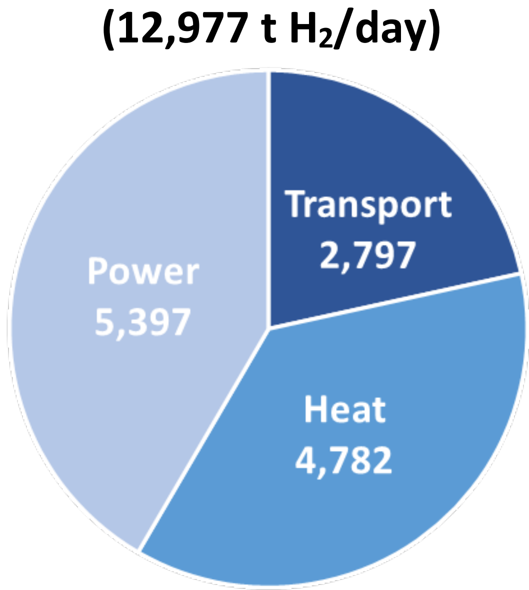


Figure 3.5 Total Alberta Hydrogen Demand by Sector

Total hydrogen potential for Alberta with Electrical Generation representing 42% of the total estimate. Heat (natural gas utilities) represents 37% and Transportation represents 21%.

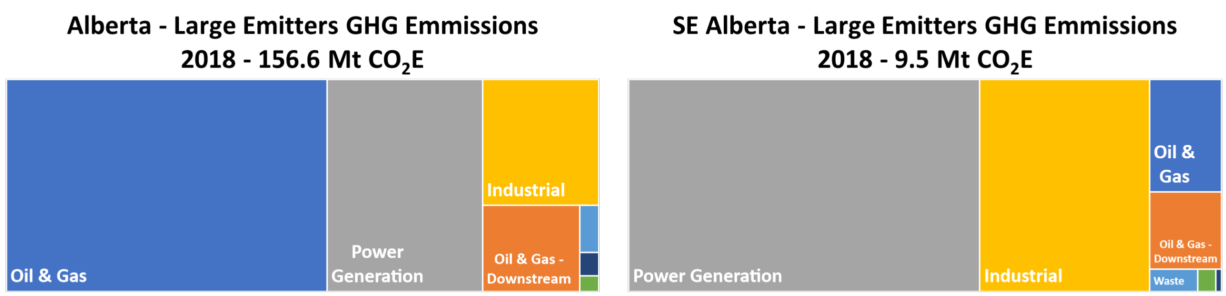


Figure 3.6 Large Emitter GHG Emissions – Environment and Climate Change Canada GHGRP

Comparison of reported 2018 large emitter data at provincial and regional level indicates higher emissions in SE Alberta (13.6%) than population proration (2.72%) suggesting that hydrogen transition in SE Alberta may be greater than estimated by population proration. Emissions from Power Generation and Industrial sectors are largest emitters in SE Alberta

4 SOUTHEAST ALBERTA REGION CHARACTERIZATION

4.1 Geographic Region and Characteristics

For purposes of this report, SE Alberta is being defined as the municipal interests that comprise the Palliser Economic Partnership. [73] As of 2020, the region has a population of 120,373 people covering an area slightly less than 50,000 km^2 and a diverse area of 20 municipalities **(Figure 4.1).** [74]

The region is predominately a rural area with its economy based on agriculture and food processing, traditional and renewable energy resources, petrochemical, manufacturing, and national defense. [75][76] Major transportation and transmission infrastructure runs through the region; road - TransCanada and Crowsnest Highways, rail – CP Rail main line, CN Rail spur, and 2 short line connections, major power transmission lines – 500 kVA EATL and dual 240 kVA, and pipelines – NGTL natural gas system as well as the Bow River, Express and Keystone crude oil pipelines.

The largest city in SE Alberta is Medicine Hat, located near the middle of the region with a population of 65,475 and is the location of a significant industrial cluster (Medicine Hat Industrial Complex), which compliments the city's ownership of power generation and natural gas distribution utilities, as well as natural gas producing assets. Medicine Hat is within Cypress County and adjacent to the town of Redcliff. Cypress County is the largest municipal district in the region representing 27% of the land area and containing 66% of the population. Both TransCanada and Crowsnest highways and CP Rail's west and south mainlines run through the county along with the only commercially serviced airport of the region in Medicine Hat. The Great Sandhills short line railway provides service to the Empress/McNeill straddle plant complex near the Alberta / Saskatchewan border. In addition to the industrial cluster, economic activity is driven by dryland farming, ranching, national defense, and energy production (oil and gas, and power generation), with Redcliff being known as the Greenhouse Capital of the Prairies. Power transmission for the area is serviced by two dual 240 kVA transmission lines as well as an intertie with Saskatchewan. Defense Research and Development Canada – Suffield Research Centre (DRDC – SRC), a research center located at Canadian Forces Base Suffield (CFB Suffield) and the Medicine Hat College are notable institutions within the county.

The County of Forty Mile is situated to the south along the Crowsnest Highway and CP Rail's south line and includes the town of Bow Island and village of Foremost. Agriculture is a major economic driver for the region with 3,700 km^2 of crop land, 1,600 km^2 being under irrigation, and specifically serviced by the Forty Mile Rail short line railway. Manufacturing and renewable power generation are also significant, with the province's largest wind project, the 353 MW Whitla wind farm operated by Capital Power, being situated in the county.

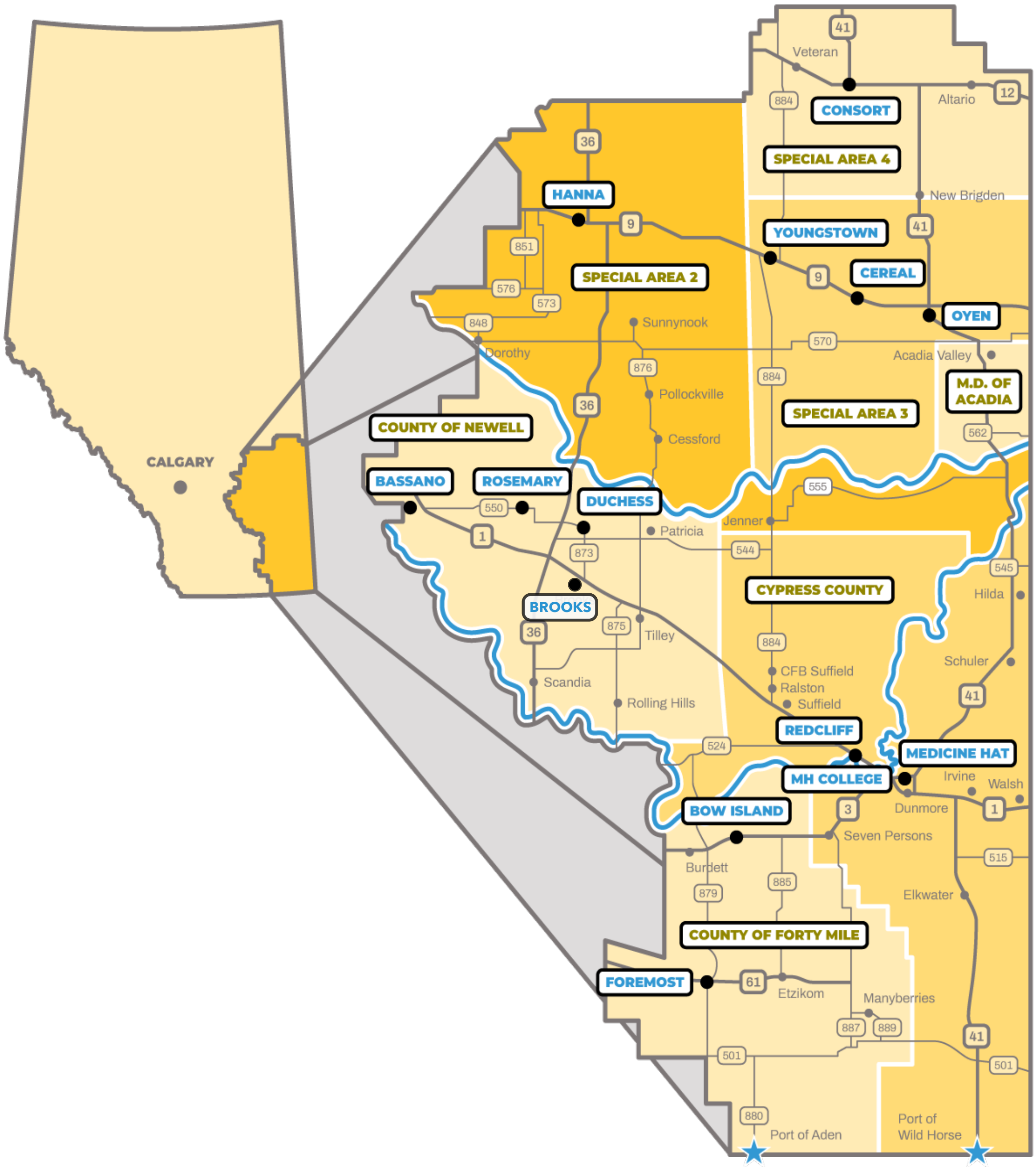


Figure 4.1 Palliser Economic Partnership Region

Palliser Economic Partnership area has been utilized to define SE Alberta Region.

SOURCE: Palliser Economic Partnership (palliseralberta.com)

The second most populous municipal district, the County of Newell, is situated on the western edge of the region along the TransCanada Highway and CP Rail's west line. Highway 36 is a main north-south highway corridor running through SE Alberta and is designated as part of the Alberta High Load Corridor that provides for the main oversized load transport corridor from the US border to Edmonton and Fort McMurray. The City of Brooks is within the county along with the town of Bassano and villages of Rosemary and Duchess. Ranch and crop agriculture coupled with food processing are significant economic drivers for the area, along with manufacturing, and oil and gas operations. The area is home to Alberta's first commercial solar power generation project, the 15 MW site is operated by Elemental Energy located at Brooks. The south terminus of the 500 kVA EATL transmission line is situated near Brooks that provides significant transmission capacity north to the Alberta Industrial Heartland.

The northern part of the region consists of the Municipal District of Acadia and the Special Areas 2, 3, and 4. This area represents 45% of the region based on area but with a sparse population, contains only 8% of the region's population. Other municipalities in the region include the towns of Hanna (within SA 2), and Oyen (SA 3), and the villages of Youngstown (SA 3), Veteran (SA 4), Consort (SA 4) and Empress (MD of Acadia). Energy and Agriculture are the primary economic drivers for the area. Located near Hanna, the 800 MW Sheerness Power Generating Station (Sheerness), operated by Heartland Generation, has recently been converted from coal fired to natural gas fired generation. This conversion has resulted in emissions from the facility being reduced by approximately 50% and the corresponding suspension and active reclamation of the Sheerness Coal Mine. Sheerness is currently the largest emission source within the SE Alberta region. The 500 kVA EATL transmission line runs proximal to Hanna and provides transmission potential for renewable energy development in the area. Highway 36 and Highway 9, another designated highway in the Alberta High Load Corridor [77], provide the area with significant transport corridors, both north/south and east/west. CN Rail provides rail service from Oyen, which connects to the CN Rail mainline in Saskatchewan.

The SE Alberta region has a history of being a first mover for new energy development and transition, to the extent that Medicine Hat was branded as **Gas City** in recognition of the discovery and utilization of natural gas as a significant energy source and used to transition from coal in the early 1900's **(Figure 4.2)**. This initial acceptance of natural gas as a new energy source led to the establishment of the unique municipally owned and operated oil and gas assets by the City of Medicine Hat and subsequent establishment of its own natural gas and power utilities. [79][80]

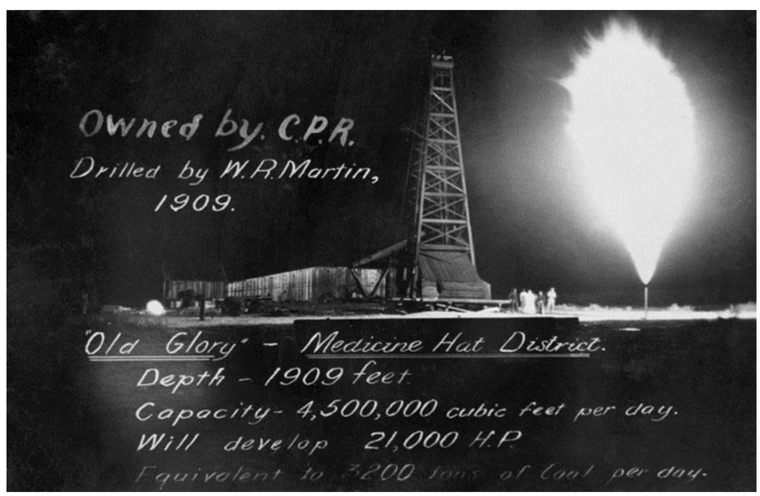


Figure 4.2 Workers at 'Old Glory' Number 1 Gas Well

Picture of one of the first natural gas wells in SE Alberta in Bow Island, Alberta, and documentation of the transition from coal to natural gas.

SOURCE: Source Digital Collections at University of Calgary (ucalgary.ca) [78]

Following the initial natural gas discovery, SE Alberta saw the build out of infrastructure to support the expansion and commercial acceptance of natural gas as primary fuel source, both by industry as well as the public. This saw the construction of one of the longest and largest pipelines of the time, a 16” 274 km natural gas pipeline, built in 1912 from Bow Island to Calgary **(Figure 4.3)** to supply gas to southern Alberta to replace coal gas as a heating, lighting, and cooking fuel.

Figure 4.3 Building it Old School: Alberta’s First Pipeline

Picture of construction on largest natural gas pipeline of the time (1912) connecting Bow Island with Calgary.

SOURCE: Alberta Energy Regulator Photo Collection (aer.ca) [81]

Continued natural gas infrastructure development saw the building of the Alberta Gas Trunk Line (now NGTL) to provide province-wide natural gas transportation, the TransCanada Pipeline system to deliver natural gas to Eastern Canada, the build out of natural gas cooperatives to deliver natural gas to small municipalities and rural residences, the build out of pipeline infrastructure to facilitate exports to the United States, and the establishment of the AECO natural gas storage hub near Suffield, which lead to the corresponding NGX AECO-C/NIT natural gas commodity trading index.

After decades of development of the plentiful shallow natural gas resource in the area, the area was quick to show acceptance to a new energy transition with construction of the province’s first commercial solar power project in Brooks **(Figure 4.4)** and the largest wind project near Bow Island **(Figure 4.5)**.

Figure 4.4 Brooks Solar Project – Elemental

SOURCE: eideard.com [82]

Figure 4.5 Whitla Wind Project – Capital Power

SOURCE: Extracted from Capital Power website [83]

4.2 Demographics & Economy

As described in **Section 3**, a top-down estimate of the potential hydrogen market for SE Alberta can be done based on population of the region. This assumes that energy consumption, and thus the potential for transition to hydrogen, is directly correlated to population. However, as demonstrated by the large emitter data, this assumption may underestimate the potential for the region and without developing an understanding of the unique characteristics of SE Alberta and how these characteristics influence the entire energy chain; consumption, generation, and distribution, a more accurate estimate of hydrogen potential and the transitional pathways cannot be obtained.

Recall, the southern portion of the region, represented by Cypress County and the County of Forty Mile, accounts for 42% of the geographic area and 71% of the total population **(Figure 4.6)**. The City of Medicine Hat is the largest urban center both in this sub-region and in the total SE Alberta region, and when combined with the adjacent town of Redcliff, represents a combined population of 71,384. CFB Suffield covers 2,700 km^2 of the sub-region.

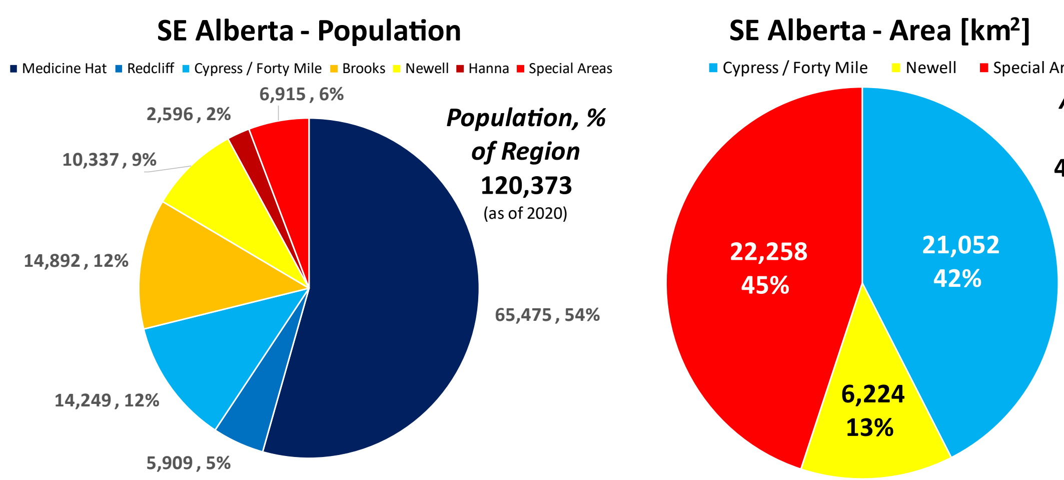


Figure 4.6 Population and Land Area – SE Alberta

Population of SE Alberta divided by each municipal district and largest urban centers with City of Medicine Hat / Redcliff representing 59% of the region's population. Total land area for region represented in three subregions: North (Special Areas), South (Cypress & Forty Mile), and West (Newell).

The northern portion of the region, comprising of Special Areas 2, 3 and 4 along with the Municipal District of Acadia is the largest sub-region representing 45% of the land area but only accounts for 8% of the population. Hanna is the largest urban center in the north with a population of 2,596. There are several other towns and villages in this sub-region, having a combined population of 2,278 further highlighting the sparce rural population.

In the western portion of the region which corresponds to the County of Newell, the City of Brooks is the largest urban center with a population of 14,892. Both the TransCanada Highway and the CP Rail west portion of the mainline run down the middle of the sub-region and thus supports population settlement throughout the county. The County of Newell has the highest rural population density in SE Alberta.

SE Alberta was one of the first industrial areas of Alberta, with diverse industries being established to take advantage of its vast natural gas resource and clay deposits. With Medicine Hat being one of the original North West Mounted Police posts and railroad construction camps, the area quickly became a key location in the trans-Canadian transportation corridor and a critical distribution point and remains one today.

Though once the third largest city in Alberta, Medicine Hat and SE Alberta has seen a lower overall growth rate in comparison to other parts of the province. Since 2001, SE Alberta's population has seen a cumulative growth of 17% **(Figure 4.7)** as compared to a growth of 44% for the province. Medicine Hat has seen continuous year over year growth, with the cumulative 20-year rate of 24%, while the rural population has remained flat, and the northern sub-region has experienced an overall net population decrease over the same time frame.

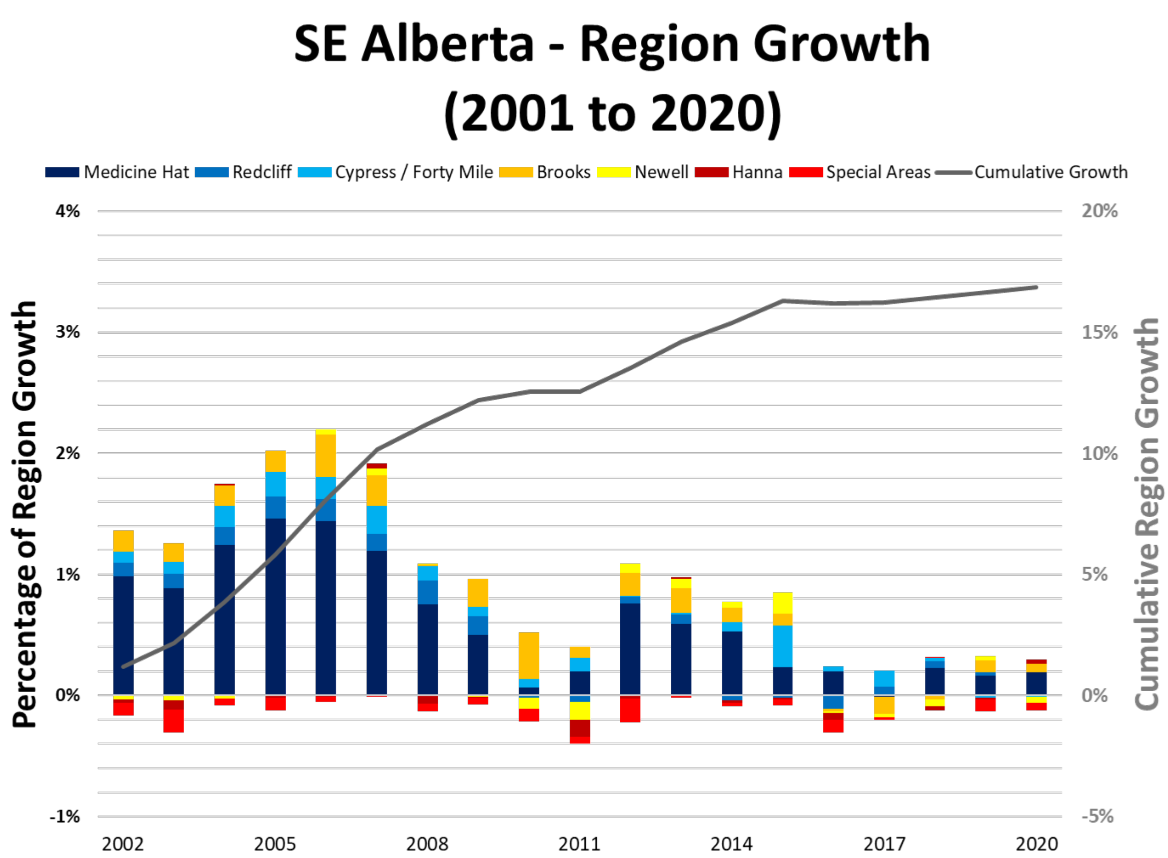


Figure 4.7 SE Alberta Population Growth

Annual population growth over previous 20 years by subregion and largest urban center with total cumulative growth for SE Alberta. Total cumulative growth driven by growth in Medicine Hat and Brooks and offset by declines in the northern subregion.

To further understand the character of the SE Alberta region, other demographic indicators can be observed in comparison to total provincial values. **Figure 4.8** illustrates several different characteristics and their relative comparison to population and its 2.72% provincial weighting. **Figure 4.9** and **Figure 4.10** illustrates other demographic statistics comparing the Alberta value to the corresponding value in SE Alberta.

SE Alberta's geographic land area represents 7.5% of the province. This would equate to a population density of 2.43 people per km^2 in comparison to the provincial average of 6.68 people per km^2. This difference is even more pronounced when you compare 21.8% of the region's population is considered rural versus 14.7% for Alberta as a whole. [84] This results in an urban density of 514 people per km^2 and rural density of 0.5 people per km^2 in SE Alberta as compared to 1,595 people per km^2 and 1.2 people per km^2 for the province. This difference highlights the rural and remote nature of the region and is an indicator that increased energy demand per capita would be expected.

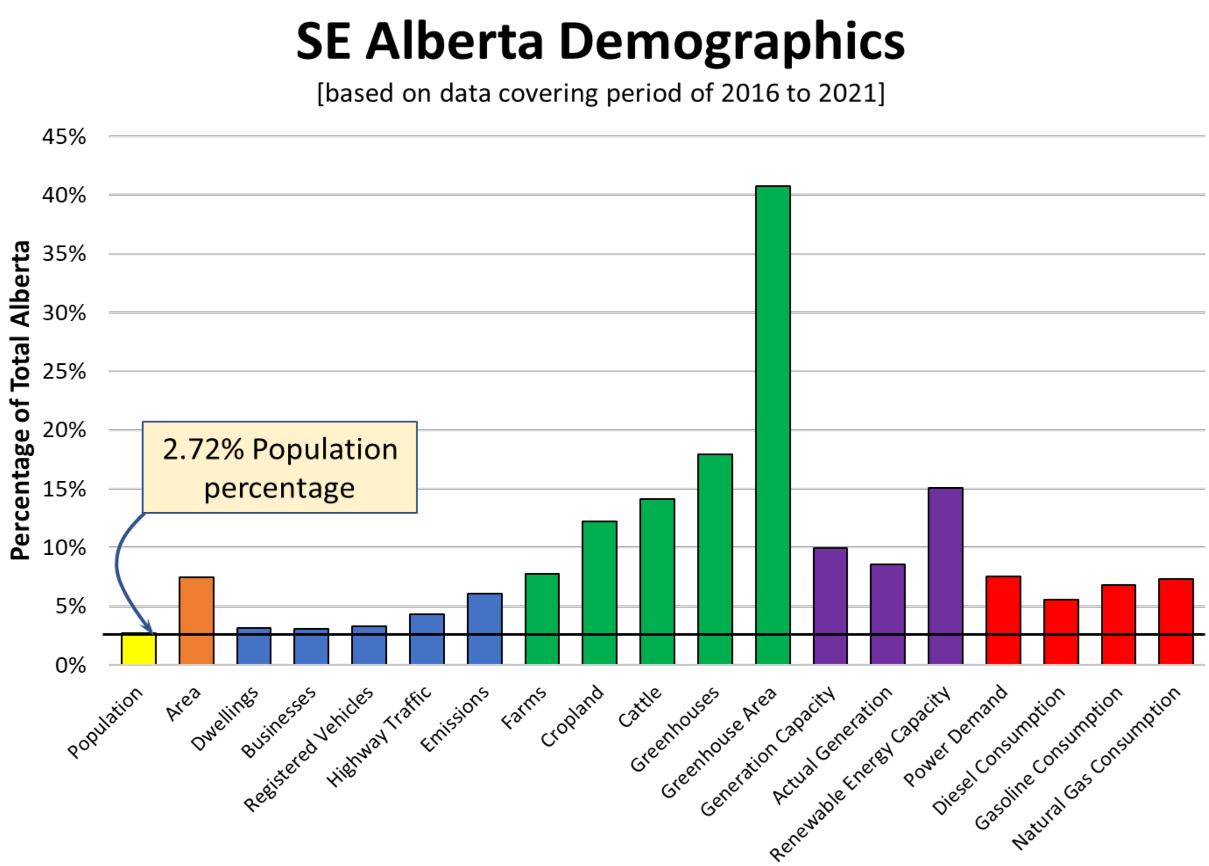


Figure 4.8 SE Alberta Demographics

Regional demographics of various energy related categories displayed as a percentage of total Alberta. Population used as a comparison to other demographic indicators, as population was utilized as a proration factor for top-down analysis. SE Alberta land area represents 7.5% of the provinces total area. Economic indicators shown in blue, Agricultural indicators shown in green, Electric Generation indicators shown in purple, and Energy Consumption indicators shown in red. Each indicator of greater percentage than population.

ECONOMIC INDICATORS

Various economic indicators for the region can be observed (shown as blue in **Figure 4.8**) that represent 3 to 6% of the provincial values. These indicators, such as number of dwellings, vehicle registrations, highway traffic, and emissions, all suggest a disproportionate amount of energy consumption in the region, and thus the likely higher potential for hydrogen transition. With less people per dwelling on average and higher vehicle ownership, consumption of fuel for transport and heating would be expected to be higher on a per capita basis than the provincial averages **(Figure 4.9)**. The make up of the property assessments (higher percentage of farm, linear property and machinery and equipment), the categories of business (higher percentage of agriculture and resources sector businesses) and the vehicle registration type (higher percentage of truck and truck and trailer classes) **(Figure 4.10)** further indicates a larger exposure to high energy demand sectors, agriculture and resource recovery operations, and would result in a greater propensity for higher energy consumption.

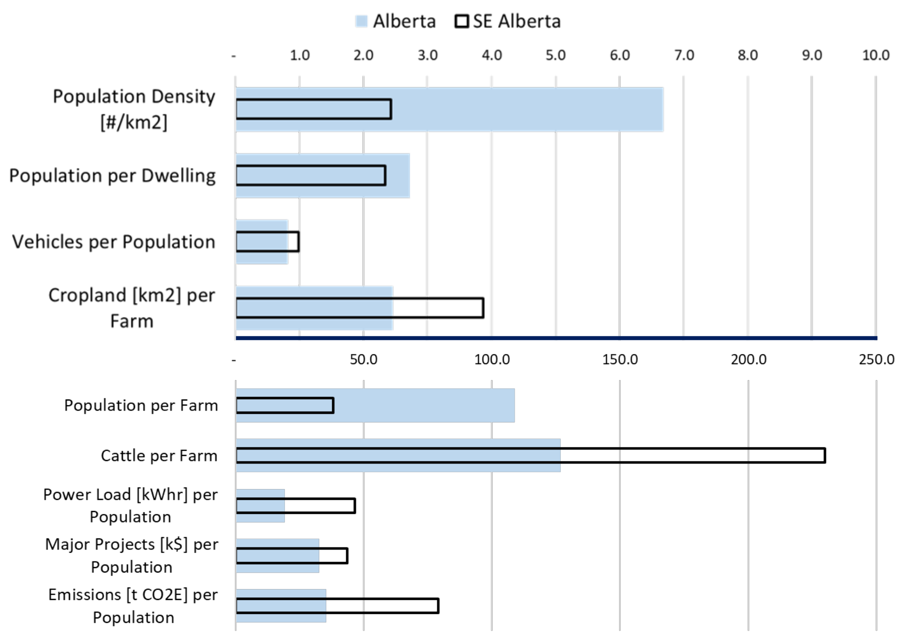


Figure 4.9 SE Alberta Demographic – Statistical Indicators

Various per capita demographic statistics compared between SE Alberta and total Alberta. Statistical indicators suggest lower population density for SE Alberta as compared to province and per capital energy demands greater than provincial averages.

AGRICULTURAL INDICATORS

Agriculture is a significant part of the SE Alberta economy. The region represents 8% of the farms in the province but these farms are larger than the average Alberta farm and account for 12% of the cropland farmed and 14% of the cattle raised. Though the statistics are not available it is assumed that the cattle values are indicative of other livestock sectors such as chickens, hogs, dairy, etc., which are all significant constituents of the mixed farming operations of the region. Further indication of the agricultural intensity of the region is the number of greenhouses and the total area of greenhouse space. Redcliff has long held the title of **'Greenhouse Capital of the Prairies'**, with the largest concentration of commercial greenhouses in Western Canada within the town's boundary. Additionally, Big Marble Farms, located just south of

Redcliff and Medicine Hat is the largest greenhouse in Alberta, having 1.5 million square feet, which represents more than $^{1}/_{3}$ of the total greenhouse area in SE Alberta. [85] As agriculture is an energy intensive industry, it should be assumed that the average energy consumption for the region would be higher than indicated by proportion of population.

ELECTRICAL GENERATION

SE Alberta represents 10% of the provincial generation capacity and 9% of the actual electrical generation in 2021. The region accounts for 15% of the renewable energy capacity of the province, 35% of the generation in the area. Natural gas is utilized for 63% of the generation in SE Alberta. The disproportionate amount of power generation from the region is another indicator of higher energy requirement.

OVERALL ENERGY CONSUMPTION

As can be seen in **Figure 4.8**, SE Alberta consumes a greater share of all energy sources, electricity, natural gas, diesel, and gasoline. This is also reflected in a greater emissions per capita value. Both suggesting an overall greater energy demand per capita and higher overall potential for low carbon energy transition to hydrogen for the region.

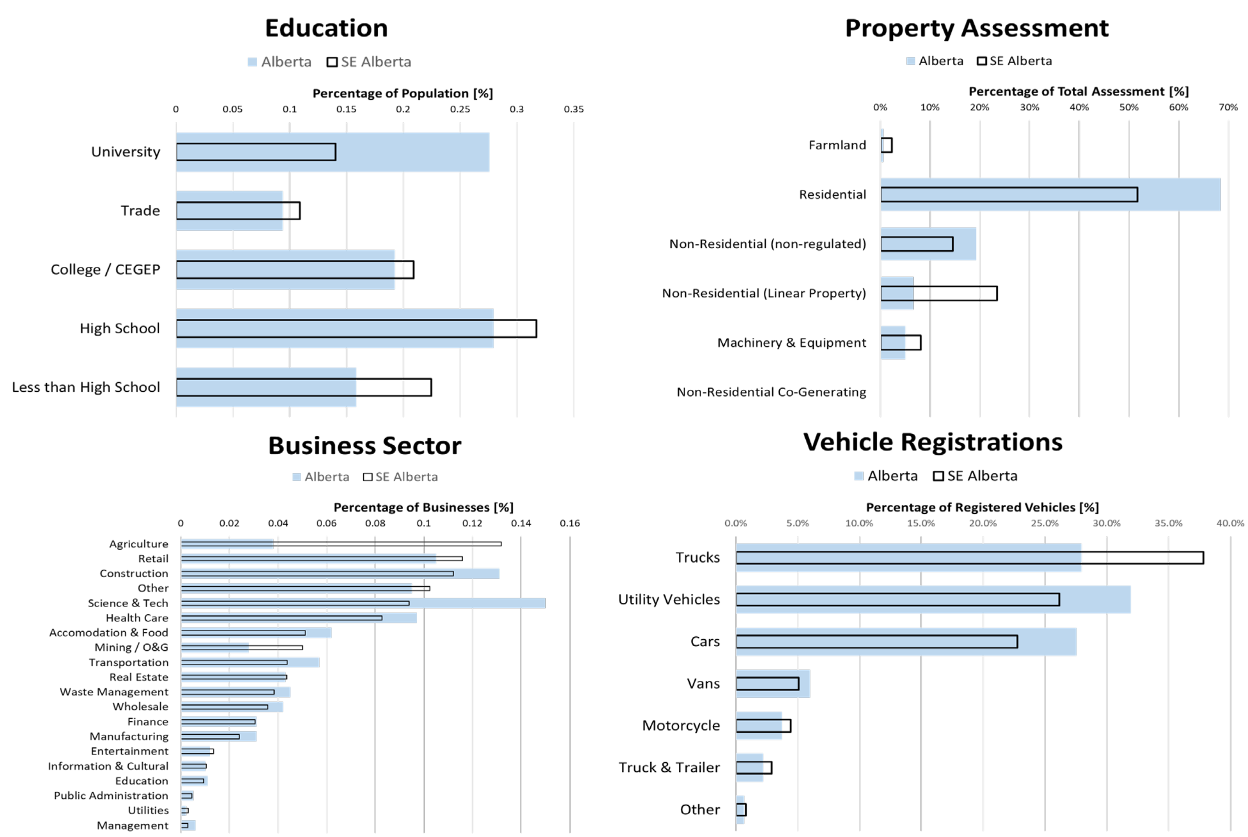


Figure 4.10 SE Alberta Demographic – Per Capita Comparisons by Category

Comparison of SE Alberta versus total Alberta for various subcategories within Education, Property Assessment, Business Sector, and Vehicle Registration demographics.

4.3 Assets and Infrastructure

4.3.1 Roads, Rail Lines, and Airports

Six primary highways cross SE Alberta providing connections to major centers through Alberta and in adjacent provinces **(Figure 4.11).** [86]

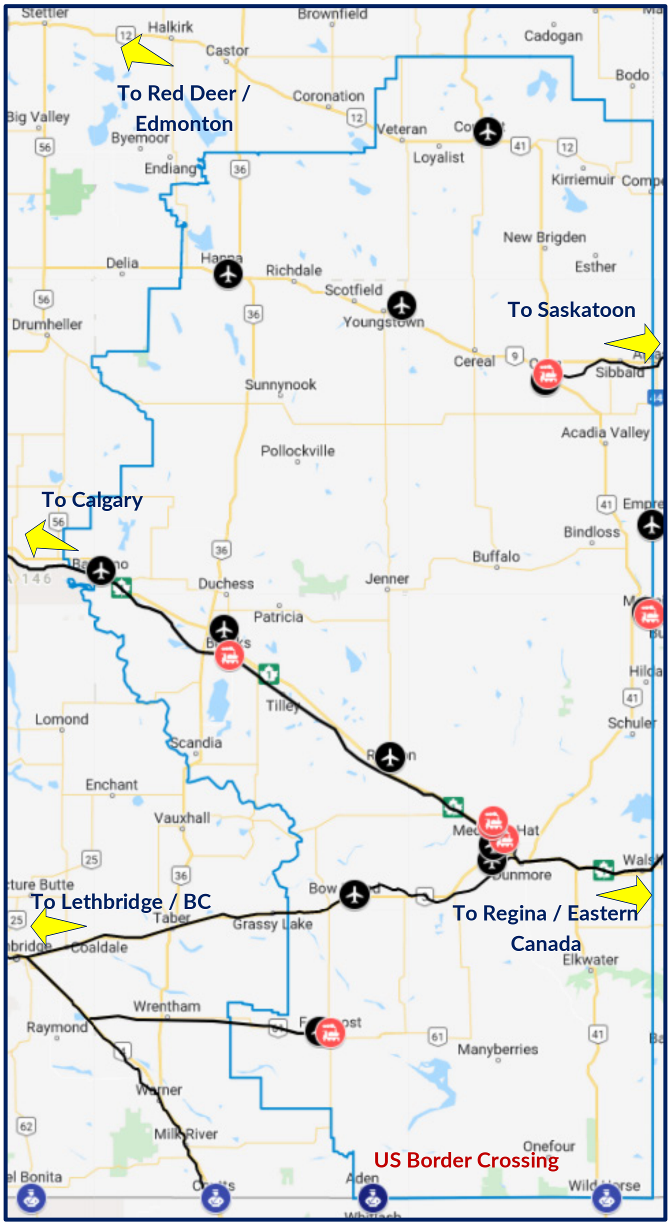


Figure 4.11 Road, Rail & Air Infrastructure in SE Alberta

SE Alberta is a major Hub within the trans-Canadian transportation corridor for road and rail with direct access to US border crossing locations.

The TransCanada Highway (Hwy 1) is Canada's longest national road extending from Vancouver, British Columbia to Sydney, Nova Scotia, on the mainland. The highway has long been a major transport route for delivery of goods and service to all ten provinces and to export markets in the United States or overseas. The highway runs through Medicine Hat and Brooks directly connecting with Calgary to the West and Regina, Saskatchewan to the East.

The Crowsnest Highway (Hwy 3) is another inter-provincial highway that provides for the direct connection between Medicine Hat and Hope, British Columbia. The highway starts in Medicine Hat and runs west through Lethbridge along the Canada / United States border and provides access to numerous border crossing points into the United States. Both Highways 1 & 3 are designated Core routes within the National Highway System.

Connecting the two east / west inter-provincial highways running north, is Highway 36. This is a designated highway in the Alberta High Load Corridor, which was established to accommodate oversized freight transport north to Edmonton and ultimately NW Alberta / NE British Columbia and to Fort MacMurray. Highway 9, another highway designated in the Alberta High Load Corridor, provides freight transport through the northern area of SE Alberta, providing a direct route between Saskatoon, Saskatchewan, and Calgary. Highway 12, at the northern edge of the SE Alberta region provides access to Red Deer in central Alberta and ultimately to Edmonton and northern Alberta. Highway 41, beginning at the Wild Horse US Border Crossing and running north through Medicine Hat, provides a north-south transportation corridor running parallel to the Saskatchewan border.

CP Rail's mainline runs parallel to the TransCanada highway through the region, providing rail freight access across North America. From Medicine Hat, the west leg provides connection to Calgary, the east leg connecting to Regina, Saskatchewan, and the south leg to Lethbridge. Additional rail service is provided by CN Rail, Great Sandhills Railway, and Forty Mile Rail. CN Rail provides service to the north portion of the region from a rail line that runs east from Oyen to Saskatoon, Saskatchewan, connecting with CN Rail's main line. Great Sandhills Railroad is a short-line railroad that provides service to the Empress-McNeill area along the Saskatchewan border with connection to the CP Rail mainline in Saskatchewan. Forty Mile Railway is a second short-line railroad that provides service to the Foremost area and connects to CP Rail's system to the west which allows for shipment south into the United States at the Coutts / Sweetgrass border crossing or north into the CP Rail mainline.

Twelve regional airports are in SE Alberta, along with the military airport at CFB Suffield. [87][88] Only the Medicine Hat Airport provides commercial service. The remaining airports provide private and charter access along with base of operations for aerial sprayer operations. Medicine Hat is also the location of Halo Air Ambulance helicopter service which covers southern Alberta and southwestern Saskatchewan.

4.3.2 Pipelines and Storage

Similar to the ground transportation infrastructure discussed in **Section 4.3.1**, SE Alberta has an extensive underground network of petroleum pipelines that provides both primary gathering as well as ultimate sales transport for the oil and gas industry.

The Nova Gas Transmission Limited (NGTL) natural gas pipeline network, shown in red in **Figure 4.12**, allows for the receipt and distribution of natural gas throughout Alberta and connects to interprovincial and international pipelines to deliver the commodity for sales across Canada and to the United States. The NGTL system is operated by TC Energy and is an open access network that is federally regulated by the Canadian Energy Regulator. The majority of natural gas within the NGTL system that is destined for sales outside of Alberta flows into SE Alberta, to then connect with either TC Energy operated Foothills Pipeline, that provides southern access either through British Columbia or Saskatchewan to US markets, or the trans-Canada Mainline at the Empress delivery point. Total natural gas receipts for February 2022 averaged 13.9 Bcf/d, with provincial deliveries of 5.7 Bcf/d, eastern exports through Empress / McNeill of 4.5 Bcf/d and western exports through British Columbia of 2.6 Bcf/d. [89][90] Additional transport options for natural gas production in SE Alberta exist via numerous private pipelines as well as the Campus Energy Partner's Suffield Transmission Pipeline, which further connects to the TC Energy Mainline and has capacity of 0.4 Bcf/d.

In addition to the natural gas pipeline infrastructure there is also significant natural gas storage located on the western edge of CFB Suffield. Rockpoint Gas Storage operates the 154 Bcf AECO Hub™ which is a combination of physical storage at Suffield and Countess and allows for more than 2.5 Bcf/day of natural gas transfer to or from storage as demand dictates.

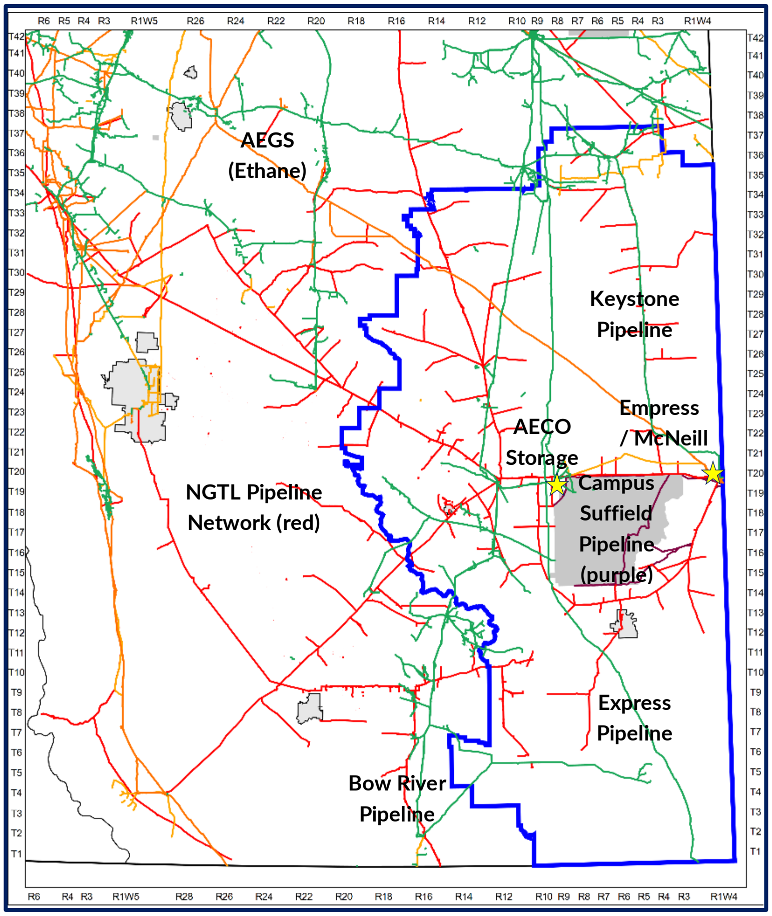


Figure 4.12 SE Alberta Major Pipeline & Storage Infrastructure

The region has numerous crude oil, natural gas liquids, and natural gas sales pipelines as well as natural gas storage for transmission and export.

The combination of the flow through the area and its interconnectivity to other North American markets and the presence of the significant storage helped create the NGX AECO C/NIT spot price and natural gas trading index. The NGX AECO C/NIT index is a virtual market hub that relates the cost of natural gas at this location with that of other market hubs across North America. Supply and demand forces ultimately determine the valuation of natural gas at this location reflecting the availability of supply and the cost of moving gas from one location to another in the differential pricing between the markets. The trading of natural gas may be in many differing forms, whether it is based on a daily spot price or future price, and whether it is a financial or physical commodity trade. In any situation, a balancing on the terms of the trade is required and the presence of the AECO Hub™ allows for sufficient natural gas commodity volume to allow for the balancing to occur at that location, and thus sets the nominal location for the traded price. The NGX AECO C/NIT hub is one of the most liquid energy markets in North America. The creation and existence of this hub should provide a model for an establishment of an Alberta based hydrogen index that would firm up financial expectations of the local value of hydrogen and its comparative value in export markets.

Three major crude oil export pipelines run through the region. [91][92][93] This includes the Keystone Pipeline system, with a capacity of 630,000 bbls/d, the Express Pipeline system, with a capacity of 310,000 bbls/d, and the Bow River Pipeline system with a capacity of 98,000 bbls/d. The Keystone XL Pipeline, an 830,000 bbls/d project, had a planned routing running parallel to the Keystone Pipeline within the region had it been completed. Additionally, the Alberta Ethane Gathering System delivers ethane from Empress to Joffre and Fort Saskatchewan with a capacity of 330,000 bbls/d.

4.3.3 Transmission and Distribution

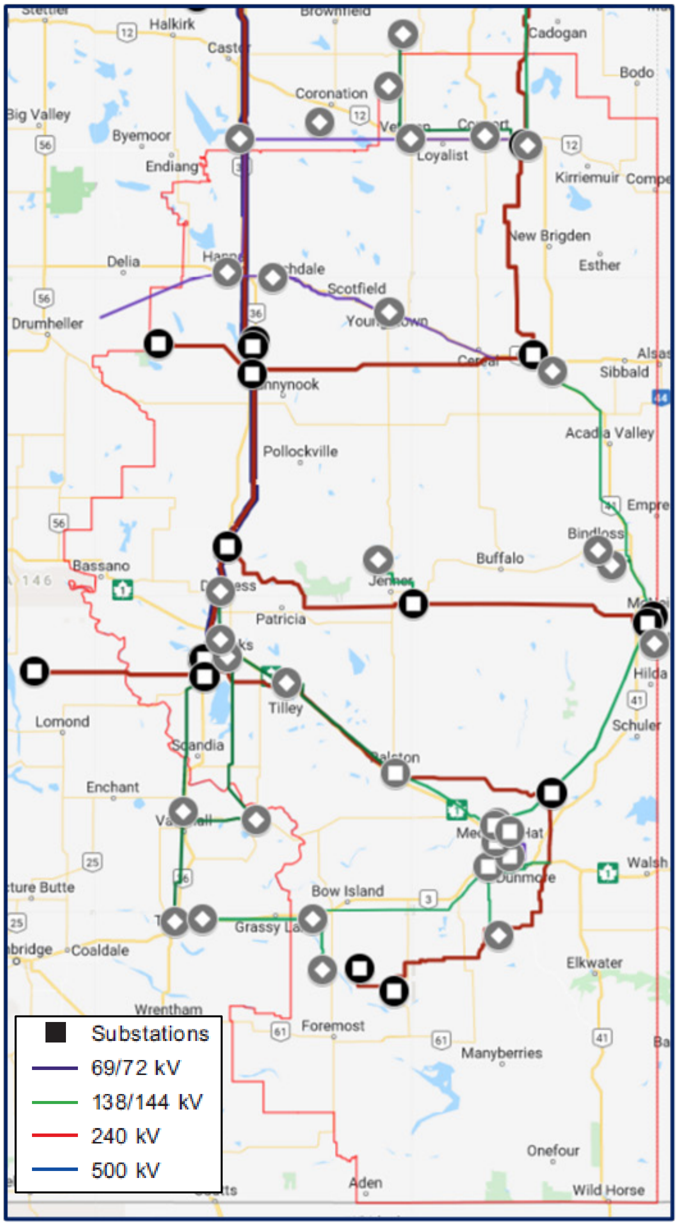


Figure 4.13 Power Transmission in SE Alberta

Area is serviced by a network of 240 kV transmission lines as well as connection to the 500 kV East Alberta Transmission Line to allows for export of power from the region to the Alberta Industrial Heartland.

SE Alberta electric power load is primarily serviced by a regional network of 138 and 240 kVA transmission lines, with the 240 kVA network connecting the main load centers with regional generation sources (**Figure 4.13**). Primary power flow direction of the 240 kVA network is west to Brooks and further relayed to Calgary. With increased generation in the region the 500 kVA East Alberta Transmission Line (EATL), which terminates near Brooks, was installed to accommodate increased renewable generation in the area by providing a means to flow excess power during peak renewable generation times north, ultimately to provide incremental power to the Alberta Industrial Heartland near Edmonton. The Alberta Electric System Operator (AESO) acknowledges that congestion will exist in the transmission lines in SE Alberta with the energizing of current active generation projects and is currently performing detailed planning studies to assess the congestion and develop the Southeast Transmission Reinforcement (SETR) project. [94] This project will be milestone based and thus will not proceed until physical congestion is proven out through the actual energizing of new generation, similar to the CETO project (Hanna area) which received Alberta Utility Commission (AUC) approval in 2021 and is currently under a re-affirmation study to confirm timing of construction, estimated to be complete between 2025 and 2027. This would imply timing of re-affirmation for SETR in or about 2023, and 2029 for installation of new 240 kVA infrastructure.

AESO manages and operates the provincial power grid. It is committed to equal access connection to the grid once project approval has been obtained through the AUC. AESO works concurrently with AltaLink, who is the largest electricity transmission provider in the province, and other industry partners to ensure current and future reliable power flow through the province to accommodate new and existing generation and load. In SE Alberta, there are four distribution facility owners; ATCO Electric, operating in the northern portion of the region – Special Areas 1, 2 and 3 and MD of Acadia, FortisAlberta, operating in the southern portion of the region – counties of Newell, Forty Mile and Cypress, Equs REA Ltd., which operates within the County of Forty Mile, and the City of Medicine Hat. [95]

4.4 Economic Drivers

As indicated above, the SE Alberta economy is diverse. From its early days of settlement and the realization of the value of coal and clay and the ability for the region to be an exporter of those products, the region has continued to embrace the potential of energy, its land, and the ability to be a preferred supplier of goods to the rest of the province, the country, and to international markets. Energy remains a backbone of the region's economy, whether for consumption, production / generation, or export. Large scale, mixed agriculture operations are prevalent throughout the region and supports a significant food processing sector. Industrial hubs have been established in key locations to utilize various combinations of local feedstock, energy source, or transportation corridor. National defense adds another important component to the region, as well, with the presence of CFB Suffield being centrally located north of Medicine Hat and requires various technical and physical support services.

4.4.1 Road Transportation

As described in **Section 4.3.1** above and shown in **Figure 4.14**, six main highways create a transportation network to facilitate movement of goods and services both from and through the region. In conjunction with these corridor highways, various businesses have been established along these routes to both support the transient traffic as well as the local resident and business needs.

To attempt to quantify bottom-up fuel consumption data for the road transport sector, three sources of data were sought. This included municipal fleets, commercial fleets and trucking companies, and retail and bulk fuel suppliers.

Figure 4.15 illustrates the locations of the various municipal public work yards as well as other municipal assets such as landfills, firehalls, and offices which contribute to fuel consumption. As can be seen in the figure, the numerous Public Work yards fall along the main corridor highways.

The municipal fleets can be divided into two categories: urban and rural. Due to the larger physical area being associated with rural fleets, these generally consume larger volumes of fuel, with a greater percentage being diesel. Rural municipal fleets have greater requirements for construction and road maintenance, as compared to urban municipal fleets, which has a greater percentage of urban support equipment.

The City of Medicine Hat has the largest urban fleet and is composed of the traditional heavy duty, light duty, and automobile equipment. Compressed Natural Gas (CNG) is being utilized for a portion of the city's

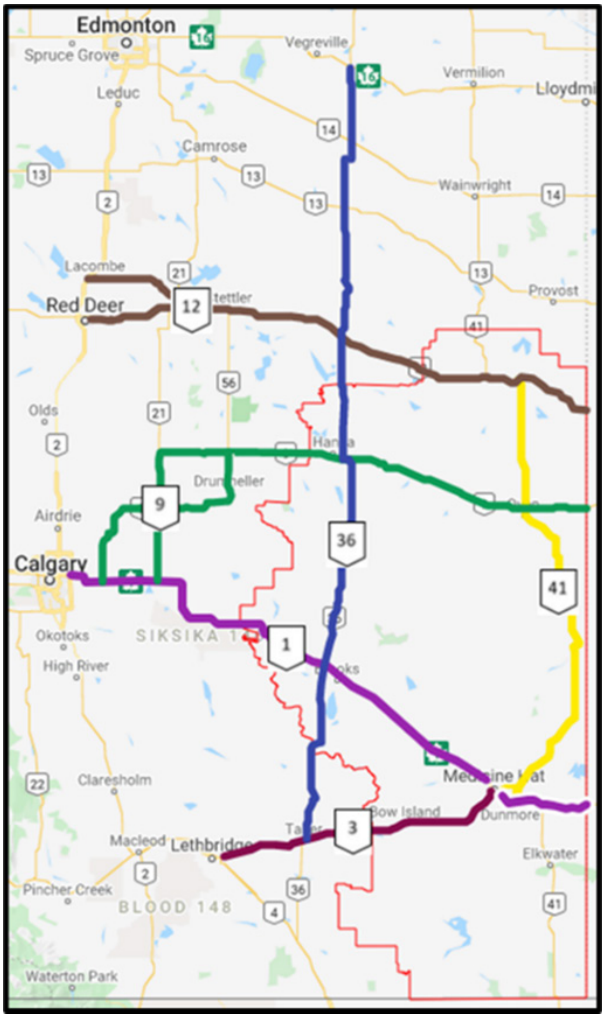


Figure 4.14 SE Alberta Road Transport Corridor

Six significant highways traverse the region including the TransCanada Highway (1), and Crowsnest Highway (3)

transit and garbage collection fleet, resulting in nearly equivalent consumption of diesel, gasoline and CNG for fuel requirements, on a diesel equivalency basis. Diesel and CNG consumption represent 67% of the fleets fuel use.

The Special Areas have the largest rural municipal fleet, located in Youngstown and though it too is composed of the traditional make-up of equipment, due to its rural nature and increased construction and road maintenance requirements, heavy duty equipment, and thus diesel consumption, make up a greater portion of the fleet's fuel use at 85%.

SE Alberta has a variety of transport companies within the region. These range from industry specific services, such as oilfield hauling and service, construction services, and livestock and agriculture product transport, in addition to the short haul and long-haul freight services. The size of companies varies from single truck operations to multi-truck fleets of various sizes. The location of identified trucks yards and depots can be seen in **Figure 4.16**. These companies are strategically located along the corridor highways with a greater concentration along Highway 1 at Medicine Hat and Brooks. In addition to the companies identified, it is expected that numerous other transport and service entities utilize the various highways, without identifiable depots, and would be transient traffic through the area.

To better understand the actual fuel consumption for transportation, the fueling stations have been identified within the SE Alberta Region (**Figure 4.17**). These fueling stations represent both retail and bulk fuel sales along with electric charging stations. As can be seen in **Table 4.1**, Suncor, Esso, and Flying J/Shell, have existing truck stop locations. South Country Co-op, UFA, and Blue Wave provide bulk card-lock services which would service the trucking sector but also substantial bulk fuels for agricultural requirements. 29 cardlock and truck stop locations have been identified within SE Alberta, with those locations shown in **Figure 4.18**. The location of these stations corresponds to major nodes along the transportation corridor.

The intersections of Highway 1 and 3 (Medicine Hat) as well as the intersection of Highway 1 and 36 (Brooks) represent the two heaviest travel locations within the region.

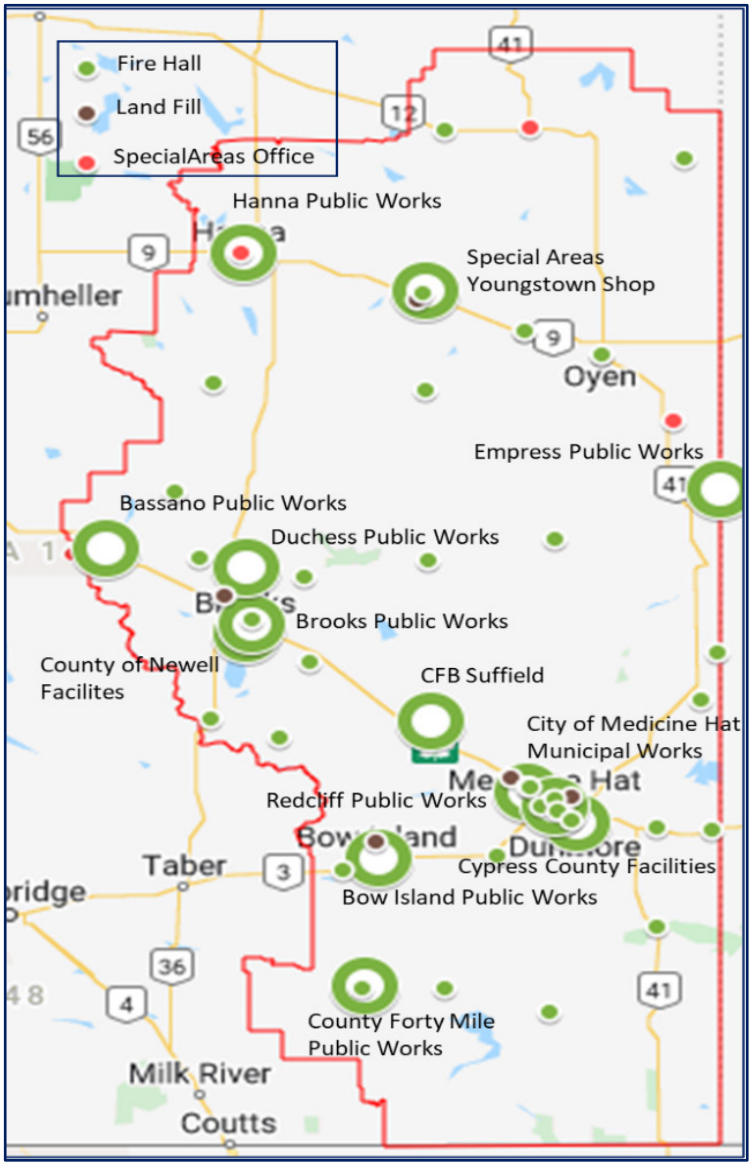


Figure 4.15 SE Alberta Municipal Fleet Location

Majority of municipal equipment located at municipal public work yards and firehalls. Rural municipal fleets, generally situated along major highways, are characterized by having a greater proportion of construction / road maintenance equipment and predominately diesel fueled.

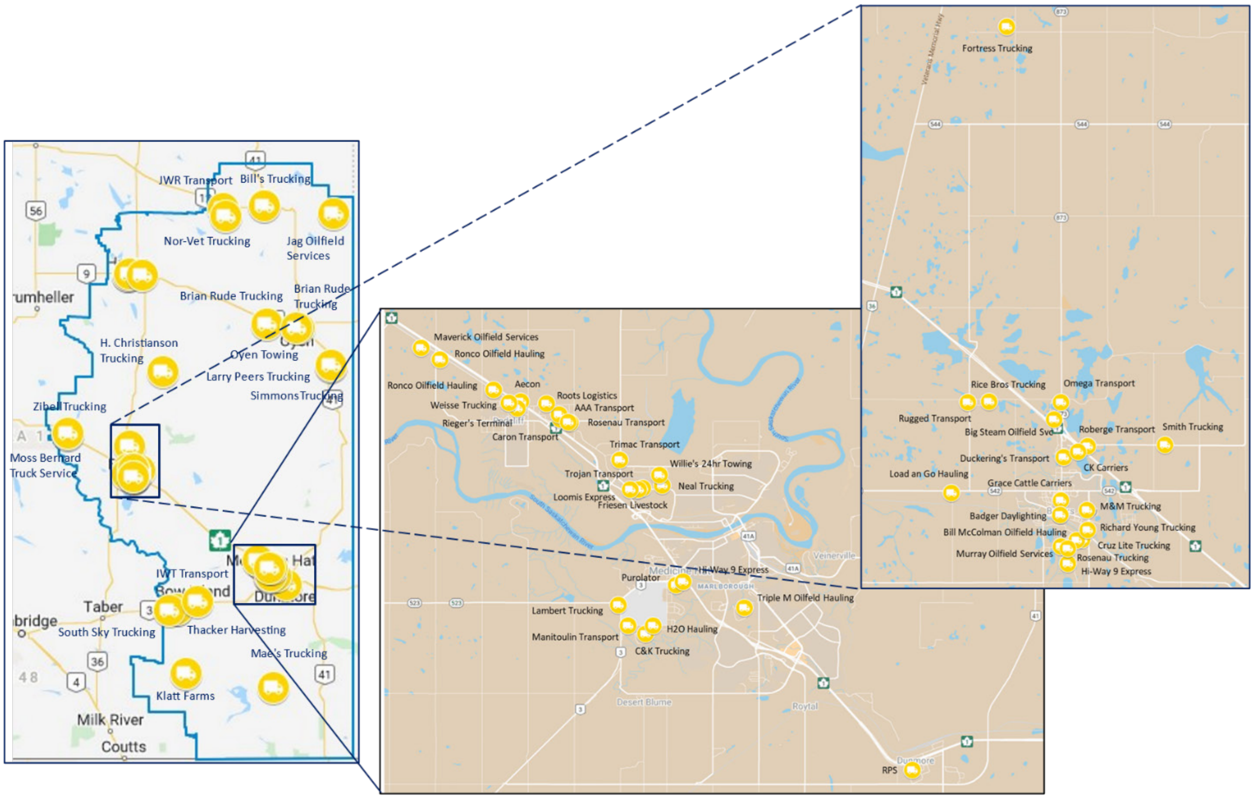


Figure 4.16 Trucking Company Yards and Depots – SE Alberta

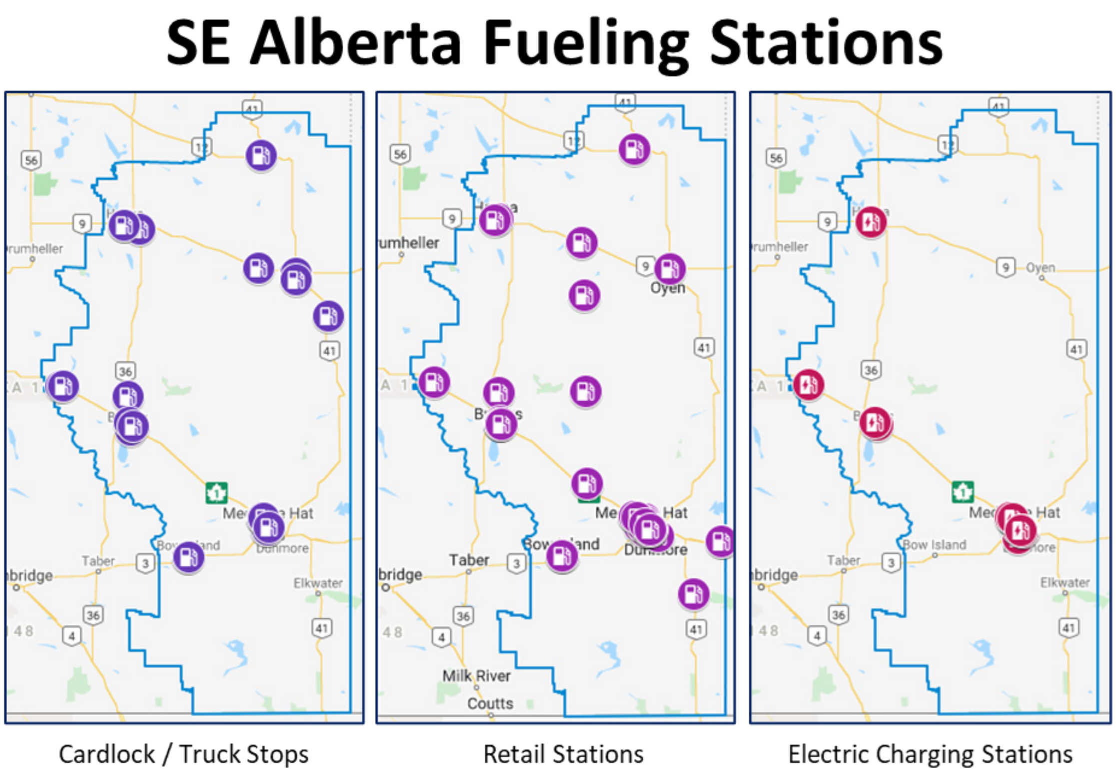


Figure 4.17 SE Alberta Fueling Stations

Table 4.1 SE Alberta Fuel Station Operators

Operator	Cardlock / Truck Stop	Retail	Electric Charging	CNG	TOTAL
South Country Co-op	9	8	1		18
Suncor (Petro-Canada	6	8	1		15
Esso	2	8			10
UFA	8				8
Flying J / Shell	3	5			8
Blue Wave	1				1
Husky		4			4
Tempo		4			4
Parkland (Fas Gas)		3			3
Safeway		3			3
GP Fuels		2			2
Gas King		2			2
Costco		1			1
Domo		1			1
Canco		1			1
Independent		3	6		9
Flo Charging			4		4
Tesla Supercharger			3		3
City of Medicine Hat				1	1
TOTAL	**29**	**53**	**15**	**1**	**98**

Fueling station operators as identified in Figure 4.18.

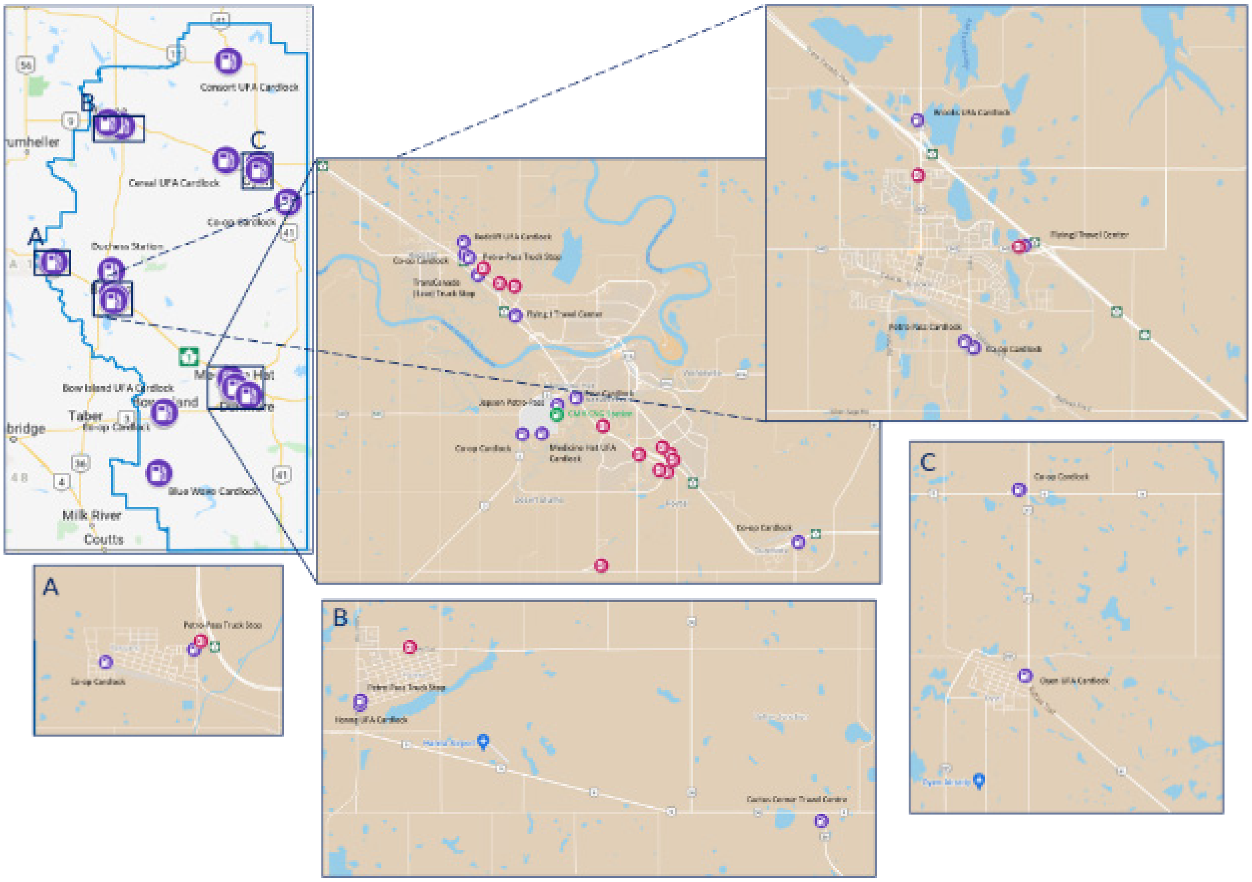


Figure 4.18 SE Alberta Fueling Station Locations

SE Alberta is serviced by a 29 Cardlock / Truck Stop locations predominately located along corridor highways, with most of the locations being along the TransCanada Highway, specifically within Medicine Hat and Brooks. Medicine Hat is serviced by 11 of the 15 electric charge stations.

4.4.2 Natural Gas Utility

Distribution of natural gas in SE Alberta for residential and commercial use is mainly carried out through a combination of eight rural Natural Gas Co-Ops, two private distributors and the City of Medicine Hat's owned distribution utility **(Table 4.2).** [96] Each of these entities have dedicated franchise areas, with APEX, ATCO and the City of Medicine Hat generally providing service to urban areas and the Gas Co-Ops being responsible for rural service.

Table 4.2 SE Alberta Nature Gas Utility Providers – Franchise Holders

Natural Gas Utility	Service Area
APEX Utilities	Hanna rural Bow Island southeast rural Medicine Hat Dunmore Irvine, Schuler, Hilda, misc. rural Cypress County
ATCO Gas	Brooks, Bassano, Duchess, Rosemary Bow Island northwest County of Forty Mile Consort, Monitor, Veteran, Oyen
Bow River Gas Co-Op Ltd.	southern Newell County
Chinook Gas Co-Op Ltd.	southern County of Forty Mile
City of Medicine Hat	Medicine Hat, Redcliff northeast rural Medicine Hat
Dinosaur Gas Co-Op Ltd.	Newell County
Dry Country Gas Co-Op Ltd.	Special Areas 3 & 4 Muncipal District of Acadia
East Central Gas Co-Op Ltd.	Special Areas 2
Forty Mile Gas Co-Op Ltd.	Cypress County County of Forty Mile
Pioneer Gas Co-Op Ltd.	western Newell County
Tirol Gas Co-Op Ltd.	southeast Newell County
Department of National Defense*	CFB Suffield

** CFB Suffield is not formally designated as a franchise area*

The majority of the distribution infrastructure is a combination of high- and low-pressure pipelines that distribute the natural gas from the primary natural gas sources to the end user. The majority of the natural gas is sourced from the NGTL pipeline network. **Figure 4.19** shows the SE Alberta region, the NGTL pipeline network (red pipelines) and the high-pressure distribution lines for the various natural gas utilities along with their field gate meter stations, which measure the natural gas being withdrawn from NGTL or the location of natural gas being distributed into extensive low pressure delivery lines (the extensive low pressure pipeline system is not shown on map).

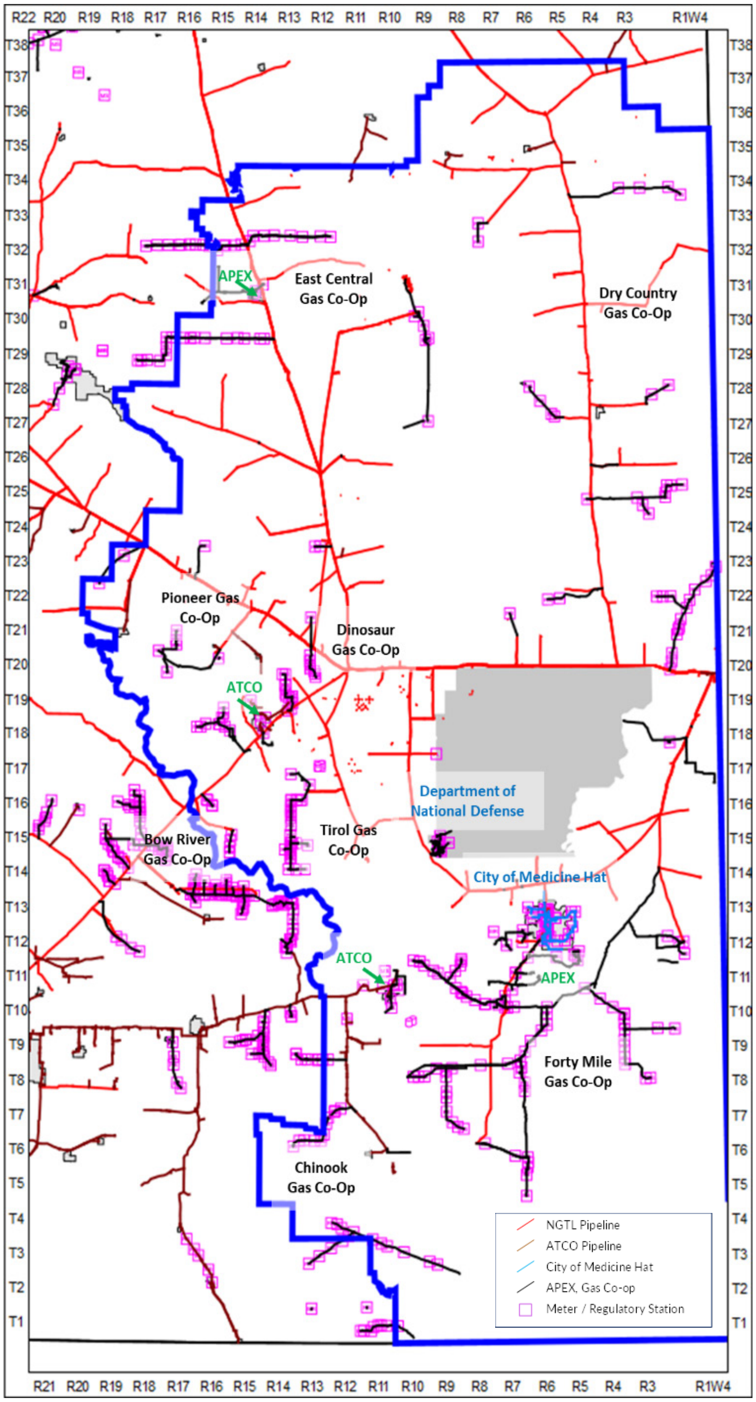


Figure 4.19 SE Alberta Natural Gas Utility Distribution Lines and Metering Gates

Industrial customers can be connected to these various distributors but dependent on their volume and pressure requirements, the low pressure deliver systems may not provide for sufficient deliver conditions and result in these entities directly connecting to the NGTL pipeline network at a dedicated meter station or shared meter station with other delivery service.

Steel or Aluminum pipe is predominately used for the higher-pressure distribution backbone pipelines but generally represents less than 10% of the overall distribution network. Poly Ethelene pipe is generally used for the low-pressure delivery, less than 650 kPa, to the final residential or commercial customer.

Cumulatively throughout SE Alberta, there is greater than 14,000 km of low-pressure distribution pipe installed, with the vast majority being utilized for rural service. There is also an additional 700 km of steel and aluminum pipe installed and utilized for higher pressure distribution. The majority of the pipe, 70% to 85% dependent on the utility provider, has been installed post 1980. However, there are portions of the distribution systems that date back to 1950 or earlier. The variation in pipeline material, installation procedures, and the span of pipe vintages all pose challenges to determining operability and compatibility for hydrogen service, in addition to determining the compatibility of the end user appliances.

4.4.3 Electrical Generation

As of January 1, 2022, SE Alberta had **1,718 MW** of total generation capacity. [97] An additional **1,345 MW** is under construction and scheduled to be energized within 2022 or 2023 bringing the total electrical generation capacity of the region to **3,063 MW**. Existing generation projects are listed in **Table 4.3**, with the project locations shown in **Figure 4.20**. SE Alberta is a net exporter of electricity.

Table 4.3 Existing SE Alberta Generation [Jan 1, 2022]

	Capacity MW	Operator
Gas Fired Steam		
Sheerness 1	400	Heartland Generation
Sheerness 2	400	Heartland Generation
Combined Cycle		
MH 1	255	City of Medicine Hat
Simple Cycle		
Lethbridge Burdett	7	Signalta
Ralston NAT 1	20	Berkshire Hathaway Energy Canada
Solar		
Brook Solar	15	Elemental Energy
Burdett	11	BluEarth Renewables
Burdett	20	BluEarth Renewables
Suffield	23	BluEarth Renewables
Jenner	23	BluEarth Renewables
Yellow Lake	19	BluEarth Renewables
Wind		
Rattlesnake Ridge	130	Berkshire Hathaway Energy Canada
Whitla 1 (Bow Island)	202	Capital Power
Whitla 2 (Foremost)	151	Capital Power
Waste Heat Recovery		
CanCarb	42	CanCarb Limited
TOTAL	**1,718**	

Current generation is composed of 35% renewable capacity and 63% being natural gas fired. After completion of current generation projects under construction, renewable generation will account for 62% of total generation capacity in the region. Wind projects account for 93% of the new generation capacity under construction.

Off-grid generation dedicated to industrial operations and microgeneration, <5MW capacity, are not included with the total generation capacity of the region and would represent incremental generation that would satisfy isolated loads or supplement existing generation. Diesel or natural gas consumption for these isolated generators would represent incremental hydrogen transition potential to what has been determined within this report.

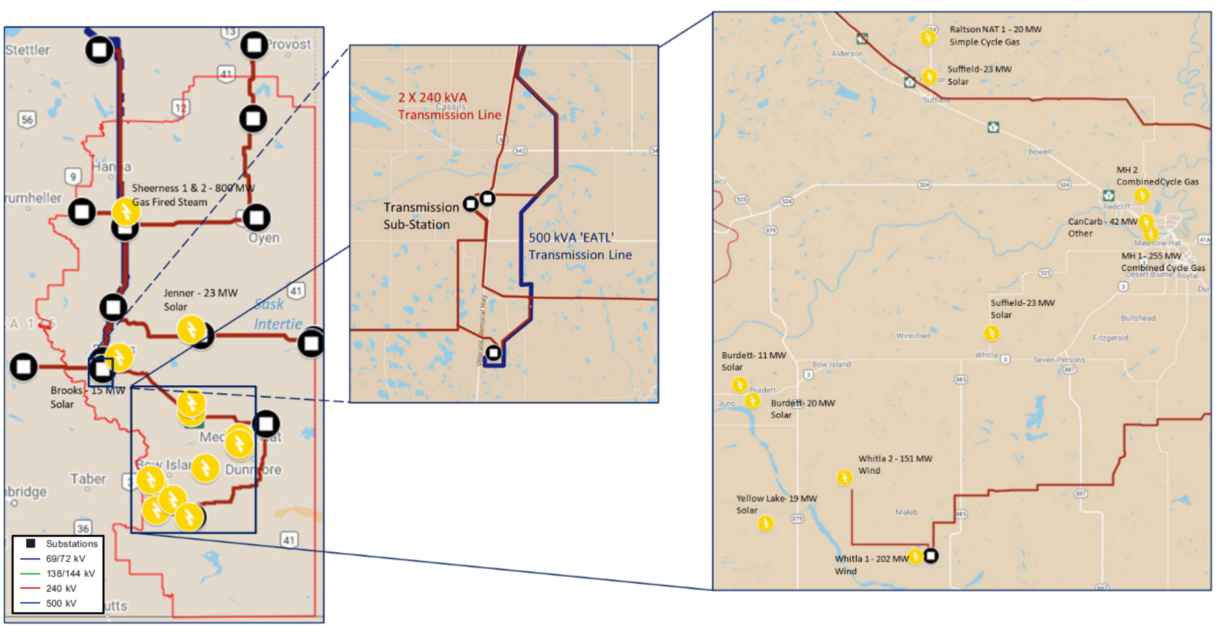


Figure 4.20 Existing SE Alberta Electrical Generation [Jan 1, 2022]

4.4.4 Industry

Four main industrial hubs exist within SE Alberta. These are located at Medicine Hat, Brooks, Hanna, and the Empress / McNeill site. This is in addition to the numerous stand alone or small cluster industrial sites in the region dedicated to the energy sector and agriculture. The identified major industrial locations are shown in **Figure 4.21**. with the greatest industrial cluster existing in NW Medicine Hat / Redcliff area.

Within the Medicine Hat Industrial Complex, existing hydrogen industry is present. CF Industries, Methanex, and CanCarb all generate hydrogen as part of their processes to produce their main products; ammonia/urea, methanol, and carbon black. All of these products utilize the abundance of natural gas and are situated in an area for easy transport of their products by rail to their export sales markets.

Northeast of Medicine Hat is the Empress Fractionation Complex, located at McNeil. This complex represents the largest natural gas processing center in North America. [98] The plants utilize the large volume of natural gas from the NGTL pipeline system to further process and extract nature gas liquids such as ethane and propane. Plains Midstream operates two of the facilities which includes three plants: Empress I (2.5 Bcf/d of natural gas processing capacity), Empress II (2.6 Bcf/d) and Empress V (1.1 Bcf/d), as well as the Empress 6 facility with one plant (2.4 Bcf/d). Pembina Pipelines, operates one Empress facility with a capacity of 1.2 Bcf/d. In 2019, the Empress plants processed 4.3 Bcf/d of natural gas, separating out 132,000 barrels per day of natural gas liquids, including 68,000 b/d of ethane gas, from 4.1 Bcf/d of dry natural gas. Products from this facility are transported to their various end markets via natural gas, ethane, propane, and diluent pipelines, as well as shipment by rail.

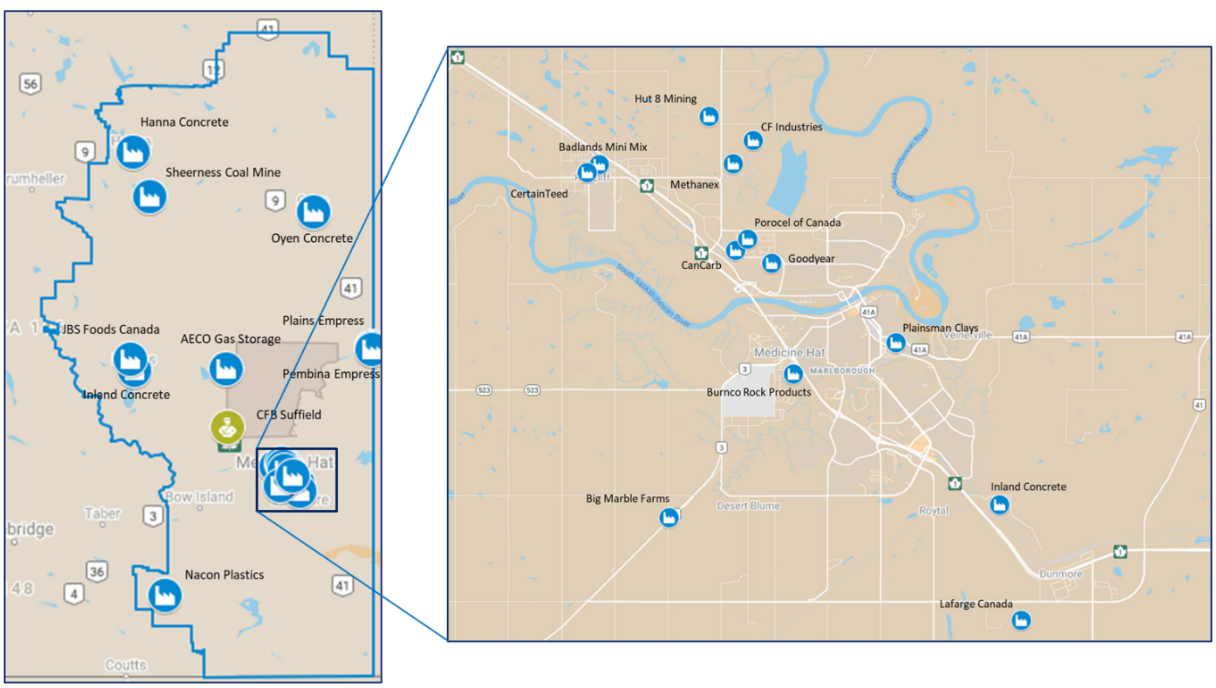


Figure 4.21 Industrial Locations within SE Alberta

In the Hanna region, historical coal deposits allowed for the mining of the fuel source to fire two 400MW Sheerness power plants. These plants were a major contributor to Alberta's base generation and continue to operate today. However, Heartland Generation undertook the conversion of the coal plants to natural gas, which has been completed as of the end of 2021. This conversion has resulted in the active abandonment of the Sheerness coal mine and reduction of CO_2 emissions by 50%. [99]

JBS Canada operates one of the largest beef processing facilities in Canada and is located in Brooks. JBS processes 4,200 head of cattle daily and provides more than 10.4 million 4 oz serving portions daily. [100] In addition to large transport logistics for both supply and sales, the facility is a large consumer of energy for boiler, processing equipment and refrigeration.

Other business exists in the region focusing specifically on support for the oil and gas and agricultural sectors as well as for providing other necessary services for the region, such as cement, building supplies, etc.

4.4.5 Oil & Gas

SE Alberta oil & gas industry had its roots established at the turn of the 20th century with the discovery of shallow natural gas and its quick recognition as an energy source to replace coal and coal gas. The City of Medicine Hat made the bold decision to physically own natural gas assets and helped to create the energy identity and economic driver for both its residents and the entire SE Alberta region. **Figure 4.22** illustrates the density of wells and major sales pipeline infrastructure that exists across the region. In excess of two hundred different companies currently operate wells, facilities, and pipelines in SE Alberta.

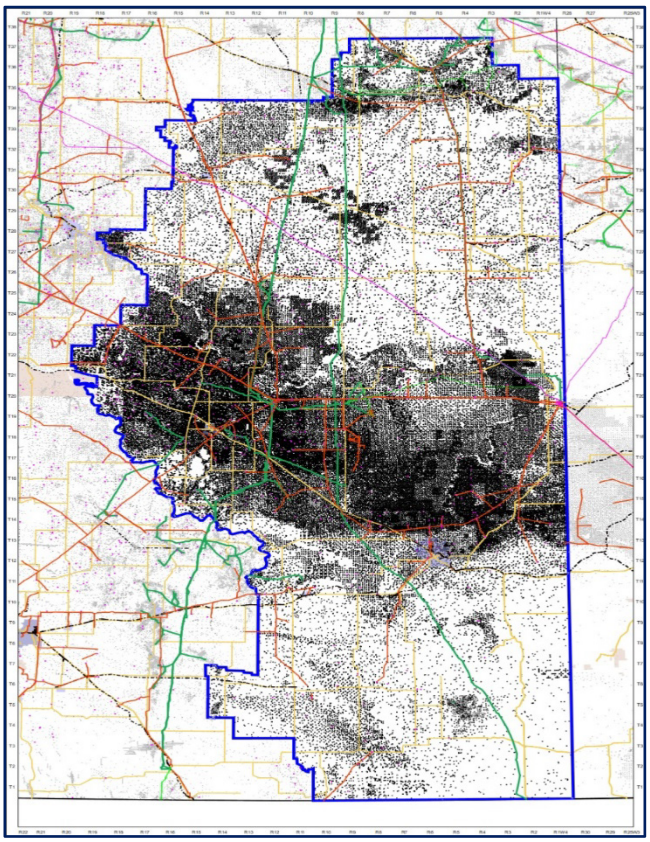


Figure 4.22 Oil & Gas Development in SE Alberta
High density of wells in central portion of region is representative of shallow natural gas wells. Oil and natural gas development is prevalent throughout region.

Within SE Alberta, there has been nearly 100,000 wells drilled to access various horizons ranging from 150 m to 2,500 m, exploring for both oil and gas production. This represents close to 30% of the 330,000 wells drilled within Alberta. Currently there are close to 65,000 active operating wells in the region. [101]

Along with extensive pipeline networks connecting each of the wells, there are numerous facilities that are required to measure, treat, and ultimately deliver both oil and gas to sales markets. **Table 4.4** is a detailed listing of the nearly 2,500 active facilities by their type along with the categorization of the various active wells in the region. **Figure 4.23** illustrates the spread of the various active facilities across the entire region.

Table 4.4 SE Alberta Oil & Gas Infrastructure Statistics

Oil & Gas Wells & Infrastructure			
Operating Infrastructure		Operating Wells	64,763
Compressors	446	*Gas*	53,160
Batteries	1,895	*Oil*	8,030
Gas Plants	50	*Observation / Standing*	1,709
Pump Stations	64	*Water Injection*	834
Custom Treating	5	*Water Source*	114
Waste Disposal	7	*Water / Waste Disposal*	329
		Farm Gas / Water	519
		Gas Storage	66
		Acid Gas Disposal	2

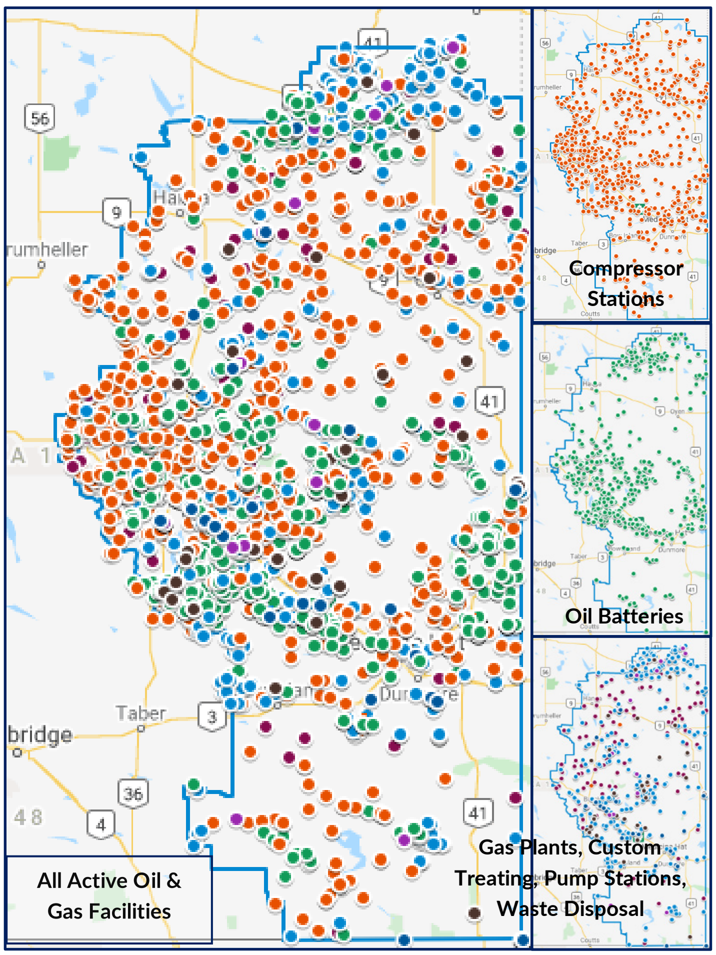


Figure 4.23 SE Alberta Oil & Gas Facilities

Canadian Natural Resources Ltd. Is the largest operator in SE Alberta, operating 25% of the wells. The top eight oil and gas operators of wells in the region are:

- Canadian Natural Resources Ltd.,
- Torxen Energy Ltd.,
- International Petroleum Corp.,
- Canlin Energy Corporation,
- Pine Cliff Energy Ltd.,
- Cor4 Oil Corp.,
- City of Medicine Hat, and
- Karve Energy Inc.

In addition to the upstream operators, other companies are active in the sector providing mid-stream processing services, pipeline transportation, and down-stream operations. This would include such companies as:

- Tervita Corp - waste disposal services,
- Altagas Ltd. – processing facilities,
- Campus Energy – facilities and pipelines,
- Enbridge – Express pipeline,
- Inter Pipeline – Bow River pipeline,
- Pembina Pipeline - fractionation,
- Plains Midstream Canada - fractionation,
- Rockpoint Gas Storage, and
- TC Energy – oil and gas pipelines.

As indicated in **Table 4.4**, in addition to active oil and gas companies, numerous farming operations are owner and operators of over

500 shallow wells utilized for sources of water or natural gas fuel source for their agricultural operations.

4.4.6 Agriculture

As indicated in **Section 4.2**, agriculture plays a major role within SE Alberta and is highlighted by having farm sizes 50% larger than average farms within Alberta. **Figure 4.24** shows the locations of selected large operations, which vary from dedicated crop to dedicated livestock operations, and a large component of mixed farming. [102][103][104][105]

With greater than 3,100 farms within the region, farming operations exist throughout the area. However, by viewing the significant larger operations, it becomes evident that there is a higher concentration of large-scale operations located in the County of Newell and in the County of Forty Mile. **Figure 4.25** shows the weighting between crop farming and cattle as it applies to the various areas. This suggests a greater focus on livestock within the County of Newell and Special Areas 2 and a greater focus on crops in the County of Forty Mile and Special Areas 3. Other areas demonstrate an equal split between crop and livestock. In addition to cattle and dairy operations, the region is also diverse in other livestock, which includes poultry, hogs, sheep, and turkey.

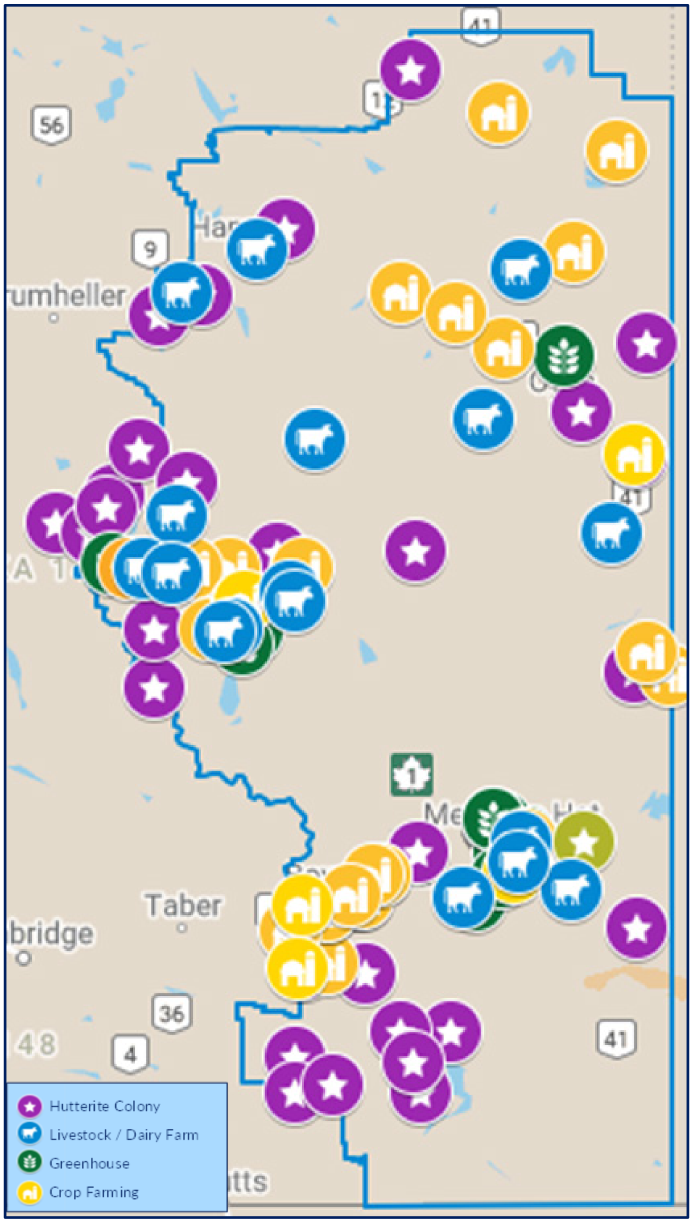


Figure 4.24 Major Agriculture Operations of SE Alberta

Selected large scale agricultural operations ranging from independent livestock or crop farms, incorporated mixed farming operations, diverse Hutterite operations, and greenhouses.

SE Alberta is also home to 35 different Greenhouse operations, which represents 18% of the greenhouses in Alberta but 41% of the actual greenhouse area at 667,522 m^2. [106] The greatest concentration of these greenhouses is in Redcliff thus the name of Greenhouse Capital of the Prairies (**Figure 4.26**). Located south of Medicine Hat, Big Marble Greenhouse is the largest greenhouse in the region and represents 40%

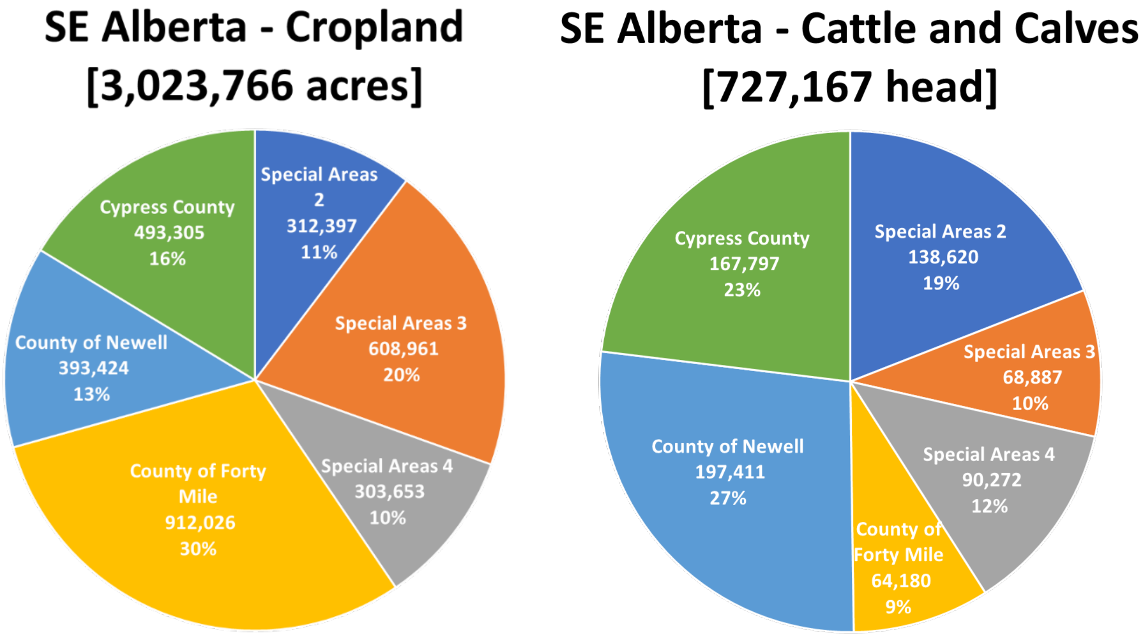


Figure 4.25 Crop and Cattle Split by Area within SE Alberta

Comparison between municipal areas based on total amount of cropland farmed and cattle raised to indicate each areas relative focus to crop or livestock operations.

of the industry's operating area within SE Alberta and is the single largest energy consumer and emitter in the sector. As per the Climate Change Canada GHGRP for 2019, Big Marble reported emissions of 13.7kt CO_2. This is likely attributable to a 12 MW natural gas fired Cogen (not grid connected and thus not included

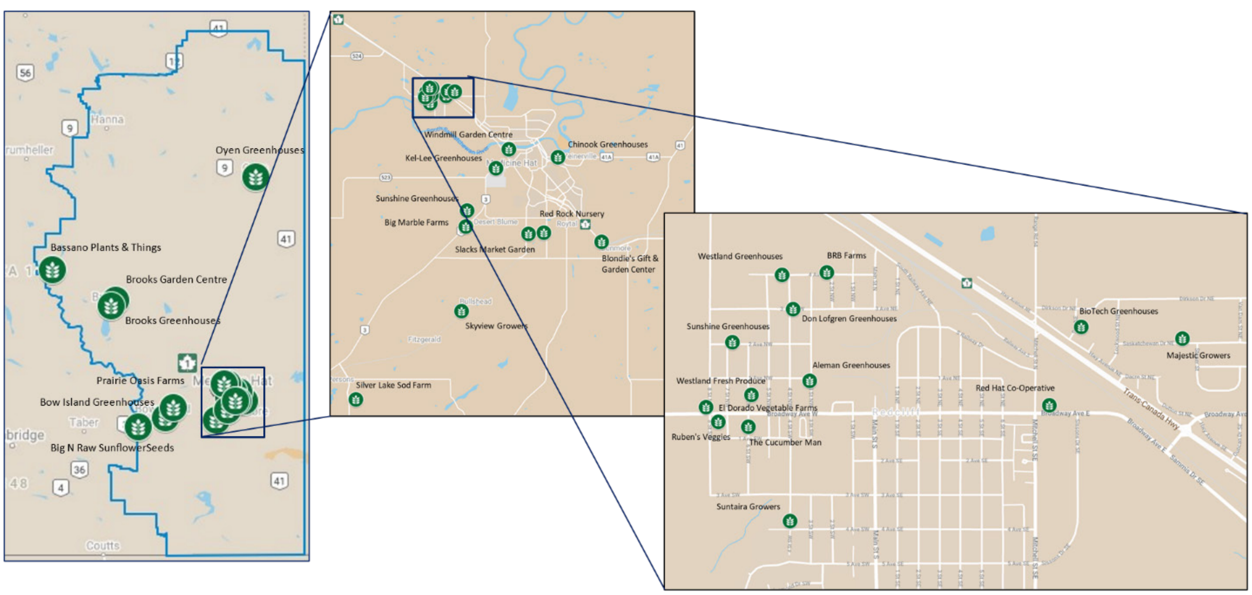


Figure 4.26 Greenhouses in SE Alberta

as part of the total region's power generation total) that is part of the company's operations for supply of both electricity and heat and could have the potential for utilization of hydrogen to achieve CO_2 emission reductions.

SE Alberta greenhouses are focused on vegetable crops and represents approximately 80% of the vegetable greenhouse area of the province, as compared to bedding plants and seedlings which are more prevalent in other regions of Alberta (**Figure 4.27**). This results a higher energy consumption from SE Alberta greenhouses as vegetable crops are more energy intensive.

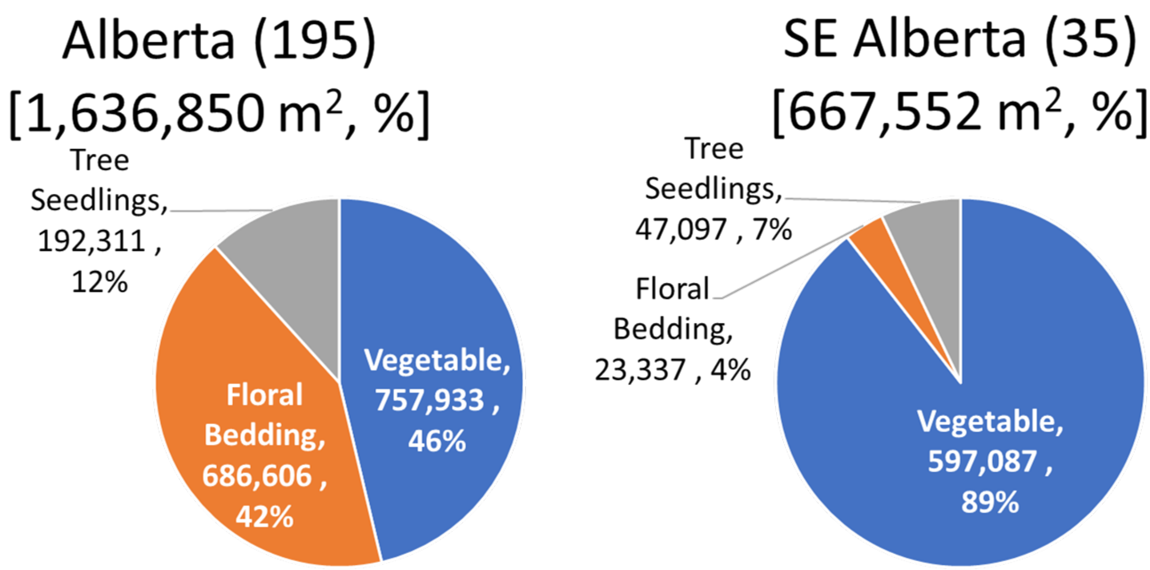


Figure 4.27 Greenhouse Crop Area

4.4.7 National Defense

In the middle of the region, located approximately 50 km west of Medicine Hat (location can be viewed in **Figure 4.19**). [107] CFB Suffield is host to the largest military training area in Canada at 2,700 km^2. CFB Suffield falls under the command of the 3rd Canadian Division of the Canadian Army and is also home to the British Army Training Unit Suffield (BATUS) live fire training establishment and the DRDC-SRC. The Department of Nation Defense (DND) provides the operational and logistic oversight for the base residents in conjunction with the neighbouring communities of Rolston and Suffield. The economic spin-off from the base has been realized in the community, with the establishment of many civilian businesses that provide complimentary service for both physical operations of the base and DRDC-SRC. DRDC-SRC offers expertise focused on explosives threats and blast effects, public safety, novel energetic materials, autonomous intelligent systems and is a Level 3 Biological laboratory, that also conducts

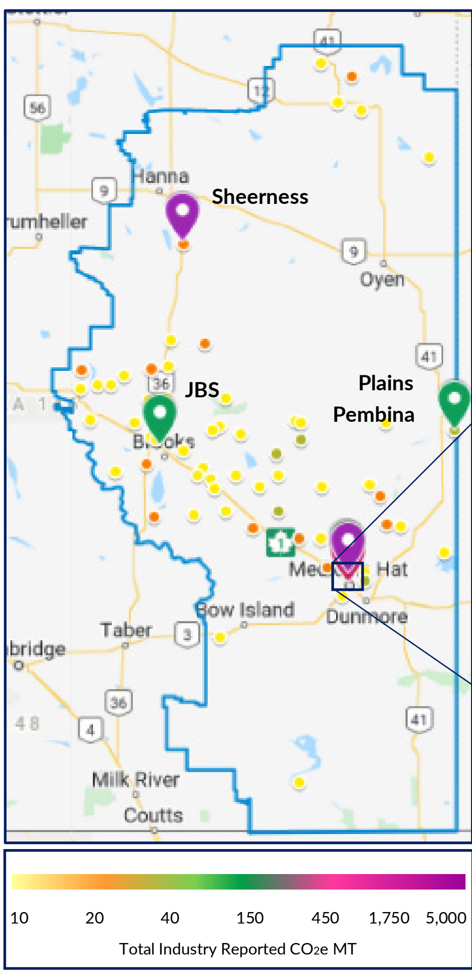
SOURCE: Canadian Forces Base Suffield (Canada.ca/en/army/corporate/3-canadian-division/Canadian-forces-base-suffield.html)

Chemical and Radiological research. In addition to providing research services to military and military related organizations, DRDC-SRC offers live agent training to both military and civilian first responder communities.

4.5 Emissions

Within the SE Alberta region, 72 entities reported emissions under the Environment and Climate Change Canada GHGRP in 2019 (**Figure 4.28**). [108][109][110][111][112] The total emissions reported for the region was 9.6 Mt of CO_2e, with only ten of the reporting entities reporting greater than 50 kt of emissions and cumulatively accounting for 89% of the emissions (**Figure 4.29**). The largest emitter for this time period was the Sheerness Generating Station at 4.8 Mt representing 50% of the total emissions for SE Alberta. However, since 2019, the generating facility has been converted from coal fired to natural gas fired and it is estimated that the annual emissions from the facility have been reduced by 50%, which would reduce the facilities emissions to 2.4 Mt and the emissions for the entire SE Alberta region by 25% to 7.2 Mt. Of the ten emitters with greater than 50 kt of emissions, the next largest emitters are:

- Canadian Fertilizers Limited at 1.8 Mt,
- City of Medicine Hat (four facilities) at 0.8 Mt,
- Methanex Corporation 0.5 Mt,
- Plains Midstream Canada ULC (two facilities) at 0.3 Mt,
- JBS Canada at 0.2 Mt,
- Cancarb Ltd. at 0.2 Mt, and
- Pembina Pipeline Corporation at 0.1 Mt.



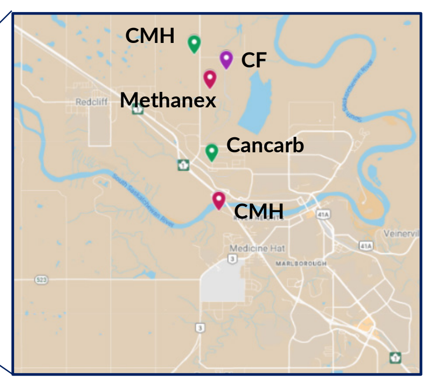


Figure 4.28 SE Alberta 2019 GHGRP CO_2e Emissions

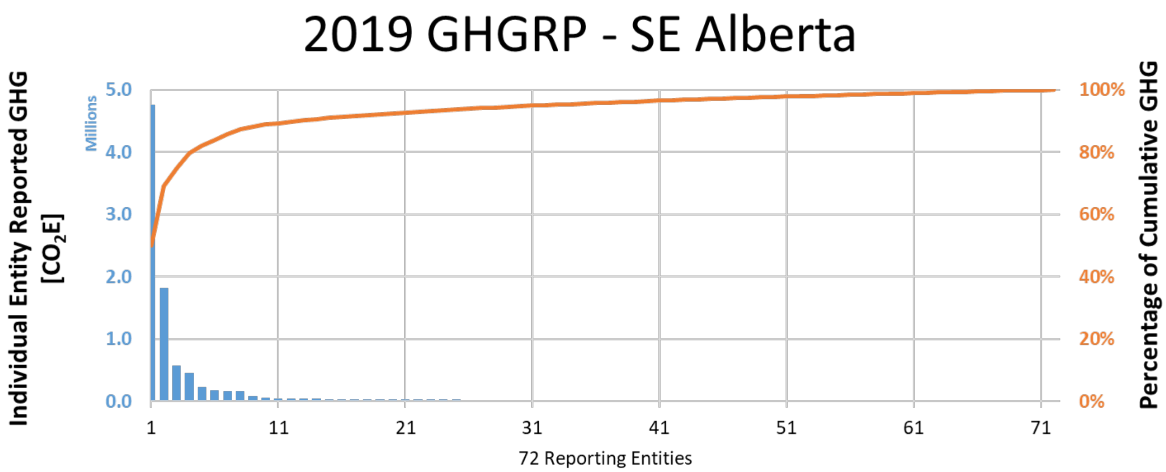


Figure 4.29 2019 GHGRP Emissions by Entity – SE Alberta

Of 72 reporting entities, 10 recorded >50kt of CO_2e emissions and account for 89% of the annual regional emissions. All 72 entities represented on graph.

As illustrated in **Figure 4.30**, Electrical Generation accounted for 58% of the total reported emissions in SE Alberta. The next largest components were Industrial at 26% and Oil & Gas – Upstream at 9% of the total emissions. However, Oil & Gas – Upstream is an accumulation of fifty-three reporting entities with none of the facilities having greater than 50 kt of emissions. Agriculture emissions are from Big Marble Greenhouse and JBS Canada processor.

In SE Alberta, 17 projects have been approved under the Alberta Emission Offset Registry (**Figure 4.31**) with a total lifetime reduction in CO_2e emissions of 8.0 Mt. [113][114][115][116] These projects include existing CO_2 sequestration, renewable energy projects, landfill composting, and methane reduction through pneumatic devices.

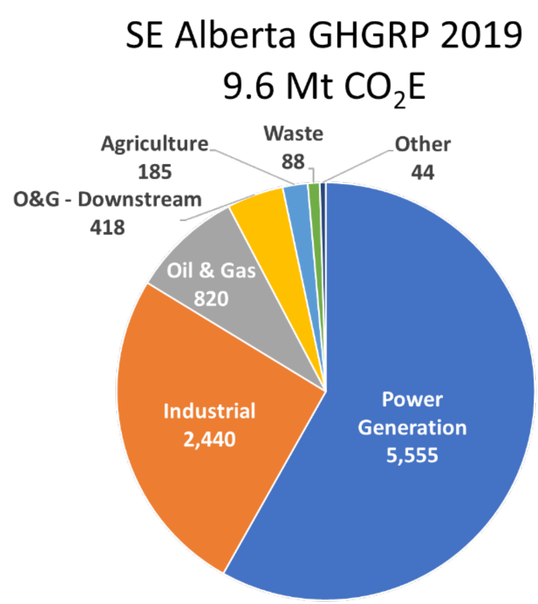


Figure 4.30 2019 GHGRP Emissions – SE Alberta

Power Generation represented 58% of the total emissions reported for SE Alberta in 2019. Industrial emissions represented 26% and Oil & Gas 13%. Conversion of Sheerness power generation to natural gas is anticipated to lower overall emissions in the region by 25% to 7.2 Mt CO_2e

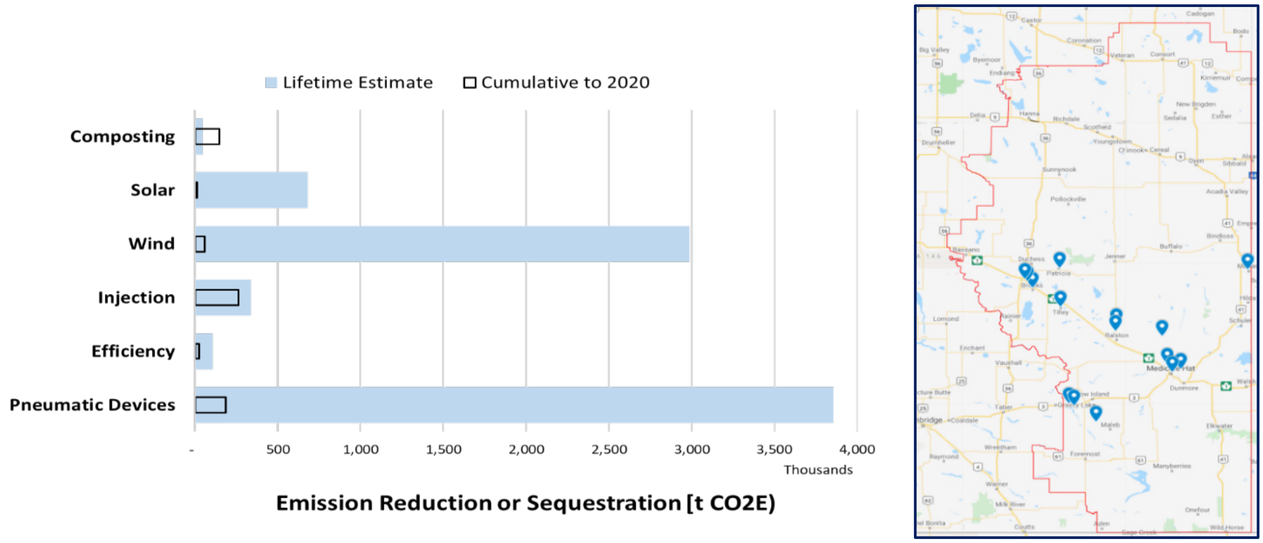


Figure 4.31 SE Alberta Approved Alberta Emission Offset Registry
Location of ERA approved carbon offset credit registry projects.

4.6 Renewables and Biofuels

The Southern Alberta Energy from Waste Association (SAEWA) is a non-profit entity set up as a coalition of 64 Municipal entities and waste management jurisdictions in southern Alberta (**Figure 4.32**) which includes the County of Newell and Special Areas 2, 3, and 4. The association is committed to the research and implementation of the mission *"... to develop an energy-from-waste facility for the treatment of solid waste with the value added benefits from development of energy-from-waste. This process will significantly **reduce** the Alberta environmental footprint through the offset of GHG credits and has the potential to generate positive socio-economics. The integrative business plan is in the process of being finalized and will capture opportunities for clean energy development. This project will steward significant positive economic gains through the deployment of the services of over 500 contractors in the construction and procurement phase, and 50 full time operational positions will be employed upon final commissioning of the energy-from-waste facility." [117]*

SAEWA has been successful in being awarded $149,164 through the Alberta Community Partnership Intermunicipal Collaboration Fund and is moving forward with development of a 300,000 t energy-from-waste facility at the County of Newell landfill that is expected to generate approximately 50 MW of electricity and 1 Mt of process steam. Three consortia groups are currently being reviewed for participation and kick-off of the project.

Other waste to energy projects has been proposed for the region but have been put on hold with no specified timing for re-initiation. [118]

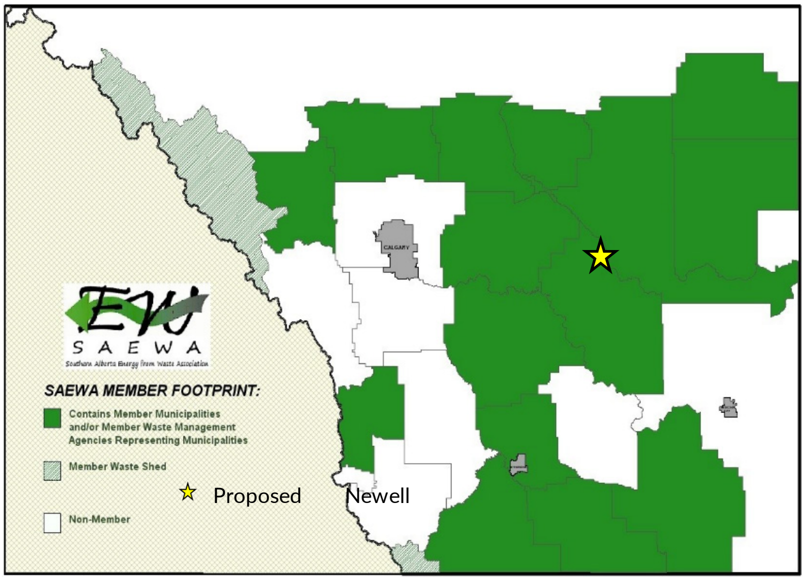


Figure 4.32 Southern Alberta Energy from Waste Association

SOURCE: SEAWA (saewa.ca)

In addition to the Newell Regional landfill, there are four other landfill sites within the SE Alberta region (**Figure 4.33**). In additional to Newell, the landfill sites in Redcliff and Medicine Hat have undertaken evaluation for the potential of renewable natural gas. Though it was determined that none of the sites were viable at the time, all possess potential for renewable natural gas in the future.

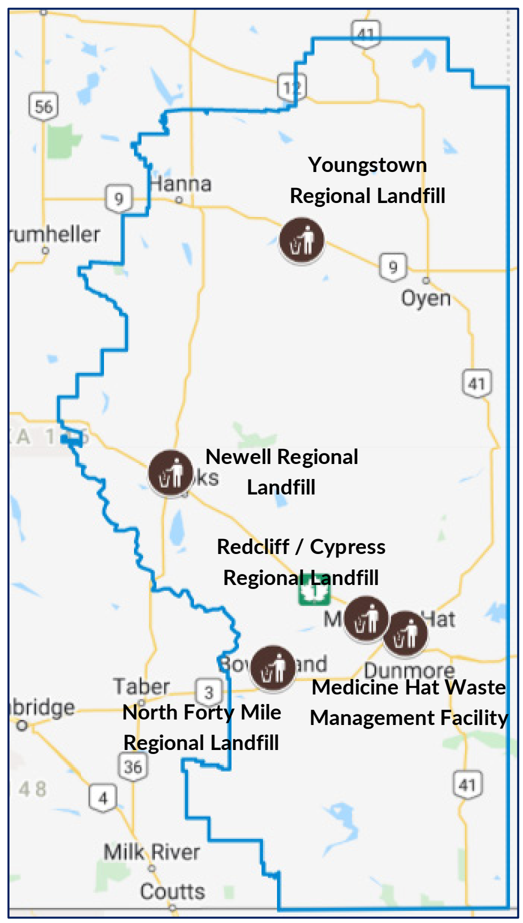


Figure 4.33 SE Alberta Landfills

4.7 Water and Irrigation

Water governance in Alberta is based on the 1999 Water Act and the Water for Life Strategy adopted in 2003 and reaffirmed in 2009. [119][120][121][122][123][124][125] The Water Act prescribes how water licenses are to be issued, how usage is to be recorded and reported, as well as the process for license transfers and allocations. The Water Act also prohibits movement of water across watershed boundaries. The Water for Life Strategy established three key priorities by which Alberta utilizes to manage the significant pressures on the provincial water resource:

1. Albertans will be assured of safe, secure drinking water,
2. Albertans will be assured that the province's aquatic ecosystems are maintained and protected, and
3. Albertans will be assured that the water is managed effectively to support sustainable economy development

The Water for Life Strategy also established three key directions:

1. Knowledge and research: to improve scientific understanding and informing of interested parties,
2. Partnerships: shared responsibilities amongst citizens, communities, industries, and government to engage partnerships with the Alberta Water Council, watershed planning and advisory councils and watershed stewardship groups, and
3. Water conservation: understanding of water scarcity and shared responsibility for efficiency and conservation.

These priorities and directives, lead to strategy action items to address regional drinking water and wastewater issues, to assess aquatic ecosystem health, to establish water monitoring, evaluation, and public reporting, and to create a viable governance system that supports sustainable water management.

For SE Alberta, three river basins (**Figure 4.34**) cover the region. The South Saskatchewan River Basin is the largest basin and can be further split into four sub-basins, three that impact SE Alberta: South Saskatchewan River sub-Basin, the Bow River Basin, and the Red Deer River Basin (**Figure 4.35**). The Milk River Basin covers the southern portion of the region and is a shared basin with the United States. The north part of the region is within the North Saskatchewan River Basin and covered by the Sounding Creek sub-Basin.

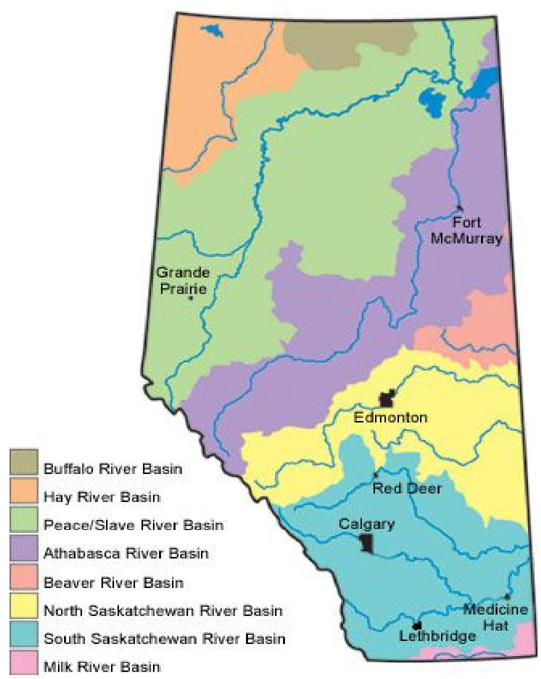


Figure 4.34 Alberta River Basins

SOURCE: Flownorth.ca[126]

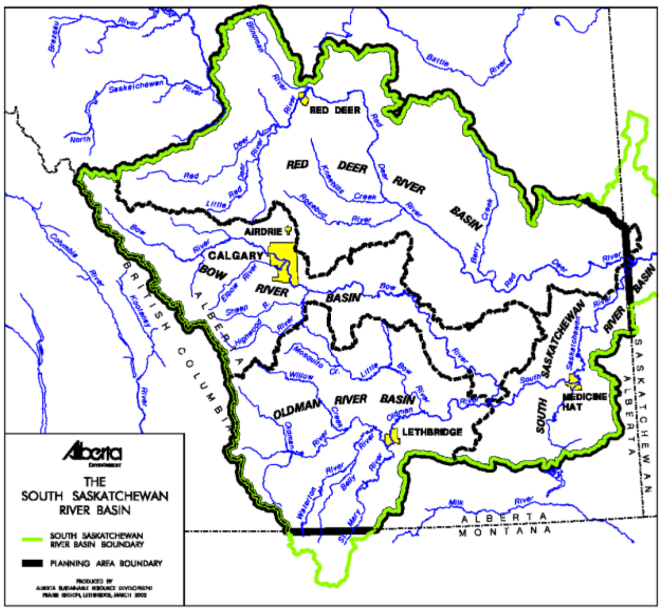


Figure 4.35 SSRB Planning Area – Alberta Environment

SOURCE: Alberta Environment

In 2007, the South Saskatchewan River Basin was acknowledged to be a stressed basin and a Water Management Plan for the South Saskatchewan River Basin was released by Alberta Environment. Under this plan, no new applications for freshwater allocations were allowed. However, it would still allow water allocation transfers under existing approved allowances. These transfers would be subject to new withdrawal limitations and provide for the potential to withhold up to 10% of the allocation for water conservation purposes. The ceasing of new water allocations also applies to the Milk River Basin. Water allocation in the Sounding Creek sub-Basin has not been closed but the number of licenses that have been granted are viewed as significant thus subjecting new applications to increased scrutiny for approval.

Currently the main utilization of existing water allocations is for municipal water access along with agriculture. Agriculture consumes 67% of the freshwater in the province and has been established as a key economic investment priority. [127][128][129][130][131][132][133][135]

The western and southern portions of the SE Alberta region utilize irrigation to optimize agricultural operations as well as providing a means of managing the region's water resources for municipal and other commercial and industrial use. Three irrigation districts operate in SE Alberta (**Figure 4.36**); Eastern Irrigation District (EID) in the County of Newell area, St. Mary River Irrigation District (SMRID) in County of Forty Mile, and Ross Creek Irrigation District (RCID) in Cypress County, with these irrigation districts

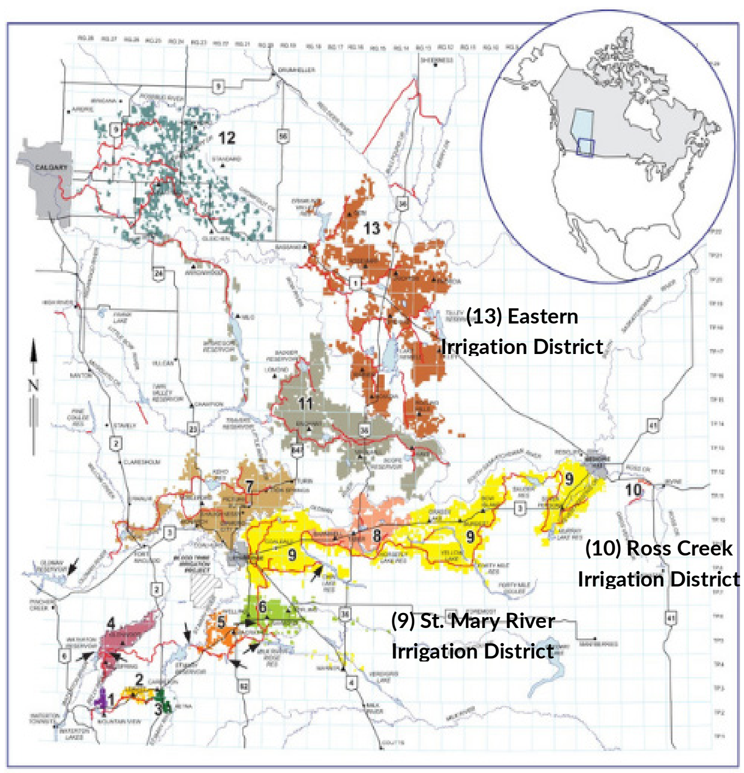


Figure 4.36 Alberta Irrigation Districts

SOURCE: Alberta Irrigation District Association [134] holding the majority of the water allocation for their regions.

As of 2019, EID covers 305,477 acres of irrigated land with a total licensed water allocation volume of 761,000 acre-feet. EID provides raw water to most of the Municipal centers within the County of Newell along with commercial and industrial requirements. In 2019, it provided 3,500 acre-feet of water to non-agricultural entities. SMRID manages 761,000 acres of irrigated lands, with approximately 50% being within the region in the County of Forty Mile. Total allocated water for SMRID in 2019 was 761,000 acre-feet with 12,000 being utilized for non-irrigation purposes. RCID is the smallest irrigation district in Alberta and falls within Cypress County. It manages 1,091 acres of irrigated land and holds allocation of 3,000 acre-feet of water approval, 100% of which is being utilized for irrigation purposes. [136]

5 BOTTOM-UP ANALYSIS – SOUTHEAST ALBERTA SPECIFIC ENERGY SUPPLY AND DEMAND

5.1 Overview

To determine potential for hydrogen transition in a geographic area, an in-depth bottom-up evaluation of the region's supply and demand was performed to form an estimate of equivalent hydrogen volumes as well as to identify the means of generating the required hydrogen. [137] This section will evaluate the potential of various hydrogen pathways and compare the results to the those generated in **Section 3**, from the top-down analysis.

In 2020, Alberta consumed **4,242 PJ** of energy. This data can be divided into five energy consumption sectors: 1) Industrial, 2) Electrical Generation, 3) Transport, 4) Natural Gas Utility, and 5) Agriculture. When combined with Export Market potential, these categories correspond to the hydrogen markets identified within the Alberta Hydrogen Roadmap:

- Heating for Residential & Commercial (Natural Gas Utility),
- Power Generation & Storage (Electrical Generation),
- Transportation, and
- Industrial Processes (Industrial & Agriculture).

Each of these categories can be evaluated in detail to identify the potential for the energy transition to hydrogen and how it applies specifically to the SE Alberta region.

Industrial consumption is the single largest category using **2,564 PJ** (**Figure 5.1**) representing 61% of the energy consumption of the province. Industrial consumption can be further sub divided; i) energy that is consumed during production and recovery of the primary energy resource (833 PJ), ii) the amount of energy used as a feedstock for purposes of generating secondary products (562 PJ), and iii) the amount of energy utilized as fuel for industrial processes (1,169 PJ).

Electrical Generation is the second largest consumption category at **701 PJ**, which represents 17% of the province's consumption. Transportation represents 11% (**469 PJ**), Utilities represents 10% (**451 PJ**) and Agriculture representing 1% (**57 PJ**).

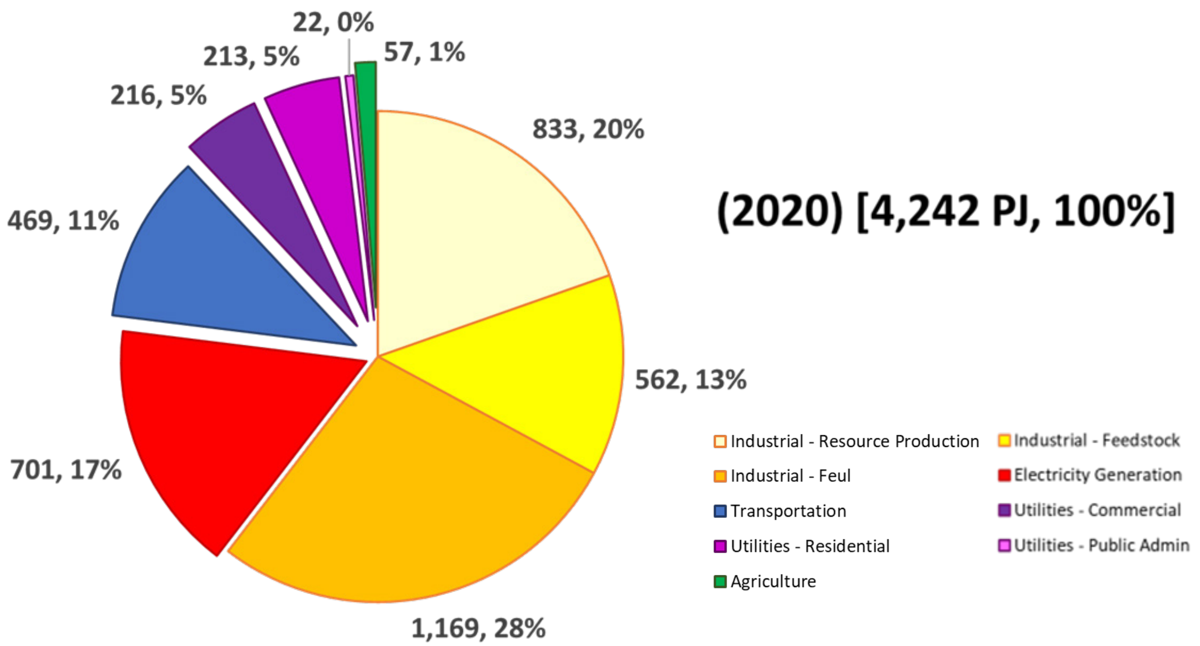


Figure 5.1 Total Energy Demand for Alberta (2020)

Energy consumption by sector; 62% Industrial, 17% Electricity Generation, 11% Transportation, 10 % Natural Gas Utilities, and 1% for Agriculture

Total energy consumption in 2020 decreased by 5% when compared to pre-Covid consumption in 2019 of 4,472 PJ. For each of the identified categories this represents a decrease of 4.6% for Industrial consumption, 2.3% decrease in Electrical Generation, 12.1% decrease in Transport, 3.6% decrease in Utilities, and a 11.8% decrease in Agriculture. Consumption in 2019 was a 1.5% increase over total energy consumption in 2018 of 4,405 PJ.

To determine the consumption on a regional basis, various information was gathered from a combination of public and private data sets to perform a bottom-up data analysis to generate an extrapolated energy demand specific for SE Alberta. From this analysis, it is estimated that in 2020, SE Alberta consumed **217 PJ** within the region (**Figure 5.2**).

The differences in various consumption categories between the provincial data and estimated regional data can be observed, providing further regional insight. Industrial consumption in SE Alberta represents 56% of the total energy demand, with Industrial fuel (27%) being proportional to the provincial demand (28%). The proportion of the energy consumed for resource production in this region (5%) is one quarter of provincial proportional consumption (20%), contrasted by Industrial feedstock (24%) being nearly twice the provincial proportional consumption (13%). This is representative of the lower energy requirements and intensity of the traditional oil and gas, and mining resource sectors in the region and the significance of the Medicine Hat Industrial Complex.

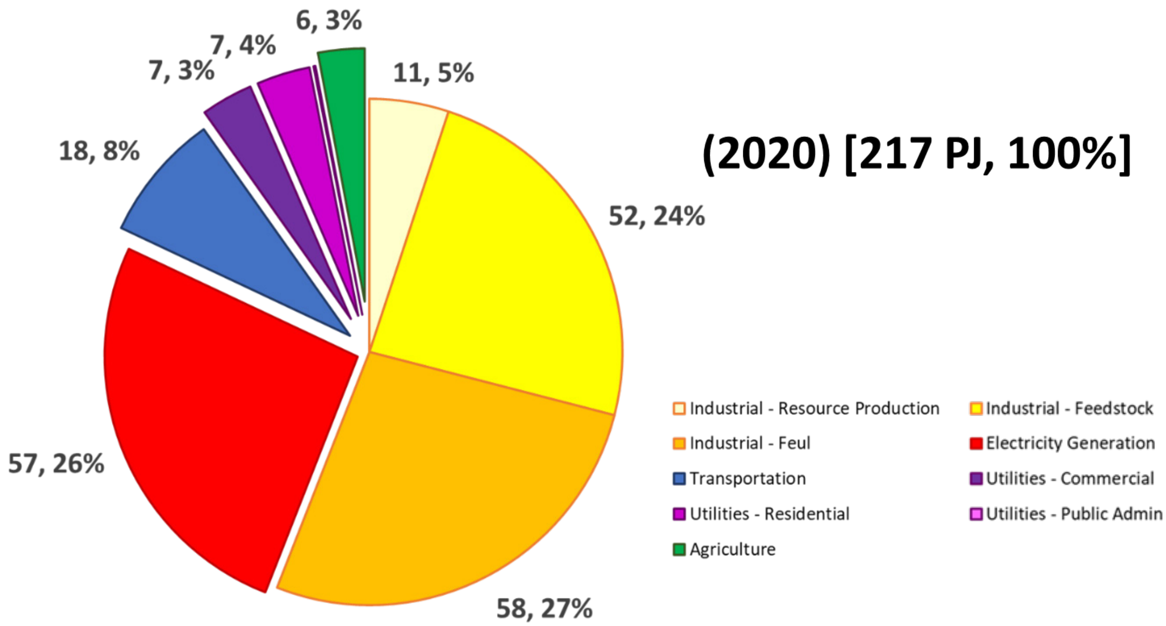


Figure 5.2 Total Estimated Energy Demand for SE Alberta (2020)

Energy consumption by sector; 56% Industrial, 26% Electricity Generation, 8% Transportation, 7 % Natural Gas Utilities, and 3% for Agriculture

Of the other demand categories, demand for Electrical Generation is notable at 26% which is greater than 50% more than provincial proportional consumption, as is Agriculture. Though this sector's consumption is still small in relation to the other categories, in SE Alberta it is triple the provincial proportional consumption at 3%. These differences correspond to the characterization of the region that was completed in **Section 4** and provides insight into SE Alberta's unique potential for hydrogen transition within the specific categories.

To further understand the differences between the SE Alberta region and total provincial energy consumption, the consumption by energy type can be compared (**Figure 5.3**). The SE Alberta Region utilizes natural gas for 76% of its energy requirements as compared to 55% on a provincial basis. As SE Alberta is the primary marketing node for natural gas in Alberta, NGX AECO/NIT, with the presence of the dry shallow natural gas production, AECO gas storage hub, and operational flow characteristics of the NGTL pipeline system, it is understandable that natural gas would be the primary industrial feed stock and fuel for the region, where other regions would utilize other petroleum products readily available in those regions. **Figure 5.4** provides an illustration of the subcategories of Natural Gas consumption, with Electrical Generation (33%), Industrial feedstock (31%) and Industrial fuel (24%) accounting for much of the natural gas demand.

For purposes of identifying energy transition potential within this report, energy consumption as Industrial feedstock or as consumed as a part of the primary resource production will not be evaluated further.

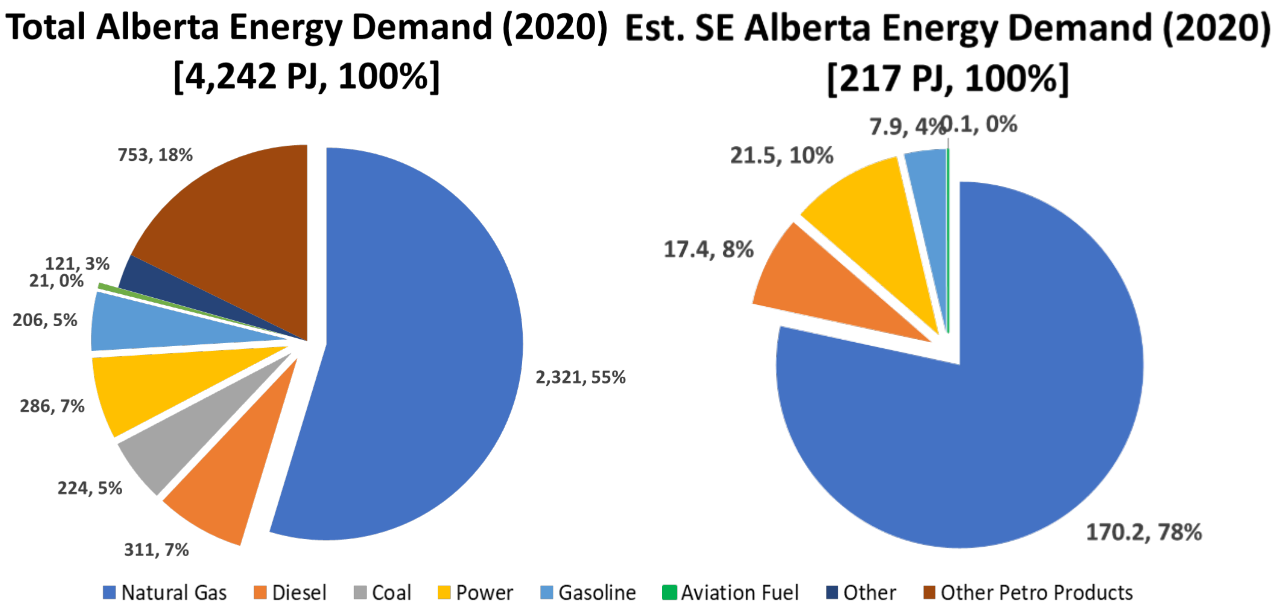


Figure 5.3 2020 Energy Consumption by Fuel Type

SE Alberta energy demand has greater weighting to natural gas consumption.

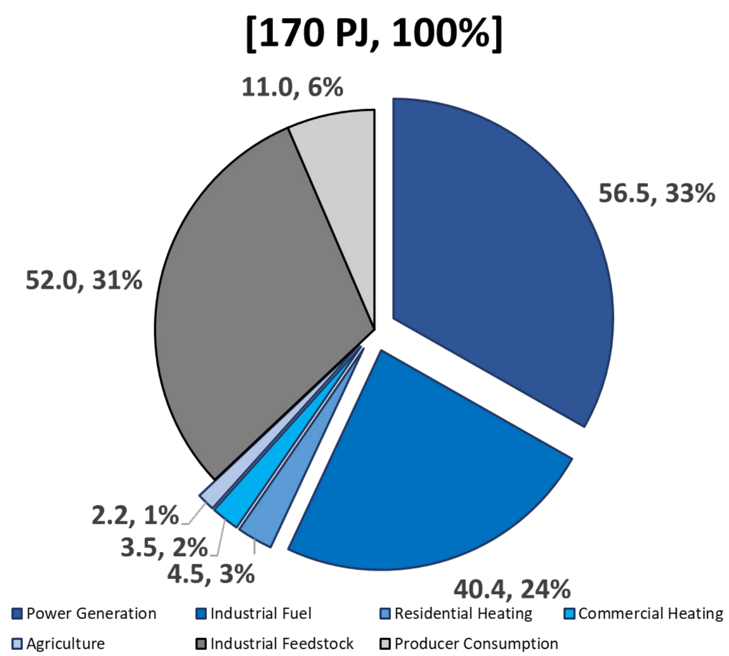


Figure 5.4 2020 SE Alberta Natural Gas Demand by Consumption Category

Natural Gas availability in the region has led to Power Generation and Industrial Fuel consumption levels higher than proportionate provincial values.

5.2 Hydrogen

SE Alberta is currently the third largest cluster of hydrogen generation within Alberta trailing the Industrial Heartland and Fort McMurray regions [138], producing an estimated **1,150 t/day** in 2020. The hydrogen is

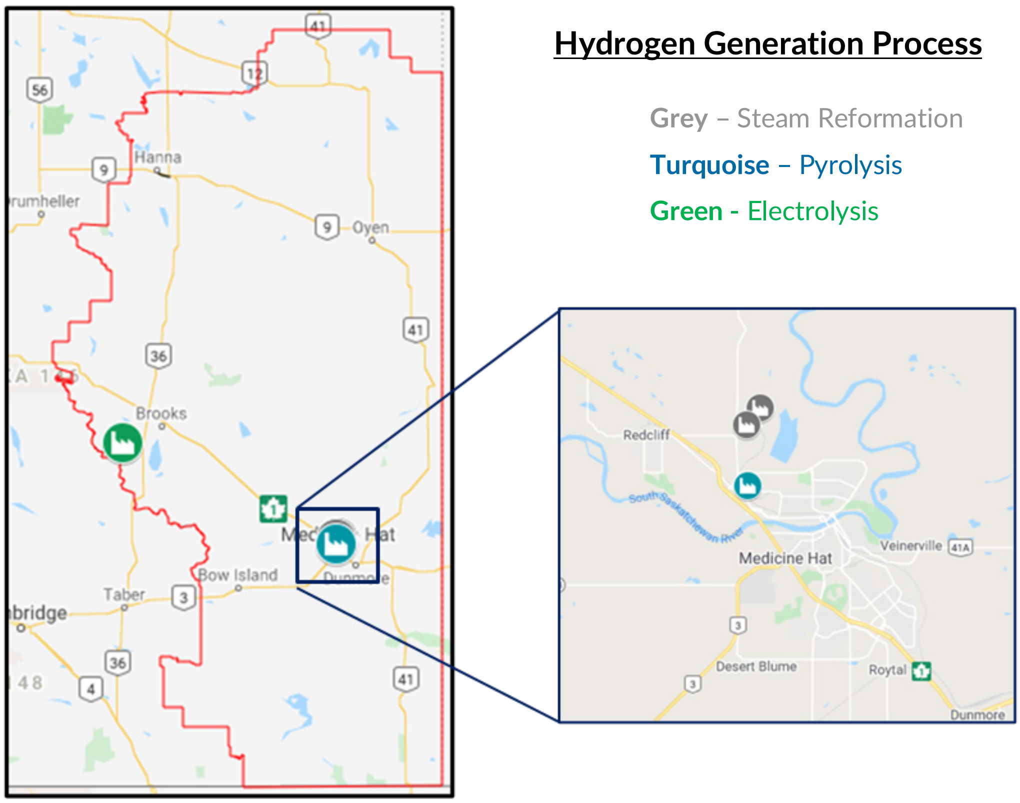


Figure 5.5 Existing and Proposed Hydrogen Generation in SE Alberta
SE Alberta is an existing generation source within Alberta and established steam reformation and pyrolysis processes, with a proposed green electrolysis project.

generated from three industrial processes; CF Industries utilizing steam reformation for the purpose of generating ammonia, Methanex utilizing steam reformation for the purpose of generating methanol, and CanCarb, utilizing pyrolysis to generate carbon black and creating hydrogen as a by-product of the reaction. All three of these industries are located within the Medicine Hat Industrial Complex (MHIC) (**Figure 5.5**).

A green hydrogen project is being proposed near Brooks by Integrated Energy & Power Solutions Canada Ltd. (IEPS), referred to as the Kitsim H_2 Project. Though still in the proposal stage, this facility would initially be a 17.5 MW project with the goal to generate 2.1 kt of hydrogen annually (6 t/day) as well as 16.8 kt of oxygen. Potential in-service for this facility has been estimated as 2024.

Of the current 1,150 t/day of hydrogen production, 91% is estimated to be utilized as a syngas for the ultimate generation of ammonia and methanol (**Figure 5.6**). Though not of merchant hydrogen quality, 105 t/day of hydrogen is recycled within the processes and utilized as a fuel for heating processes, ultimately displacing natural gas that would otherwise be required. CanCarb operates a 42 MW waste heat recovery generation unit that is in practice, partially derived from heat generated by the co-combustion of hydrogen.

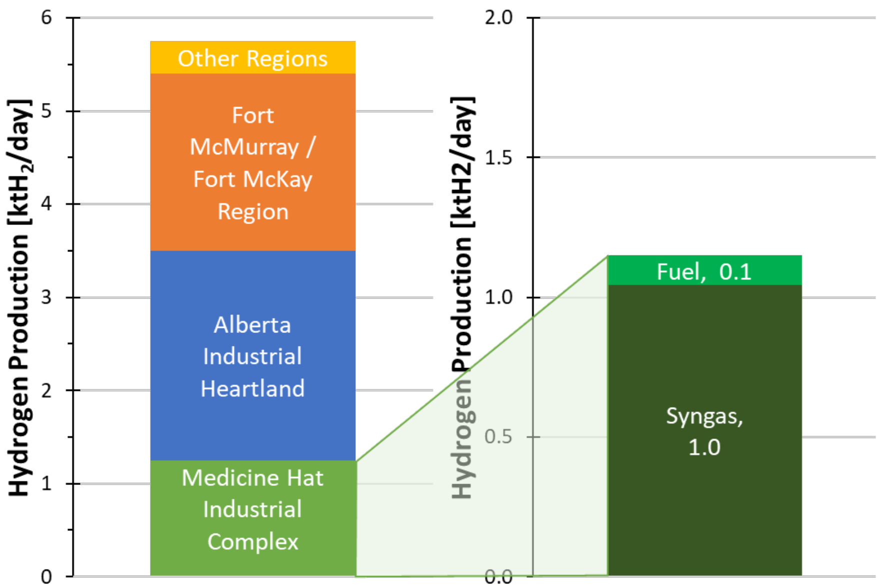


Figure 5.6 SE Alberta Hydrogen Utilization

Existing hydrogen generation from the Medicine Hat Industrial Complex within SE Alberta is the third largest volume within Alberta with most of utilized as a syngas to produce ammonia and methanol.

5.3 Transportation

Transportation is characterized by passenger and freight movement via road, rail, air, or water. As described earlier, SE Alberta is identifiable by the fact that it is a node on major east / west and north / south transport corridors and is a strategic point on the TransCanada highway system and CP railway network.

To generate an estimate of 2020 energy consumption related to transportation in SE Alberta, numerous sources were contacted to provide data to allow for the bottom-up confirmation of energy supply and demand and to calibrate the top-down macro data. Rail and airport consumption was gathered and extrapolated for the region. Fueling stations were identified with the intent of gathering total fuel sales for the region based on annual bulk and retail sales. However, due to the competitive nature of the industry, specific volume data was not disclosed.

Fleet usage data was pursued for both commercial and municipal operators. Significant data was obtained from commercial fleet sources, however insufficient data was obtained to rely on this data source for purposes of extrapolation across the region. Sufficient municipal fleet data was obtained to allow for extrapolation as it relates to differentiating on road vs. off road fuel consumption.

To quantify the total on-road transportation fuel demand for the region, provincial highway traffic data was analyzed and normalized to total provincial fuel consumption data. [139] Based on this analysis, 2020 energy consumption in SE Alberta (**Table 5.1**) was estimated to be **17.7 PJ** as compared to **381 PJ** for the province. This represents 4.7% of the provincial consumption, with the region utilizing very little fuel other than Diesel and Gasoline.

Table 5.1 2020 Energy Consumption for Transportation

Energy Source	Alberta		SE Alberta		% of provincial consumption
	TJ	%	TJ	%	
Diesel	181,495	47.7%	10,137	57.1%	5.6%
Gasoline	180,534	47.5%	7,546	42.5%	4.2%
Natural Gas	1,594	0.4%	24	0.1%	1.5%
Jet Fuel	15,137	4.0%	48	0.3%	0.3%
Electricity	390	0.1%	0	0.0%	0.0%
LPG	971	0.3%			
Aviation Gasoline	243	0.1%	10	0.1%	4.0%
Light Fuel Oil	6	0.0%			
TOTAL	**380,370**		**17,764**		**4.7%**

Total energy of each fuel source utilized in Alberta and its corresponding consumption within the SE Alberta region. Percentage of use by SE Alberta of total for province is calculated.

5.3.1 Road Transport

To complete a bottom-up analysis of road transport fuel consumption for SE Alberta, three public data sets were utilized. StatsCan and NRCan data sets provide transport specific energy data corresponding to transportation mode, vehicle type, and fuel type at a provincial level. Alberta Open Data provides complete traffic data for all Alberta Provincial Highways, which can be segregated by geographic region.

In utilizing the data from Alberta Open Data, it is possible to determine the average annual traffic on all provincial highways both for the entire province and within the SE Alberta region. Average fuel consumption estimates by vehicle type can then be used to estimate annual fuel consumption, with these estimates then being validated against the StatsCan and NRCan databases. [140][141][142][143]

The Alberta Open Data Highway data measures Average Annual Daily Traffic (AADT) along each provincial highway (**Figure 5.7**). This data is divided into five categories: Passenger Vehicles (PV), Recreational Vehicles (RV), Buses (BU), Single Unit Trucks (SU), and Tractor Trailer Combinations (TT). The combination of Buses, Single Unit Trucks and Tractor Trailers are classified as Commercial Vehicles (CV), though light duty freight

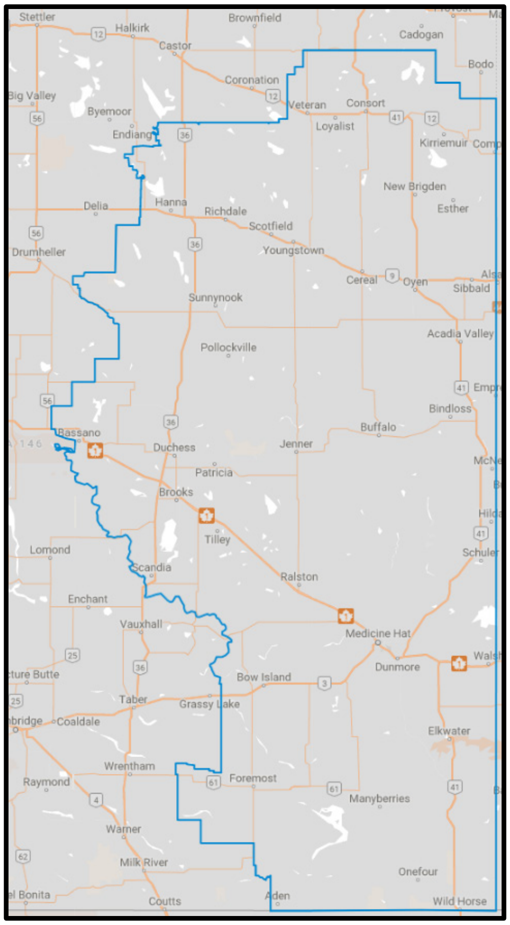


Figure 5.7 SE Alberta Provincial Highways

All provincial highways within SE Alberta indicated in orange.

trucks would be classified as a Passenger Vehicle. The combination of vehicle count with length of highway segments allows for the calculation of actual distance traveled by each vehicle category thus allowing for the estimation of the fuel utilized to travel the total distances.

Figure 5.8 illustrates the breakdown by vehicle class of the total kilometers measured on all provincial highways within the SE Alberta region (1,169 million km) as compared to the entire province (26,906 million km). SE Alberta represented 4.3% of the total mileage of the province with Tractor Trailer mileage being a higher percentage of regional traffic, 17% compared to 10%, and less for Passenger Vehicles, 76% compared to 84%. This reflects being a rural area and the nature of the industrial activity in the SE Alberta region, specifically agriculture and resource development, as well as an indication of the freight traffic utilizing the corridor highways that transect the region.

Once the mileage of the region is determined by class an estimate of the fuel required for this transportation type can be made utilizing average fuel efficiency (**Table 5.2**). Utilizing these assumptions and applying it to the total provincial traffic data, the total Alberta highway transportation fuel consumption for 2020 can be estimated at 130 PJ (**Figure 5.9**). This estimate proved to be too conservative as it is less than the total road transport fuel value of 337 PJ from StatsCan. Additionally, the estimated weighting between diesel consumption and gasoline consumption did not correspond. This result suggests that provincial highway traffic is only a

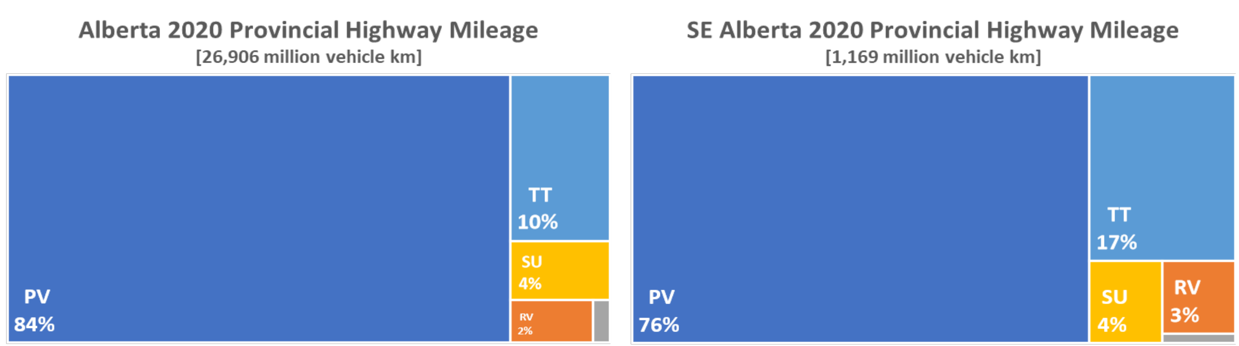


Figure 5.8 2020 Provincial Highway Mileage

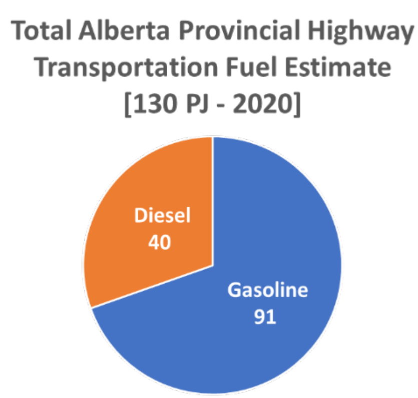
Comparison of total mileage in 2020 recorded on provincial highways sorted by vehicle type between total Alberta and SE Alberta.

portion of all on-road transportation that occurs in the province. This data does not capture the fuel utilized for vehicles traveling on rural roads or within municipalities. **Figure 5.10** further supports this as it shows that Passenger Vehicle consumption is overweighted by highway data and Single Unit Trucks are vastly underweighted. This would suggest that Passenger Vehicles are utilized for significant highway travel and that Single Unit Trucks are utilized for off-highway short haul freight delivery. Thus, a calibration factor specific to each vehicle category is required to prorate highway traffic to regional road transportation fuel consumption.

Table 5.2 Average Vehicle Fuel Efficiency NRCan 2018

Vehicle Type	Gasoline (L/100km)	Diesel (L/100km)	% Gasoline
PV	11.3	9.6	98%
Car	*8.1*	*6.9*	*97%*
Truck	*12.3*	*10.4*	*98%*
Light Freight	*12.4*	*10.5*	*98%*
RV	16.4	15.4	4%
BU	12.3	11.2	4%
SU	20.4	20.3	51%
TT		29.2	0%

Average fuel consumption by vehicle class and fuel type. Diesel and gasoline split determined by total fuel consumption.



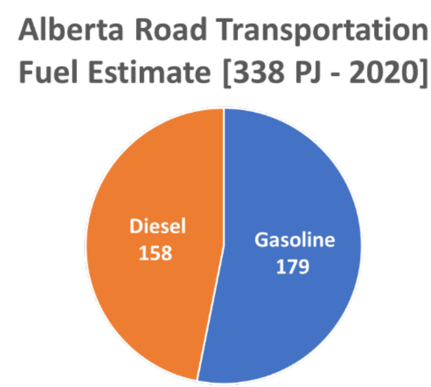


Figure 5.9 Alberta Highway vs. Total Province Road Transport Fuel Consumption by Fuel Type

Total Provincial Highway traffic does not capture 100% of the fuel consumption in the province associated with transportation, both in total quantity and by fuel type.

Utilizing this calibration, the total road transportation fuel for SE Alberta can be estimated at **17.2 PJ** for 2020. The region has a greater demand for diesel fuel (**Figure 5.11**), reflective of the larger percentage of Truck and Trailer traffic and, relative to provincial data, the decreased consumption from Passenger Vehicles (**Figure 5.12**).

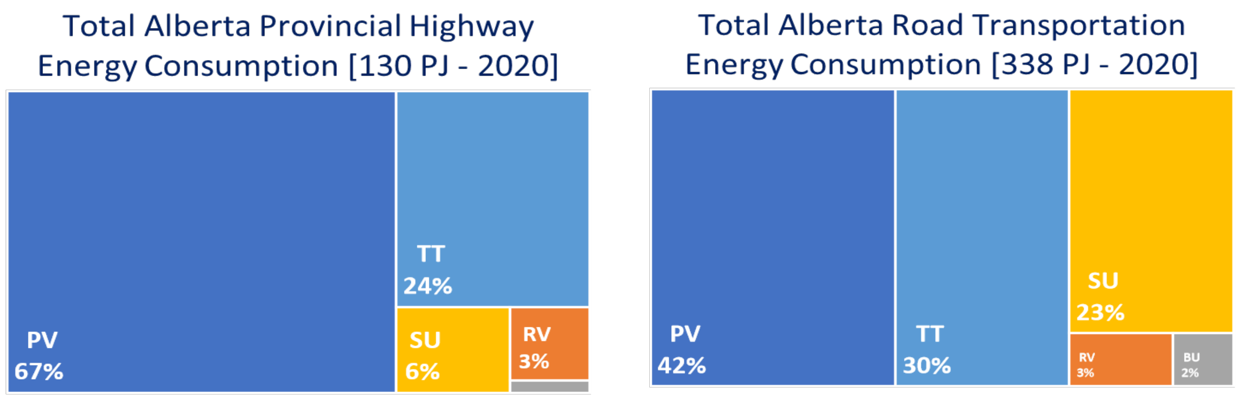


Figure 5.10 Alberta Highway vs. Total Province Road Transport Fuel Consumption by Vehicle Type

Provincial highway data by vehicle type overestimates the amount of fuel consumption by passenger vehicle and underestimates the amount consumed by commercial vehicles.

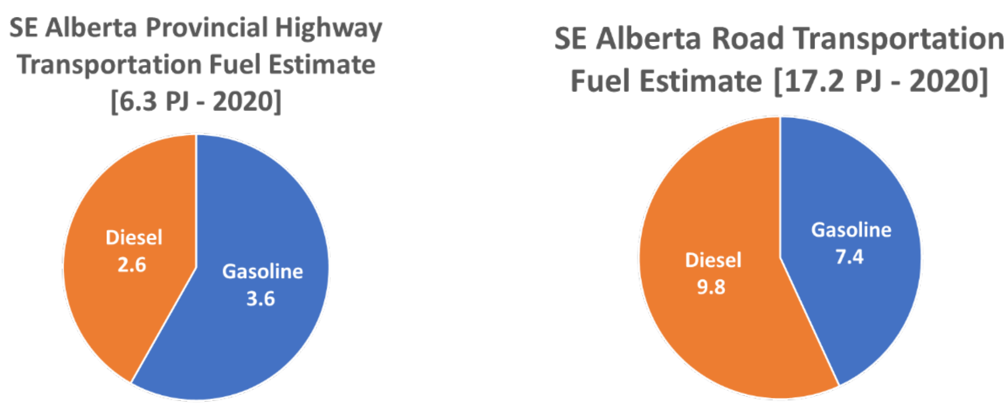


Figure 5.11 SE Alberta Road Transport Fuel Consumption by Fuel Type

SE Alberta fuel estimate for provincial highway travel calibrated to total regional travel with greater consumption of diesel.

As further supported by vehicle registration data for the region which shows greater percentage of registry in SE Alberta of Trucks and Truck and Trailers as compared to less Car and Single Unit Trucks (**Figure 5.13)** as compared to provincial registry data. [144][145] This can be attributed to the rural nature of SE Alberta and a reflection of less short haul travel within smaller urban centers.

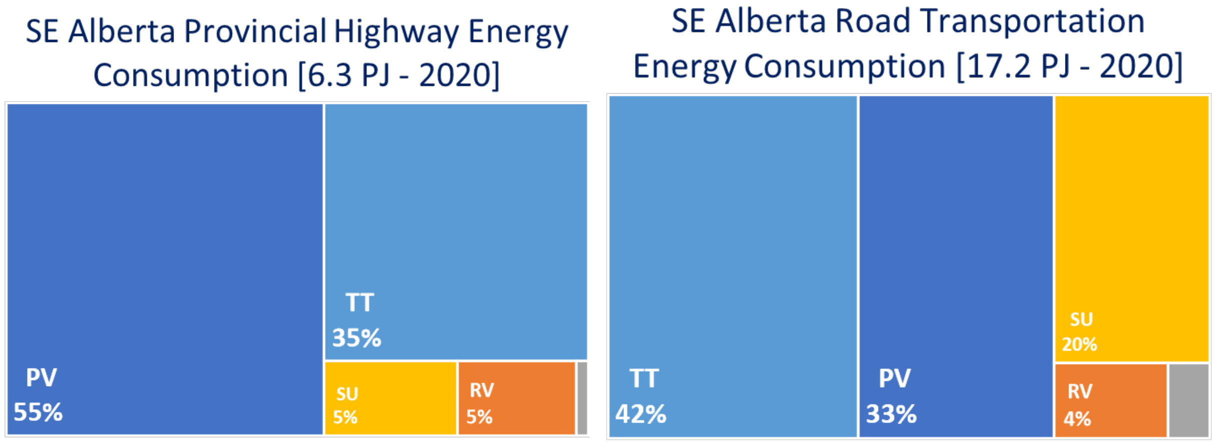


Figure 5.12 SE Alberta Road Transport Fuel Consumption by Vehicle Type

Calibrated fuel data for SE Alberta increases weighting to truck and trailer and single unit truck fuel consumption.

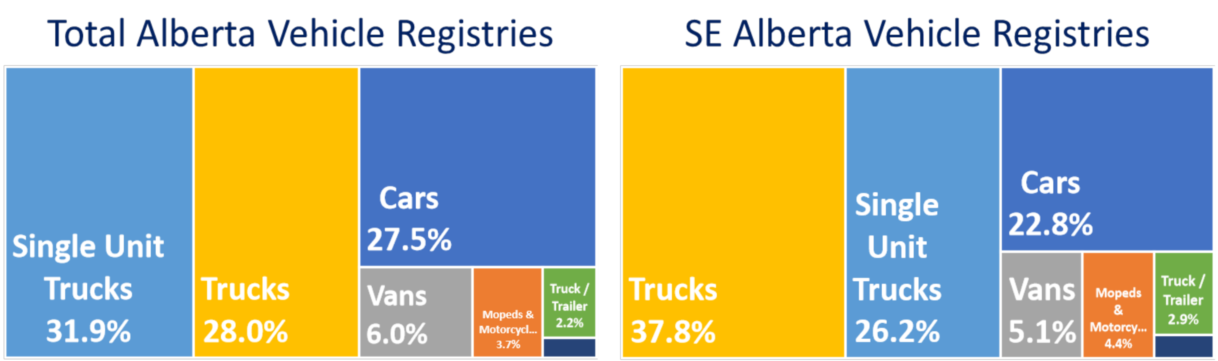


Figure 5.13 Percentage of Vehicle Registration by Vehicle Type (2020)

Registry data for SE Alberta indicates greater percentage of truck and trailer and single unit truck as compared to provincial average, supporting increased percentage of fuel use by both vehicle types in region.

With the estimation of fuel usage for the region, transition assumptions can be applied to generate the hydrogen transition potential as it relates to on-road transport. The transition assumptions and hydrogen efficiencies were previously presented in **Section 3** and listed in **Table 3.1**. However, just as the unique characteristics of SE Alberta has impacted the estimation of fuel consumption for the region, in comparison to provincial data, so to would it impact the transition assumptions.

Approximately 75% of the Passenger Vehicles and Single Unit Trucks are registered within an urban center (**Figure 5.14**). However, greater than 89% of the mileage associated with Passenger Vehicles and 92% associated with Single Unit Trucks are accumulated in rural areas of the region. Thus, to reflect the greater likelihood of rural Passenger Vehicles and Single Unit Trucks transitioning to hydrogen rather than electric battery vehicles, the transition percentage has been increased from 10% to 65% for the rural mileage of these categories for fuel consumption.

With this assumption, the hydrogen transition potential in SE Alberta for on-road transportation is estimated at 163 t/day (60 kt/year) (**Table 5.3**) with Truck and Trailer units accounting for nearly 60% of the estimate at 95 t/day.

As SE Alberta covers a large and diverse geographic area, it is necessary to understand where within the region the greatest initial demand for hydrogen will be. Further, as it is expected that transition will occur in Commercial Vehicles first; Truck & Trailer, Single Unit Trucks, and Busses, the CV mileage associated with each municipal district can be utilized to generate hydrogen potential for each area.

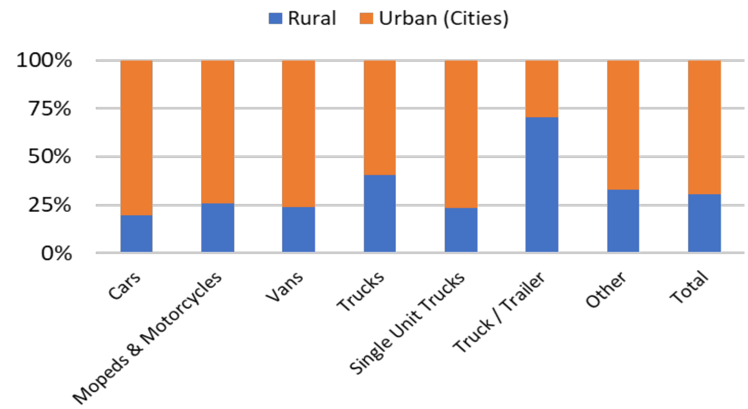


Figure 5.14 Percentage of Rural Vehicle Registries in SE Alberta (2020)

Nearly 75% of all vehicles are registered within the cities of Medicine Hat and Brooks with only Truck & Trailer registries being higher in rural areas. Majority of mileage is attributable to rural registered vehicles.

Table 5.3 SE Alberta Hydrogen Potential – Road Transport

Transportation Sector	Consump Total A [PJ/yr]	Assumed Transition B %	C Rel. Efficiency [J H_2 / J petro]	Hydrogen Potential [kt/yr]	D [t/day]
Passenger Vehicles (Urban)	0.59	10	0.40	0.2	0.5
Passenger Vehicles (Rural)	5.00	65	0.40	9.2	25.2
RV	0.71	50	0.86	2.2	5.9
Buses	0.26	55	0.59	0.6	1.6
Single Unit Heavy Truck (Urban)	0.28	20	0.86	0.3	0.9
Single Unit Heavy Truck (Rural)	3.18	65	0.86	12.5	34.3
Truck and Trailer	7.14	80	0.86	34.6	94.9
Total	**17.2**			**60**	**163**

Total fuel consumption (diesel & gasoline) for each class of vehicle [A] is provided in the table with the assumption of percentage of each vehicle class transition [B] and the relative efficiency of the hydrogen transition for each class [C]. This results in the estimated hydrogen potential for each class and presented on a total annual and daily basis [D].

As shown in **Figure 5.15**, Commercial Vehicle mileage is greatest in Cypress County, the County of Newell, and Special Area #2 and thus likely represent the areas with the greatest potential for short term hydrogen transition. This would directly correlate to the main TransCanada Highway (Hwy 1) corridor that runs east / west through both counties, and Highway 36, which runs north / south through the County of Newell and Special Areas 2.

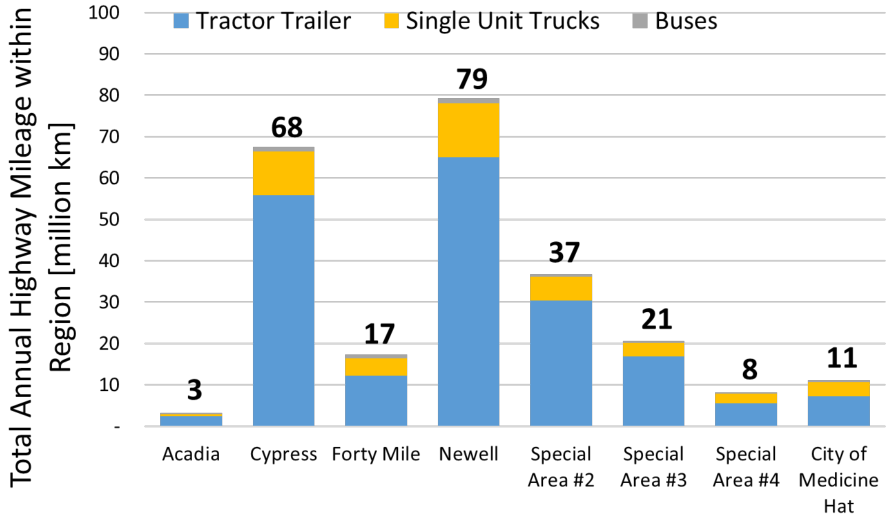


Figure 5.15 Commercial Mileage by SE Alberta Municipal District

Cypress County, the County of Newell, and Special Area #2 have the highest commercial mileage in SE Alberta corresponding to the two most significant corridor highways; TransCanada Highway and Highway 36.

Dividing SE Alberta into three rural sub-areas; Cypress County and County of Forty Miles to the south, the County of Newell to the west, and the Special Area's 2, 3, and 4 along with the MD of Acadia to the north, each represent comparable hydrogen potential (**Table 5.4**) reflecting the significance that all of the corridor highways have in determining hydrogen demand for on-road transport throughout the entire SE Alberta region.

Table 5.4 SE Alberta Hydrogen Potential – Road Transport by Area

	Gasoline	Diesel	Total	Potential	
	[PJ/yr]	[PJ/yr]	[PJ/yr]	[kt/yr]	[t/day]
Medicine Hat	0.72	0.46	1.19	1.9	5.2
Cypress / Forty Mile	2.67	3.41	6.08	21.5	58.9
Newell County	2.24	3.18	5.42	19.6	53.8
Special Areas	1.74	2.74	4.48	16.6	45.4
Total SE Alberta	**7.4**	**9.8**	**17.2**	**60**	**163**

Total fuel consumption (diesel & gasoline) for each class of vehicle and separated by sub-area within SE Alberta is provided in the table with the assumption and relative efficiency of hydrogen transition. This results in the estimated hydrogen potential for each class and presented on a total annual and daily basis. All three rural subareas represent comparable hydrogen potential.

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5.3.2 Traffic

Medicine Hat and SE Alberta as a whole is an important node on the Federally designated National Highway System. Highways 1, 3 and 9 are all designated Core routes to recognize their significance as key east / west interprovincial and international corridor routes. Highways 36 and 9 are designated highways within the Alberta High Load Corridor.

To gain a better insight as to specific locations for potential hydrogen fueling stations, the traffic on the six provincial highway corridors running through the region, Highways 1, 3, 9, 12, 36, and 41 (**Figure 5.16**), were evaluated to determine the AADT for the overall length of highway, by taking the weighted average of each specific segment along the highway, and the classification of the vehicles that account for the traffic along the corridors.

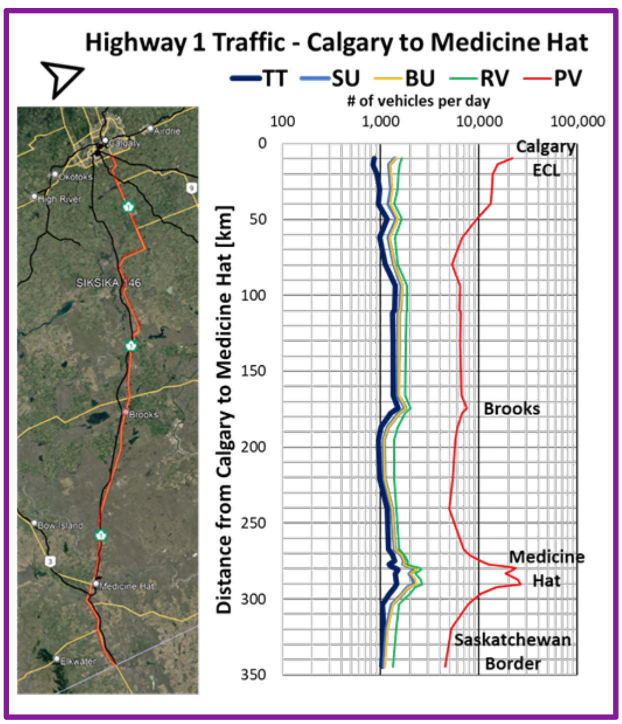


Figure 5.17 Highway 1 Traffic Flow

Average Commercial Vehicle AADT of 1,567 for highway segment between Calgary and Medicine Hat.

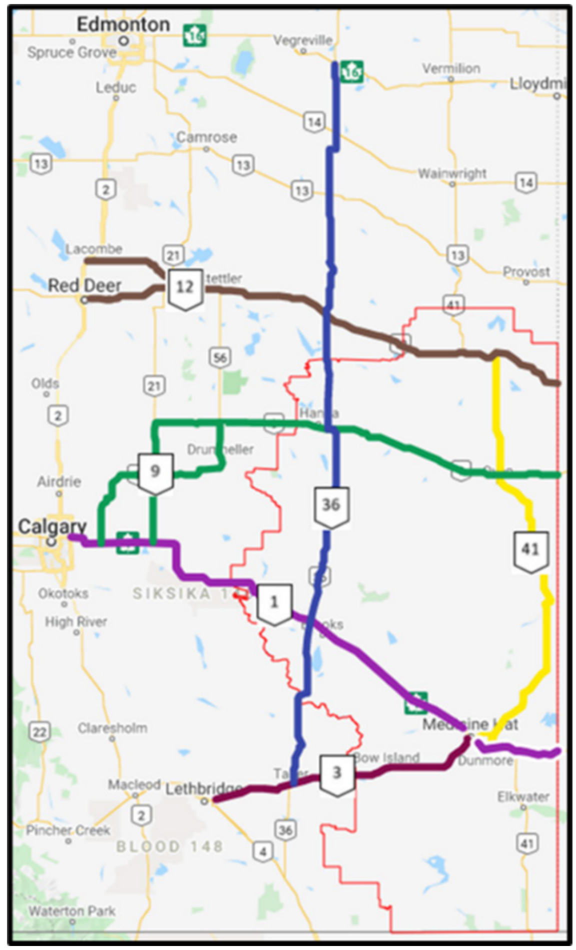


Figure 5.16 SE Alberta Transport Corridor Highways

SE Alberta is a key node in the National Highway System with three designated Core Highways and two designated within the Alberta High Load Corridor.

Highway 1, the TransCanada Highway, is the busiest highway in the region and one of the busiest highways in the country as it provides a major east / west transportation corridor from British Columbia through to Nova Scotia. The 2020 traffic from Calgary through Medicine Hat and to the Saskatchewan Border was analyzed (**Figure 5.17**). The average AADT of the highway is 8,096 with 75% of the traffic being Passenger Vehicles. Commercial Vehicles account for 21.6%, with Truck and Tractor averaging 1,250 vehicles per day. The traffic profile demonstrates a consistent traffic flow on the entire highway segment indicating strong long haul traffic flow from and to Saskatchewan.

Highway 3, the Crowsnest Pass Highway, is another east / west interprovincial highway, connecting Medicine Hat with the west coast in British Columbia. AADT for the highway is 5,527 with a notable increase between Lethbridge and Taber, suggesting more traffic flow out of the SE Alberta region (**Figure 5.18**). The AADT between Taber and Medicine Hat is less in comparison but Commercial Vehicle traffic on this portion of the road is greater with a more notable presence of Single Unit trucks. Total Commercial Vehicle traffic for the highway is 831 with 217 being SU.

The third Core route in the National Highway System, Highway 9, is another key east / west transport corridor running through SE Alberta providing direct connection between Calgary and Saskatoon, Saskatchewan. Highway 9 is also designated as a Core route in the Alberta High Load Corridor Network. The highway has an AADT of 1,796 with a Commercial Vehicle average of 20.5% (**Figure 5.19**). Truck and Trailer represent an average traffic flow of 390 units, which is the predominate Commercial Vehicle traversing the SE Alberta portion of the route.

Another highway that is designated as a Core route in the Alberta High Load Corridor Network is Highway 36, the Veterans Memorial Highway. This is a key north / south highway running through the western portion of SE Alberta, providing a direct connection from the Coutts Border Crossing via Highway 4 to Highways 63 and 881 to Fort McMurray and the northern oilsands areas. Through the SE Alberta region, Highway 36 provides a significant corridor for Commercial Vehicle transport from southern

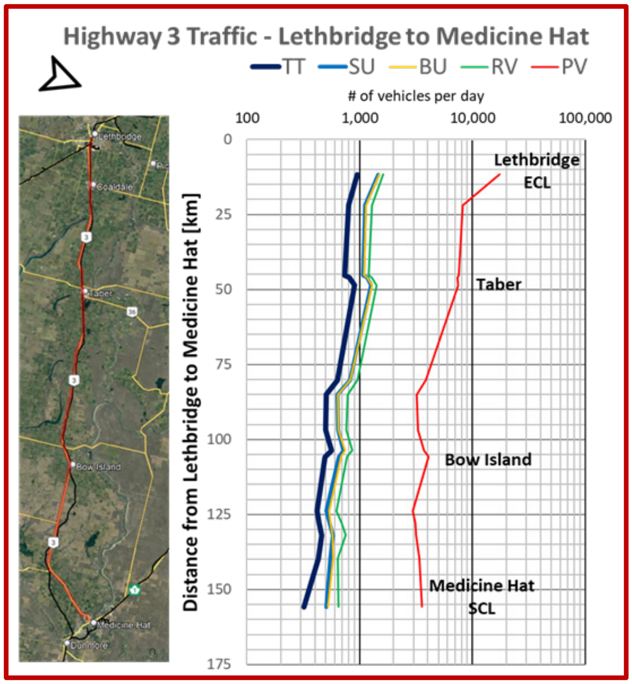


Figure 5.18 Highway 3 Traffic Flow

Average Commercial Vehicle AADT of 831 for highway segment between Lethbridge and Medicine Hat.

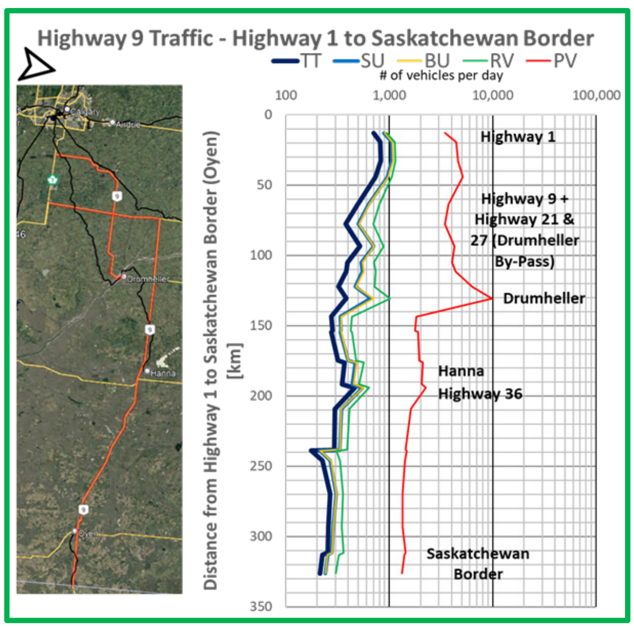


Figure 5.19 Highway 9 Traffic Flow

Average Commercial Vehicle AADT of 505 for highway segment between Hwy 1 and Saskatchewan Border.

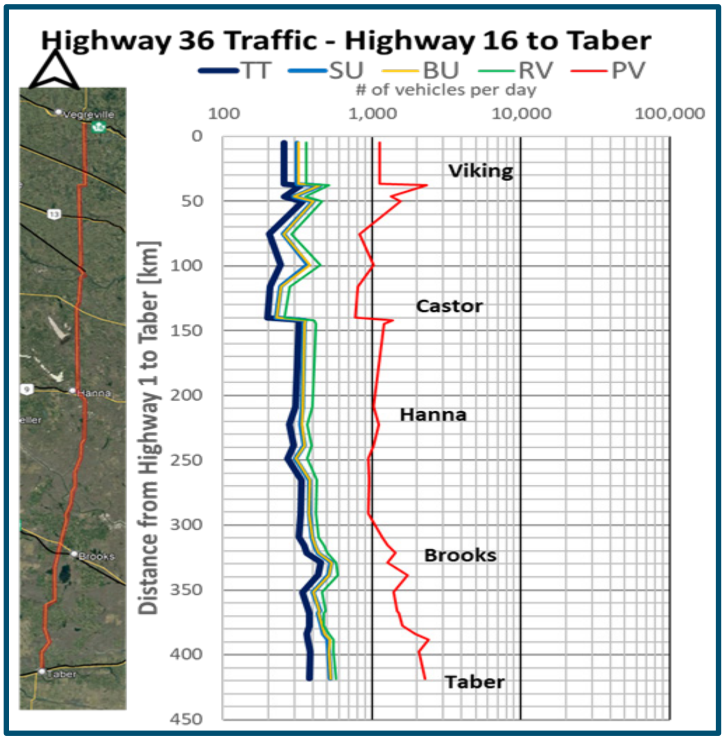


Figure 5.20 Highway 36 Traffic Flow

Average Commercial Vehicle AADT of 385 for highway segment between Hwy 16 and Taber.

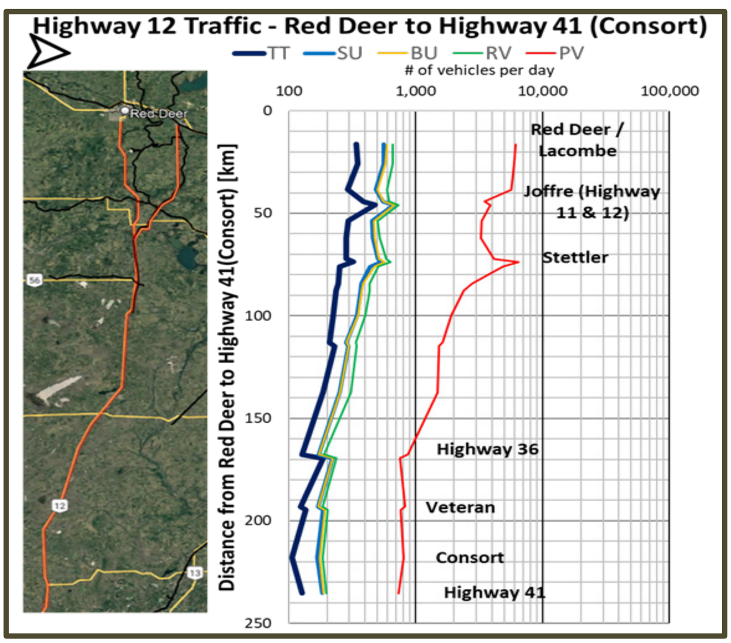


Figure 5.21 Highway 12 Traffic Flow

Average Commercial Vehicle AADT of 397 for highway segment between Red Deer and Consort.

Alberta to central Alberta for access to Red Deer and Edmonton, representing 30% of the AADT of 1,204 (**Figure 5.20**). Truck and Trailer traffic averages 350 units daily, through the region.

Highway 12, in the northern part of SE Alberta region provides a traffic route feeding into Red Deer in central Alberta (**Figure 5.21**). AADT of the entire section is 1,629 with a significantly higher volume being seen closer to Red Deer, but a higher percentage of Commercial Vehicle traffic evident through the SE Alberta region between Highway 36 and Highway 41, with average Commercial Vehicle traffic west of Highway 36 being 15.1% as compared to 24.6% east. Similar to Highway 3, Single Unit Trucks represent a greater share of the Commercial Vehicle traffic accounting for more than 5% of the total AADT, likely representing higher degree of short haul traffic in the area.

The sixth major corridor highway in SE Alberta is Highway 41 which runs north / south along the Saskatchewan border. This highway is the main transport corridor between Medicine Hat and the Empress fractionation complex at McNeill. AADT for the entire segment is 814 but increases to greater than 1,200 for the portion between McNeill and Medicine Hat (**Figure 5.22**). Commercial Vehicle traffic represents 22.1% of the daily flow.

A summary of the AADT for each of the six highways is shown in **Figure 5.23**, split by Commercial Vehicle AADT vehicle types along with the total AADT. Highway 1 represents the busiest corridor in the region with the segment likely to be representative of traffic both east and west of the region along the TransCanada route. Of the other highways, Highway 36 is notable due to its lower overall AADT but with Commercial Vehicle traffic representing one third of the total traffic flow.

To translate each highways daily traffic for potential fueling stations, the intersection of all six corridor highways in SE Alberta were further evaluated as potential fueling nodes. Each of the five identified locations are approximately 100 km apart and generally correspond to current bulk and truck stop locations for diesel supply. An additional node was evaluated at Bow Island to capture the potential of fueling requirements specific to Highway 3 within the SE Alberta region.

Five of the nodes represent intersection of two corridor highways thus maximizing the location specific AADT by capturing traffic flow along two highways. The six nodes evaluated are:

- Highway 1 and Highway 3,
- Highway 1 and Highway 36,
- Highway 9 and Highway 36,
- Highway 9 and Highway 41,
- Highway 12 and Highway 41, and
- Highway 3 at Bow Island

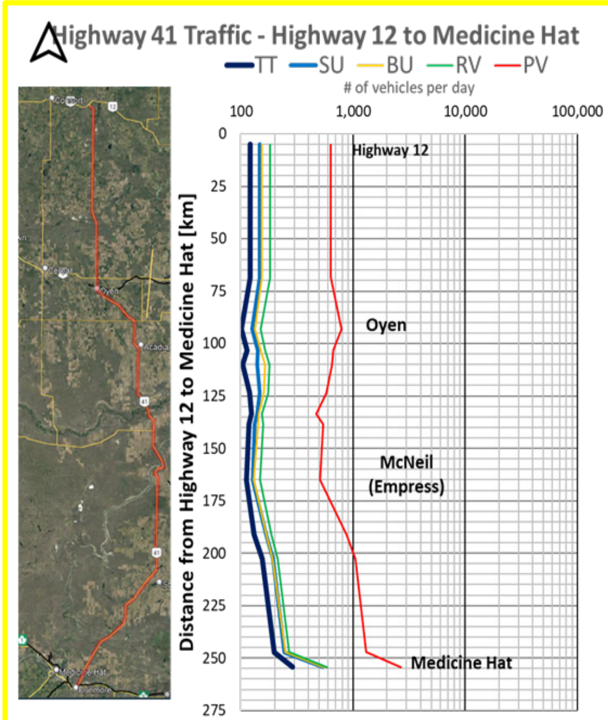


Figure 5.22 Highway 41 Traffic Flow

Average Commercial Vehicle AADT of 194 for highway segment between Hwy 12 and Medicine Hat.

The concept of fueling nodes is consistent with current Government of Alberta initiatives for developing new Partnership Rest Areas. One such location has been developed near Castor at the intersection of Highway 12 and 36, which falls just outside the SE Alberta designated area but on a node of two SE Alberta corridor highways. Partnership Rest Areas are public / private partnerships, with the intent for these locations to provide commercially driven innovative, efficient, and environmentally sustainable services with newer infrastructure and potential for new technologies such as vehicle charge stations and hydrogen fueling stations. These locations are designed for both Passenger and Commercial Vehicle travel and would enhance travel by offering food, fuel, and other services. Though not a specific Partnership Rest Area, Cactus Corner at the intersection of Highway 9 and 36, is another private rest area and combination retail and truck stop. Both locations would be logical locations to accommodate hydrogen fueling.

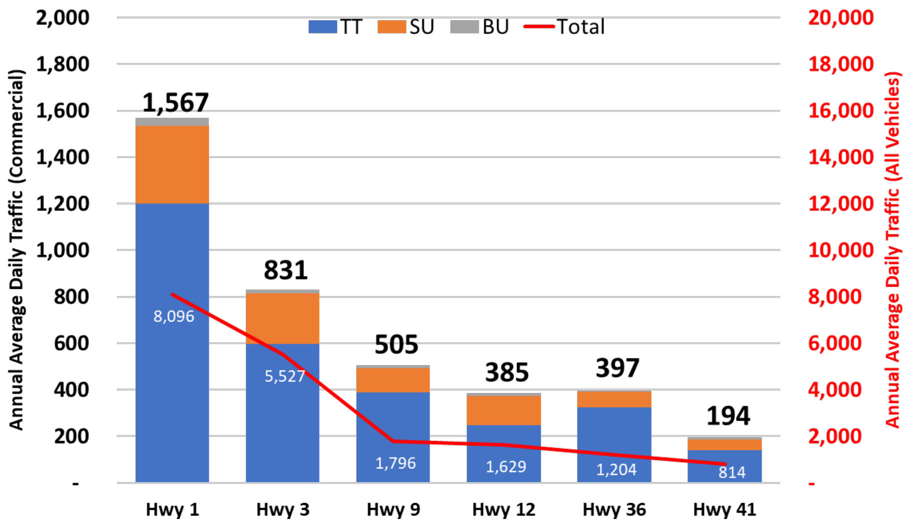


Figure 5.23 2020 Weighted Average AADT for SE Alberta Highways

Comparison of weighted average AADT for Commercial Vehicles, by vehicle type, to total AADT for all vehicle types.

The two most active fueling nodes are located at the intersections of Highway 1 & 3 and Highway 1 & 36 (**Figure 5.24**) with each having greater than 2,000 Commercial Vehicle AADT. The intersection of Highway 1 & 3 has the greatest total traffic flow as compared to any of the fueling nodes at 27,850, resulting in the commercial portion being less than 10% of the traffic. This is significant for consideration if accommodation for potential passenger vehicle transition is considered. Conversely, Commercial Vehicle traffic represents nearly 30% of the total traffic for the Highway 1 and 36 and Highway 9 and 36 nodes.

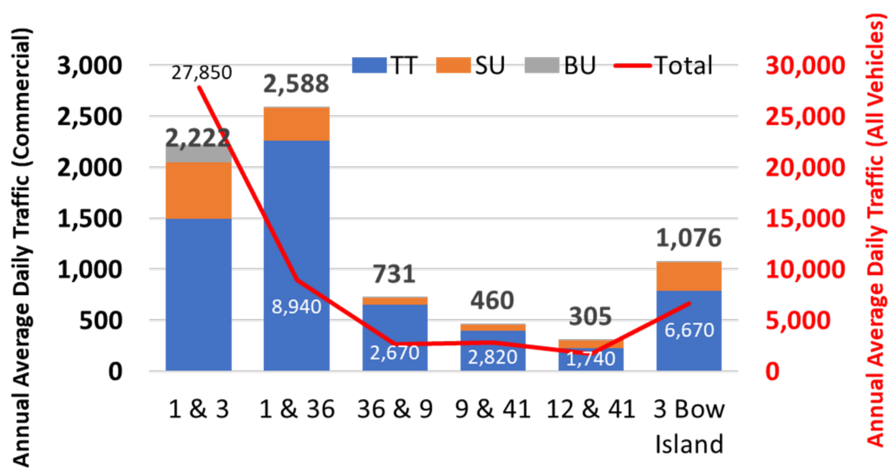


Figure 5.24 2020 AADT for SE Alberta Highway Intersections

Average Commercial Vehicle AADT of 194 for highway segment between Hwy 12 and Medicine Hat. Comparison of AADT for Commercial Vehicles, by vehicle type, to total AADT for all vehicle types, at potential fueling nodes.

Development of new or updated truck stops at the other fueling nodes could be pursued in conjunction with the government initiative to expand the network of Partnership Rest Areas. As of March 1, 2022, the Government of Alberta has a Request for Expression of Interest for future private / public partnerships on 18 identified government Safety Rest Area sites throughout the province, targeting AADT of 2,000 or more. [146] Four of these sites are along Highway 1, two being eastbound and two westbound, situated on either side of Brooks. It is reasonable to believe that a Partnership Rest Area situated near the intersection of Highways 1 and 36 would accommodate the desire for a Safety Rest Area as well as provide an important fueling node for hydrogen.

Medicine Hat currently has existing bulk and truck stop locations located on the west side of the city in the Redcliff area. It is probable that at least one of these existing locations would be expanded to incorporate hydrogen within its current fueling options. On the east side of Medicine Hat, a new fueling location may be a reasonable site to accommodate the Highway 1 and 41 intersections. For the other nodes, located in proximity to Consort, Oyen, and Bow Island, existing retail and card lock bulk locations exist and could be utilized to build out updated sites to incorporate hydrogen and the other desired amenities associated with the Partnership Rest Areas.

To quantify the actual hydrogen potential of these fueling nodes the potential exposure to hydrogen refueling has been estimated by making assumptions as to the percentage of the traffic that would be hydrogen fuel cell vehicles and the capacity each of these vehicles would have. **Table 5.5** lists the assumptions by vehicle class which corresponds to the conversion percentages used in **Section 5.3.1**. and average tank size for each class of vehicle. [147][148] **Figure 5.25** indicates 100% of the volume of all hydrogen vehicles passing at the given fueling node. Each of the nodes within SE Alberta would provide exposure to greater than 14 t/day, with the two nodes along Highway 1 being more than 100 t/day of hydrogen.

Table 5.5 Hydrogen Fueling Tank Assumptions by Vehicle Class

Vehicle Class	Transition %	H2 Fuel Tank Size *kg H2*
PV	27%	10
RV	50%	30
BU	55%	40
SU	31%	30
TT	80%	50

Transition percentage and vehicle tank size used for estimating the fueling potential at the identified nodes, based on AADT

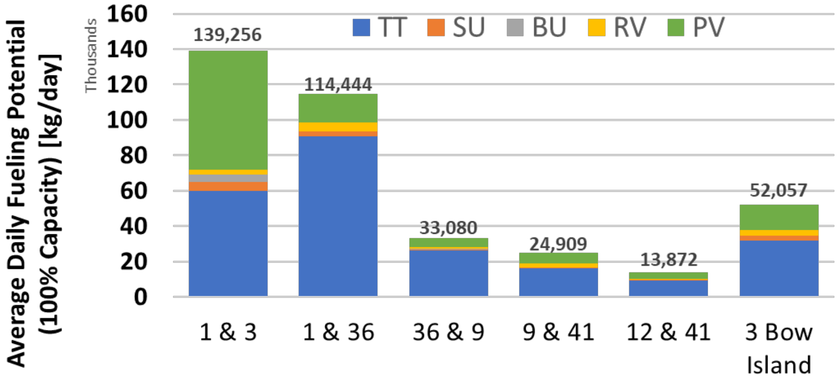


Figure 5.25 SE Alberta Transportation Fueling Nodes – Potential Hydrogen Fueling Demand Exposure
Maximum refueling exposure at fueling node based on percentage of AADT transitioned to hydrogen and assumed tank size by vehicle type.

Based on the estimated range of each vehicle class of between 400 to 1000 km, and fueling station spacing distances of 100 km, a model for each class of vehicle was created to determine the potential to refuel at a given node. This resulted in a probability of 10 to 25% - 10% for longer range / larger tank size, 25% for shorter range / smaller tank size. This assumption reduces the estimated fueling node potentials to a range of 10 to 27 t/day for the fueling nodes in the Special Areas, 69 to 94 t/day for the fueling nodes along Highway 1, and 34 t/day at Bow Island. These estimated values are in line with total regional demand estimated in **Section 5.3.1** and shown in **Figure 5.26**.

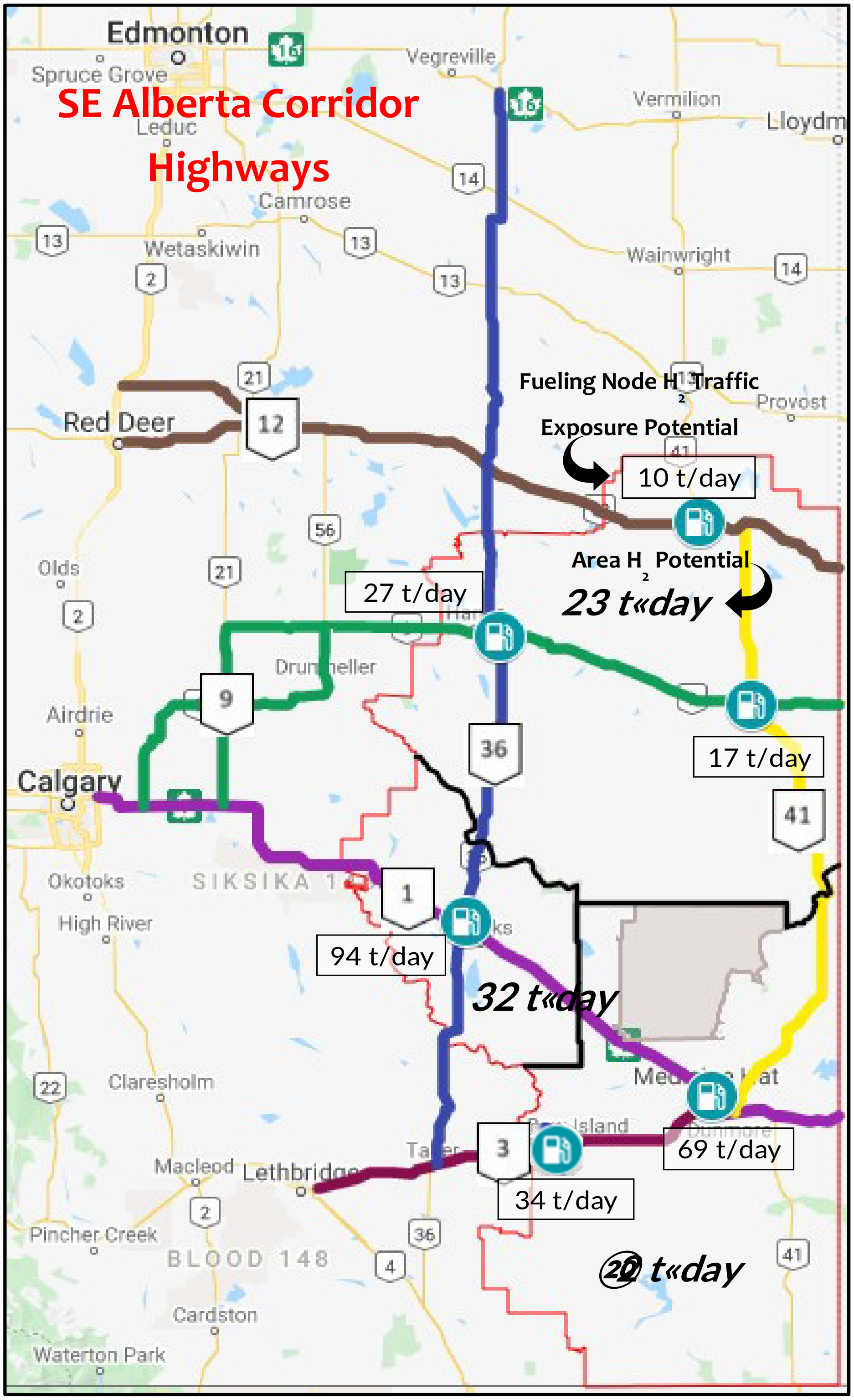


Figure 5.26 SE Alberta – Hydrogen Transportation Potential by Fueling Node and Regional Demand

Map indicating potential fueling nodes and estimated fueling potential of each node plus calculated regional potential.

5.3.3 Rail

Within SE Alberta, four rail lines provide service for industrial and agricultural sectors (**Figure 5.27**). The main rail line traversing through the region runs parallel to Highway 1 to Calgary and Highway 3 to Lethbridge.

Medicine Hat and Brooks are nodes on the CP Rail North American long-haul network within the SE Alberta region. To the east, the rail line continues into Saskatchewan, through Regina, where it can deliver cargo to eastern Canada as well as export capabilities to the United States Midwest. Going west of Medicine Hat, the line splits, with the western leg continuing to Calgary and ultimately to international export markets from Vancouver, British Columbia on the west coast. The southern leg follows Highway 3 to Lethbridge where cargo can then either be exported to the United States or continue to be sent westbound into British Columbia. In SE Alberta, CP Rail operates approximately 10 switching locomotives and has 52 locomotives per day traveling through the region. July through October are busier months for freight transport with diesel consumption increasing by 1/3 as compared to the other months. CP Rail provides service to several industries situated in the Medicine Hat Industrial Complex, specifically the Brier Park industrial park, with switching engines being deployed.

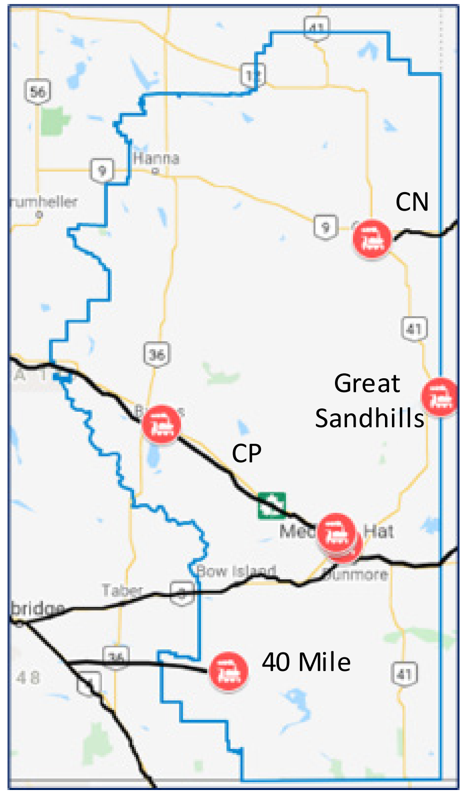


Figure 5.27 SE Alberta Rail Lines

Two short-line railroads servicing the region connect into the CP Rail network. Forty Mile Rail Inc. is primarily an agricultural service provider and is comprised of 75 km of rail from Foremost to the CP interconnect near Stirling, south of Lethbridge. The line sees on average two unit trains per week between the Southern Grain Exchange in Foremost and Stirling. The Great Sandhills Railway is a 198 km track that provides service within western Saskatchewan and at Empress/McNeill in Alberta. The rail line interconnects with the CP Rail network in Swift Current Saskatchewan. Great Sandhills Railway provides switching service to the Pembina and Plains operated straddle facilities at Empress/McNeill, in addition to NGL shipping service.

For the SE Alberta Region it is estimated that a total of 11ML of diesel is consumed for purposes of rail transport, which corresponds to 0.43 PJ of energy use annually. Utilizing an assumed 100% transition of Freight Rail to hydrogen and an efficiency of 55%, rail could account for an average of 4.5 t/day (1.7 kt/year) of hydrogen demand (**Table 5.6**).

Table 5.6 SE Alberta Hydrogen Potential - Rail

Transportation Sector	Comsump Total	Assumed Transition	Rel. Efficiency	Hydrogen Daily Ave	
	[PJ/yr]	%	[J H2 / J petro]	[kt]	[t/day]
Rail	0.43	100	0.55	1.7	4.5

Estimate of hydrogen potential for rail in SE Alberta based on 100% transition of the total fuel consumption based on a relative efficiency of 0.55.

At the end of 2020, CP Rail announced the company's intentions to develop North America's first line-haul hydrogen locomotive. Details of the pilot project released at the end of 2021 indicates, that in conjunction with a matching $15 million grant by Emissions Reduction Alberta (ERA), the pilot will be composed of three locomotives and a hydrogen production and fueling facilities located in Calgary and Edmonton. With the proximity of Calgary to SE Alberta and the direct rail connection between Calgary and Medicine Hat, expansion of the pilot to include line-haul locomotives may be a consideration. [149][150]

Alberta is well connected to the full North American rail network (**Figure 5.28**) and has consistently been within the top three exporting provinces by rail (approximately 22% of Canadian exports) with Fertilizer and Chemical shipments being amongst the highest tonnage of commodities hauled. For 2019, in Western Canada, chemical transport on rail accounted for approximately 5% by both carload and tonnage, whereas fertilizer transport accounted for 10% of carloads but 17% of tonnage. Exports from Alberta account for approximately 50% of total Canadian exports of Chemicals (38% of Alberta's exports), and 20% of Fertilizer exports (16% of Alberta's exports). [151][152][153][154][155][156][157][158] With the estimation that rail usage is three to four times more fuel efficient than truck traffic and that 1 freight train can remove upwards of 300 trucks, utilization of rail for hydrogen and carbon dioxide transport may be the key to providing export and delivery service in the short term while physical pipeline infrastructure is being constructed and in the long term where pipeline infrastructure cannot be economically constructed.

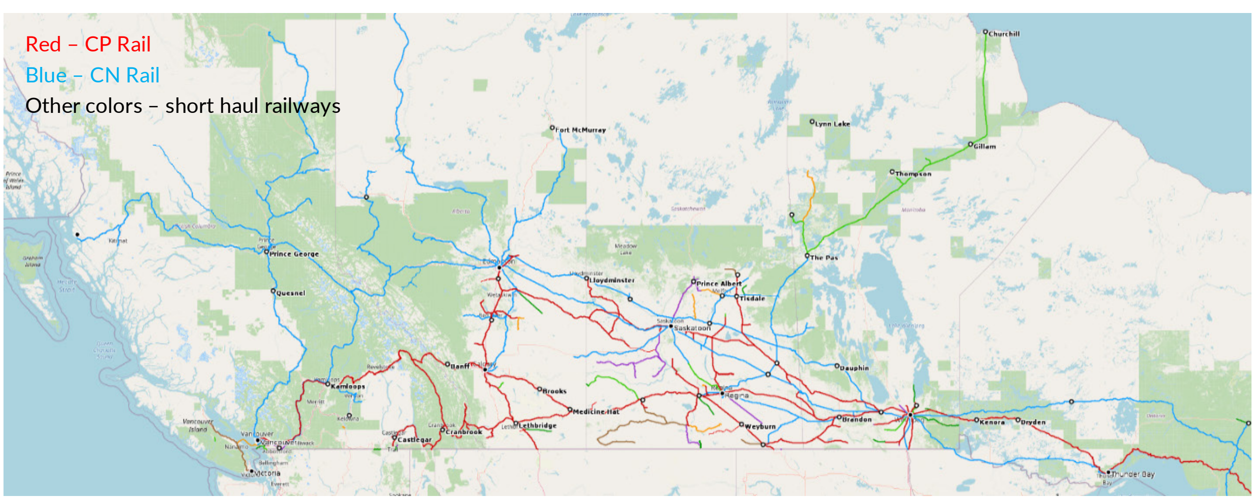


Figure 5.28 Canadian Railway Network

SOURCE: Railway Association of Canada Atlas

5.3.4 Aviation

SE Alberta has only one regional airport that services commercial airline traffic. The Medicine Hat Airport currently sees 10 flights between Calgary and Medicine Hat operated by WestJet Airlines. HALO Air Ambulance helicopter service is also situated at the airport and provides emergency services throughout SE Alberta. The other 11 regional airports and airfields provide service for charter and agricultural applicator flights. CFB Suffield has an airport to provide service to the base (**Figure 5.29**).

Consumption of both A1 Jet fuel (<1.5 ML) and Aviation Gasoline (<0.5 ML) accounts for less than 0.4% of the aviation fuel consumed within the province of Alberta. Due to the nature of the airports and the use of small piston driven aircraft for arial spraying operations, consumption of Aviation Gasoline represents 4% of the provincial consumption though only 22% of the aviation fuel consumption of the region. Transition of aviation to hydrogen will likely require hydrogen fueling services at Medicine Hat and some of the larger airports but will be of minimal impact with a demand of **0.6t/day** (200 t/year) (**Table 5.7**). [159]

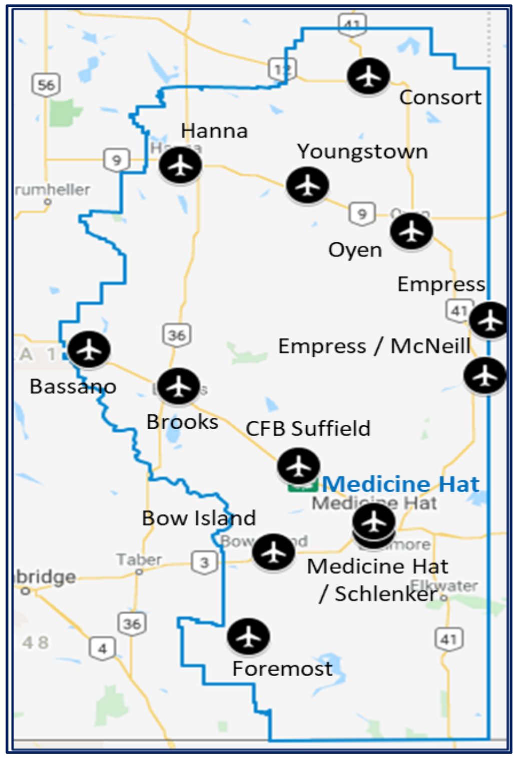


Figure 5.29 SE Alberta Airports

Table 5.7 SE Alberta Hydrogen Potential - Aviation

Transportation Sector	Comsump Total	Assumed Transition	Rel. Efficiency	Hydrogen Daily Ave	
	[PJ/yr]	%	[J H2 / J petro]	[kt]	[t/day]
Airplanes	0.06	50	1.00	0.2	0.6

Estimate of hydrogen potential for aviation in SE Alberta based on 50% transition of the total fuel consumption based on a relative efficiency of 1.0.

5.3.5 Transportation Hydrogen Transition Potential

Total Hydrogen transition potential for Transportation in SE Alberta has been estimated at **168 t/day (61 kt/year)** (**Table 5.8**). The vehicle class with the greatest transitional potential is with Truck and Trailer, heavy freight at 95 t/day hydrogen demand. This would be driven by freight transport associated with the corridor highways which cross the region in addition to the local industrial requirements. Additionally, the large geographic area associated with the rural portion of the region will create a significant hydrogen fueling demand. Seasonal fluctuations would result in an increased daily consumption of 15 to 20% during summer months as compared to winter.

Table 5.8 SE Alberta Hydrogen Potential - Total Transportation

Transportation Sector	Comsump Total [PJ/yr] A	Assumed Transition % B	C Rel. Efficiency [J H2 / J petro]	Hydrogen Daily Ave [kt]	D [t/day]
Passenger Vehicles (Urban)	0.59	10	0.40	0.2	0.5
Passenger Vehicles (Rural)	5.00	65	0.40	9.2	25.2
RV	0.71	50	0.86	2.2	5.9
Buses	0.26	55	0.59	0.6	1.6
Single Unit Heavy Truck (Urban)	0.28	20	0.86	0.3	0.9
Single Unit Heavy Truck (Rural)	3.18	65	0.86	12.5	34.3
Truck and Trailer	7.14	80	0.86	34.6	94.9
Rail	0.43	100	0.55	1.7	4.5
Airplanes	0.06	50	1.00	0.2	0.6
Total	**17.6**			**61**	**168**

Total fuel consumption (diesel & gasoline) for each class of vehicle [A] is provided in the table with the assumption of percentage of each vehicle class transition [B] and the relative efficiency of the hydrogen transition for each class [C]. This results in the estimated hydrogen potential for each class and presented on a total annual and daily basis [D].

5.4 Nature Gas Utility – Building Heat

Natural Gas consumption represented 55% of the total energy consumption for the province at **2,321 PJ** in 2020 (**Table 5.9**). Of the provincial consumption, 321 PJ is for residential heating, commercial heating, and

Table 5.9 2020 Natural Gas Consumption by Category

Purpose	Alberta TJ	Alberta %	SE Alberta TJ	SE Alberta %	% of provincial consumption
Power Generation	467,609	20.1%	56,537	33.2%	12.1%
Transportation	83,506	3.6%	24	0.0%	0.0%
Industrial Fuel	933,102	40.2%	40,382	23.7%	4.3%
Residential Heating	169,997	7.3%	4,467	2.6%	2.6%
Commercial Heating	146,353	6.3%	3,521	2.1%	2.4%
Agriculture	5,014	0.2%	2,247	1.3%	44.8%
Industrial Feedstock	64,750	2.8%	51,997	30.6%	80.3%
Producer Consumption	450,319	19.4%	10,998	6.5%	2.4%
TOTAL	**2,320,650**		**170,171**		**7.3%**

Total natural gas consumption by sector in Alberta and the corresponding consumption within the SE Alberta region. Percentage of use by SE Alberta of total for province is calculated.

agriculture, and could be classified as space heating, with all of these typically supplied by natural gas distribution utilities.

5.4.1 Space Heating

For SE Alberta, total natural gas consumption attributable to residential and commercial heating via natural gas distributer utilities was **10.2 PJ** in 2020. When compared to provincial consumption, the most significant regional difference is the volume attributable for agricultural use. Agricultural use of natural gas in SE Alberta is equivalent to 50% of the residential usage in the region and 45% of the total agricultural use throughout the province. Agriculture utilizes natural gas for various purposes such as space and water heating of various buildings and barns, boiler operations, grain drying, and irrigation pumps.

In SE Alberta, Medicine Hat and Redcliff account for slightly greater than half of the total residential and commercial demand and is supplied via the City of Medicine Hat owned natural gas distribution utility system and represents the largest single distribution system in the region (**Figure 5.30**). Rural consumption represented 33% of the total volume, distributed by a network of independent rural gas co-ops as detailed in **Section 4.4.2 (Table 4.2)**. [160][161]

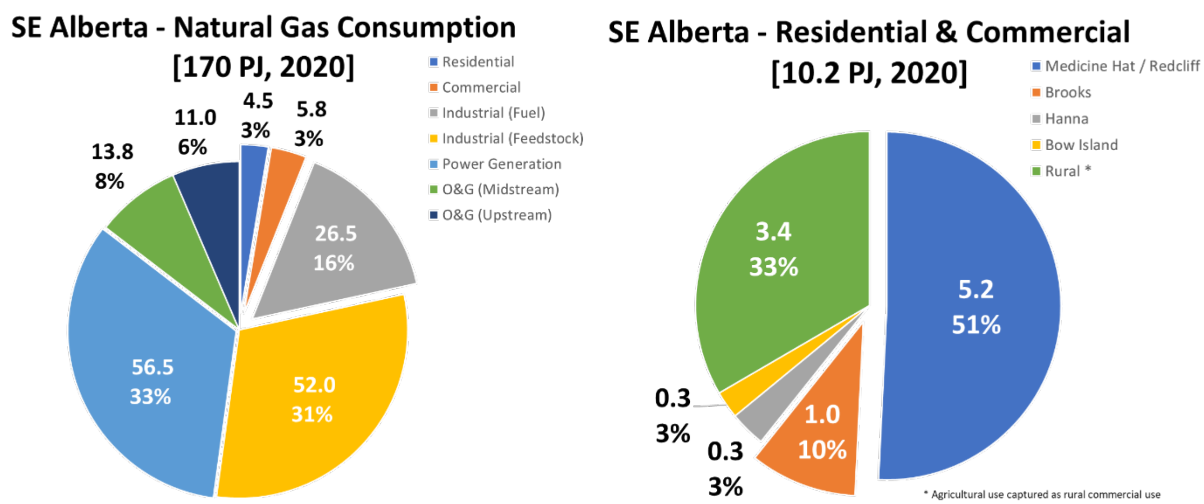


Figure 5.30 SE Alberta 2020 Natural Gas Consumption

Power generation represents the single largest natural gas consuming sector in SE Alberta, slightly greater than industrial feedstock. Residential and Commercial consumption represent 6% of total consumption with commercial demand being slightly greater than residential. Medicine Hat / Redcliff represents slightly more than half of the total residential and commercial consumption, with rural consumption, inclusive of agricultural use, being the second largest demand.

5.4.2 Space Heating Hydrogen Transition Potential

Utilizing the assumption of 75% transition to hydrogen and a relative efficiency factor of 1.065 J H_2 / J NG, to accommodate for the heating value differences between natural gas and hydrogen, total hydrogen potential in SE Alberta is estimated at **158 t/day (58 kt/year)** (**Table 5.10**). However, unlike other energy demands, significant seasonal variations occur for space heating due to the impact of cold weather and results in a five to eight times increase in consumption during the winter, with even greater extreme variations occurring on a given day, dependent on the severity of the seasonal event. This fluctuation could result in maximum daily requirement that is greater than 100% of the annual average daily volume.

Table 5.10 SE Alberta Hydrogen Potential - Total Natural Gas Space Heating

			A	B			Hydrogen Transition C				D	
	Residential	Commercial	Total	Rel. Eff.	[75%]		Summer	Winter	Min	Max	[20%]	
	[PJ/yr]	[PJ/yr]	[PJ/yr]	[J H_2 / J NG]	[kt]	[t/day]	[t/day]	[t/day]	[t/day]	[t/day]	[Mt]	[t/day]
Medicine Hat / Redcliff	2.49	2.70	5.2	1.065	29.3	80.2	26.5	128.4	24.1	160.5	7.8	21.4
Brooks	0.49	0.53	1.0	1.065	5.7	15.7	3.9	26.7	3.1	35.4	1.5	4.2
Hanna	0.19	0.15	0.3	1.065	1.9	5.3	1.3	9.0	1.1	11.9	0.5	1.4
Bow Island	0.13	0.14	0.3	1.065	1.5	4.0	1.0	6.9	0.8	9.1	0.4	1.1
Rural *	1.17	2.25	3.4	1.065	19.3	52.8	5.3	29.5	2.7	392.9	5.1	14.1
Total SE Alberta	4.5	5.8	10.2		58	158	38	200	32	256	15	42

* Agricultural NG consumption included under Rural Commercial volumes for purposes of this table

Total residential and commercial natural gas consumption by municipal area [A] is used to determine the hydrogen transition potential based on a relative efficiency of 1.065 and 75% transition[B]. Due to seasonal variations in use, estimated hydrogen demand for summer and winter seasons have been estimated with a minimum and maximum demand indicated corresponding to historical natural gas use [C]. As short-term transition may be initially limited to 20% transition, the corresponding annual average hydrogen volumes have been estimated [D]

A representation of the monthly hydrogen demand potential for the various distribution systems within SE Alberta can be seen in **Figure 5.31,** based on historical natural gas consumption in each area. Typical seasonal fluctuation can be observed in urban residential and commercial demand as well as the unique demand requirements for agriculture, which requires significant supply during the summer and fall. On a regional basis, the agricultural demand partially offsets the typical seasonal fluctuations, though this would not necessarily be within the same distribution network. With the hydrogen requiring three times the volume to achieve the equivalent energy supply and infrastructure unlikely to be built out to the same degree as natural gas, the seasonal fluctuations and the increased winter demand will likely result in hydrogen supply being

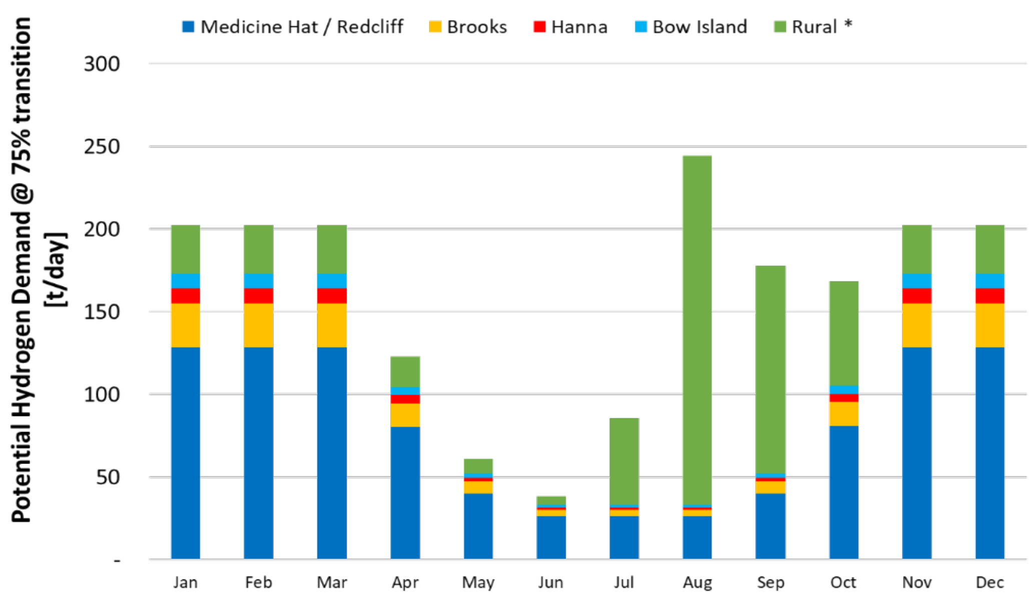


Figure 5.31 SE Alberta Potential Monthly Residential & Commercial Hydrogen Demand

Monthly hydrogen demand variance forecast utilizing average monthly natural gas demand data, relatively constant throughout the year and thus result in being a varied percentage of total supply dependent on total energy requirements. This could see potential hydrogen supply of 100% of energy requirements during the summer and lesser percentage in the winter, with natural gas or electric heating providing the nimble make up supply for peak demand.

5.5 Electrical Generation

SE Alberta current installed generation capacity of **1,718 MW** represents approximately 10% of the total generation capacity of the province, **17,224 MW** (**Figure 5.32**). In 2021, total physical generation for the province, before intertie imports was **81,213 GWhr** or equivalent to an average hourly generation of **9,271 MW** (**Figure 5.33**). This represents an average realized capacity factor of 53.8% for the total system. For SE Alberta, total estimated physical generation for 2021 was **6,955 GWhr** or an equivalent average hourly generation of **793 MW**, delivering an average realized capacity factor of 46.2%. SE Alberta contributed 8.6% to the total provincial generation. Total Alberta Internal Load (AIL) for 2021 was 85,214 GWhr, with 4,018 GWhr being supplied via intertie imports from British Columbia, Montana, and Saskatchewan. The Saskatchewan intertie is at McNeill within the SE Alberta region and represented 16% of the imports in 2021.

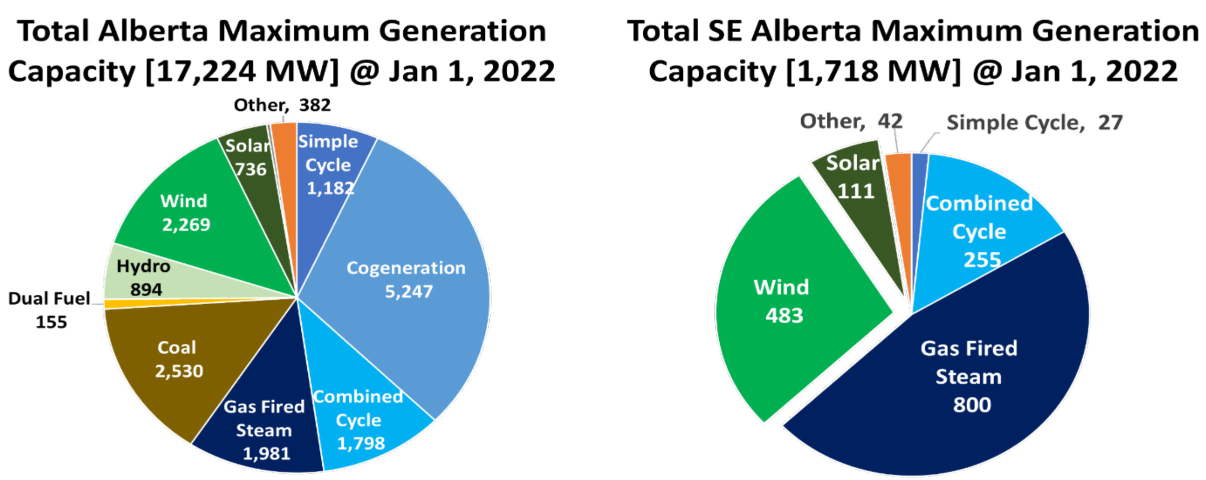


Figure 5.32 Total Electrical Generation Capacity for Alberta and SE Alberta Region at January 1, 2022
Total natural gas fueled generation capacity for Alberta is 59% of the total available capacity as compared to 63% for SE Alberta. However, renewable generation makes up 35% of SE Alberta's generation capacity whereas only 23% for the province.

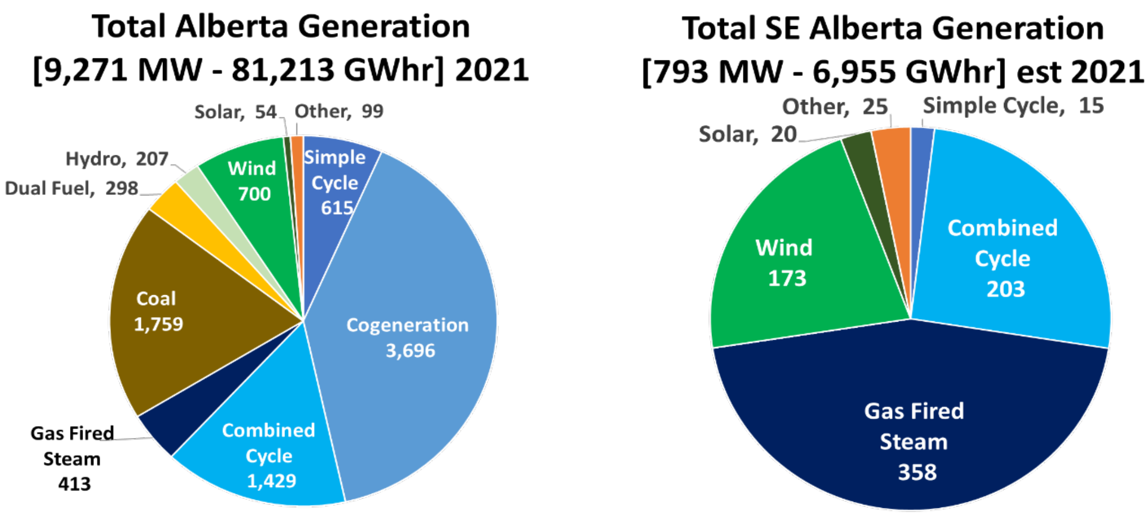


Figure 5.33 Total 2021 Electrical Generation for Alberta and SE Alberta Region

In 2021 natural gas fueled generation accounted for 66% of actual power generation in the province as compared to 73% in SE Alberta. Renewable power generation accounted for 10% of actual power generation for the province and 24% in SE Alberta.

5.5.1 Demand

SE Alberta regional demand has remained consistent since 2017 at approximately **650 MW** (**Figure 5.34**). Within the region, demand by area can be observed (**Figure 5.35** and **Table 5.11**) and correlated to the source of the demand. The Empress Area is the largest load area in the region reflective of the Empress / McNeill straddle plant complex. The industrial nature of the demand introduces very little seasonal fluctuation. The Medicine Hat and Brooks areas correspond to demand from both cities, which corresponds to a mixture of industrial and residential demand. Some seasonal fluctuation can be observed which would correspond to peak demands in the winter for lighting and electrical heating, as well as lesser increases in the summer corresponding to air conditioner use. The Vauxhall area, which corresponds to the County of Forty Mile and the southeastern potion of the County of Newell, Sheerness, and Hanna areas are reflective of rural agricultural dominated demand. Similar winter/summer cyclic demand can be observed however peak demand in summer is equal or greater than peak winter demand. This, like natural gas utilities previously discussed, reflects the high summer and fall energy consumption by the Agricultural sector.

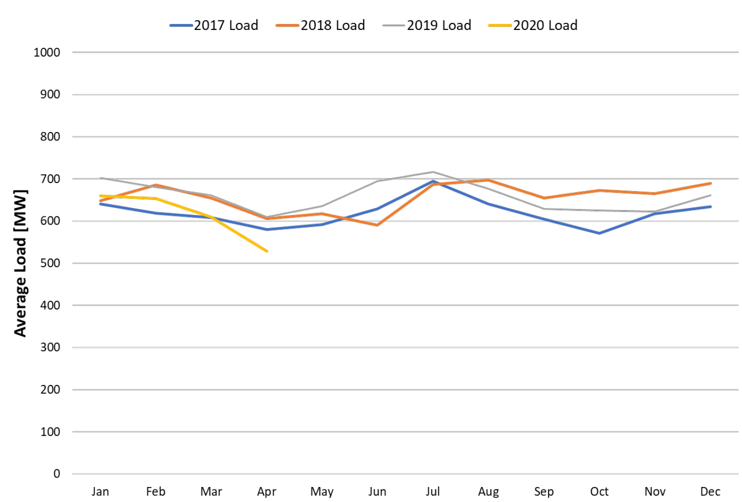


Figure 5.34 SE Alberta Historical Monthly Load

Consistent load profile for SE Alberta from 2017 to 2020

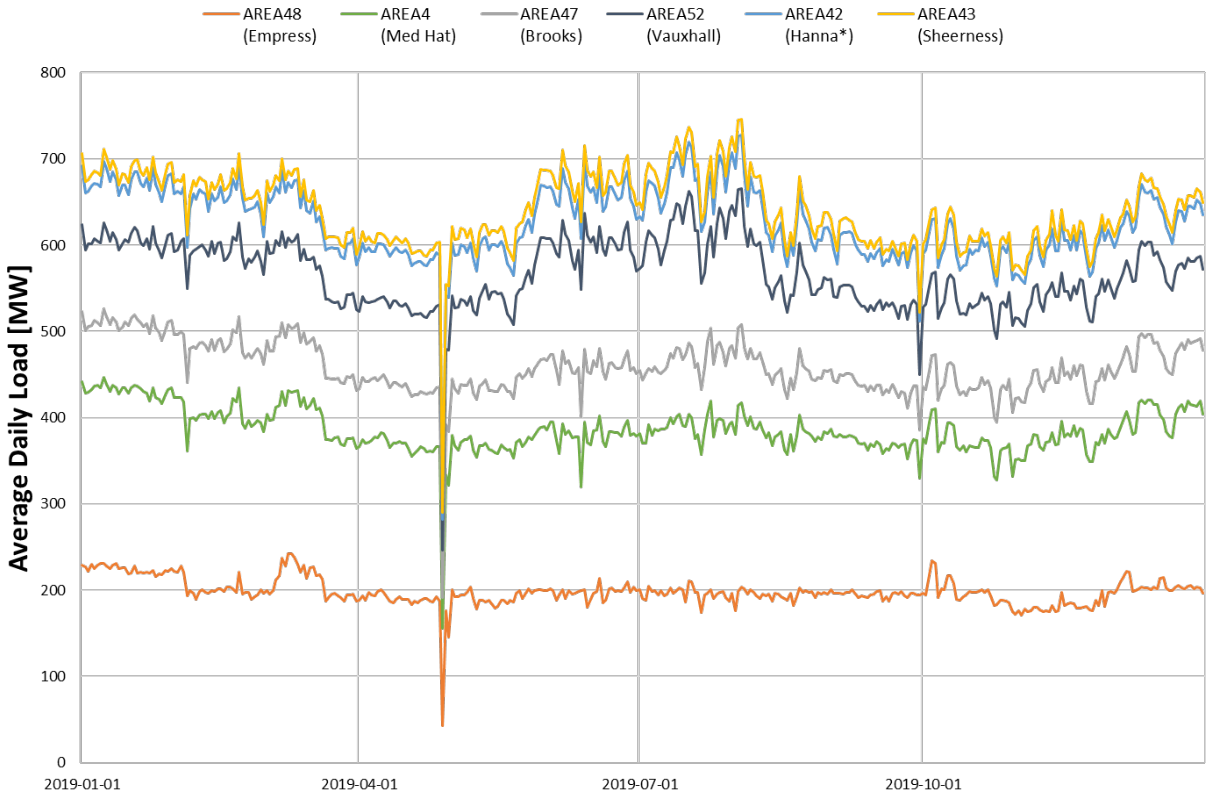
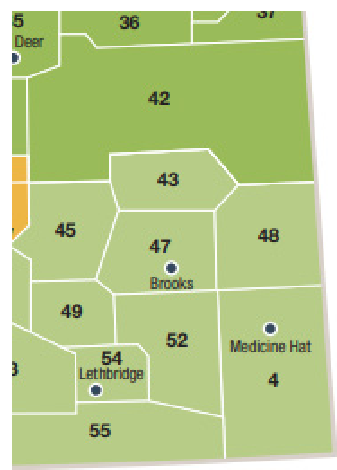


Figure 5.35 2019 SE Alberta Regional Load by Area

Table 5.11 2019 SE Alberta Load by AESO Transmission Planning Area

	annual average 2019	*min*	*max*
TOTAL LOAD [MW]	**641**	**522**	**746**
AREA 48 (Empress)	198	146	243
AREA 4 (Med Hat)	188	121	221
AREA 52 (Vauxhall)	108	64	176
AREA 47 (Brooks)	73	56	91
AREA 42 (Hanna*)	60	38	71
AREA 43 (Sheerness)	14	9	21

** For purposes of evaluating SE Alberta Region, 35% of area 42 was utilized.*



Empress and Medicine Hat represent the two largest electric load areas in SE Alberta. Empress load driven by Empress/McNeill petrochemical cluster whereas Medicine Hat load a combination of residential, commercial, and industrial load.

5.5.2 Generation

SE Alberta is a net exporter of power to other regions of the province. In 2019 the region had an average load of 660 MW and physically generated an average of 783 MW from the total available capacity for the year of 1,207 MW. This represents a 65% capacity factor, reflective of the natural gas and natural gas / coal fired steam base load generation and relatively low renewable contribution. [162][163][164][165]

The largest generation sources currently operating in the region are the Heartland Generation's twin unit Sheerness generation facility, at total capacity of 800 MW, the City of Medicine Hat's combined cycle generation, at 255 MW, and the Capital Power Whitla 1 & 2 wind farms, at 353 MW.

In 2019, the generation capacity was comprised of 7% renewable energy. As of Jan 1, 2022, the 512 MW growth in generation capacity for the region, since 2019, has been exclusively renewable energy, increasing the percentage of total renewable capacity in SE Alberta to 35%. Actual capacity factor for the region in 2021 dropped to 52%, reflecting the partial year of generation from a number of new renewable energy projects. Utilizing the average capacity factors for various types of generation from 2021, the expected capacity factor for the currently active generation in 2022 would decrease to 46%, further reflecting the impact of added renewable generation. **Figure 5.36** demonstrates that even though total capacity for the region grew by 42% from 2019 to 2022, actual generation is only expected to grow by 1%.

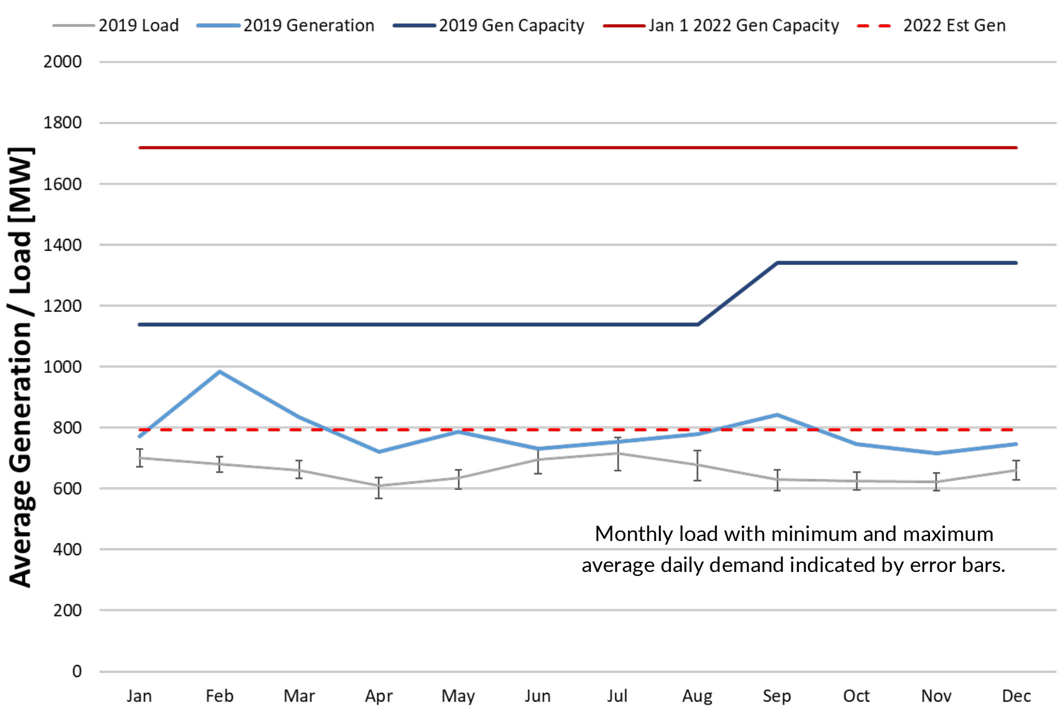


Figure 5.36 SE Alberta – Load | Generation | Capacity

SE Alberta load in 2019 was satisfied by actual generation from the region with no excess generation during peak demand periods in June and July. In spite of significant capacity additions from 2019 to 2022, forecast generation in 2022 is not significantly greater than 2019 generation due to increase of low-capacity factor renewal generation.

The actual generation by project is compared to total available capacity for SE Alberta for the period of 2017 to 2021 is shown in **Figure 5.37**. In 2021, the increased generation from wind, 35% capacity factor, and solar, 17% capacity factor, was offset by decreased generation at the Sheerness facility, which had been under transition from coal to natural gas, resulting in little growth in actual generation even though total capacity increased significantly. The Sheerness facility completed its conversion from coal to natural gas at the end of 2021 and may see an increase in generation as compared to the 2020 to 2021 period.

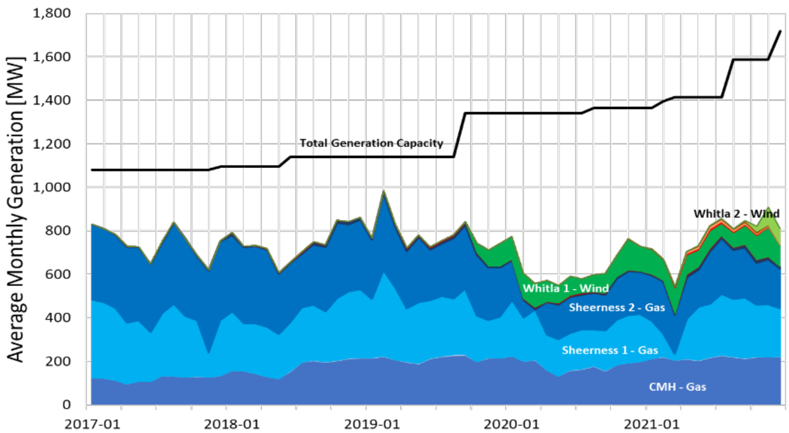


Figure 5.37 Historical SE Alberta Generation and Total Capacity

Increase in total generation capacity for SE Alberta has not resulted in material increase in actual generation due to the low-capacity factors realized by renewal generation projects.

SE Alberta continues to see a build out of incremental generation in the region. **Figure 5.38** illustrates the current generation in the region, along with the active under construction projects, as well as additional projects that are at various stages of development from announcement to approval.

In 2016 the Government of Alberta implemented a program through AESO to bring on new renewable generation capacity. The goal of the Renewable Electricity Program (REP) was to increase renewable generation to 30% of the total generation capacity in Alberta by 2030. [165] SE Alberta was an active participant in the bidding process as six of the nine awarded projects in REP 1, 2 and 3, were in the region for a total capacity of 892 MW. Having been awarded in 2017, 2018, and 2019, all of the projects were to have been on stream by 2021. However, only one of the SE Alberta projects had been energized and included within the Jan 1, 2022, capacity. The remaining projects, including two with 25% indigenous ownership, are currently active and planned to be operational by the end of 2023. In 2019, the Government of Alberta discontinued the program, with the intention of continuing to grow renewable power generation through positive market forces.

Figure 5.39 illustrates the potential growth in SE Alberta generation capacity. 1,345 MW of new generation is anticipated to be completed and energized by the end of 2023, bringing SE Alberta total generation capacity to 3,063 MW. This would increase the percentage of renewable power generation from 35% to 62%. In addition to these projects, there are an incremental 2,175 MW of approved projects and 7,793 MW of announced projects in SE Alberta for a total potential generation capacity of 13,031 MW and representative of 83% renewable energy.

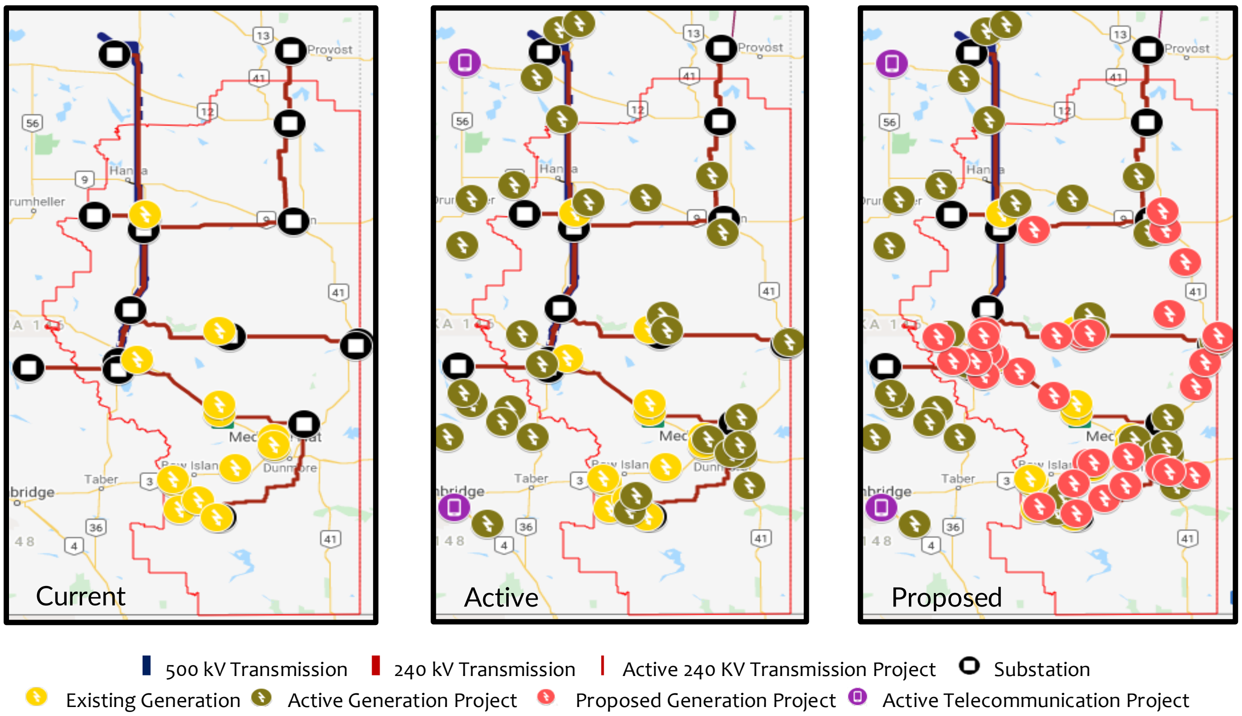


Figure 5.38 Current and Proposed Generation Projects – SE Alberta

Continued build out of new generation projects in proximity to existing 240 kV Transmission infrastructure.

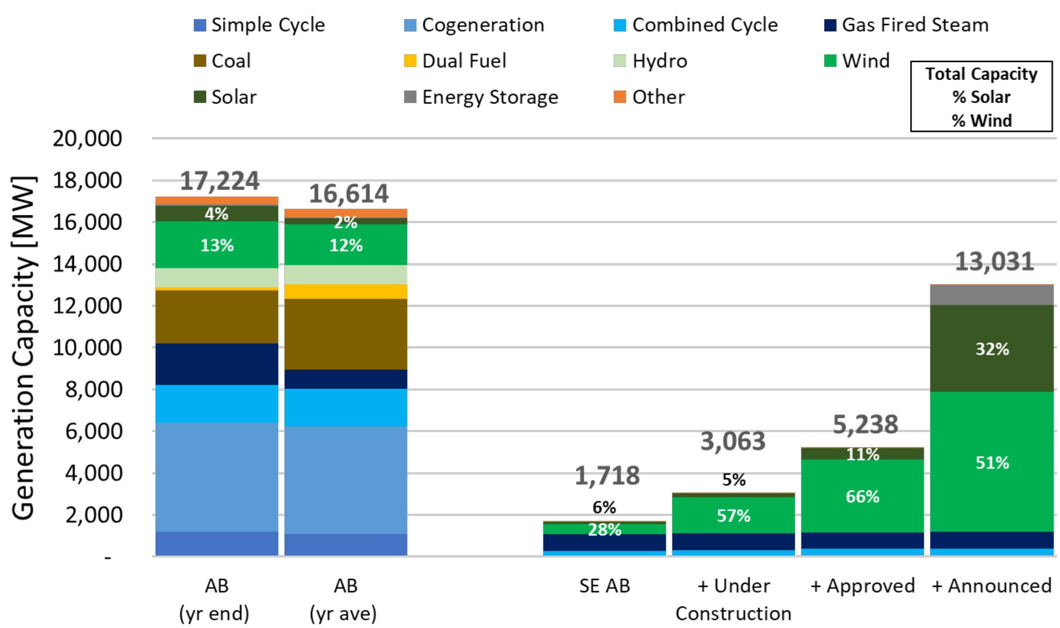


Figure 5.39 2021 Power Generation Capacity and Potential Generation Growth for SE Alberta

5.5.3 Transmission & Distribution

In the 2019 Transmission Capability Assessment report by AESO, it was acknowledged that post REP 1, 2 and 3 that optimal integration capacity in the central east / southeast part of the system would be reduced to 130 MW or lower dependent on the specific connection strategy utilized. To accommodate future generation growth the Central East Transfer-out (CETO) transmission plan was developed that would add approximately 1,000 MW of incremental integration capacity. [166][167][168][170][171]

In the updated 2022 Long-term Transmission Plan (LTP), it was indicated that the upper limits on congestion in the central east / southeast was realized in 2021 and that CETO was approved to move forward, with re-affirmation of congestion to be completed in 2022 and direction for transmission construction to be delivered to AltaLink for an in-service date between 2025 and 2027. The CETO project is at the northern end of the SE Alberta region and will accommodate greater transmission offtake to the Red Deer area. This project is anticipated to provide 700 to 900 MW of capacity to accommodate new renewable projects. Further development interests in this area are predicated on the forecast schedule for retirement of Sheerness. Initially, retirement was presumed to occur in 2024. However, with the conversion of the generation to natural gas from coal, a retirement of 2030 or potentially later could be anticipated.

With the increased renewable energy growth and build-out in the Medicine Hat area, the Whitla segment has been identified as approaching capacity and thus a Southeast Transmission Reinforcement (SETR) project has been identified with three various options to provide incremental transmission from the area to accommodate future renewable projects. However, even though it has been acknowledged that the aggregate capacity of the proposed projects exceeds the capacity of the existing transmission network, the SETR project has been deemed a milestone project similar to CETO and will need approval and re-affirmation once new projects have been completed and congestion can be confirmed. Only at that point in time will a formal project be brought forward, which may include one of three options: i) a 240 kV double circuit between Bowmanton to Cypress, ii) a 240 kV double circuit from Whitla to Picture Butte in southwest Alberta and further connection between Picture Butte to Milo, or iii) a direct 240 kV double circuit from Whitla to Newell and connection to the 500 kV EATL. Potential completion of SETR, if it does proceed, would be in the 2029 timeframe, assuming re-affirmation of congestion in 2023.

Between 2019 and 2022, there has been an acknowledgement by AESO that the pace of energy transition has accelerated, along with the pace of renewable development, whether it is smaller distribution connected projects or large developments backed by Power Purchase Agreements. This aggressiveness has led to a disconnect between the time for generation project construction and the time for transmission construction, particularly when these projects occur in net outflow areas.

As renewable generation has different fault responses and frequency response characteristics from conventional base load generators, the shifting in supply mix is starting to impact the frequency performance of the system. The 2022 LTP seeks to optimize existing transmission by providing guidance on pace of development, use of Remedial Action Schemes and other optimization measures first prior to looking for additional transmission. Planned congestion and curtailment could be an option that is pursued to manage system performance.

The rate of change of frequency of the power system is affected by the increased prevalence of Inverter-Based Resources (IBR), such as wind and solar, and the retirement of synchronous machines. The kinetic energy stored in synchronously rotating mass provides the immediate response following a loss of supply or demand and arrests a too large of a decline in the frequency of the system and potential cascade of trips and instability of the power system. An additional reliability concern related to the increased prevalence of IBR's is the inability for these projects to provide expected real and reactive power on the system and the potentially for voltage instability.

To address these issues, AESO has identified the need for increased connection of Primary Frequency Response (PFR) devises which could include generator response, load response, or fast frequency response across the interconnected electric system. Hydrogen can play a meaningful role in addressing these concerns, whether it is in the form of combustible hydrogen peaking plants or the introduction of hydrogen fuel cells to be available for immediate discharge when required. Hydrogen generation is also a means to address congestion, system optimization and off-peak renewable power generation in excess of baseload requirements, by optimizing the capital expenditure on transmission infrastructure and maintaining an overall higher system capacity factor.

Historic overall capacity factor for provincial generation has been 60% [172]. With the introduction of increased amounts of renewable energy, the capacity factor has been decreasing and was 56% in 2021. Specific to SE Alberta, the increase in renewable power has resulted in the capacity factor for the region to decline from 65% in 2019 to 52% in 2021. Utilizing average capacity factors for solar and wind adds in the future, this SE Alberta capacity factor will likely decrease to 42% with energizing of current active projects and potentially as low as 32% if all approved and announced projects were to proceed (**Figure 5.40**).

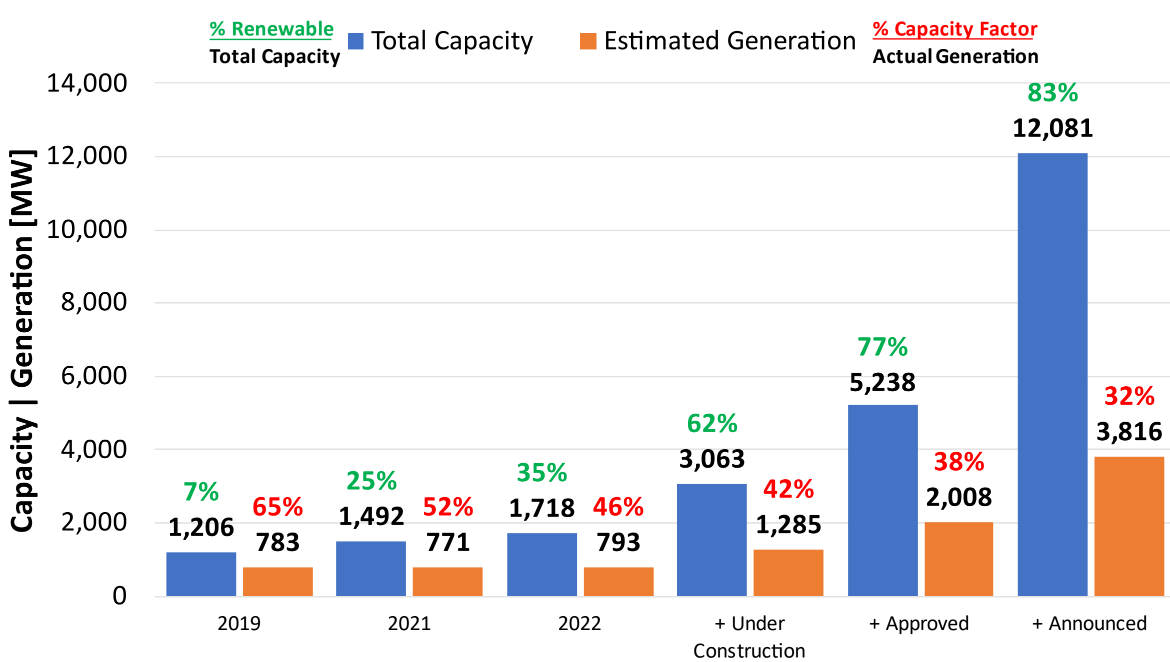


Figure 5.40 SE Alberta Total Capacity and Generation – Renewable and Capacity Factor

5.5.4 Electrical Generation Hydrogen Transition Potential

The combination of the large potential for future renewable energy growth in the region, the resulting decrease in overall generation capacity factor and impact on system stability, the identified transmission capacity limitations, as well as the increased off-peak generation, creates a strong environment for coupling of power generation and hydrogen transition in SE Alberta.

Utilizing hydrogen as a displacement fuel for existing natural gas combustion generation, would address projects that are unable to utilize CCUS to reduce CO_2 emissions. Using an assumption of 25% displacement of existing natural gas would result in **264 t/day (97 kt/year)** of hydrogen demand at a relative efficiency of 3 GJ H_2 / GJ e-.

In utilizing hydrogen as a PFR to address the transmission stability and optimization issues presented by renewable generation, an incremental demand of **214 t/day (78 kt/year)** would be realized to achieve an overall system capacity factor of 55% or greater, based on supplementing 15% of the wind generation capacity and 40% of the solar generation capacity of existing generation projects. An incremental **379 t/day (139 kt/year)** of hydrogen demand would be associated with renewable projects currently under construction.

Table 5.12 SE Alberta Hydrogen Potential – Total Electrical Generation

	A	B	C	D		E	
Installed	Installed Capacity (Jan 1 2022) [MW]	Estimated Generation [GWh]	Energy Equiv [Pje-/yr]	H_2 Demand* [%]	Relative Efficiency [GJ H_2/GJ e-]	Hydrogen [kt H_2/yr]	Hydrogen [t H_2/d]
Gas - Simple Cycle	27	133	0.5	25%	3.00	3	7
Gas - Cogeneration							
Gas - Combined Cycle	255	1,776	6.4	25%	3.00	34	93
Gas - Gas Fired Steam	800	3,133	11.3	25%	3.00	60	164
Wind	483	1,513	5.4	15%	3.00	48	133
Solar	111	173	0.6	40%	3.00	30	81
Other	42	221	0.8				
Total SE Alberta 1	1,718	6,948	25			174	477
Under Construction							
Gas - Simple Cycle	27	133	0.5	25%	3.00	3	7
Gas - Cogeneration							
Gas - Combined Cycle	299	2,082	7.5	25%	3.00	40	109
Gas - Gas Fired Steam	800	3,133	11.3	25%	3.00	60	164
Wind	1,736	5,435	19.6	15%	3.00	174	476
Solar	160	249	0.9	40%	3.00	43	117
Other	42	221	0.8				
Total SE Alberta 2	3,063	11,253	41			318	872

* H2 Demand based on actual estimated generation for Gas and on installed capacity for Wind & Solar

Table has the total installed capacity for the various generation projects in SE Alberta [A] split by currently installed capacity as of Jan 1, 2022 [1] and total capacity inclusive of active under construction projects [2]. Using 2021 capacity factor by generation type, an estimated generation is determined [B]. The generated power is shown as an energy equivalent [C] which is then used along with the relative efficiency and hydrogen demand assumptions [D] to determine the hydrogen potential [E].

Total potential in SE Alberta for hydrogen transition in the Electrical Generation sector would be **872 t/day (318 kt/year)** (**Table 5.12**).

This volume of hydrogen does not include the potential supply or demand that the SE Alberta electrical generation sector could provide through use of excess regional electrical generation or from the development of future projects, such as the ones previously identified as approved or announced, whether grid connected or as off grid generation projects. This green hydrogen generation would contribute to the reduced cost of generation and become an enabler for further hydrogen transition in the area or as a premium export commodity, whether in pure hydrogen form or as a hydrogen carrier.

5.6 Industrial

SE Alberta's diverse industry consumes approximately **121 PJ** of energy, primarily based on local natural gas and power resources. This represents 4.7% of the provincial energy consumption for industrial purposes, **2,564 PJ** (**Table 5.13**).

Table 5.13 2020 Energy Consumption for Industry by Category

Energy Source	Alberta		SE Alberta		% of provincial consumption
	PJ	%	PJ	%	
Industrial - Resource	**833**	**32.5%**	**11**	**9.1%**	**1.3%**
Natural Gas	688	82.7%	11	100.0%	1.6%
Power	62	7.5%			
Coke	56	6.7%			
Other	26	3.1%			
Industrial - Feedstock	**562**	**21.9%**	**52**	**42.8%**	**9.2%**
NGL	379	67.5%			
Natural Gas	65	11.5%	52	100.0%	80.3%
Other	118	21.0%			
Industrial - Fuel	**1,169**	**45.6%**	**58**	**48.1%**	**5.0%**
Natural Gas	933	79.8%	40	69.1%	4.3%
Power	104	8.9%	14	24.1%	13.5%
Diesel	62	5.3%	4	6.9%	6.4%
Other	70	6.0%			
TOTAL	**2,564**		**121**		**4.7%**

Total energy of each fuel source utilized for the three industrial sub categories in Alberta and its corresponding consumption within the SE Alberta region. Percentage of use by SE Alberta of total for province is calculated.

Energy consumption for purposes of resource extraction has been assumed to be 4% of the total natural gas recovered in the region. This represents a smaller fraction of energy consumption for resource recovery than what is seen on a provincial basis and is reflective of the less intensive nature of production operations prevalent. This estimate may be conservative, however does not have an impact for purposes of this report as transition of resource extraction energy has not been considered for purposes of hydrogen potential.

Industry in SE Alberta utilizes 80% of the natural gas consumed in the province for purposes of a feedstock, which corresponds to the region being situated within the AECO market hub area and the historical prevalence of natural gas production. This would ultimately be attractive to a natural gas focused industrial consumer as it would provide ease of access to a plentiful and low-cost supply.

The coupling of the municipal economic development drivers associated with the City of Medicine Hat electrical generation assets results in favourable conditions to attract high electricity consuming industries to the Medicine Hat Industrial Complex, such as the Hut 8 crypto mining company. This results in a higher proportion of power usage amongst SE Alberta industry as compared to provincial usage.

5.6.1 Oil & Gas

As of the end of 2021, the region has produced 25 trillion cubic feet of natural gas, 1.2 trillion barrels of oil, and 16.8 trillion barrels of water. At the end of 2021, monthly production consists of 21 billion cubic feet of natural gas per month, 1.9 million barrels of oil per month, and 46.6 million barrels of water per month (**Figure 5.41**). [174][175][176][177]

Oil production from the region, 62.4 thousand bbls/d, represents 15% of the total crude oil production of the province of 424.2 thousand bbls/d (**Figure 5.42**). Due to continued application of horizontal drilling and completion techniques and enhanced recovery, production is forecast to grow by 10% to 70 thousand bbls/day.

Gas production for the region, 676 mmcf/d, represents 7% of the province's 10.2 Bcf/day (**Figure 5.43**). Production is forecast to decrease by approximately 55% by 2030 to 315 mmcf/day. However, due to the shallow decline of the gas wells in the SE Alberta, the region's remaining recoverable gas reserves are estimated at 4.2 Tcf with an energy content of 4,441 PJ, representing 16% of the remaining reserves in Alberta, 25.7 Tcf with an energy content of 28,517 TJ. Expressed in term of a reserve life index (number of years of production at current rate) this would suggest SE Alberta has a natural gas reserve life index of 16.9 years, compared to 6.9 years for the province, as it applies to discovered and developed reserves.

On a regional gas consumption basis, SE Alberta, as indicated in **Section 5.1**, consumed 170.2 PJ of natural gas in 2020. On a standalone basis, the remaining recoverable gas reserves for the region would represent 26 years of equivalent consumption, as compared to 12.3 years on a total provincial basis.

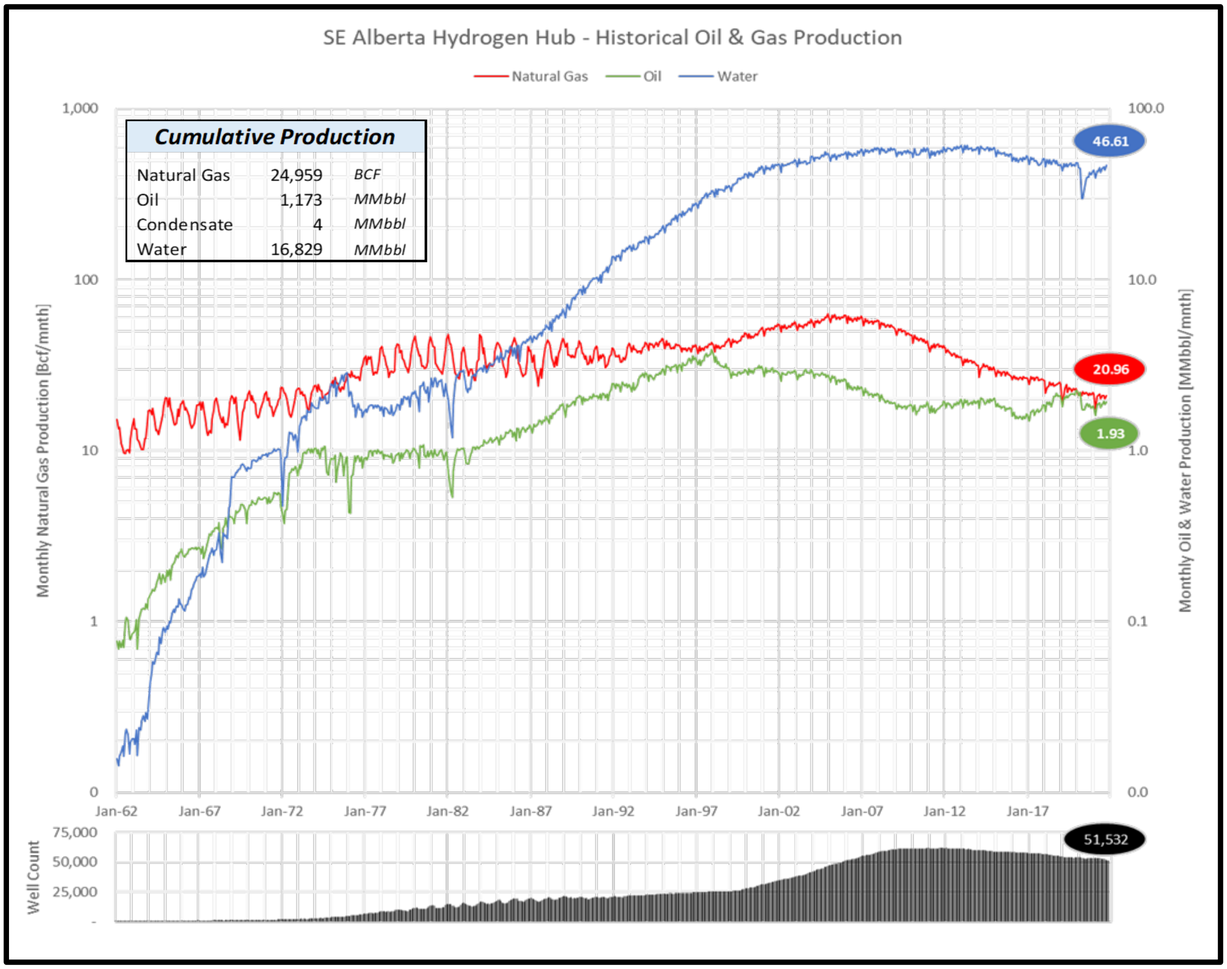


Figure 5.41 SE Alberta Oil, Gas, and Water Production

Monthly production and producing well count for SE Alberta for crude oil, natural gas, and water from 1962 to 2021. Peak natural gas production occurred in 2005, with drop in new natural gas well drilling in 2009. Peak crude oil production occurred in 1998, and peak water production occurred in 2013. Oil production has remained stable with implementation of enhanced recovery.

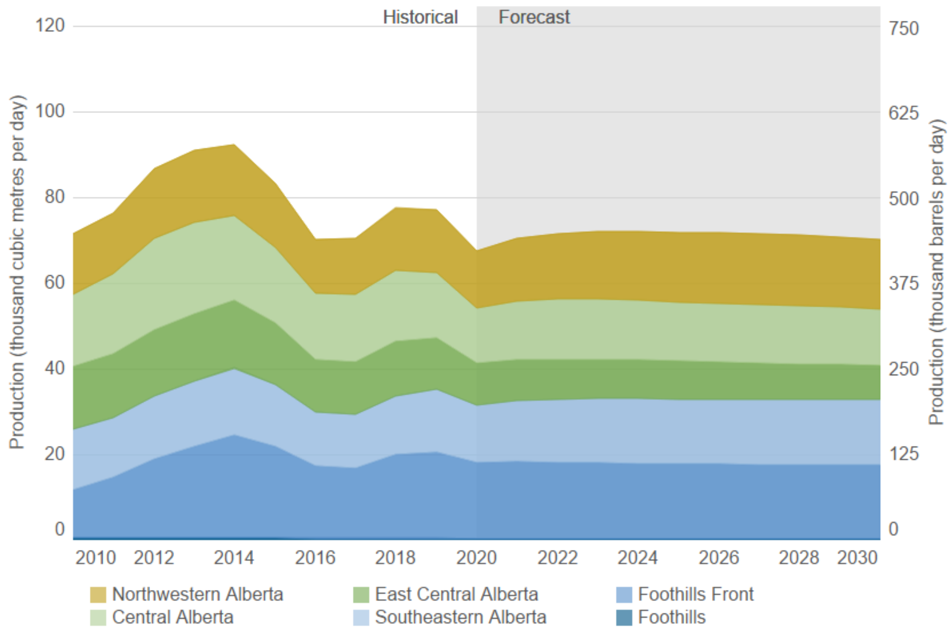


Figure 5.42 Average Daily Crude Oil – Historical Production and Forecast

Alberta Energy Outlook June 2021: Provincial daily crude oil production by PSAC Area. SE Alberta oil production has increased by 5% since 2010 and is forecast to grow by 10% by 2030. Does not include crude bitumen production.

SOURCE: Alberta Energy Outlook: 2021 (aer.ca)

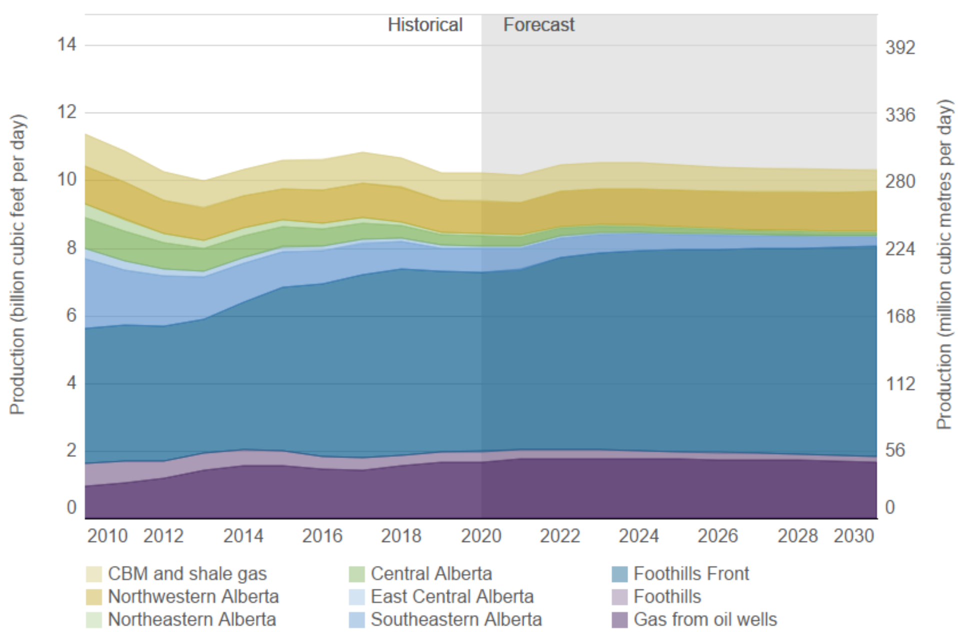


Figure 5.43 Average Daily Marketable Natural Gas – Historical Production and Forecast

Alberta Energy Outlook June 2021: Provincial daily marketable natural gas production. Due to minimal drilling activity focused on shallow gas since 2012, SE Alberta natural gas production has declined by 60% since 2010 and is forecast to decline by 55% by 2030.

SOURCE: Alberta Energy Outlook: 2021 (aer.ca)

5.6.2 Industrial Hydrogen Transition Potential

SE Alberta will remain an attractive region for natural gas and electricity dominant industry due to the region being able to offer ease of access and the lowest cost for these resources. This would include traditional industry as well as emerging hydrogen focused industries.

Hydrogen will have a role in transitioning industrial fuel requirements where carbon sequestration is not a viable option. As natural gas will remain a required commodity for purposes of feedstock, limited transition will likely occur for transition of natural gas fuel due to the reality of one common delivery stream for natural gas, for both feedstock and fuel. Where CCUS is not available hydrogen would need to be accessible via a separate inlet stream, whether as delivered hydrogen, a separate comingled hydrogen and natural gas pipeline, or an ability to generate hydrogen on demand at site from natural gas inlet (such as previously discussed pyrolysis process). For purposes of this report, it is assumed that no transition of natural gas fuel in industry will occur in a meaningful way.

One area that transition will occur is through the diesel-powered construction equipment, similar to hydrogen introduction into transport. An estimate of the diesel consumption amongst SE Alberta construction equipment of 4 PJ has been utilized for the region with the assumption that 50% transition will be realized, as some equipment will likely transition to battery electric. This would result in a potential hydrogen demand for heavy industry construction equipment of **30 t/day (11 kt/year)** (**Table 5.14**). [178]

Table 5.14 SE Alberta Hydrogen Potential – Total Heavy Equipment

	Comsump Total	Assumed Transition	Rel. Efficiency	Hydrogen Daily Ave	
	[PJ/yr]	%	[J H2 / J petro]	[kt]	[t/day]
Off Road Heavy Equipment					
Construction Equipment	4.02	50	0.77	10.9	29.9

Assumed 50% transition of estimated diesel consumption based on a relative efficiency of 77%.

5.7 Agriculture

Agricultural energy consumption in Alberta for 2020 accounted for **65 PJ**, the majority of which was provided in the form of diesel fuel (**Table 5.15**). For SE Alberta, it is estimated that **6.5 PJ** of energy was consumed for agriculture representing 10% of the provincial demand. Though diesel remained the primary fuel, SE Alberta proportionally utilized greater amounts of natural gas and electricity, likely as a result of both local availability but also a reflection of the nature of the farming and greenhouse operations prevalent in the region.

Table 5.15 2020 Energy Consumption for Agriculture

Energy Source	Alberta		SE Alberta		% of provincial consumption
	TJ	%	TJ	%	
Diesel	36,004	55.5%	2,903	45.0%	8.1%
Gasoline	14,616	22.5%	323	5.0%	2.2%
Electricity	7,236	11.2%	968	15.0%	13.4%
Natural Gas	5,161	8.0%	2,247	34.8%	43.5%
Coal	931	1.4%			
LPG / Light Fuel Oil	939	1.4%	12	0.2%	1.3%
TOTAL	**64,887**		**6,453**		**9.9%**

Total energy consumption by fuel type for agriculture in Alberta and the corresponding consumption within the SE Alberta region. Percentage of use by SE Alberta of total for province is calculated.

5.7.1 Farming

Crop farming represents the greatest demand for diesel due to the intense nature of farm implements that are required for both sowing and harvesting crops. Though this demand is year-round, the greatest demand for fuel would occur between April and October. Total diesel demand is estimated at 25 L/acre but does vary between 15 and 50 L/acre depending on the type of crop being grown, size of operation, and farming practice.

Crop farm sizes vary from under 10 acres to greater than 31,000 acres and represents a mixture of single-family farms, multi-family colonies, and incorporated farming operations. As illustrated in **Figure 5.44**, less than 1% of total farms have greater than 15,000 acres of cropland and represent more than 15% of the cumulative farmed acres, with 50% of the total farms having more than 2 sections of farmland (1,280 acres) and cumulatively represents 80% of the region's farmland. The large farm operations represent fuel consumption of between 300,000 to 600,000 L of diesel on an annual basis which would equate to a hydrogen demand of between 75 and 150 t/year, equal to or greater than many of the municipalities in the region.

Livestock farming also has significant variance in size and operations. The largest cattle operations have herds of greater than 1,000 animals. Though energy intensive, the majority of the energy demand for these operations are satisfied by natural gas and electrical use, which individually have been addressed in previous sections.

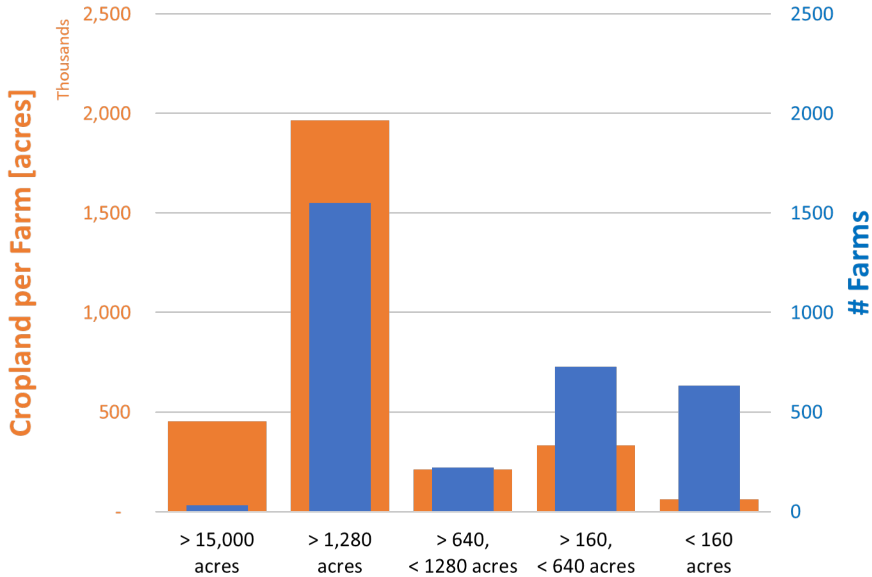


Figure 5.44 SE Alberta Farm Size Distribution

Less than 1% of the region's farms crop greater than 15,000 acres and account for more than 15% of the region's total cropland. Farms with greater than 1,280 acres represent 80% of the region's total cropland.

5.7.2 Greenhouse

The greenhouse sector in SE Alberta consumes 2.8 GJ/m^2, (**Figure 5.45**) with natural gas being the largest fuel source utilized. The biggest demand for energy is driven by heating of the greenhouse areas, lighting, and fans / air exchangers. This is higher than the Alberta average consumption of 2.4 GJ/m^2 as a result of SE Alberta being primarily focused on vegetable crops as comparted to floral bedding plants or tree seedlings which consume less energy.

Vegetable crops consume approximately 40% more natural gas and 150% more power than the average consumption of bedding and seedling crops (**Figure 5.46**).

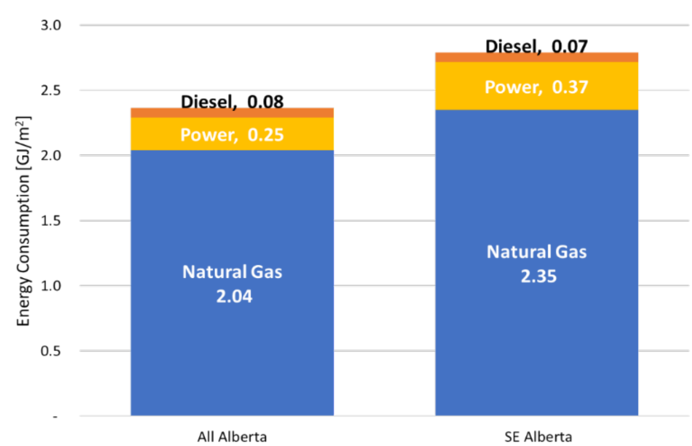


Figure 5.45 Greenhouse Energy Consumption

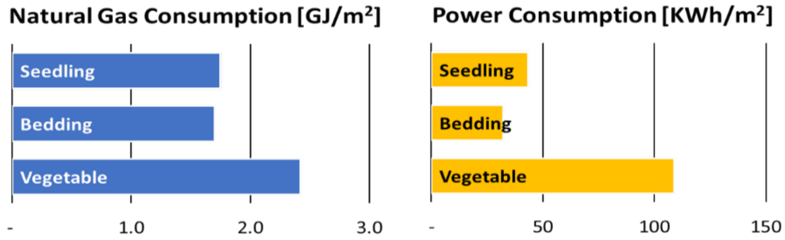


Figure 5.46 Natural Gas and Power Consumption by Greenhouse Crop Type

Vegetable crops within greenhouses have greater energy intensity

In SE Alberta the total energy consumption of the greenhouse sector is estimated at **1,862 TJ,** with the largest portion of the consumption being natural gas (**Figure 5.47**).

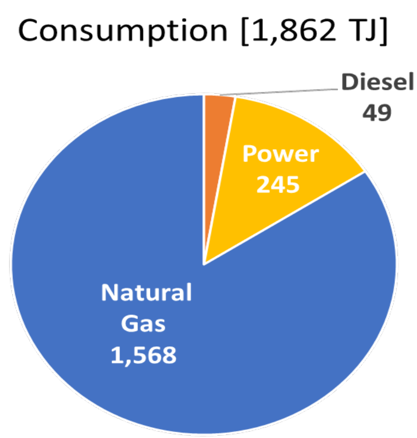


Figure 5.47 SE Alberta Greenhouse Energy Consumption

Natural gas represents 84% of estimated greenhouse energy consumption

5.7.3 Agriculture Hydrogen Transition Potential

In addition to the 35 t/day or 12.7 kt/year transition potential identified in **Section 5.4.2** for the 75% transition of commercial agricultural use of natural gas to hydrogen, the agricultural sector could see additional hydrogen demand with the transition of diesel-powered farm machinery. [179][180] Utilizing a transition assumption of 50% and a hydrogen efficiency of 77%, the total annual demand for hydrogen would be **8 kt/year** (**Table 5.16**). This would equate to a daily demand of **21.6 t/day** but due to the seasonal demand could see maximum daily demands increase by a factor of four during peak activity times.

Table 5.16 SE Alberta Hydrogen Potential – Agricultural Equipment

	Comsump Total	Assumed Transition	Rel. Efficiency	Hydrogen Daily Ave	
	[PJ/yr]	%	[J H2 / J petro]	[kt]	[t/day]
Off Road Heavy Equipment					
Agriculture	2.90	50	0.77	7.9	21.6

Assumed 50% transition of estimated diesel consumption based on a relative efficiency of 77%. Due to peak seasonal demand, hydrogen potential could be as high as 80 t/day.

5.8 Total SE Alberta Hydrogen Transition Potential

The bottom-up analysis suggests SE Alberta has significantly more transition potential to Hydrogen than what would be suggested by the top-down approach. Total hydrogen demand for purposes of Transport, Natural Gas Utility, Electrical Generation, and heavy equipment for construction industry and agriculture is estimated at **1,250 t/day (456 kt/year)** (**Table 5.17**), far greater than the **353 t/day (129 kt/year)** that was estimated through the top-down evaluation utilizing population percentage as the proxy. The estimated demand represents 9.6% of the provincial estimate and would correspond to other demographic indices that suggest the area is a high energy consuming region, both as a result of the demands associated with a sparce rural settlement as well as the energy intensive industries that are already established in the region. This transition to hydrogen would result in a reduction of **1.5 Mt CO_2e**, which is representative of a 14% reduction in SE Alberta CO_2e emissions.

Based on full realization of the estimated potential on a post transition basis, total annual energy consumption for the region would increase to **248 PJ** from 217 PJ as a result of the net difference in hydrogen energy efficiency and the increased energy associated with incremental power generation to optimize and stabilize the transmission grid (**Figure 5.48**). Hydrogen would account for **65 PJ** or 26% of the total energy supply for the region. Hydrogen use for power generation is the largest portion of demand

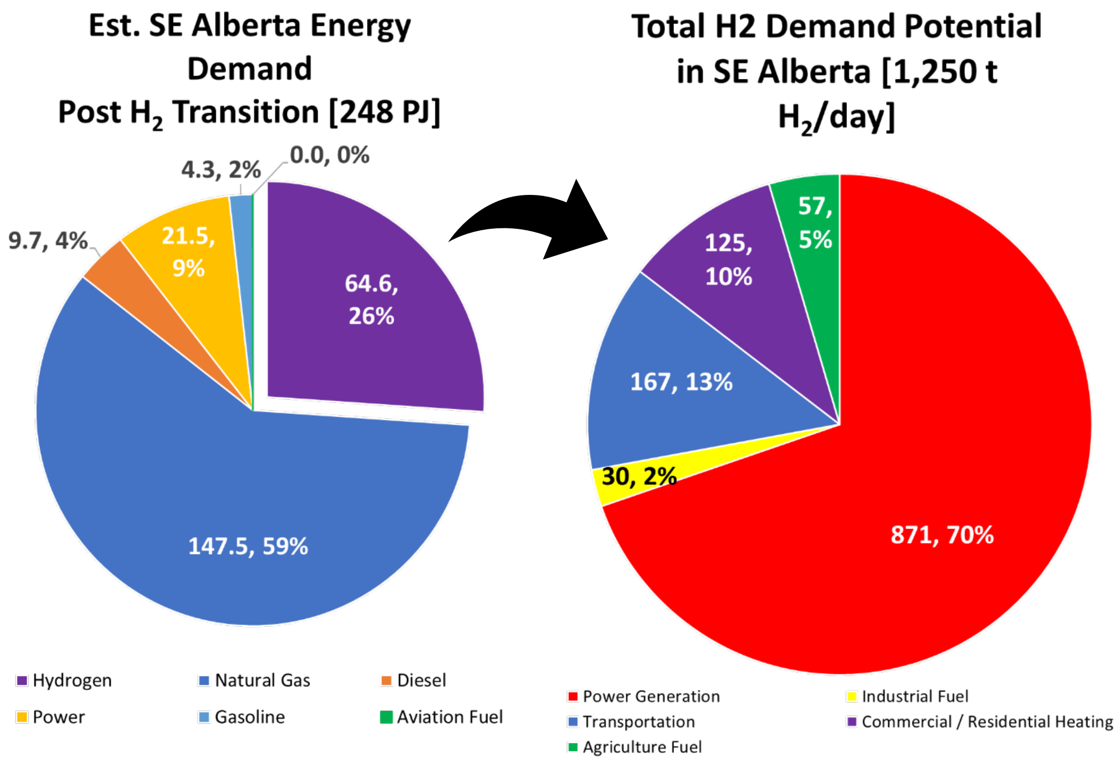


Figure 5.48 SE Alberta Energy Demand Post Hydrogen Transition

Post hydrogen transition results in total energy demand increasing by 14% for SE Alberta, 26% of which would be satisfied by hydrogen. Power generation would represent 70% of the total hydrogen potential for the region mainly driven by the high percentage of renewable power and the use of hydrogen to provide transmission stabilization and optimization.

representing **871 t/day** or 70%. Hydrogen would represent approximately 50% of the energy consumption for all sectors except Industrial demand (**Figure 5.49**). Electrical generation would be impacted the most by increasing the portion of energy utilized for electrical generation by adding 40 PJ of consumption and increasing annual power generation from the region by 2,840 GWhr or an equivalent annual average of 325 MW.

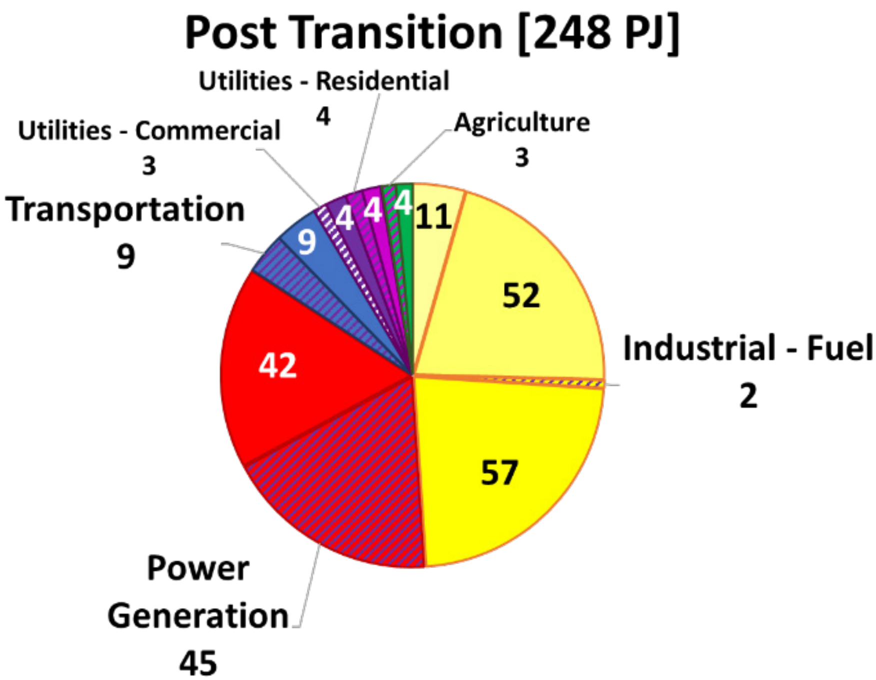


Figure 5.49 SE Alberta Energy Split Post Hydrogen Transition

Post transition, hydrogen would represent approximately 50% of the total energy demand for power generation, transportation, heating utilities and agriculture (hydrogen fuel signified by cross hatch as compared to incumbent fuel by solid color).

In addition to the demand for the region, existing industry and resources are advantageously present within SE Alberta to create the potential of being the lowest cost hydrogen generation location for green, blue and turquoise hydrogen. This is further complemented by being a critical node in the overall transportation and transmission corridor, which further enhances the demand potential by incorporating export markets. This could be in the form of direct hydrogen supply via truck, rail or pipeline infrastructure, or via the already established transport and export of hydrogen carriers such as Ammonia and Methanol. SE Alberta is ideally positioned within the trans-Canadian energy corridor to become the preferred supplier node of hydrogen or hydrogen carriers to high demand / low supply nodes, whether that is within Alberta, such as the Calgary region, or in adjacent provinces and internationally.

Table 5.17 Total SE Alberta Hydrogen Transition Potential

Sector	End use	A All Alberta		B SE Alberta @ 2.72%		C SE Alberta	
		ktH_2/yr	tH_2/day	ktH_2/yr	tH_2/day	ktH_2/yr	tH_2/day
Transport	LD vehicles	46	125	1	3	9	26
	Buses	21	57	1	2	1	2
	MD trucks	118	323	3	9	13	35
	HD trucks	556	1,523	15	41	35	95
	Rail	93	256	3	7	2	5
	Airplanes	146	401	4	11	0	1
	Off road	41	111	1	3	2	6
Total for transport		**1,021**	**2,797**	**28**	**76**	**61**	**168**
Heat	Residential space and water heating	933	2,557	25	70	26	70
	Commercial space and water heating	812	2,226	22	61	19	53
Total for heat		**1,746**	**4,782**	**47**	**130**	**45**	**123**
Power	Peaking to firm intermittent renewables	657	1,799	18	49	216	592
	Co-generation	1,313	3,598	36	98	102	280
Total for electric generation		**1,970**	**5,397**	**54**	**147**	**318**	**872**
Total for industrial						11	30
Total for agriculture						21	57
Total hydrogen demand		**4,737**	**12,977**	**129**	**353**	**456**	**1,250**

Comparison of top-down [B] and bottom-up [C] estimation of hydrogen potential for SE Alberta as a portion of total potential for Alberta [A]. Bottom-up evaluation results in a 3.5X greater hydrogen potential estimate for the region as compared to top-down estimate and represents 9.6% of provincial potential. Bottom-up forecast for transport is 2.2X greater than top-down and represents 6% of the provincial estimate. Bottom-up forecast for heat is within 5% of top-down forecast suggesting per-capita prorating for this category is a reasonable measure. Bottom-up forecast for electric generation is 6X greater than top-down and represents 16% of provincial estimate and is reflective of the disproportionate amount of generation within SE Alberta as well as the high percentage of renewable power generation.

6 ENABLING LOW-CARBON PATHWAYS

To achieve the low carbon transition and to supply the required hydrogen demand as identified in **Section 5**, multiple pathways will be required, with many of these pathways being unique to our current practices. These pathways will require multiple advancements in supply source, supporting infrastructure, policy, and public acceptance to enable transition and ensure economic sustainability is achieved.

6.1 Public Buy-In: Education and Advocacy

As with any change, resistance of the unknown is one of the first challenges that needs to be overcome to be able to achieve the full potential of the change being proposed. Energy transition can only be successful if there is a willingness from the public at large to support the requirements of the transition. This would include:

- support for the establishment of the industry to generate the hydrogen or low carbon energy source,
- support for the installation of the infrastructure to transport and distribute the hydrogen or low carbon energy, and
- the desire to purchase and use the equipment designed to utilize the hydrogen or low carbon energy.

Though one of the first jurisdictions to pursue low carbon transition and utilization of hydrogen, it has been found in Europe that there was insufficient effort to engage with the public early and thus caused concerns and resistance based on misinformation. Resistance from the public can slow down and hinder the transition process and if not addressed in an acceptable manner can lead to cancelation of projects and threaten the economic sustainability of the transition. [181][182]

SE Alberta has a history of supporting energy development and energy transition and thus is well positioned to embrace the transition to hydrogen. However, this historical perspective should not be taken for granted and it will be incumbent on participants in this transitional sector; industry, regulators, and municipalities, to ensure that the merits and facts of a hydrogen low-carbon economy are disseminated to the public and accepted. This knowledge and acceptance are critical to gain the required momentum to realize the timely establishment and roll out of the hydrogen transition, and development of robust consumption.

Four factors have been identified that influence acceptance:

1. **"NIMBY, Not in My Back Yard"** – there needs to be an acceptance of the technology and the related projects at a local level rather than just at a general level. The public must be engaged and in agreement with the need for both small- and large-scale projects to be situated in their communities.
2. **"Risk vs Reward"** – there is a need for the public to understand the technology and address the perceived risks the operations and transition introduces. Knowledge is key to ensure misinformation and myths are not the driving factors in public perception. Additionally, the public needs to understand what the benefits are in accepting the transition technology both in general terms and as it affects them directly.
3. **"Trust"** – the degree of positive perception the public attributes to the main industrial stakeholders in the technology and the municipal or other regulatory bodies that oversee the approval, construction and operation of that technology plays a critical role in acceptance and embrace of the transition. Negative perception can rally resistance to projects regardless of the potential merit.
4. **"Incentives"** – what is the attitude and expectations of the public towards the government support and incentives towards new technologies, both in funding industry as well as funding the public to encourage transition acceptance.

To gain public acceptance and buy-in for energy transition, a concerted effort is required to provide the public with information on the facts and technology of hydrogen. To achieve success of that dissemination of information and to identify acceptance gaps, efforts to engage and survey the public need to be undertaken to gain insight into the public's views and concerns, as well as to stimulate discussion and knowledge exchange.

6.2 Hydrogen Supply

Generation and access to low-cost hydrogen will be required to achieve transition acceptance, and economic sustainability. This can be realized in SE Alberta via processes already established in the region.

6.2.1 Physical Hydrogen

With both an abundant local supply of renewable power and natural gas, SE Alberta should be able to achieve the lowest cost for hydrogen generation in Alberta.

Existing processes in the area utilize steam reformation and pyrolysis, though both are utilized for the purpose of generating other commodities, such as ammonia, methanol, and carbon black, rather than for the physical generation of merchant hydrogen. Initial capture of non-reactive hydrogen from existing operations, currently utilized as process fuel, could be utilized to provide hydrogen volumes for initial pilot projects. The utilization of renewable power for green hydrogen generation is an additional process that can be supported within the region and scaled up as growth occurs, though a pathway to viable economic production would need to be identified.

6.2.2 Hydrogen Carriers

Hydrogen carriers will play an important role in establishing effective transport options for distribution and export of hydrogen, especially during early implementation stages due to the lag in construction of hydrogen transportation infrastructure. With the generation of ammonia and methanol already prominent in the SE Alberta region, it is anticipated that the potential for growth in hydrogen carriers for the region will be realized. When coupled with CCUS, hydrogen carriers provide for a low-carbon intensity hydrogen product that already has established transportation and export infrastructure in place with the potential for these to be expanded to become an immediate focus to satisfy the economic challenges of smaller scale hydrogen demand in rural fueling nodes or with last mile fuel service to the agricultural sector.

6.2.3 Physical Carbon

Utilization of pyrolysis in SE Alberta has already been established as a successful commercial operation for the generation of carbon black with hydrogen being a by-product and currently utilized within the process as a fuel for heat generation. Hydrogen from the process could be extracted and developed as a merchant hydrogen stream.

Ongoing development of pyrolysis holds promise and could be expanded upon within SE Alberta where application in smaller remote locations with access to natural gas could provide a hydrogen supply without the challenges of transportation and CO_2 capture. Further development of transforming the raw carbon black to graphene and carbon nanotubes will be critical to the effective development and deployment of pyrolysis and could represent further economic benefits for the region by attracting a number of auxiliary industrial interests (**Figure 6.1**). [183]

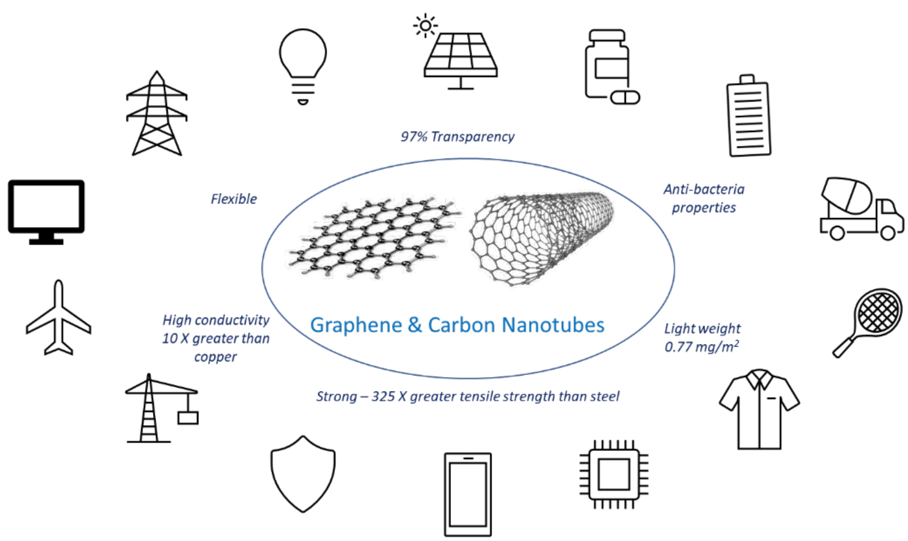


Figure 6.1 Potential to Utilize Pyrolysis to Generate Graphene and Carbon Nanotubes

Carbon black is currently utilized as a pigment and strength additive to paints, polymers, and tires and offers the potential to be converted to graphene and carbon nanotubes with numerous future applications.

6.3 Saline Water Supply – Oil & Gas

As discussed in **Section 4.7**, utilization of fresh water in SE Alberta is restricted for new industrial processes, as access is limited to existing approved water withdrawal licenses. For initial hydrogen generation pilots, this may prove to be adequate if new projects are successful in utilizing volumes attributable to existing irrigation district licenses, municipal withdrawal licenses or grandfathered industrial licenses. However, as the scale of generation increases, a second water source may be required and in SE Alberta that source may be the 46 million bbls ($7.4e^6m^3$) of water that is being produced each month associated with the oil and gas extraction from the region. [184]

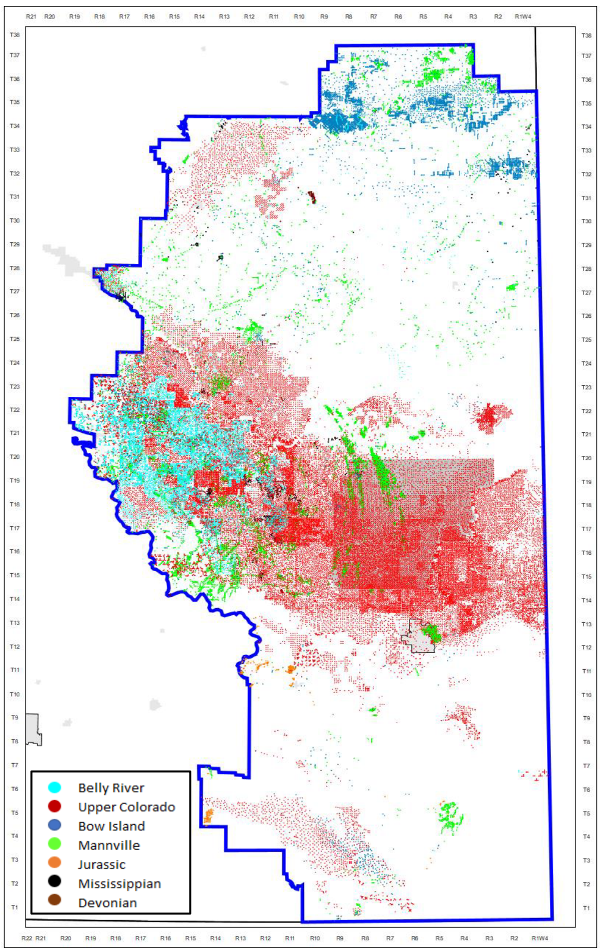


Figure 6.2 SE Alberta Oil & Gas Production by Formation

Treatment and desalination of subsurface brackish and saline water could be a viable option for large scale hydrogen generation projects that require long term access to larger volumes of water. Water production varies in the region, dependent on the formation and specific pool. Currently the handling and disposal of this produced water is an expense to the oil and gas producer and typically costs $2 to $3/bbl. This expense would be a partial offset of the cost of treating the water for industrial use if the operator did not require to treat and dispose of the produced water.

Figure 6.2 shows locations of the oil and gas wells by producing horizon. A Table of Formations for SE Alberta is shown in **Figure 6.3**, so as to identify the younger and shallower horizons, such as the Edmonton Group, Belly River, and Milk River, which generally produce at depths of less than 300m and could provide the best access to brackish water (<3,000 mg/L). Water production from the region has averaged above 40 million bbls per month since 2000, with a dip in produced volumes corresponding with the onset of COVID. Production volumes have regained pre-COVID levels with water production in October 2021 being 46.6 million bbls. The breakdown of this production to the associated zone is illustrated in **Figure 6.4**.

The Mannville horizon represents the majority of the produced volumes, though the Belly River and other shallower horizons would account for greater than 1.0 million bbls (160 e^3m^3). For illustrative purposes composite water analysis from the region by zone are included in **Figure 6.5** and **Figure 6.6**. Total salinity

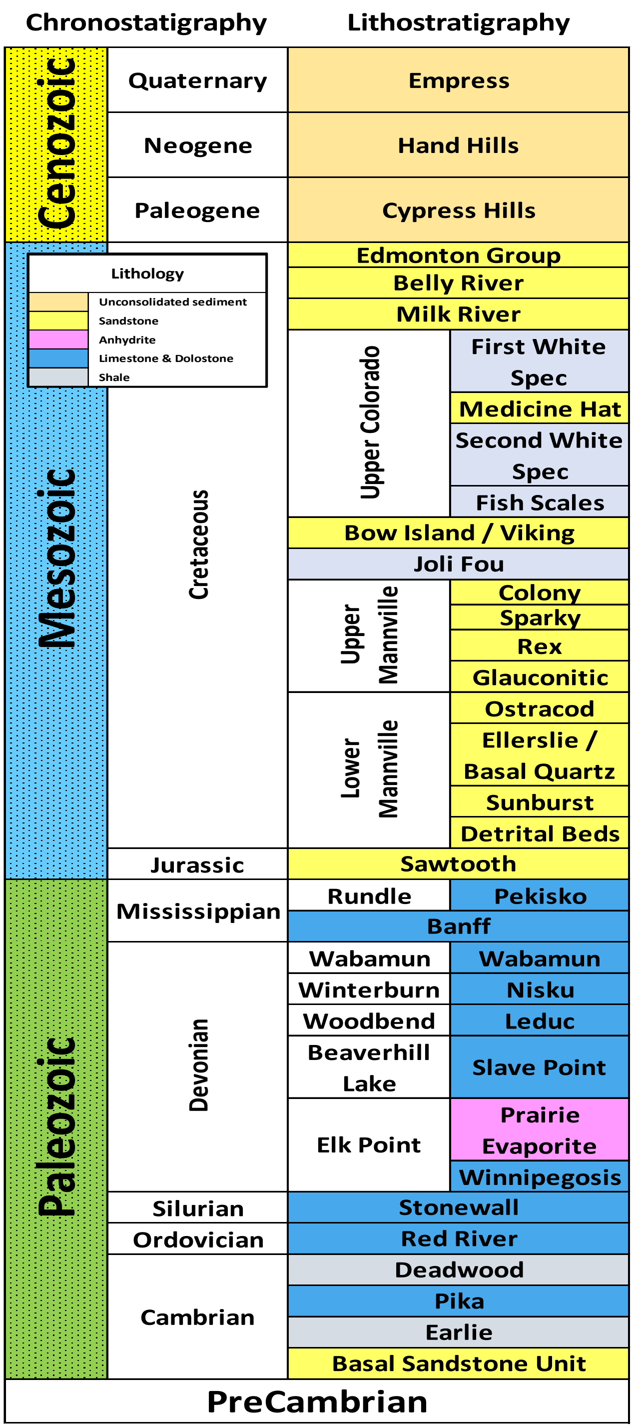


Figure 6.3 Table of Formations for SE Alberta

generally increases with increased depth. However, due to the shallower depths of deposition of a given formation in the SE Alberta region as compared to other location s in Alberta, produced water salinity in a given formation in region is lower than in other parts of the province and provides greater opportunity to access and treat any produced water from SE Alberta.

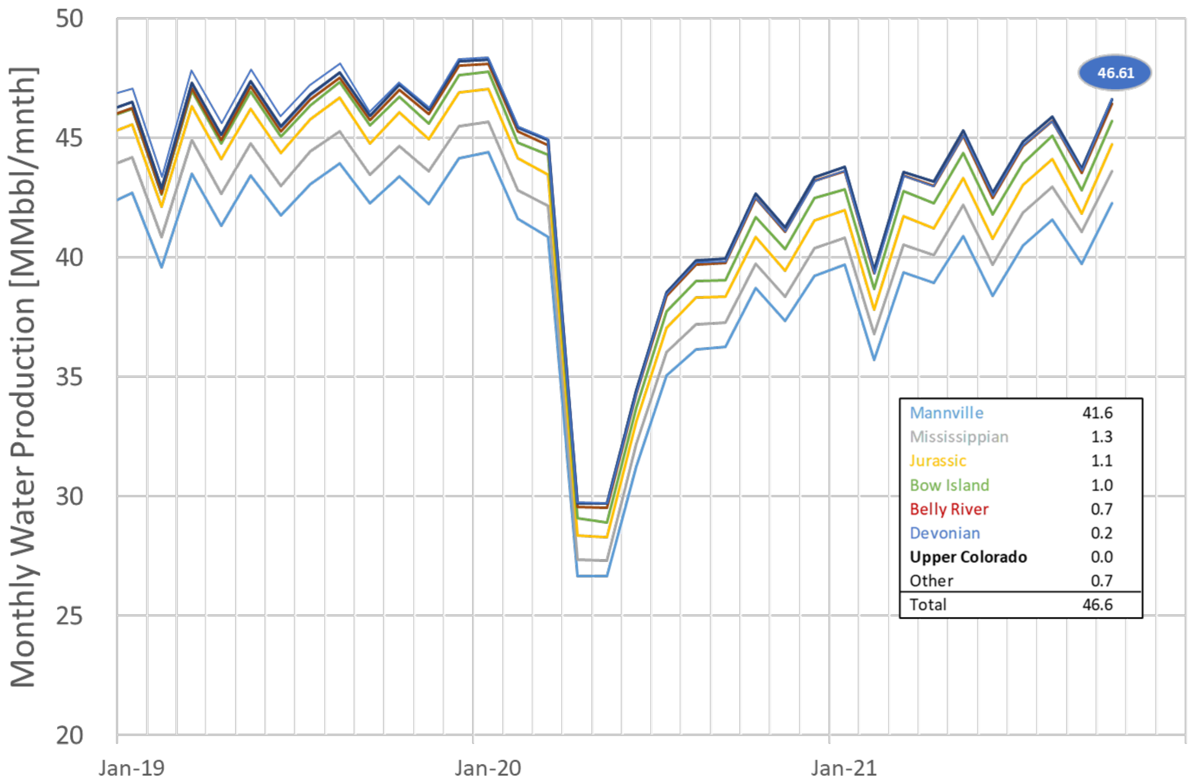


Figure 6.4 SE Alberta Water Production by Formation

Majority of water production from oil and gas wells in SE Alberta is from the Mannville formation.

Cations

ION	mg/L	meq/L
Na	745	32.4
K	6	0.1
Ca	3	0.1
Mg	1	0.0
Fe	0	0.0
Total Cations		32.6

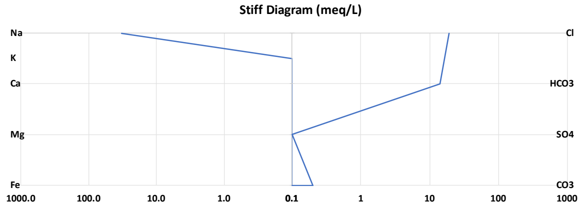
Anions

ION	mg/L	meg/L
Cl	685	19.3
HCO3	880	14.2
SO4	2.5	0.0
CO3	6	0.2
OH	0	0.0
Total Anions		33.7

Other Measurements

Measurement	Value
Total Dissolved Solids mg/L	1865
Observed pH	8.3
Relative Density	1.000
Resitivity OHMm	2.89
Formation	**Edmonton**

Stiff Diagram (meq/L)



Cations

ION	mg/L	meq/L
Na	826	36.0
K	4	0.1
Ca	7	0.4
Mg	2	0.2
Fe	0	0.0
Total Cations		36.7

Anions

ION	mg/L	meg/L
Cl	1020	28.8
HCO3	514	8.4
SO4	16	0.3
CO3	13	0.4
OH	0	0.0
Total Anions		37.9

Other Measurements

Measurement	Value
Total Dissolved Solids mg/L	2403
Observed pH	8.4
Relative Density	1.001
Resitivity OHMm	2.98
Formation	**Belly River**

Stiff Diagram (meq/L)

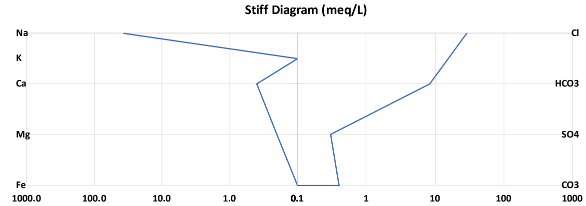


Figure 6.5 Composite Water Analysis by Formation – Brackish Formations

Low salinity associated with shallow Edmonton / Belly River formations.

Cations

ION	mg/L	meq/L
Na	3649	158.7
K	33	0.9
Ca	48	2.0
Mg	92	4.7
Fe	1	0.0
Total Cations		166.4

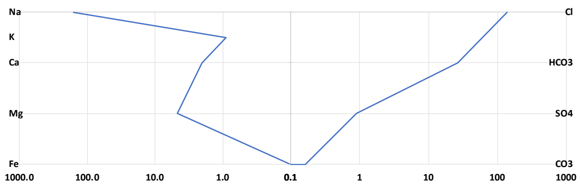
Anions

ION	mg/L	meq/L
Cl	4936	139.2
HCO3	1614	26.5
SO4	56	0.9
CO3	6	0.2
OH	0	0.0
Total Anions		166.8

Other Measurements

Measurement	Value
Total Dissolved Solids mg/L	10352
Observed pH	8
Relative Density	1.005
Resitivity OHMm	0.67
Formation	Upper Colorado

Stiff Diagram (meq/L)



Cations

ION	mg/L	meq/L
Na	2796	121.6
K	21	0.5
Ca	22	0.9
Mg	10	0.8
Fe	1	0.1
Total Cations		123.9

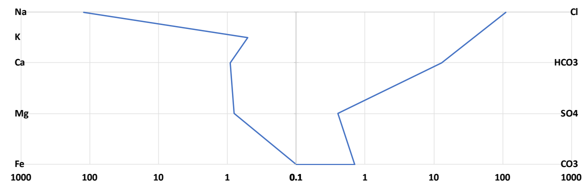
Anions

ION	mg/L	meq/L
Cl	3979	112.2
HCO3	785	12.9
SO4	26	0.4
CO3	33	0.7
OH	0	0.0
Total Anions		126.2

Other Measurements

Measurement	Value
Total Dissolved Solids mg/L	7675
Observed pH	8.3
Relative Density	0.996
Resitivity OHMm	0.78
Formation	Bow Island

Stiff Diagram (meq/L)



Cations

ION	mg/L	meq/L
Na	4260	185.3
K	28	0.7
Ca	56	2.8
Mg	28	2.3
Fe	1	0.1
Total Cations		191.2

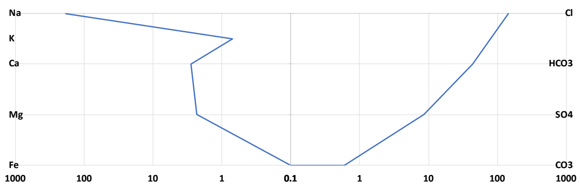
Anions

ION	mg/L	meq/L
Cl	5131	144.7
HCO3	2669	43.7
SO4	406	8.5
CO3	19	0.6
OH	0	0.0
Total Anions		197.5

Other Measurements

Measurement	Value
Total Dissolved Solids mg/L	12605
Observed pH	8.2
Relative Density	1.006
Resitivity OHMm	0.66
Formation	Upper Mannville

Stiff Diagram (meq/L)



Cations

ION	mg/L	meq/L
Na	6234	271.2
K	209	5.4
Ca	241	11.6
Mg	92	7.4
Fe	11	0.3
Total Cations		295.8

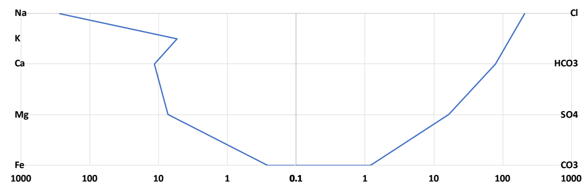
Anions

ION	mg/L	meq/L
Cl	7370	207.5
HCO3	4821	79.0
SO4	809	16.4
CO3	35	1.2
OH	0	0.0
Total Anions		304.1

Other Measurements

Measurement	Value
Total Dissolved Solids mg/L	19547
Observed pH	7.8
Relative Density	1.015
Resitivity OHMm	0.51
Formation	Lower Mannville

Stiff Diagram (meq/L)



Cations

ION	mg/L	meq/L
Na	2336	101.6
K	38	1.0
Ca	26	1.3
Mg	10	0.8
Fe	0	0.0
Total Cations		104.7

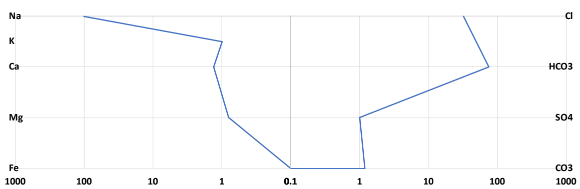
Anions

ION	mg/L	meq/L
Cl	1151	32.5
HCO3	4566	74.8
SO4	49	1.0
CO3	36	1.2
OH	0	0.0
Total Anions		109.5

Other Measurements

Measurement	Value
Total Dissolved Solids mg/L	8211
Observed pH	8.2
Relative Density	1.006
Resitivity OHMm	1.12
Formation	Sawtooth

Stiff Diagram (meq/L)



Cations

ION	mg/L	meq/L
Na	7534	327.7
K	463	11.9
Ca	771	23.7
Mg	68	4.2
Fe	24	0.4
Total Cations		367.9

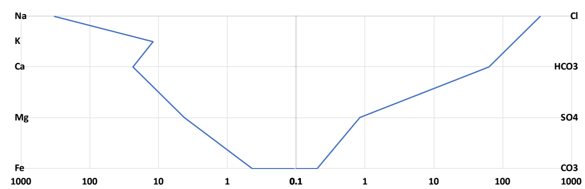
Anions

ION	mg/L	meq/L
Cl	12563	354.3
HCO3	3762	63.4
SO4	76	0.8
CO3	23	0.2
OH	0	0.0
Total Anions		418.7

Other Measurements

Measurement	Value
Total Dissolved Solids mg/L	23577
Observed pH	7.6
Relative Density	1.030
Resitivity OHMm	0.30
Formation	Pekisko

Stiff Diagram (meq/L)



Cations

ION	mg/L	meq/L
Na	5490	238.8
K	2543	65.0
Ca	1996	87.2
Mg	83	5.8
Fe	35	1.5
Total Cations		398.3

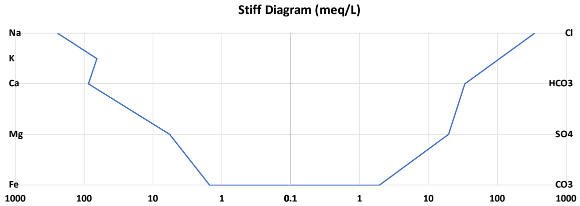
Anions

ION	mg/L	meq/L
Cl	12105	341.4
HCO3	2050	33.6
SO4	936	19.5
CO3	57	1.9
OH	0	0.0
Total Anions		396.4

Other Measurements

Measurement	Value
Total Dissolved Solids mg/L	24876
Observed pH	7.2
Relative Density	1.020
Resitivity OHMm	0.35
Formation	Banff

Stiff Diagram (meq/L)



Cations

ION	mg/L	meq/L
Na	7093	308.6
K	948	24.2
Ca	870	43.4
Mg	316	26.0
Fe	0	0.0
Total Cations		402.2

Anions

ION	mg/L	meq/L
Cl	8699	245.4
HCO3	3052	50.0
SO4	6140	127.8
CO3	0	0.0
OH	0	0.0
Total Anions		423.2

Other Measurements

Measurement	Value
Total Dissolved Solids mg/L	27118
Observed pH	7.3
Relative Density	1.022
Resitivity OHMm	0.29
Formation	Nisku

Stiff Diagram (meq/L)

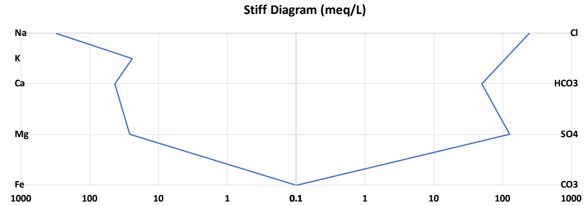


Figure 6.6 Composite Water Analysis by Formation – Saline Formations

Salinity generally increases with depth, though water from formations in the SE Alberta region have significantly lower salinity then water from equivalent formations in other areas of Alberta.

6.4 Carbon Capture, Utilization and Storage

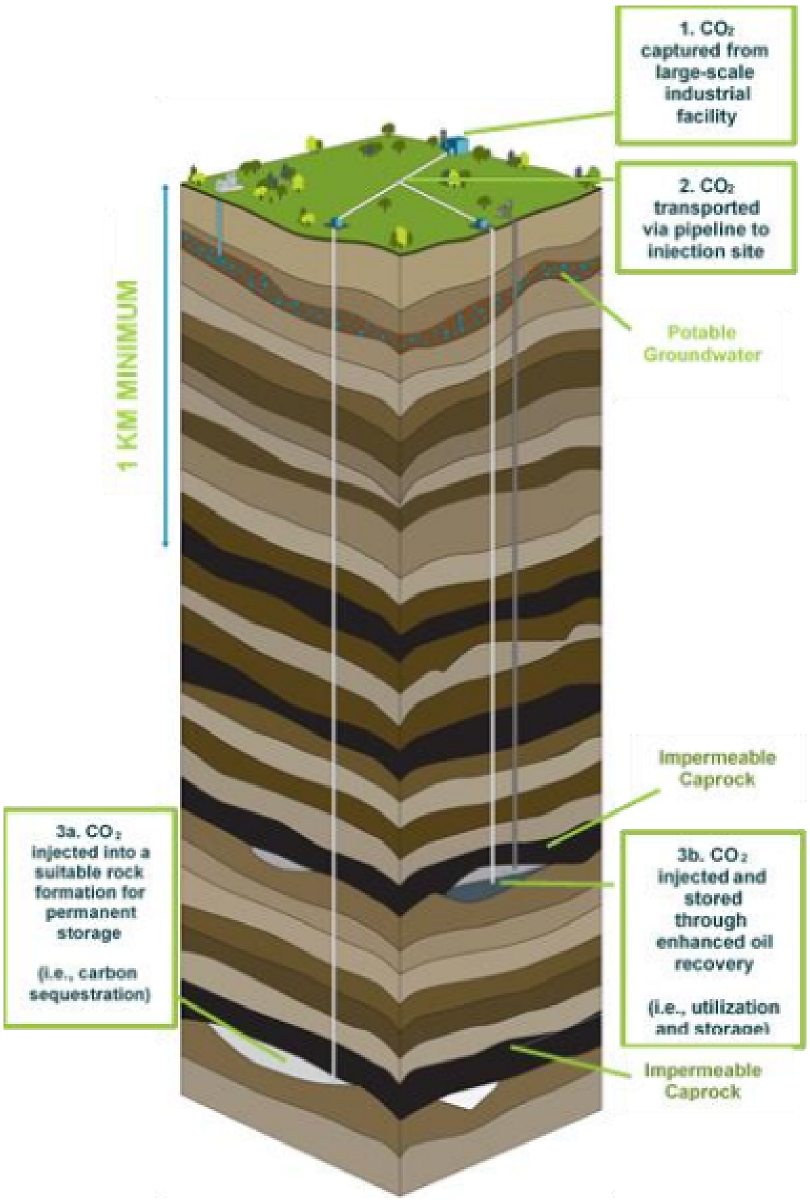


Figure 6.7 Carbon Capture, Utilization, and Storage

SOURCE: Government of Alberta, CCS Factsheet

An essential component in transitioning to a low carbon energy system is the utilization of Carbon Capture, Utilization, and Storage. CCUS allows for the reduced CO_2 emissions from existing industrial operations as well as for the generation of low-carbon intensity fuels such as blue hydrogen.

As illustrated in **Figure 6.7**, obtained from the Government of Alberta CCUS fact sheet, CO_2 emissions are captured at the industrial source prior to release and treated so that high quality CO_2 can be extracted from a composite stream, compressed to a super critical dense state for transport and final injection into a suitable underground reservoir. This reservoir could be an existing oil pool and utilized for purposes of enhanced oil recovery, into depleted reservoirs, or deep aquifers. [185][186][187]

SE Alberta is fortunate as there are suitable opportunities for both utilization of CO_2 for enhanced recovery of existing producing oil pools in the region as well as the existence of a suitable deep aquifer in the Basal Cambrian formation.

6.4.1 CO_2 Extraction & Sequestration

The complexity of extraction of CO_2 from existing industrial facilities is dependent on the conditions of the composite stream which is dependent on whether the CO_2 is captured pre or post combustion.

Precombustion, such as in the steam reformation process that is used to generate hydrogen, requires capture of the separated CO_2 from the syngas produced by the process, with the CO_2 subsequently being compressed and sequestered.

Post combustion would be the most common process for most existing operations. Extraction of the CO_2 from a low-pressure flue gas stream must be done. The complexity of this process is high due to the low pressure of this stream and inability to introduce back pressure along with the fact that most combustion streams are air enriched resulting in high overall volume but low CO_2 concentration. Separation of the CO_2 requires complex chemistry along with large, high volume specialized equipment.

It is possible to also capture CO_2 **during combustion** if an industrial operation were to utilize an oxy-combustion process where pure oxygen is combined with methane rather than air. This would result in a flue gas that would be of lower volume and pure CO_2. As increased volumes of oxygen become available as a by-product of hydrogen generation via electrolysis, this method of CO_2 recovery may become increasing desired to offset the equipment and capital costs associated with post-combustion recovery.

Once CO_2 is extracted, other pollutants such as sulfur oxides, nitrogen oxides and particulates need to be removed, with the amount of these other pollutants being directly dependent on the recovery process and the quality of the combustion stream. CO_2 is then typically absorbed in a solvent which is then heated once CO_2 ladened to extract the near pure CO_2. The solvent can typically be reused after it is regenerated, thus creating a continuous process. As the heated stream is water saturated, the CO_2 is dehydrated to remove the water so that it can be further handled without the issues presented by the formation of carbonic acid. The dry CO_2 is then compressed, transported, and injected.

CO_2 is compressed to a supercritical state for transportation, at a pressure between 8,000 to 11,000 kPa. In the supercritical state, CO_2 has low viscosity like a gas but high density like a liquid. This state is the most effective for efficient transport and underground storage due to the smaller space the CO_2 would occupy. An equivalent mass at surface would occupy around 0.3% of the volume at depth in a supercritical state. One of the greatest challenges for underground sequestration is to ensure that the CO_2 maintains it supercritical state and does not revert to a gas phase.

This is especially challenging when considering use of existing oil and gas reservoirs due to the likelihood of being pressure depleted, thus allowing the CO_2 to return to a gas phase which could introduce negative consequences on the capability of the reservoir to receive and store the planned volumes. For EOR purposes, initial injection of water is typically required to increase the pressure of the reservoir prior to introducing the CO_2 injection. [188]

A suitable deep reservoir for sequestration will have sufficient storage capacity for the life of the project. The reservoir should have a continuous seal and cap rock to prevent upward migration of CO_2 out of zone. The region must be geologically stable with no indication of geological faulting or anticipated activity affecting the zone so as to potentially compromise the containment. The reservoir needs to be sufficiently deep, greater than 1000 m, to contain the CO_2 at the pressure required to remain as a supercritical fluid and to provide ample barriers for protection of shallow water acquirers. The rock composition and mineralization of the reservoir is important so as to assure rock compatibility with the CO_2. A successful project will also require the ability to measure and monitor the CO_2 plume within the reservoir to ensure migration is contained throughout its life.

It is believed that four phases of CO_2 trapping occur within a deep aquifer as shown in **Figure 6.8** extracted from the PCOR Partnership Atlas, 6th Edition, 2021. [189] The primary mechanism is the *structural and stratigraphic trapping*, which requires a necessary seal to exist to hold the CO_2 accumulation in place. Over time, other forms of trapping may occur. This would include *residual phase trapping* that occurs when residual CO_2 droplets are trapped in reservoir pore space and immobilized due to the surrounding brine. *Dissolution trapping* occurs when CO_2 dissolves into the brine and forms a denser brine in comparison to its surroundings and sinks to the base of the reservoir further minimizing the risk of migration. A final trapping mechanism is *mineral trapping* that occurs when a chemical reaction between the CO_2 laden brine and the formation minerals forms new solid minerals and locks the CO_2 in place. This mechanism would typically occur over an extended timeline. [190][191][192][193][194]

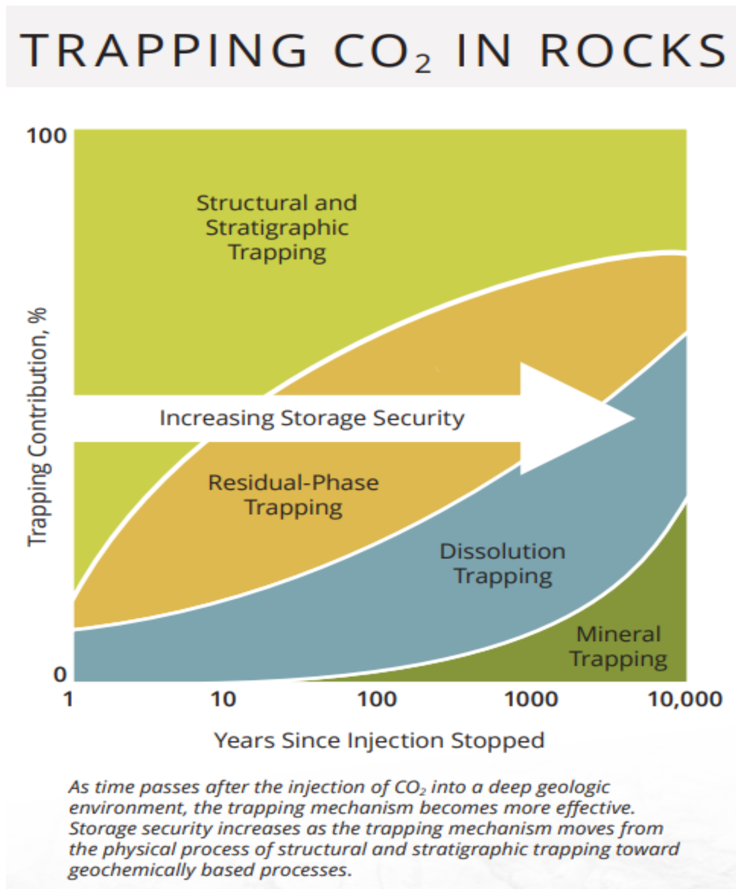


Figure 6.8 CO_2 Trapping Mechanisms

SOURCE: PCOR Partnership Atlas 2021

6.4.2 Existing Projects

The process of CCUS is not new to Canada as it has been utilized in comparative form for purposes of acid gas disposal (H_2S plus associated CO_2) in the oil and gas industry. Though not at the magnitude of the required CCUS projects to obtain the carbon reduction required, the industry is well equipped with the expertise to understand the mechanisms of CO_2 capture, compression and injection, and suitable reservoir selection.

Specific to CCUS, there are a number of existing projects that are successfully sequestering millions of tonnes of CO_2 currently.

Boundary Dam

Located near Estevan, Saskatchewan, the project is operated by SaskPower for the CO_2 capture from its coal fired generation facility. Began carbon capture in 2014, providing CO_2 for enhanced recovery in Weyburn via 66 km pipeline. To the end of 2021, the operation has captured 4.14 Mt of CO_2 and is capable of capturing 1.0 Mt/year of CO_2. [195]

Aquistore Project

Operated by the Petroleum Technology Research Centre, the project is a single injection well into the Winnipeg and Deadwood formation, 3,400 m below surface. The project commenced injection of CO_2 from the Boundary Dam project in April 2015 and has sequestered 370 kt of CO_2.

Weyburn

Midale CO_2 EOR Project – Operated by Whitecap Resources Inc., the CO_2 injection into the field commenced in 2000 and has injected more than 34 Mt of CO_2. Originally sourced CO_2 solely from North Dakota but has since added CO_2 from the Boundary Dam project. In 2020, Weyburn stored 2 Mt of CO_2 in formation at 1500m depth. [196]

Midale

Midale CO_2 EOR Project – Operated by Cardinal Energy Ltd., commenced CO_2 injection in 2005 and has injected 240 kt of CO_2 in 2021. Expanding the project to increase injection to 300 kt/year. [197]

Joffre

CO_2 EOR Project – Central Alberta Viking project operated by Whitecap Resources Inc., began injection in 1984 utilizing CO_2 captured from NOVA Chemicals' Joffre facility. To date, has sequestered 1.4 Mt of CO_2 with average annual injection of 36 kt.

Quest Project

Shell operated project near Edmonton, capturing CO_2 from three H_2 manufacturing units at the Scotford Upgrader. CO_2 is injected 80 km north of the facility via 12" pipeline. Injection began in November 2015 into the Basal Cambrian aquifer at a depth of 2,000 m. To the end of 2021, 6 Mt of CO_2 has been sequestered. The project has a planned life of 25 years with storage of more than 27 Mt CO_2. [198][199]

Alberta Carbon Trunk Line

Wolf Midstream operated project (**Figure 6.9**) that gathers CO_2 from the NWR Sturgeon Refinery and Nutrien Redwater Fertilizer facility and transports it 240 km via 16" pipeline to the Enhance Energy Clive CO_2 EOR project. Full capacity of 14.6 Mt/year and is designed to ultimately deliver CO_2 to both sequestration and EOR projects. As of March 2021, 1 Mt of CO_2 had been delivered to Clive. [200][201][202]

Clive

CO_2 EOR Project – Operated by Enhance, began injection into the Leduc formation in June 2020 at a depth of 2,000m. As of March 2021, 1 Mt of CO_2 had been injected into the Clive pool with 1.6 Mt/year being gathered. [203][204]

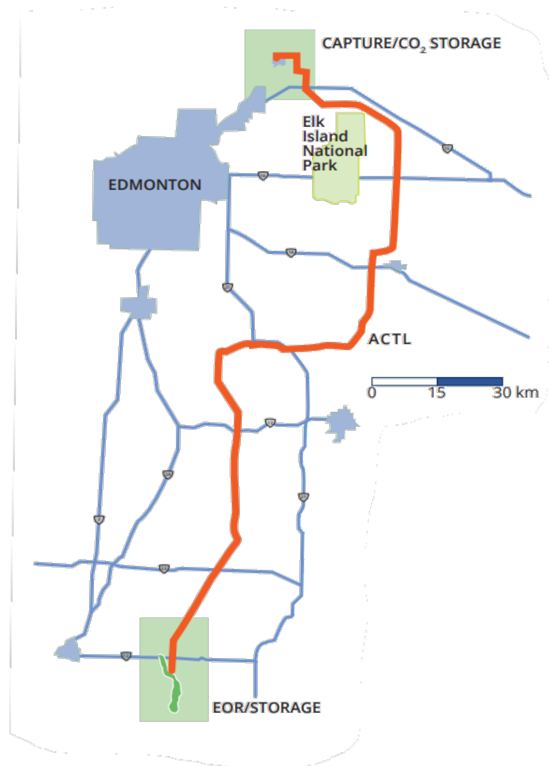


Figure 6.9 Alberta Carbon Trunk Line (ACTL)
SOURCE: www.actl.ca

6.4.3 SE Alberta CCUS Potential

SE Alberta has strong potential for the sequestration of CO_2 in the deep Basal Cambrian sandstone aquifer (**Figure 6.10**) that is prevalent in large portions of Alberta, Saskatchewan, Manitoba, Montana, and North Dakota. **Figure 6.11** illustrates the SE Alberta region and each well penetration. The Basal Cambrian is at a depth of approximately 2,500 m. The 30 wells colored blue, pink and green are the only wells that have been drilled deep enough to evaluate the formation. The majority of the wells are of older vintage with four wells being drilled post 2000, three post 2015.

Log character of the Basal Cambrian in three of the latest wells drilled are shown in **Figure 6.12**. Reservoir thickness increases to the north and the east, with an estimated 30 m of porous reservoir indicated in the City of Medicine Hat's MedHat 103/13-09-016-04W4 well, located between Medicine Hat and Empress. Development of CCUS in this location would be within 45 km of 3.6 Mt/year of emissions from both Medicine Hat and Empress combined.

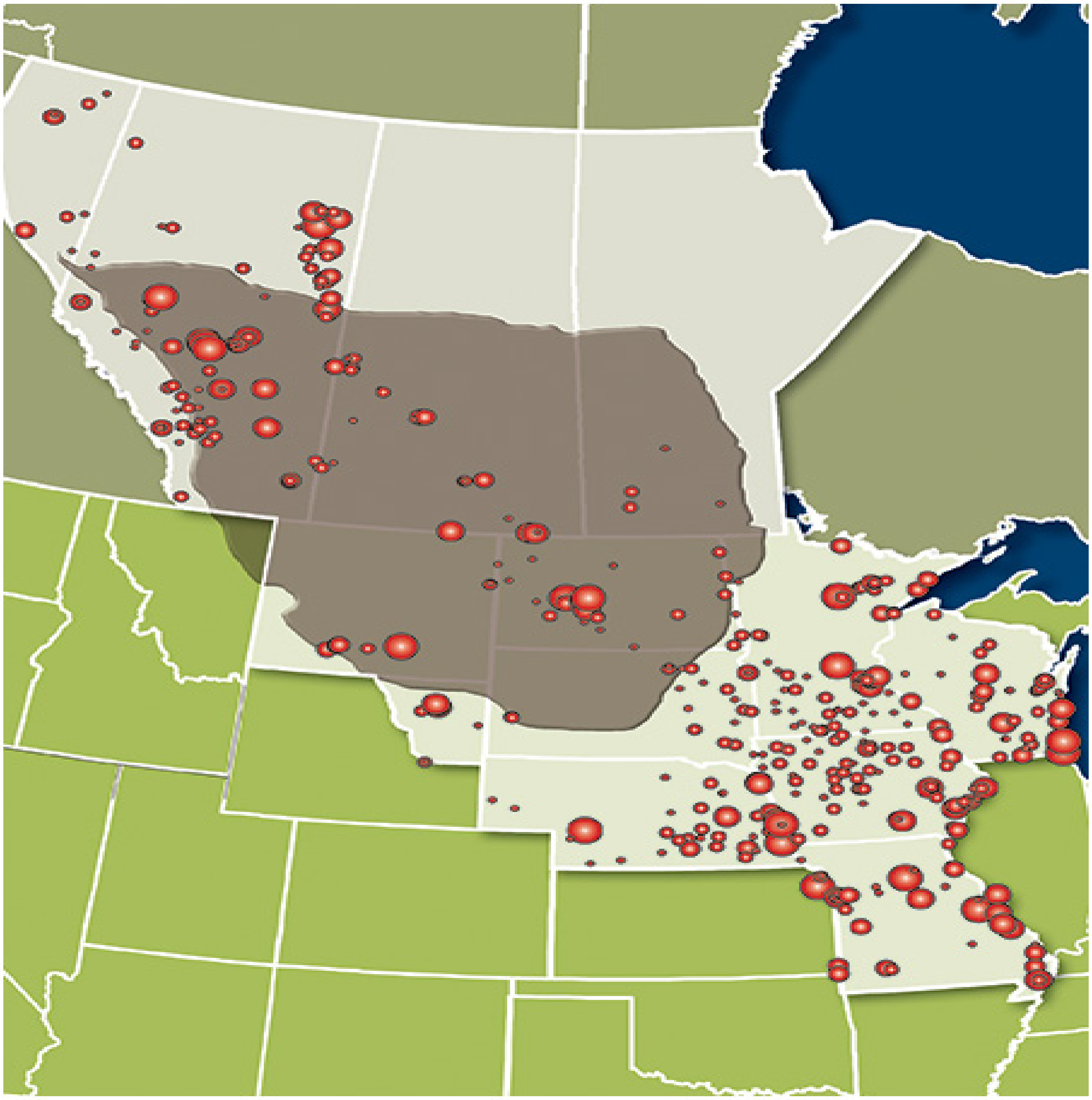


Figure 6.10 Areal Extent of Basal Cambrian Aquifer with Major CO_2 Emission Sites

SOURCE: PCOR Partnership Atlas 2021

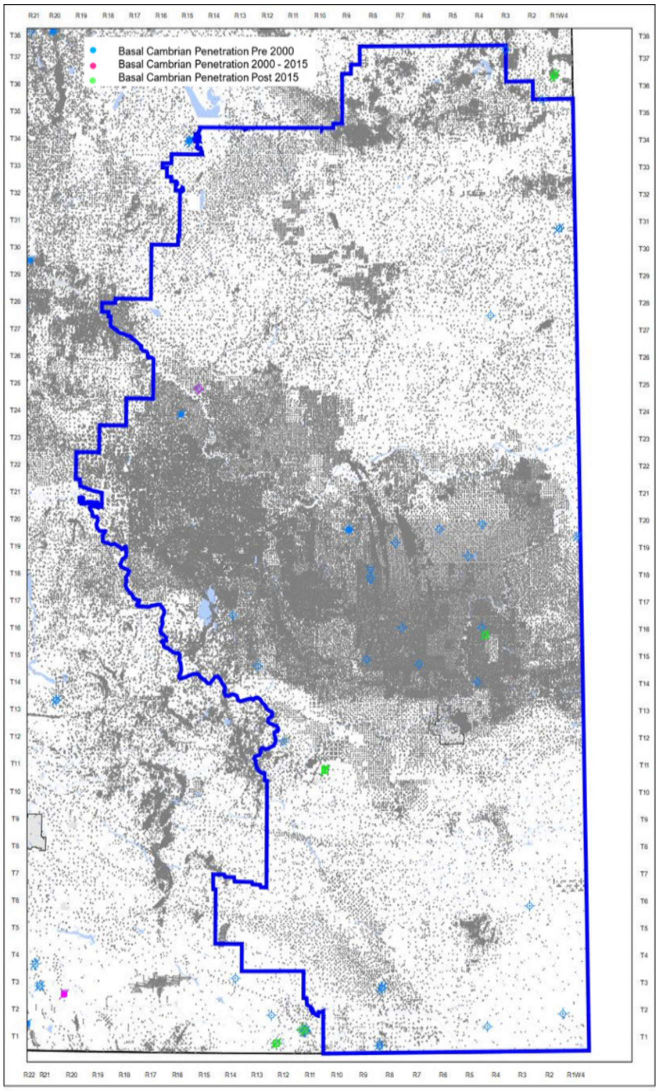


Figure 6.11 SE Alberta Well Penetrations

Basal Cambrian penetrations are indicated by the colored wells; blue well drilled pre-2000, pink 2000 – 2015, green post 2015.

The 1764821AB Connors 102/06-14-025-15W4 well is located approximately 30 km south of the Sheerness power generation facility with the estimated 2.4 Mt/year of CO_2 emissions, post natural gas conversion. CCUS development in this general area could also accommodate emissions from the Brooks area, located 55 km to the south.

In addition to CCUS potential, the region has 34 oil pools of greater than 25 million bbls of oil in place that have potential for CO_2 EOR application, 8 of which are already under conventional waterflood. Within the PCOR 2021 Atlas, it is estimated that Alberta has the potential to recovery an additional 1.7 billion bbls of oil through CO_2 EOR, with 868 Mt of CO_2 injection. Utilizing an average incremental EOR recovery range of 10 to 15% of oil in place, the pools within the SE Region could recovery an incremental 245 to 356 million bbls of oil and sequester 125 to 185 Mt of CO_2. [205][206]

The majority of the prospective pools are situated in the central portion of SE Alberta, between Medicine Hat, Brooks, and Hanna. A number of the pools are located within 45 km of the Sheerness and Brooks emission sources, and all within 80 km from at least one of the four emission sources.

One gas pool, nearing the end of its productive life, has been identified within the SE Alberta region and may have potential for CO_2 sequestration. The Bindloss Viking A pool has an original gas in place of 410 Bcf and has recovered 87% of the reserves, 360 Bcf to date. Currently the pool is producing 2.3 mmcf daily. The pool is located approximately 35 km northwest of Empress.

Combining the potential for CCUS sequestration and CO_2 EOR, a pipeline network between Medicine Hat and Hanna could be developed with a backbone pipe of approximately 190 km connecting the two highest emission centres with auxiliary lines connecting to Brooks and Empress. In addition to allowing for the collection of CO_2 from the four main emitting areas, it would also provide opportunity for CO_2 capture of the numerous small emitter sources present in the area, specifically between Brooks and Medicine Hat (see

Figure 4.28 within **Section 4.5**). This CO_2 network could be considered for combination with the existing Alberta Carbon Trunk Line, with a 180 km connection being required between Clive and Hanna. Further extension could be pursued with a cross border crossing into Saskatchewan to both access additional saline aquifers and prospective EOR oil pool candidates.

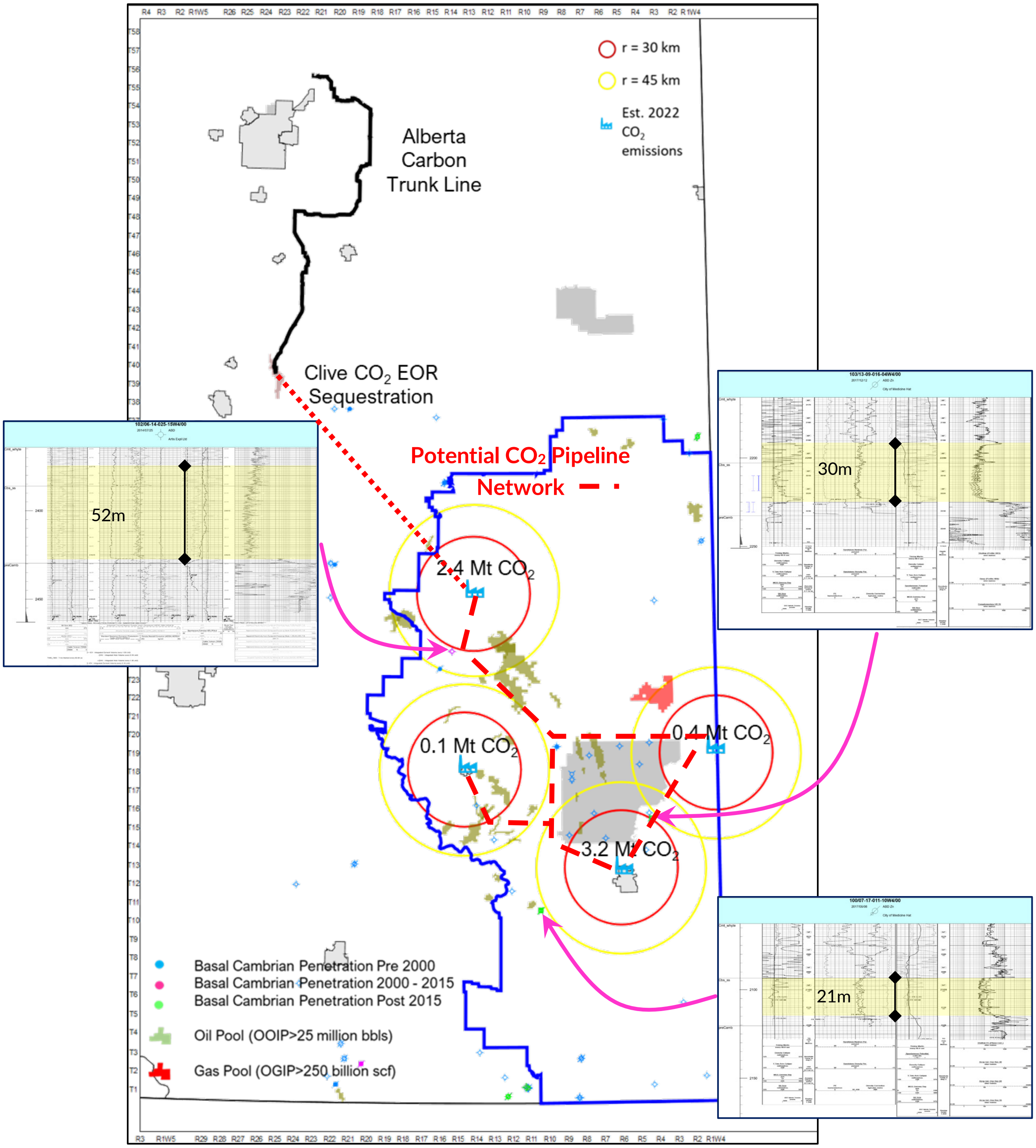


Figure 6.12 SE Alberta CCUS Potential

Basal Cambrian penetrations with log characteristic of the prospective zone for three wells within the region. Oil pools (green) with potential for CO2 EOR and material depleted gas pool (red) for sequestration. Dashed lines signify potential CO2 transport network connecting major emission sources as well as dotted line for potential connection to the ACTL.

6.4.4 CCUS Field Research Station

In addition to the local knowledge and expertise that exists as a result of an active oil and gas industry, other private research and technology companies are situated within SE Alberta to facilitate the optimum design and operation of CCUS projects. One example is Carbon Management Canada (CMC), an Alberta-based, not-for-profit corporation, providing research facilities and technical expertise in carbon capture, utilization, and storage.

The Containment and Monitoring Institute (CaMI) of CMC, in collaboration with the University of Calgary, built and now operates a comprehensive Field Research Station (FRS) in the County of Newell, Alberta for development and testing of monitoring technologies for CCUS projects (**Figure 6.13**). At this site, small volumes of CO_2 are being injected into a sandstone reservoir at 300 m depth, simulating an upward CO_2 leak from a deep sequestration formation which, by regulation in Alberta, have to be at depths greater than 1,000 m. The goal of the program is to determine the detection threshold of gas-phase CO_2 at shallow to intermediate depths, to improve monitoring technologies in order to validate permanent CO_2 storage, and to de-risk CCUS in general.

The FRS CO_2 injection facility is comprised of a CO_2 storage tank, pump, gas heater, an injection well, and two monitoring wells. A broad range of geophysical and geochemical technologies have been installed to monitor CO_2 injection and storage, including optical fiber sensors for distributed acoustic sensing (DAS) and distributed temperature sensing (DTS). There are also permanent borehole and surface electrodes for electrical resistivity tomography (ERT), a permanent array of borehole and surface seismometers for seismic imaging surveys and micro seismicity, and several shallow wells for sampling groundwater and soil gas. Regular surveys and measurements are undertaken at the site to monitor the injected CO_2 plume and other changes in the subsurface over time.

Figure 6.13 CaMI – University of Calgary CCS Field Research Station in the County of Newell

SOURCE: photo provided by Carbon Management Canada

6.5 Renewable Power Generation

6.5.1 Potential

SE Alberta has been an early adopter of renewable power generation as shown by the numerous wind and solar projects in operation, under construction and proposed for the region. The region has been identified as being an area with one of the highest potentials for the combined solar and wind resources (**Figure 6.14**).

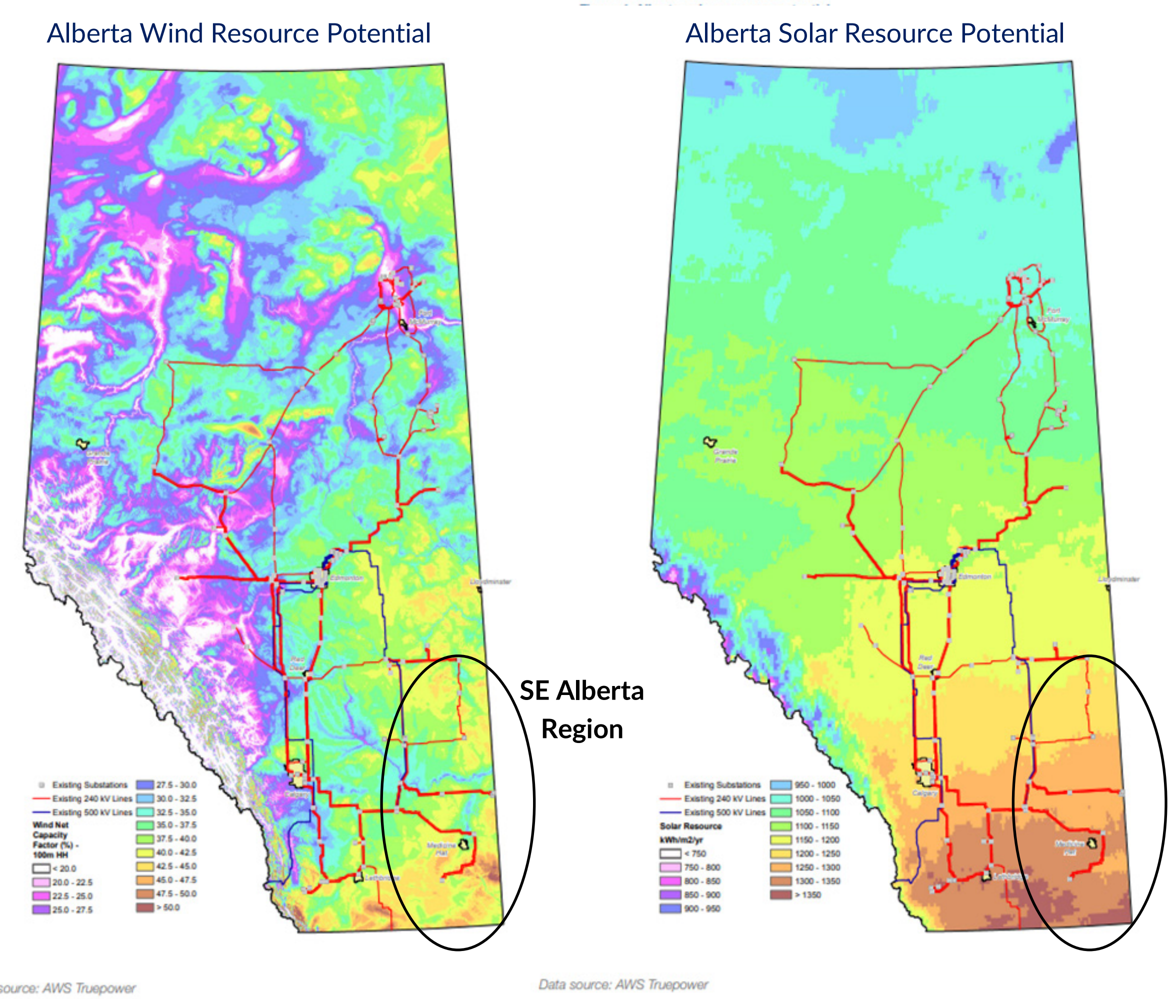


Figure 6.14 Wind and Solar Potential for Alberta

SE Alberta Region with strong potential for both wind and solar generation.

SOURCE: AESO 2019 Transmission Capability Assessment Final Report

Wind resource in the region has the added benefit of having two flow regimes, one that is predominately blowing to the northeast and one that is predominately to the southeast (**Figure 6.15**). As these winds will generally not occur at the same time, this provides the opportunity for wind generation from the region to have an overall wider range of contribution by being off cycle. Limitations in transmission capability could slow this resource development but also could provide the impetus for utilization of renewable power, whether on grid or islanded, for the purpose of generating hydrogen. [207][208][209][210]

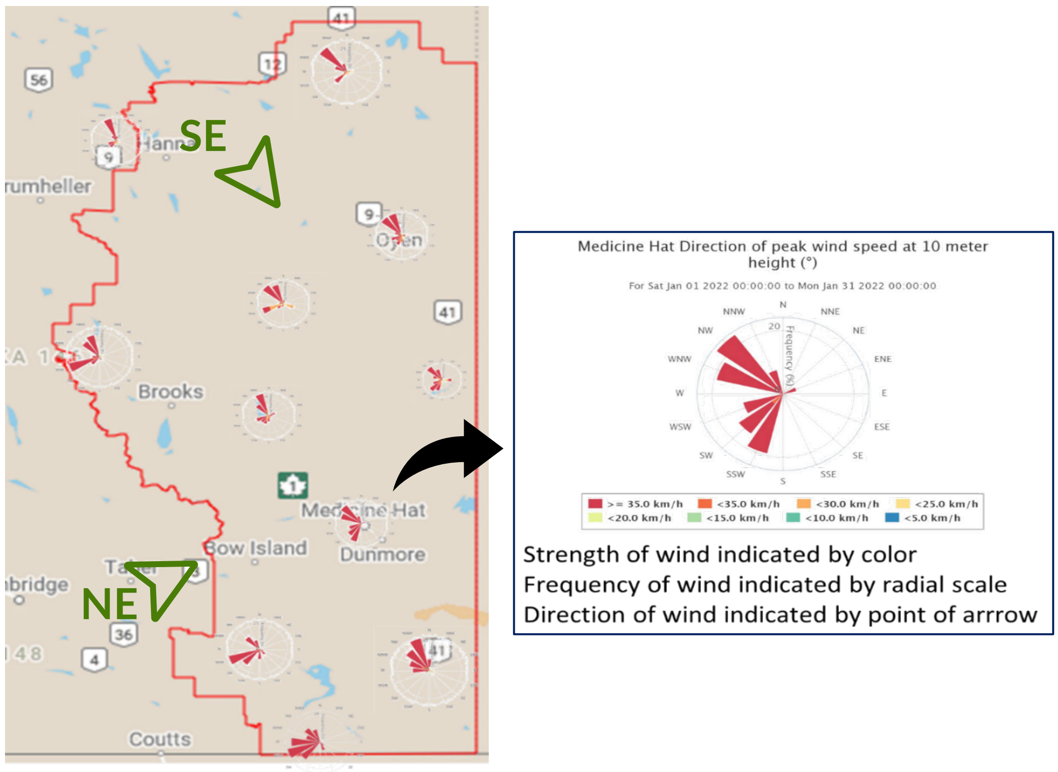


Figure 6.15 SE Alberta Wind Resource Direction

Wind roses across the region for January 2022 demonstrating dual wind flow regimes

6.5.2 Renewable Power Capacity Factor and Price

To understand the implications of renewable generation to transmission grid stability, capacity factor needs to be understood and how it affects the stability of electrical flow. Wind and Solar are considered to be of the highest availability usage rate of all generation types, with availability being defined as the time a generator is able to deliver electricity when capable of generating electricity. However, the issue with wind and solar is that the availability is directly related to the capability of generating electricity and that neither are capable of generating electricity on a continuous 24-hour basis; wind generation does not generate power if there is no wind and solar generation does not generate power if there is no sunlight. Combined Cycle baseload generation currently operates at the highest capacity factor (**Figure 6.16**), with the capacity factor being indicative of its availability to generate power at any given time. [211][212][213][214]

In 2020, Combined Cycle had a 71% availability factor and a resultant 64% capacity factor, thus 90% generation reliability. In comparison, wind had an annualized capacity factor of 39% for 2020 but this factor varied as physical wind varied. Typically wind potential is greatest between 7 PM and 3 AM on a daily basis but also varies with the season, with the greatest potential being in the winter, November to February, and lowest in the summer, May to August (**Figure 6.17**).

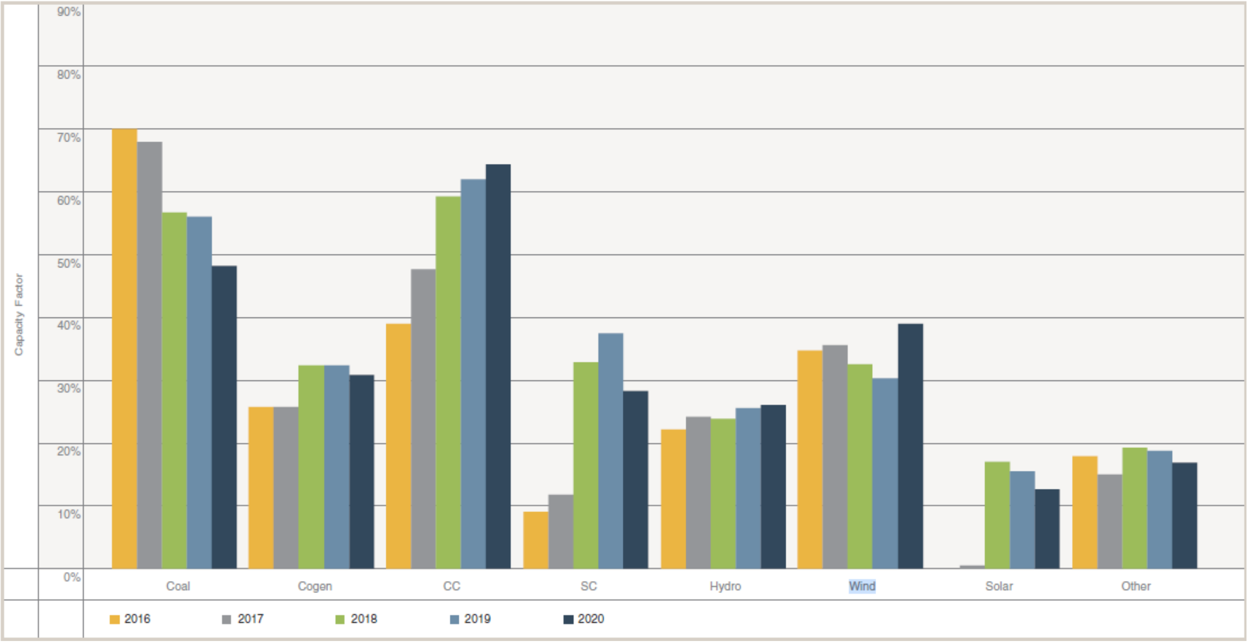


Figure 6.16 Five-Year Average Capacity Factor by Technology

Comparison of annual capacity factor by generation type showing baseload shift between coal and combined cycle natural gas generation at 60% capacity. 2020 Wind capacity factor of 40% and Solar capacity factor less than 15%.

SOURCE: AESO 2020 Annual Market Statistics

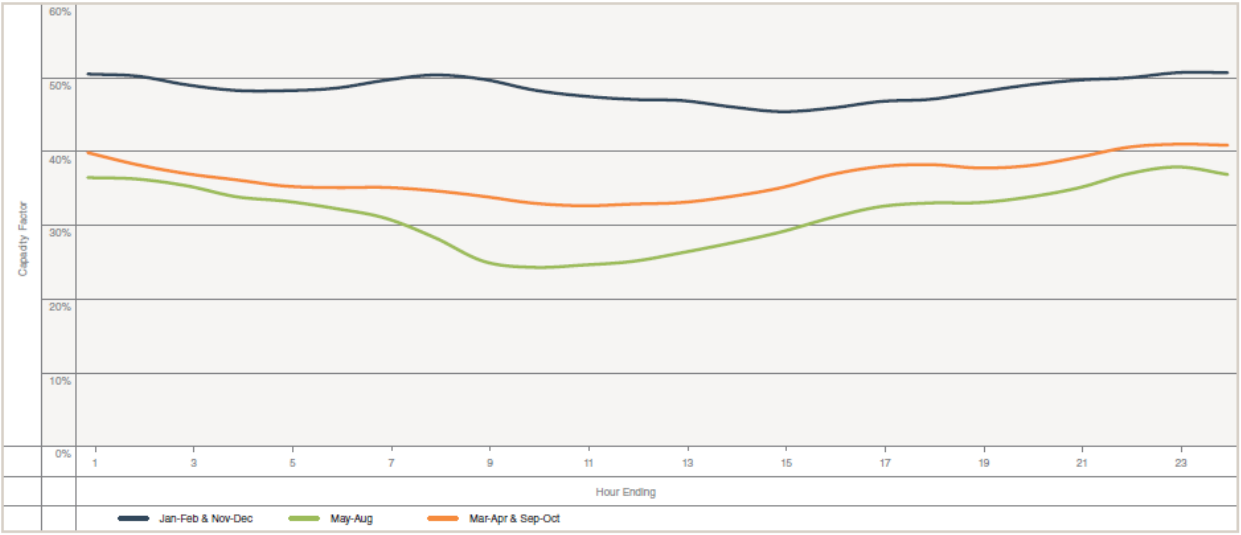


Figure 6.17 2020 Wind Generation Seasonal Average Hourly Output

Highest capacity factor during winter months and lowest during summer with less capacity during peak daylight hours.

SOURCE: AESO 2020 Annual Market Statistics

For solar, the capacity factor variance is even more dramatic (**Figure 6.18**), where generation in the winter is restricted to approximately 8 hours with diminished solar potential as compared to the summer, with higher capacity and longer hours. However, solar power does drop to zero capacity factor for much of the day due to darkness. In 2020, solar averaged 12.5% for the year with a range of 5.9% in the winter and 20.3% in the summer.

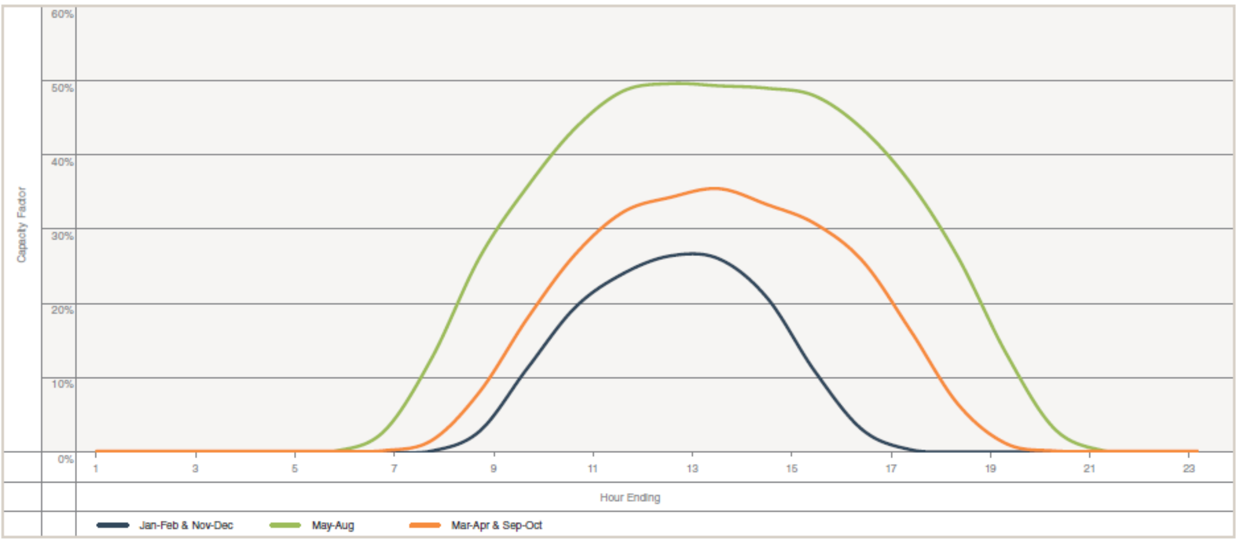


Figure 6.18 2020 Solar Generation Seasonal Average Hourly Output

Highest capacity factor during summer months and lowest during winter.

SOURCE: AESO 2020 Annual Market Statistics

As both wind and solar generation are not controllable, in terms of being reactive to load requirements or reliable over a 24-hour period, they are not able to be considered base load generation and PFR devises are necessary to provide transmission frequency stability. The greater the total load of a system is provided by IBR (renewable power) sources the greater the requirement for balancing PFR devices. For hydrogen transition purposes, this could be in the form of peaking plants run on combustible hydrogen, or the more efficient hydrogen fuel cells.

In addition to system stability, the optimization of system capacity becomes an issue with the increased concentration of IBR sources due to the potential requirement of overbuilding transmission systems to accommodate short term total generation capacity but run at overall low-capacity factors. As shown in **Figure 5.40** within **Section 5.5.3)**, SE Alberta generation has seen its overall capacity factor drop from 65% to an estimated 46% in 2022 as a result of the addition of incremental wind and solar generation sources. If the system were to be upgraded to accommodate the entire inventory of approved and proposed projects, total incremental transmission capacity of approximately 9,000 MW would be required but with only 2,600 MW of actual generation being realized. Irrespective of potential frequency issues, this would not represent an effective or optimum capital investment and would likely lead to the implementation of planned congestion or generation apportionment within a constrained capacity system. The introduction of hydrogen based PFR generation would both contribute to system stability as well as system optimization to maintain an overall area generation capacity factor of 55% or greater.

A third issue that is created by the increase in IBR generation, specifically wind generation, is the nature of when peak generation from wind is realized. As previously mentioned, peak wind generation is typically during the period from 7 PM to 3 AM, which corresponds to typical non-peak electrical demand. Thus, when compared to other generation sources, wind power typically realizes the lowest premium to average pool pricing (**Figure 6.19**), essentially becoming the benchmark price during off peak demand, with the degree of negative premium over the last five years corresponding to the increased wind generation capacity.

Having a low but still positive premium indicates baseload generation with high-capacity factor, thus continuously running and therefore capable of capturing off peak and peak pricing equally. Having a high premium is indicative of two things; 1) peaking generation, such as simple cycle natural gas generation which only run during peak demand times thus maximizing the price premium, or 2) serendipitous generation, such as solar generation which does not control its timing of operation to correspond to peak periods but does have its production capability correspond to typical peak periods during the day.

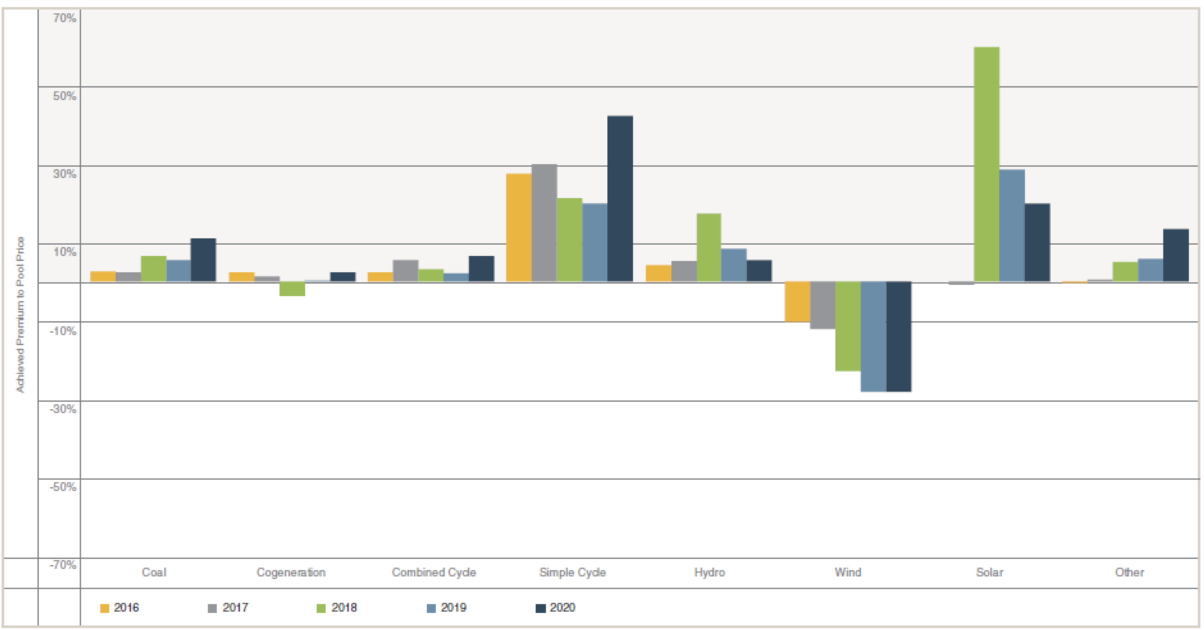


Figure 6.19 Annual Achieved Premium to Pool Price

Five-year representation of realized pricing by generation type as a percent premium of Pool Price. Higher premium corresponds to higher correlation to generation during peak hours while negative premium corresponds to higher correlation to generation during non-peak hours. Wind realizes the lowest premium to Pool Price.

SOURCE: AESO 2020 Annual Market Statistics

This effectively results in wind generated electricity potentially becoming surplus generation during non-peak hours as more wind generation is added to the overall pool and continuing to be the cheapest available power source. These situations suggest a strong potential use for generating green hydrogen, which in turn could be utilized to provide the fuel for the PFR devices required to balance the lower and more volatile capacity factor of solar generation and provide on demand generation during peaking shortfalls. In addition to PFR devices, the hydrogen generated from the excess power could be utilized for other hydrogen demand or for physical export, whether in pure form or as a hydrogen carrier such as methanol or ammonia.

6.6 Transportation & Storage

Initial utilization of existing transportation infrastructure will be critical in the establishment of access to hydrogen supply. This includes the existing highway and rail routes, which provides direct city to city connection and are currently used for delivery of hydrogen carriers and could be utilized for movement of compressed hydrogen. [215][216]

New infrastructure will be required to transport large volumes of hydrogen and hydrogen carriers over greater distances to minimize the cost of transport. Extensive pipeline infrastructure exists in Alberta and

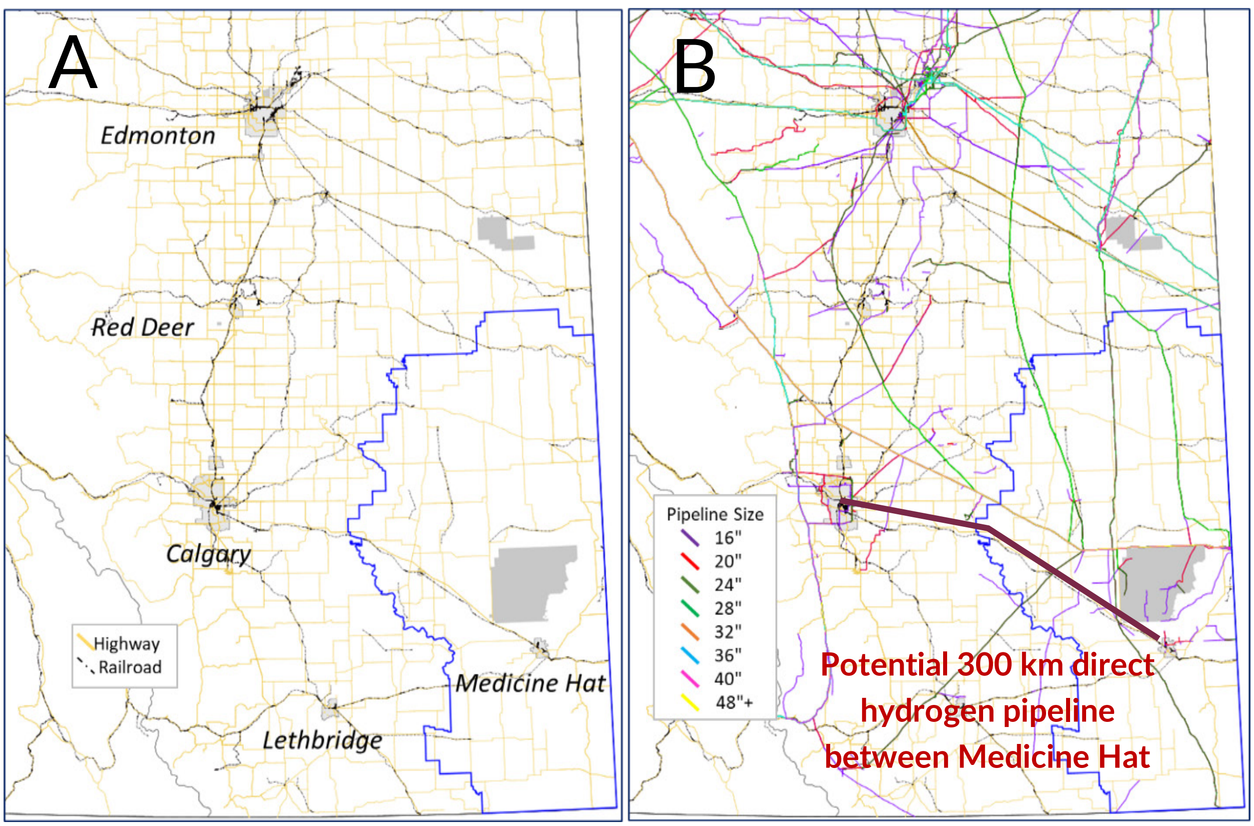


Figure 6.20 Comparison of Highway and Railroad Infrastructure to Large Pipeline Infrastructure

In Panel A, both highway and railroad infrastructure directly connect each city. In Panel B, significant large diameter pipelines emanate from Edmonton (Alberta Industrial Heartland) but do not connect directly to any other city. To connect supply from the Medicine Hat area to Calgary would require a 300 km built for service hydrogen line.

could be evaluated for potential comingled transportation with natural gas or repurposing other petroleum pipelines. However, much of the existing infrastructure does not connect the major industrial centers directly and is in dedicated use for transport of its licensed commodity. As shown in **Figure 6.20**, road and rail infrastructure connect the cities, while pipelines do not. New fit for purpose pipeline infrastructure will likely be required to form a backbone transmission network which could feed major supply / demand nodes and further distributed from those locations.

Within the Transition Accelerator technical brief "The Techno-Economics of Hydrogen Pipelines", evaluation of pipeline sizing, operating, and cost estimating was completed and determined that if done at scale, transportation of hydrogen can realize costs of less than $1.00/kg (<$7.00/GJ). The brief proposed a rule of thumb of 1 t_{H2}/day / $km_{pipeline}$ was required to drive economic viability. [217]

If a hydrogen demand of 5,000 t/day is assumed for the Calgary region and a pipeline distance of 300 km is required to deliver hydrogen from SE Alberta to Calgary, a minimum 36" pipeline would be required (**Figure 6.21**). This would suggest a transport cost of approximately $0.27/kg, based on only inlet compression. If an assumption for the cost to generate blue hydrogen of $1.50 to $2.00/kg is used, the combined delivered cost of hydrogen from Medicine Hat to Calgary would be $1.77 to 2.27/kg (**Table 6.1**).

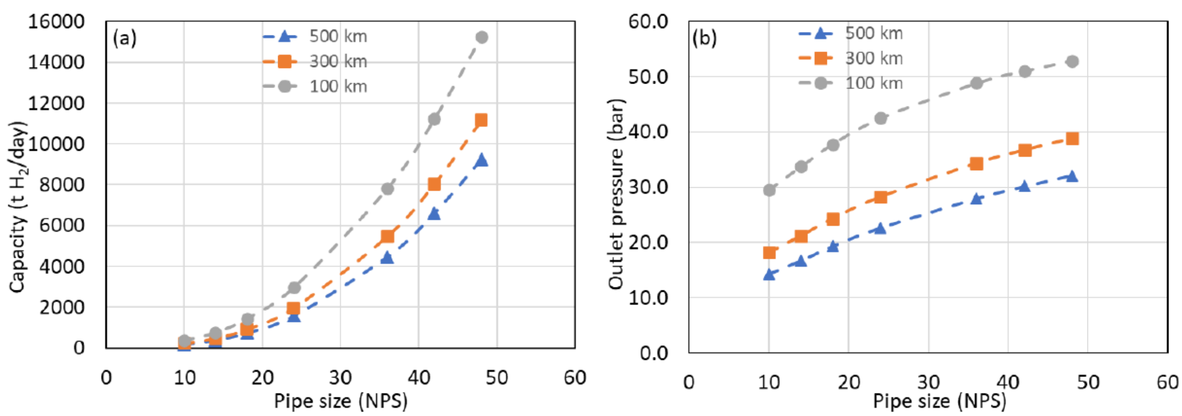


Figure 6.21 Capacity / Pressure vs. Nominal Pipeline Size

(a) Pipeline H_2 Capacity (tH_2/day) and (b) Outlet pressure (bar) versus pipe size (NPS) as function of distance between compressor stations. Note: inlet pressure of 70 bar, outlet gas velocity of 35 m/s and total distance of 1500 km.

SOURCE: "The Techno-Economics of Hydrogen Pipelines"

Table 6.1 Case I – Hydrogen Delivery Cost Calculation for Medicine Hat to Calgary

Assumptions:	36" NPS, 300 km length, inlet compression only, 20 bar inlet suction, 70 bar inlet pressure, Outlet velocity 35 m/s, Outlet Pressure ~ 34 bar, Electricity Cost $0.11/kWh			
Capacity:	5,500.0 tH_2/day			
		[MM$]		[$/$kgH_2$]
Components:	**Pipeline**			
	Capital Cost	1,620.0		
	Annualized Capital (50 yr 8%)	132.4	$	0.073
	Opex	212.1	$	0.117
			$	0.191
	Inlet Compression			
	Capital Cost	192.4		
	Annualized Capital (15 yr 8%)	22.5	$	0.012
	Opex	107.6	$	0.060
	Energy (Electricity Costs)	9.6	$	0.005
			$	0.077
	TOTAL DELIVERY COST		**$**	**0.268**

Calculation as per *Techno-Economics of Hydrogen Pipelines* adjusted for length and Inlet Compression length assumption. All Values Canadian dollars.

To evaluate export potential to the United States, an 1,800 km pipeline would provide access to California or the US Mid-West. Utilizing the same economic assumptions with in-line compression spaced at 300 km intervals, the total transport cost would be approximately $0.92/kg (all values in Canadian dollars). This would equate to a total delivered cost of $2.42 to $2.92/kg. Using **Figure 6.22**, if the decision were made to install a 48" pipeline, the capacity would increase to 11,000 t/day and transport cost would be reduced by 20%, thus resulting in a delivered cost of hydrogen of $2.24 to $2.74/kg (**Table 6.2**).

Based on the macroeconomics presented in **Section 2.5**, this delivered price would provide a margin of $4.00 to $6.00/kg for replacement of diesel in the transport sector.

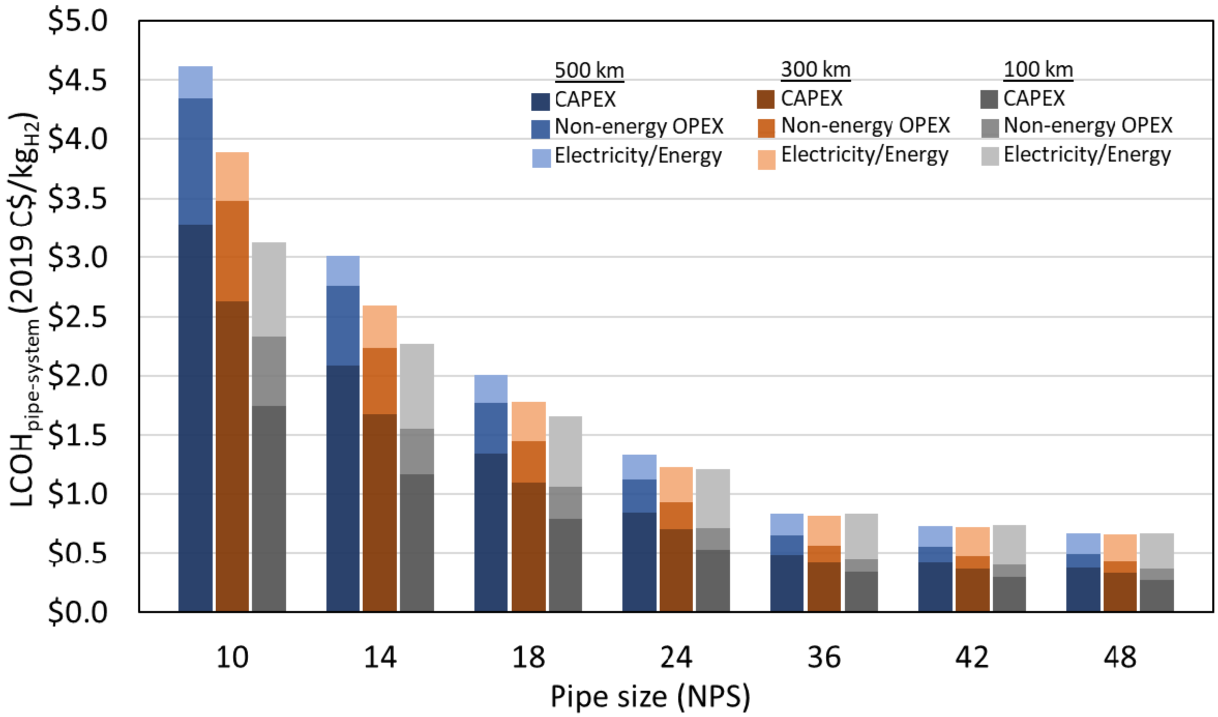


Figure 6.22 Levelized Cost of Hydrogen vs. Nominal Pipeline Size

$LCOH_{pipe\text{-}system}$ dived into: $Capex_{pipe\text{-}system}$, Non-Energy $OPEX_{pipe\text{-}system}$, and $Energy_{pipe\text{-}system}$ vs. Nominal Pipeline Size based on 100, 300, and 500m compressor spacing at 70 bar inlet pressure and 35 m/s outlet gas velocity at a distance of 1,500 km.

SOURCE: "*The Techno-Economics of Hydrogen Pipelines*"

Hydrogen storage is likely to be pursued in the Edmonton region due to the presence of existing salt caverns and the ability to establish further caverns within existing thick salt deposits. In SE Alberta, existing natural gas storage is within conventional reservoirs. As operator of the AECO Hub™, Rockpoint Gas Storage has indicated they are evaluating the ability to utilize existing or new reservoirs for commingled hydrogen / natural gas storage as well as pure hydrogen storage. SE Alberta does contain subsurface salt horizons, but the thickness has historically been viewed as too thin for purposes of establishing conventional down hole storage caverns. However, re-evaluation of these intervals utilizing horizontal drilling techniques are being conducted to determine if application for hydrogen storage is feasible.

Table 6.2 Case II – Hydrogen Delivery Cost Calculation for Medicine Hat to United States

			[MM$]	[$/kg$H_2$]
Assumptions:	36" NPS, 1,800 km length, inlet compression + in-line compression at 300m, 20 bar inlet suction, 70 bar inlet pressure, Outlet velocity 35 m/s, Outlet Pressure ~ 34 bar, Electricity Cost $0.11/kWh			
Capacity:	5,500.0 tH_2/day			
Components:	**Pipeline**			
		Capital Cost	9,720.0	
		Annualized Capital (50 yr 8%)	794.4	$ 0.440
		Opex	212.1	$ 0.117
				$ 0.557
	Inlet Compression			
		Capital Cost	192.4	
		Annualized Capital (15 yr 8%)	22.5	$ 0.012
		Opex	107.6	$ 0.060
		Energy (Electricity Costs)	9.6	$ 0.005
				$ 0.077
	In-line Compression			
		Capital Cost	688.5	
		Annualized Capital (15 yr 8%)	80.4	$ 0.044
		Opex	385.1	$ 0.213
		Energy (Electricity Costs)	42.3	$ 0.023
				$ 0.281
		TOTAL DELIVERY COST		**$ 0.915**

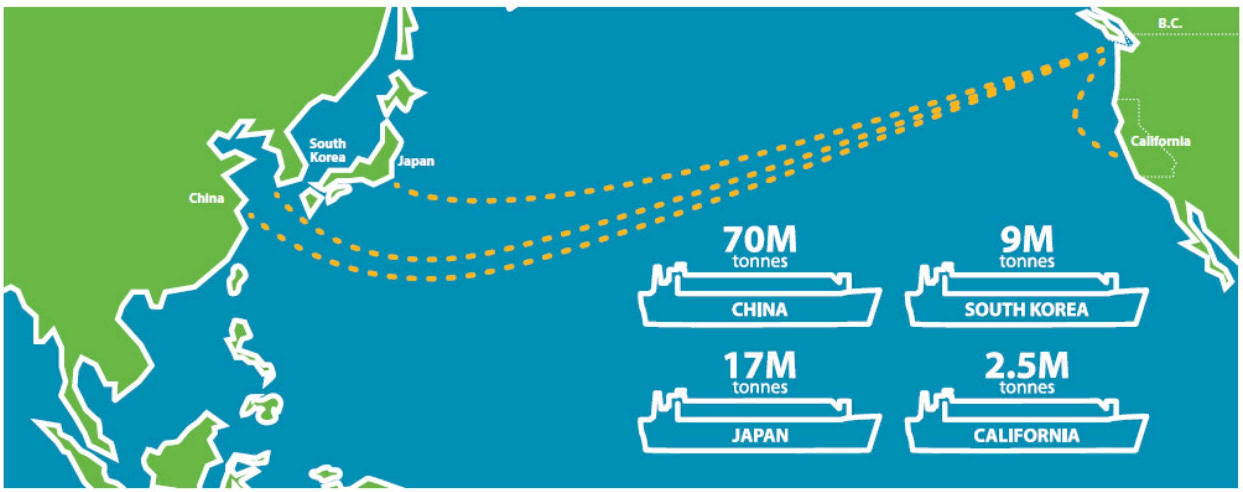
Calculation as per *Techno-Economics of Hydrogen Pipelines* adjusted for length and Compression length assumption. All Values Canadian dollars.

6.7 Exports

Global hydrogen demand in 2020 is estimated to have been **90 Mt**. The IEA has calculated an estimate of **250 Mt/year** of hydrogen demand by 2050 to meet global carbon reduction pledges. In the IEA Net Zero Emissions Scenario, the hydrogen demand would increase to **530 Mt/year** by 2050. [218][219][220]

Exports have been identified as a critical component within each of the Canadian, BC and Alberta hydrogen roadmaps. The Canadian Hydrogen Strategy estimates that by 2050, Canadian exports of hydrogen could be 40 Mt/year, double the demand in the Canadian domestic markets. This estimate may be conservative in relation to the opportunity that is being forecast to exist.

The BC hydrogen strategy has estimated a total global market of 230 Mt of hydrogen by 2050 with the top export markets of China, Japan, South Korea, and California representing 50% of the total global demand having a combined market size of $305 billion, with import requirements being estimated at 100 Mt (**Figure 6.23**). Export of hydrogen carriers (ammonia and methanol) as well as liquid organic hydrogen carriers could be critical in establishing export opportunities. [221][222]



Demand projections by jurisdiction in 2050

Figure 6.23 Pacific Region Hydrogen Export Markets

Schematic demonstrating the advantageous shipping pathways for hydrogen export to Japan, South Korea, China, and California.

SOURCE: BC Hydrogen Strategy Report

It is anticipated that demand for hydrogen imports will be initially greater from Europe with the potential demand of 10 Mt/year by 2030 and increasing to 30 Mt/ year by 2050. Asian demand is anticipated to surge by 2040 and outstrip Europe's demand in 2050, with South America potentially evolving into a significant export target.

Five key markets have been identified for Canadian export:

1. United States: California would specifically be a target for Alberta due to existing rail and pipeline infrastructure. It is estimated that the California market could be upwards of 4 Mt/year by 2050 and the entire US market being 22 to 40 Mt/year. Canada is well situated to satisfy import requirements due to current success in exporting hydrogen carriers to the US by rail.
2. Japan: Hydrogen market of 5 to 35 Mt/year by 2050. The Japanese government has indicated a requirement of 3 Mt/year import of ammonia by 2030 with an estimated increase to 30 Mt/year by 2050. Two Canadian export initiatives have been announced to date, with both tied to Japan's import requirements for low-carbon ammonia.

i. On August 3, 2021, it was announced that Itochu Corporation (Itochu) and Petronas Energy Canada Ltd. (Petronas) had entered into a joint feasibility study to evaluate the commercial production of ammonia in Canada by 2026 via a US$1.3 billion, one million ton per year facility utilizing Petronas' gas reserves, for export to Japan. On May 24, 2022, Itochu updated the announcement indicating an agreement with Petronas and Inter Pipeline Ltd (IPL) for the manufacture of blue ammonia and blue methanol and the initiation of detailed design work, including the associated CCUS. The sanctioning of the project is anticipated to occur by the end of 2023 with construction planned for 2024 and operations to commence in 2027. The two facilities would be located in Alberta and would have the blue products railed to an export facility for global shipping. [223][224]

ii. On September 8, 2021, Mitsubishi Corporation (Mitsubishi) and Shell Canada Products (Shell) signed an agreement to produce blue hydrogen, with the facility and CCUS located near Edmonton. The project is to be sized for 165 million tons, which would then be further processed and converted to blue ammonia for export to Asian markets. [225]

3. South Korea: Hydrogen market of 4 to 20 Mt/year. Have been aggressively investigating supply options from Australia.
4. China: Hydrogen market of 18 to 160 Mt/year. Government has made significant investments in hydrogen and fuel cell vehicles.
5. Europe: Germany is a leader in hydrogen development in Europe with an estimated demand of 2.7 to 3.3 Mt/year by 2030 with significant growth through 2050. Import hubs are being developed in Netherlands, UK, and Portugal.

The Government of Alberta has indicated that it recognizes the gap in global supply chain. Current success in exporting hydrogen carriers to the US via rail should allow for near term opportunity to increase export capacity but could be limited by rail capacity and public interest. Alberta has several advantages to supply global demand for clean hydrogen but will need to overcome infrastructure limitations and be committed to approving and constructing the required infrastructure (pipelines, liquefaction, transportation, storage). Further, Alberta has identified the need for support from the Canadian federal government, BC and the Indigenous and local communities to establish the hydrogen export supply chain.

SE Alberta is favourably situated to both capture international export potential in addition to being a "domestic exporter" of hydrogen to Canadian supply deficient regions such as Calgary and Eastern Canada. As discussed in **Section 6.6**, existing rail infrastructure is in place to allow for early trans-Canadian and US supply. In addition to satisfying regional demand, which would see SE Alberta hydrogen production double from current levels to approximately 2,500 t/day, an incremental supply of 5,000 t/day could be targeted for the Calgary region. Initially this could be satisfied via rail as demand is established but would ultimately be satisfied by a fit for purpose 300 km 36" pipeline.

Further, SE Alberta is advantageously situated to be the lowest cost supplier to adjacent provinces, Eastern Canada, and the western United States. For Eastern Canadian markets, export volumes could potentially be accommodated by repurposed spare pipeline capacity within the TC Energy natural gas mainline infrastructure that originates at Empress. For shipment to the United States, whether to the Californian market or directly to the US Mid-West, hydrogen pipelines could be constructed in existing right-of-ways or similar pathways as existing petroleum pipelines that travel through SE Alberta to their ultimate destinations. An 1,800 km pipeline system could be constructed and directly connect low-cost supply from SE Alberta to either US marketplace, which could support incremental regional generation of 5,000 to 11,000 t/day.

With successful establishment of merchant hydrogen supply for local regional demand and CCUS infrastructure, focus could be shifted to exports of hydrogen or hydrogen carriers out of the region that could reach magnitudes of 5 to 15 ktH_2/day, an increase of 5 to 15 times current hydrogen production volumes, at a supply cost ranging from $1.77/kg for supply within southern Alberta and Saskatchewan to $2.92/kg for supply to California or the US Mid-West. [226][227]

6.8 Regulations, Codes, and Standards

6.8.1 Enabling Policies and Regulations

Both the federal and provincial governments have recognized the importance of addressing hydrogen transition within the existing policies, regulations, codes and standards. Early adopters from around the world have shown that regions with clear supporting policies and regulations have been successful in moving forward with clean hydrogen projects.

The Government of Canada recognized that the absence of clear, long-term policy signals that recognize hydrogen's essential role in Canada's net-zero greenhouse gas future can cause uncertainty for investors and slow implementation and adoption. There is a need for a more cohesive national framework with a common vision to provide a clear signal of the importance of hydrogen and avoid patchwork polices and regulations across jurisdictions. Additionally, there needs to be mechanisms to help de-risk investments for end-users as they adapt to regulations.

Within the Alberta Hydrogen Roadmap, the government made the statement that the government needs to ensure the regulatory regime is inclusive of hydrogen and enshrine a safety-first mindset across the value chain. The province is also looking to harmonize codes, standards, and regulations with other jurisdictions to ensure Alberta's competitiveness across the hydrogen economy. To this end, they are looking to work with industry and hydrogen proponents to address existing regulations, codes and standards that require amendment or revision to allow for the inclusion of hydrogen. It is believed that policy actions need to support emerging hydrogen markets. The province intends to follow a performance-based regulatory framework that will allow hydrogen to move forward while reducing risk.

As a precursor to the release of the hydrogen strategy, Alberta moved forward with what they believed was an integral part of the low carbon future, with the release of the May 12, 2021, Information Letter 2021-19 on Carbon Sequestration Tenure Management. As it was felt that proponent demand for carbon sequestration tenure was not adequately addressed in current regulations, the government moved forward with a system that will establish an appropriate path for tenure management and a system that will establish a high level of rigor for approval of permanent storage of CO_2.

On March 23, 2022, the government of Alberta directed the AUC to open an inquiry into the hydrogen blending within natural gas distribution systems. Bulletin 2022-05 [228][229]

The inquiry is intended to make findings or observations on:

- The role of regulated natural gas distribution systems and unregulated competitive markets for hydrogen blending into natural gas distribution systems up to 20 percent blending by volume.
- The impacts of blended hydrogen into low-pressure natural gas distribution systems, including:
    - Impacts on delivery of services to municipal and rural natural gas consumers.
    - Competitive retail impacts.
    - Potential rate impacts.
    - Impacts on utility cost recovery for hydrogen blending, with reference to Section 37 of the Gas Utilities Act and any other relevant legislation, including the Public Utilities Act.
- The safe and reliable delivery of blended hydrogen through natural gas distribution systems, including potential harmonization with municipal or other relevant safety standards.
- Addressing regulatory ambiguity, removing unnecessary regulatory barriers, and improving certainty as required to enable hydrogen blending into natural gas distribution systems.
- Areas for future sturdy relating to hydrogen blending into natural gas distribution systems.

The AUC is currently in the process of gathering information from interested parties and intended to submit a report to the Minister of Energy by June 30, 2022.

As new opportunities are brought forward and regulations and policies are found to be ineffective or incompatible with energy transition, the government has shown the willingness to address those issues and work to resolve them to support the hydrogen industry.

6.8.2 Codes and Standards

In addition to policy and regulatory issues, gaps in existing codes and standards were identified as needing to be addressed to enable greater adoption of hydrogen and hydrogen technologies. This includes modernizing existing codes and standards to keep pace with the rapidly changing industry and removal of barriers for deployment of hydrogen technologies, both domestically and internationally.

The Canadian Standards Association Group (CSA) has identified various standards that are associated with the Hydrogen Ecosystem and have various initiatives underway evaluating those standards to ensure they support the advancement of transition to hydrogen and hydrogen technologies, whether directly or indirectly. The CSA is exploring hydrogen technologies that touch the entire value chain and includes power to gas, hydrogen distribution, delivery, storage, and CCUS, as well an extensive hydrogen standards portfolio in support of the transportation sector that includes fuel cells, storage, and fueling stations. The group is also providing insights into activities that are being conducted by various other standards committees which are impacted by hydrogen. [230]

As per the CSA Groups Standards for Hydrogen Ecosystem Infographic, the currently identified Standards and Research that are part of their review:

Energy Source

- Renewable Energy
  - CSA C22.2 No. 272 – wind turbine electrical systems
  - CSA 61400 – standards for wind energy generation systems
  - CSA C22.2 No. 61730 – standards for photovoltaic module safety qualifications
- Biomass and Biogas
  - CSA / ANSI B149.6 – code for digester gas, landfill gas, and biogas generation and utilization
  - 40+ CSA / ISO standards for solid biofuels
- Nuclear
  - 60+ CSA standards covering entire life cycle of a nuclear facility
- Oil & Gas
  - 20+ CSA standards covering production, delivery, storage, security and management of petroleum and natural gas products

Hydrogen Production & Storage

- Generation
  - CSA C22.2 No. 22734 – hydrogen generators using water electrolysis; industrial, commercial, and residential applications
  - CSA / ANSI FC 5 – hydrogen generators using fuel processing technologies
- CCUS
  - CSA Z741 – geologic storage of carbon dioxide
- Storage
  - CSA B51, Parts 1-3 – boiler, pressure vessel, and pressure piping code
  - CSA Z341 – storage of hydrocarbons in underground formations

Hydrogen Delivery

- Pipelines
  - CSA Z662 – oil and gas pipeline systems
- Ground Transportation

- Suite of CSA standards covering the transportation of dangerous goods

Hydrogen End-Use

- Transportation
  - CSA / ANSI HGV 4 – standards for hydrogen fueling stations and components
  - CSA / ANSI HGV 2 – compressed hydrogen gas vehicle fuel containers
  - CSA / ANSI HGV 3.1 – fuel system components for compressed hydrogen gas powered vehicles
  - CSA / ANSI HPRD 1 – thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers
  - CSA EXP11 – Canadian risk evaluation and assessment for railway systems
  - CSA research – alternative fuels and energy for the marine sector
- Residential / Appliances
  - CSA Z21 – 60+ standards for appliances on controls for residential and commercial heating, cooking, HVAC, drying and hearth products
  - CSA Z83 – 9 standards for gas-fired heating and cooking
  - CSA B149.1 – natural gas and propane installation code
  - CSA P – 11 standards for energy efficiency of various fuel appliances
  - CSA research – appliance and equipment performance with hydrogen-enriched natural gas
- Commercial / Industrial
  - CSA HPIT 1 – compressed hydrogen powered industrial truck on-board fuel storage and handing components
  - CSA HPIT 2 – dispensing systems and components for fueling hydrogen powered industrial trucks
  - CSA / ANSI FC 1 – fuel cell technologies – stationary power systems – safety
  - CSA / ANSI FC 3 – portable fuel cell power systems
  - CSA / ANSI FC 6 – fuel cell modules
  - CSA M424.4 – non-rail-bound, self propelled, electrically driven mobile machines for use in gassy or non-gassy underground mines

Current activity includes:

- Exploration of all hydrogen production methods (electrolysis, steam methane reforming, pyrolysis and related CCUS) and energy sources for production (renewable energy, biogas, nuclear, and oil & gas).
- Establishing a task force (CSA Z625) to look at the potential for hydrogen storage and production using depleted wells.

- Establishing a task force (CSA Z341) for requirements on hydrogen storage in underground formations.
- Establishing a task force (CSA Z662) for requirements for oil and gas pipeline systems to incorporate hydrogen and renewable gas blends. Currently a public review notice has been advertised to identify the various changes and proposed inclusion within current standards.
- Continued active role in establishing national and international codes and standards as it applies to alternative fuels and fuel cells utilized for transportation.
- Undertaking research projects to identify and test appliance and equipment performance with hydrogen enriched natural gas (up to 15% hydrogen) and providing insight into technical concerns and challenges as well as identifying gaps in current standards.
- Continue to update fuel cell power storage and hydrogen storage standards to reflect technology advancement to both ensure public safety but to also help promote hydrogen as a viable vehicle fueling option.
- RP-0196 NOI Classification of Carbon Intensity for Production of Hydrogen – as it has been identified that there is an urgent need to define a better hydrogen carbon intensity system as the current color category classifications have large variabilities in emission profiles exist and do not adequately address life-cycle considerations.

7 CALL TO ACTION

Action must equal the words.

Supply and demand must grow in equivalent broad steps to support the build out of the necessary infrastructure to allow for generation, transportation, distribution, and consumption of hydrogen at scale to realize commercially viable and economically sustainable conditions.

> Supply and demand must grow in equivalent broad steps … to realize commercially viable and economically sustainable conditions.

All stakeholders must show commitment and achieve a line of sight to meaningful rewards for an energy transition to be successful, and utilization of hydrogen is no different. Bold steps and a financial investment are required both to initiate and then to grow supply and demand with no illusions that one or the other will occur without **a coordinated effort from all parties:** industry, academia, financial institutions, regulatory and municipal economic development stakeholders, and consumers. Ultimate sustainability and widespread transition will follow in time if alignment is achieved amongst the various stakeholders, and initial steps lead to the vision of beneficial change and economic advantage, thus creating a dedicated commitment to continue to build capacity and optimize processes.

To this end, SE Alberta is taking, and has increased potential and ability to take, the initial measured steps for hydrogen transition.

Four initial low carbon projects or pilots have been announced for the region:

- Kitsim Green Hydrogen generation project,
- Rockpoint hydrogen storage and marketing pilot,
- SAEWA Regional Green Economy Attraction and Energy from Waste Investment Partnership Project, and
- Project Clear Horizon CCUS project.

It is the belief of the author and the Transition Accelerator that additional opportunities exist for immediate consideration. This would include:

1. Working with AMTA to establish partnerships with transport and fuel distribution companies to build out hydrogen fueling infrastructure along the TransCanada Highway,
2. Capitalize on the serendipity of the Medicine Hat Industrial Complex for both hydrogen generation and pilot use for road and rail transportation, electrical generation, natural gas distribution utility, and greenhouse or other industrial use.

In addition to the industrial commitment to deliver supply and to establish the infrastructure to distribute that supply, the ability to gain access to and deploy the equipment required to utilize the hydrogen supply becomes equally critical. Initial deployment of hybrid equipment or conversions, such as discussed in **Box 7.1**, to accommodate co-combustion of hydrogen-diesel or hydrogen-natural gas is likely to both accommodate early-stage infrastructure development but also to allow for the continued efficient use of existing equipment during the early transition stages.

BOX 7.1 HYDROGEN-DIESEL DUAL FUEL ENGINES

Hydrogen can also be co-combusted with diesel in existing internal combustion engines, where it is known to improve the combustion of diesel fuel and reduce particulate matter emissions, as well as GHG emissions. Numerous reports [60][61] have shown engine performance equivalent to or better than diesel alone, with up to 98% mixture of H_2:diesel on an energy basis [62]]. Companies like Vancouver's Hydra Energy [231], or UK's Ulemco [232]] retrofit existing diesel engines so hydrogen can be injected into the cylinders along with diesel fuel. With Transition Accelerator support, Dr. Bob Koch's lab at the University of Alberta [233] is working with an engine OEM to integrate hydrogen injection technology into the software of the engine's electronic control unit. Other companies are building ships [234][235] or large mining trucks [63] to use H_2-diesel dual fuels.

These vehicles require high pressure hydrogen storage tanks similar to what is used on HFCE vehicles, and therefore their widespread deployment should help to bring down the price of these tanks. In addition, hardware is needed to deliver the hydrogen to each cylinder, and control hardware and software is needed for each engine type.

The hydrogen purity required for H_2-diesel vehicles is not as high as that required for HFCE vehicles. However, if H_2-diesel vehicles are to assist in development of fueling infrastructure that supports HFCE vehicles, any publicly funded fueling station should require a hydrogen standard to serve both markets.

SOURCE: Box 7.1 extracted from Building a Transition Pathway to a Vibrant Hydrogen Economy in the Alberta Industrial Heartland, The Transition Accelerator, November 2020

7.1 Announced Hydrogen Pilots

Two hydrogen projects have been proposed for the SE Alberta region.

1. IEPS Canada has proposed the Kitsim Hydrogen Project in the Brooks area (**Box 7.2**). The initial phase of the project proposes 5.75 t/day of hydrogen production that could displace 24,355 L of diesel per day for heavy trucks. If this hydrogen is generated with a direct connection to renewable power, this displacement of diesel consumption would reduce CO_2 emissions by 25kt/year.

BOX 7.2 KITSIM HYDROGEN PROJECT

On July 27, 2021, Integrated Energy & Power Solutions (IEPS) announced The Kitsim H_2 Project which would be situated southwest of Brooks, Alberta. [236] The proposed green hydrogen project would utilize PEM electrolyzers and be built out in four phases with full build out by 2030. It is proposed to produce approximately 50 kt of H_2 and 400 kt of O_2 annually utilizing 450 MW of electricity and 670 dm^3 of water. The first phase is planned for 2024 with an annual target of 2.1 kt of H_2 and 16kt of O_2, and each subsequent phase to increase production by 16 kt of H_2 and 130 kt of O_2. Final plant siting is currently ongoing.

IEPS CANADA

2. A four-company consortium led by Rockpoint Gas Storage, has proposed a pilot to offer early-stage marketing of hydrogen / CO_2 offset credits (**Box 7.3**). The project proposes to create a storage and energy offset mechanism, whereas end users who do not have direct access to hydrogen as a fueling source can arrange to purchase hydrogen which would be stored within the natural gas distribution system and ultimately result in the displacement of an equivalent energy volume of natural gas from the whole system. This mechanism is similar to existing opportunities which allows for consumers to purchase renewable natural gas within a natural gas distribution system or renewable power within an electrical power pool. For this pilot, regulatory restrictions will prevent the physical commingled storage of hydrogen with the natural gas. Thus, Rockpoint will look to physically consume the hydrogen volumes rather than storing, with this equivalent energy volume of hydrogen consumption offsetting the typical natural gas consumption that Rockpoint would incur. Any resulting carbon credits that this consumption generates would be transferred from Rockpoint to the FortisBC consumer who made the arrangements to purchase the hydrogen, though they were not physically able to utilize it directly.

BOX 7.3 ROCKPOINT – HYDROGEN STORAGE TRANSACTION

On May 5, 2022, Rockpoint Gas Storage, Plug, Certarus Ltd., and FortisBC announced a small-scale pilot project at the Suffield natural gas storage facility (part of the AECO Hub™) with an anticipated commencement date in the fall of 2022. [237]

Under the project, green hydrogen generated by Plug will be transported to the Rockpoint storage facility in Suffield, where it will be consumed above surface by the Rockpoint equipment. FortisBC will be the purchaser of the green hydrogen and be credited with hydrogen storage at AECO Hub™, which will provide FortisBC the option of marketing the hydrogen to its customers as displacement of existing natural gas usage. Consumption of the hydrogen by Rockpoint is a result of existing regulatory regime not yet allowing for the blending of hydrogen and natural gas in subsurface storage facilities.

The pilot is intended to demonstrate how existing natural gas storage infrastructure can be utilized to accelerate transition by bridging timing and location challenges of hydrogen production and demand. FortisBC will be able to provide its customers in British Columbia with another low carbon gas alternative, similar to renewable natural gas.

7.2 Energy from Waste – GHG Reduction

The Southern Alberta Energy from Waste Association is moving forward with the review of three expressions of interest for the development of the 300,000 t/year Energy-from-Waste facility that is located at the County of Newell landfill site. The facility is estimated to produce 50 MW of electricity and 1 Mt of process steam and would result in the GHG reduction of 230 kt/year and 7 Mt over its lifespan of 30 years. It is currently estimated to be in operation within 2.5 years following execution of contract with preferred partner.

7.3 Carbon Capture

A critical component to realizing net-zero carbon energy transition is the establishment of carbon capture, utilization, and storage (CCUS). In addition to CCUS being required to address carbon emissions from sources not suitable for transition to low-carbon alternatives, such as hydrogen or renewable power, it is also critical to achieve economic low carbon intensity blue hydrogen generation. Thus, establishing CCUS capability in the region as quickly as possible is a critical initial step to realize economic hydrogen transition.

The City of Medicine Hat has announced their intention of moving forward with Project Clear Horizon, which would be a 3 million tonne per annum CO_2 sequestration project. The project was announced at the end of 2021 with a call for proposals for Conceptual Design and Cost Estimation closing on February 15, 2022. The project is conceptually planned to be located north of the Medicine Hat Industrial Complex and targeting the Basal Cambrian aquifer. CO_2 emissions associated with the city's natural gas electrical generation assets would be captured along with the potential of capturing the emissions from CF Industries and Methanex which are located in close proximity. After being awarded deep sequestration rights, drilling and down hole evaluation work could take upwards of two years to complete, with a plant in service date of 2027 estimated. [238][239]

Dependent on the ultimate subsurface evaluation results and final siting of the project, additional sequestration from the other three industrial areas in SE Alberta could potentially be incorporated into the project via CO_2 pipeline connection or accommodated by the development of area specific projects located in closer proximity to the emission sources.

Capturing of these emissions within the region is critical to both overall reduction in carbon emissions but also to realize the lowest cost blue hydrogen supply from the region. To achieve the successful and sustainable economic transition to hydrogen, both the cost to generate hydrogen and the carbon intensity must be minimized. Carbon capture is required to achieve this goal and thus it is critical for CCUS to be established in SE Alberta as soon as possible.

Ideally, CCUS availability would correspond to initial hydrogen project piloting to realize an immediate CO_2 reduction. However, initial piloting with existing grey hydrogen or available hydrogen carriers should not be delayed, insofar as ultimate realization of low carbon intensity can be achieved for full transition commercialization.

7.4 TransCanada Transportation Corridor

A project worthy of immediate consideration would be to move forward with establishing partnerships with transport and fuel distribution companies, as previously identified in the report for the SE Alberta region, as well as engaging with AMTA and both provincial and federal agencies, to construct hydrogen fueling stations along the TransCanada Highway between Calgary and Medicine Hat. This would be the initial steps of ultimately constructing further stations both east and west along the TransCanada corridor and the establishment of a hydrogen fueling network across Canada. Creation of a multi-station network will be necessary to encourage expansion of hydrogen fueled trucks within transport fleets as well as the transition of other class of vehicles such as commercial or passenger vehicles.

This initiative is a logical follow-up to the previously announced pilot for the Edmonton to Calgary corridor (**Box 7.4**) and is a necessary step to establishing commercial operation of hydrogen fueled fleets. Hydrogen supply for these stations could be sourced from SE Alberta, where merchant hydrogen (non-syngas hydrogen) or hydrogen carriers could be accessed from the Medicine Hat Industrial Complex.

Hydrogen supply for the stations along the corridor could potential be supplied by a combination of truck and rail. The CP Rail mainline runs parallel to the TransCanada Highway and presents an opportunity to optimize transport costs by utilizing rail cars with ten times the capacity of truck trailers. This corresponds to the CP Rail pilot announced for Calgary (**Box 7.5**) and could be viewed as a natural extension of the project for demonstration of both locomotive use along the mainline and for hydrogen transport.

BOX 7.4 ALBERTA ZERO-EMISSION TRUCK ELECTRIFICATION COLLABORATION (AZETEC) PROJECT

Led by the Alberta Motor Transport Association (AMTA) and two of its member companies (Trimac and Bison Transport), AZETEC is working with industry leaders Freightliner, Ballard and Dana to design and build two heavy-duty (63.5 tonne) hydrogen fuel cell electric (HFCE) hybrid trucks and put them on the road in Alberta in late 2021. The Trucks will be fueled in Edmonton, carry a full load to Calgary about 325 km to the south, where they will pick up another load and return to Edmonton. This project has been funded by Emission Reduction Alberta and Natural Resources Canada, as well as the Transition Accelerator.

SOURCE: Box 7.4 extracted from Building a Transition Pathway to a Vibrant Hydrogen Economy in the Alberta Industrial Heartland, The Transition Accelerator, November 2020

To establish a hydrogen fueled heavy transport sector, hydrogen fueling must be established along the major transportation corridors in conjunction with a commitment from owners of trucking fleets to purchase and use hydrogen fueled vehicles. Once success is established by the initial pilots, subsequent expansion of fueling along secondary highways and ultimately throughout the entire highway network must follow in quick succession so as to not become an impediment for further hydrogen vehicle introduction and to allow for the transport company to realize optimum utilization of its fleet. Once organizations make commitments to either hybrid hydrogen or standalone hydrogen fuel cell vehicles, fueling infrastructure must be put in place in a timely fashion to allow for the continued optimization and expansion of those fleets to achieve the economic sustainability that is required.

BOX 7.5 CP RAIL'S HYDROGEN-POWERED LOCOMOTIVE PILOT PROJECT

In December 2020, CP Rail announced its Hydrogen Locomotive Program for Calgary, that will see the retrofit of an existing diesel-electric line-haul locomotive to a Hydrogen Zero Emissions Locomotive (H2 0EL). Ballard is supplying six 200kW fuel cell modules, which will supply a total of 1.2MW of electrical power to the locomotive. In November 2021, CP received a $15 million grant via the Government of Alberta's Emissions Reduction Alberta (ERA) program. This will see the project expand from one to three locomotives (an additional line-haul plus shunting unit) and will add hydrogen production and fueling facilities in both Calgary and Edmonton. Atco Group will build two hydrogen production and fueling stations in CP Rail's Calgary and Edmonton rail yards. The infrastructure at each site will include one megawatt electrolyzers, compression, storage, and dispensing. Potential operation of the locomotive is expected by the end of 2022 with the hydrogen fueling infrastructure by the end of 2023. [240][241][242]

SOURCE: CPR Website, ATCO Website, and Railway Age Oct 5, 2021

The TransCanada Highway is a logical extension of the fueling network that will be created initially for travel on the Queen Elizabeth II Highway (Highway 2) and would see a western fueling network being created from Vancouver in the west to Winnipeg in the east (**Figure 7.1**).

Medicine Hat, within the SE Alberta region, is well positioned to be an anchor node for this trans-Canadian infrastructure, as it is situated on a very active portion of the route and could be a supplier of the hydrogen for the fueling stations along the entire corridor. Medicine Hat is located near the middle of the western portion of the TransCanada Highway and is situated 294 km from Calgary to the west and 466 km from Regina to the east and nearly equal distance between Vancouver and Winnipeg.

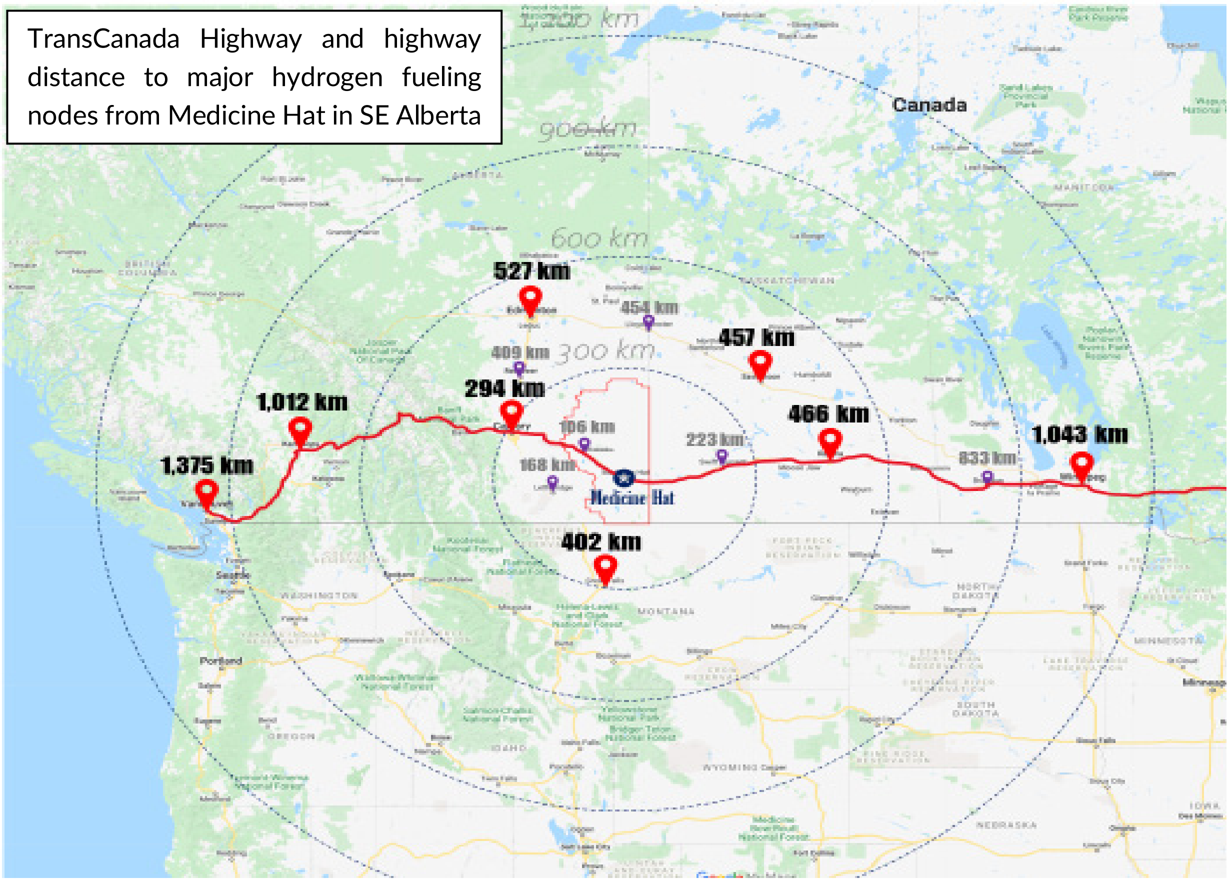


Figure 7.1 Trans Canadian Hydrogen Corridor and Relevance to SE Alberta

Initial fueling supply will likely be via truck transport though rail would appear to be an option to provide larger volume transport to further distanced major node locations with the existing CP Rail mainline running parallel to the majority of the TransCanada Highway in western Canada (**Figure 7.2**). As all major centers are serviced by rail, whether CP Rail or CN Rail, railroad transport of hydrogen or hydrogen carriers appears to have the potential to provide the most economical means of transportation prior to the establishment of other infrastructure such as pipelines.

SE Alberta is well positioned to be a catalyst location for both the initial establishment of fueling stations along the TransCanada Highway, as well as for the necessary secondary expansion that will be required. The region is central to the four largest cities in Alberta and Saskatchewan; Edmonton, Calgary, Regina, and Saskatoon and has an established secondary highways network of existing bulk fuel and truck stop locations

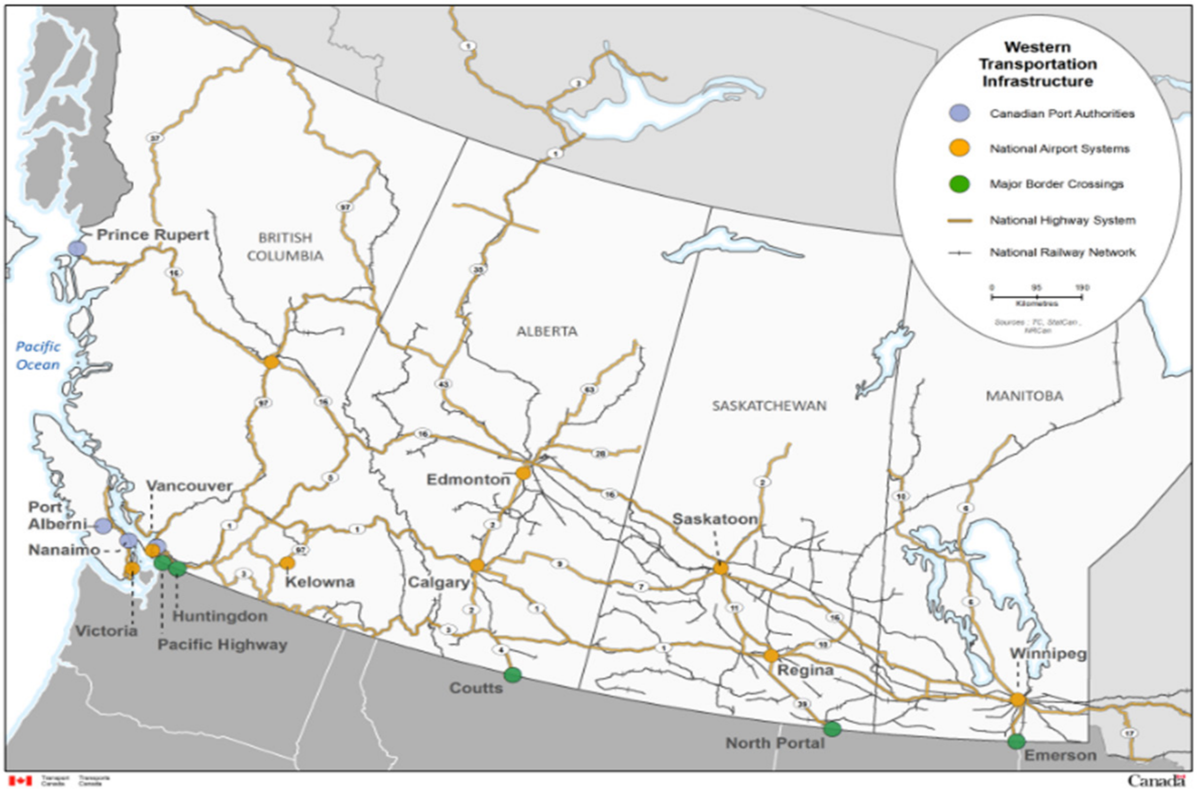


Figure 7.2 Transport Canada – Western Road and Rail Transportation Infrastructure

SOURCE: Transport Canada

providing for inter-connectivity between these cities and the primary highways running between them; The Queen Elizabeth II Highway (Hwy 2), the TransCanada Highway (Hwy 1), the Yellowhead Highway (Hwy 16) and the Louis Riel Trail (Hwy 11). This allows for ease of supply to a broad radius of locations while having strong traffic flow itself to support the build out of fueling stations along the secondary highways (**Figure 7.3**). Hydrogen supply from SE Alberta is well positioned to be distributed in any given direction, whether within the province, the adjourning provinces or to the United States.

As detailed in **Section 5.3.2**, hydrogen refueling potential of 69 t/day has been identified at the intersection of Highway 1 and 3, and 94 t/day at the intersection of Highway 1 and 36. Both of these locations would be ideal locations for initial hydrogen fueling stations, whether as part of existing bulk or truck stop locations or in new strategically situated locations.

In Medicine Hat, the confluence of three corridor highways supports hydrogen fueling in three different areas; the western city limits, in the Redcliff / Medicine Hat Industrial Complex area, the southern city limits, near the Medicine Hat Airport on Highway 3, and on the eastern city limits near Dunmore at the intersection of Highways 1 and 41 and township road 120 that acts as a southern bypass of Medicine Hat (**Figure 7.4**). Each of the three locations would service greater than 500 single unit and tractor trailer freight vehicles per day and the fueling potential of greater than 20 t/day of hydrogen, with incremental potential from both intra-city freight fleets and municipal fleets.

The intersection of Highways 1 and 36, located west of Brooks would be another strong location to establish a Partnership Rest Area with hydrogen fueling. The fueling potential at this location would be 94 t/day due to servicing both highways. The intersection is located in proximity to the SAEWA Waste-to-Energy site at the County of Newell Municipal Landfill (**Figure 7.5**) which could be paired with a hydrogen generation project for a local source of hydrogen. Being situated on the western city limits of Brooks, other potential opportunities exist to incorporate hydrogen transition.

- JBS Foods Canada, one of the largest energy consumers in Brooks and the largest CO_2 emitter in the area, would be located within 3 km of the site,
- Strong CCUS potential north of Brooks in the Basal Cambrian aquifer could be pursued in conjunction with the Sheerness Power Generation facility for more than 3 Mt of CO_2 annual sequestration,
- The location is proximal to the EATL transmission line and provides for access to transmission capacity to accommodate renewable power generation,
- Numerous truck and transport fleets have bases / depots within Brooks and could utilize this site for piloting purposes, and
- City of Brooks natural gas utility operated by ATCO is the second largest distribution system in SE Alberta and could utilize an annual average of 15 t/day of hydrogen.

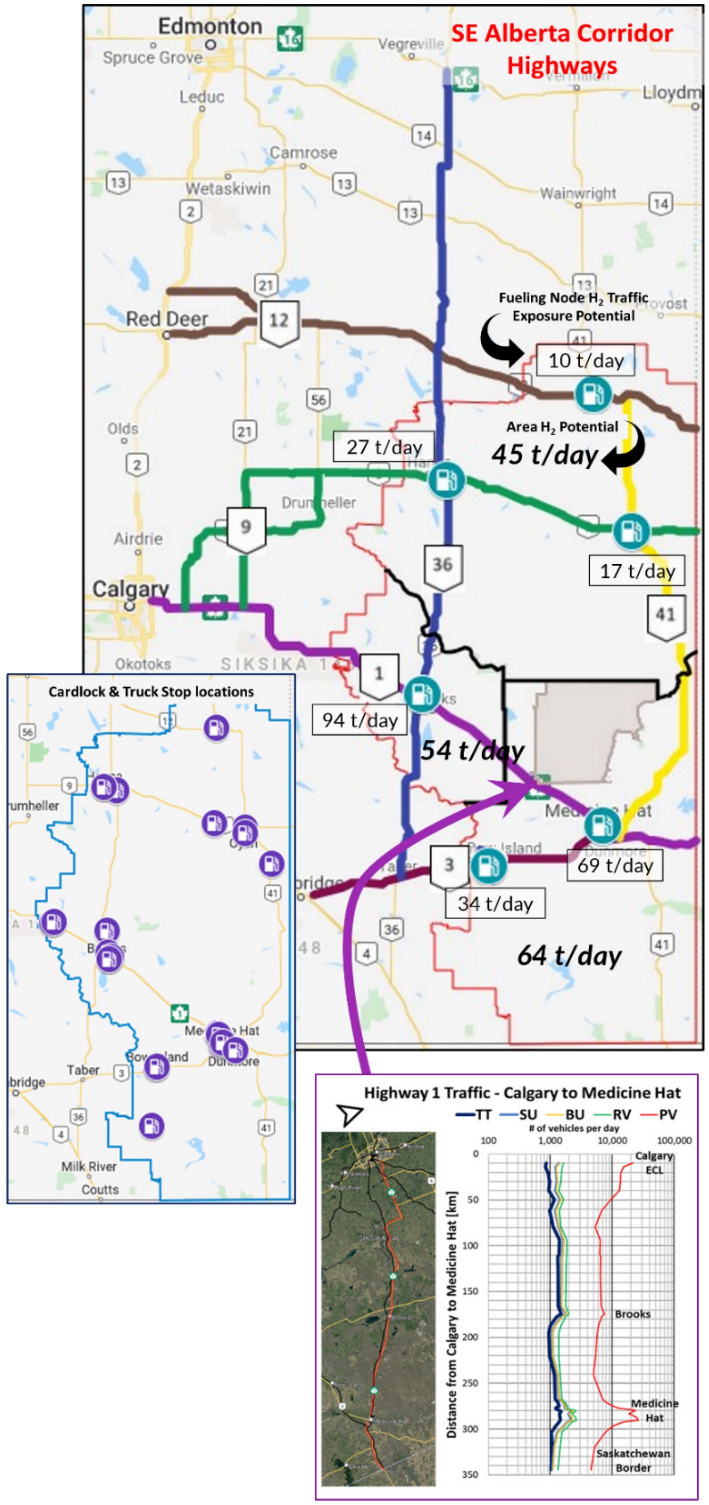


Figure 7.3 TransCanada Fueling Potential and SE Alberta Corridor Highways

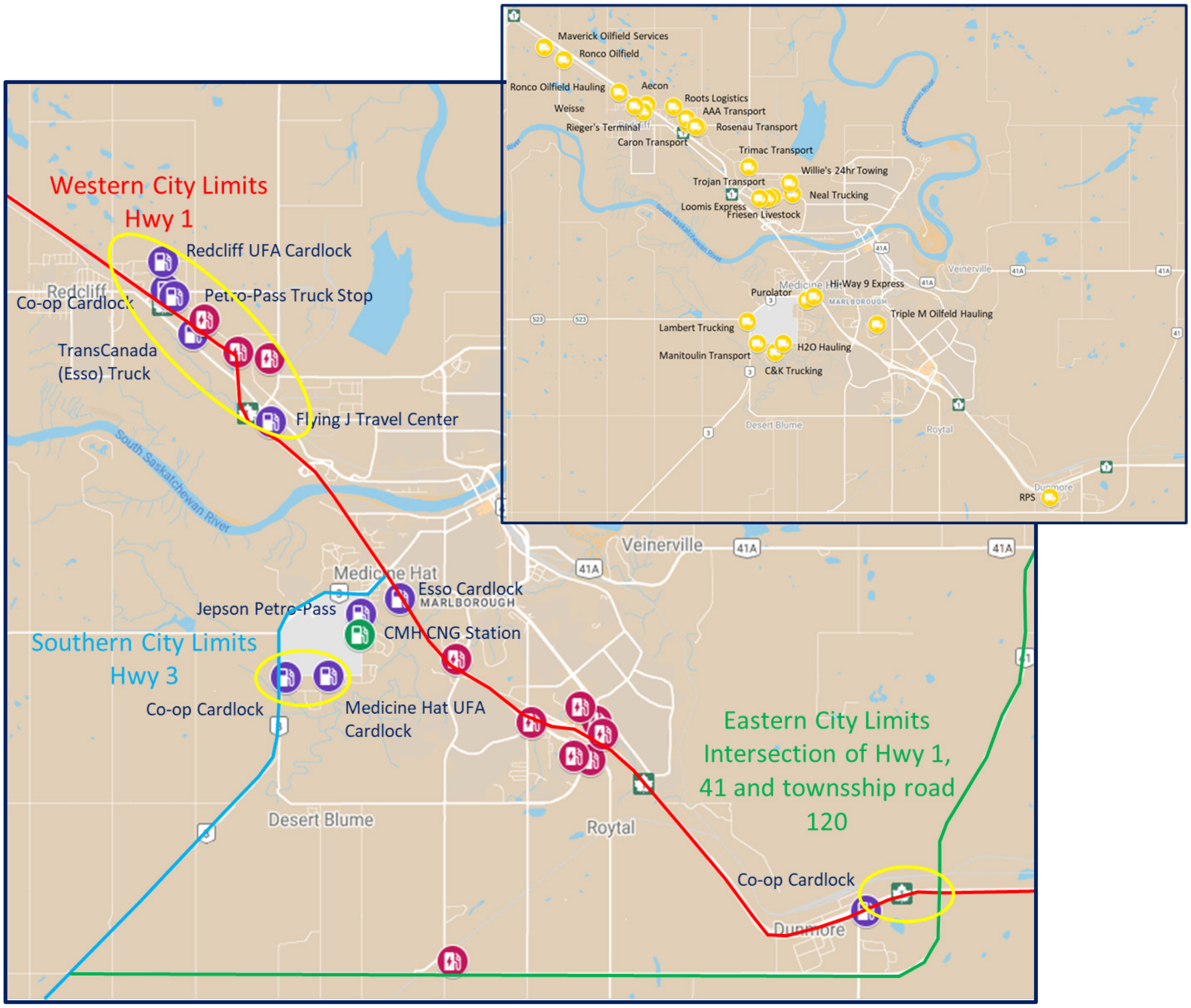


Figure 7.4 Medicine Hat Bulk Fuel / Truck Stop and Transport Company Locations.
Three potential locations for hydrogen fueling stations to accommodate the intersection of three corridor highways in the SE Alberta region: Western City Limits, Southern City Limits, and Dunmore (Eastern City Limits).

Success in establishing fueling nodes in Medicine Hat and Brooks could be quickly followed with development of nodes on connected secondary highways, such as at Cactus Corner located at the intersection of highways 9 and 36, at Oyen located at the intersection of highways 9 and 41, and at Consort located at the intersection of highways 12 and 41. Each of these nodes have fueling potential of 10 to 30 t/day of hydrogen based on highway traffic.

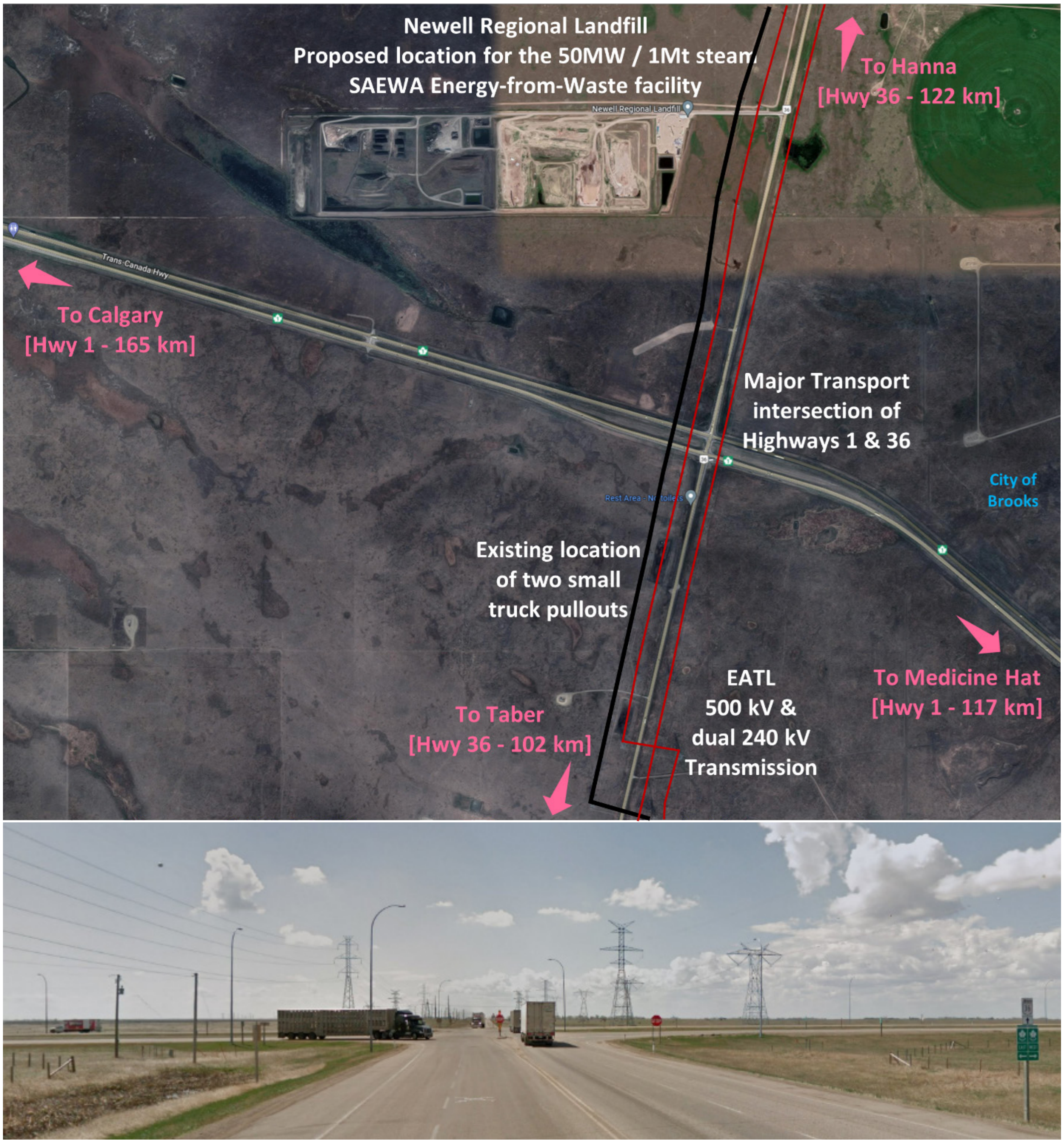


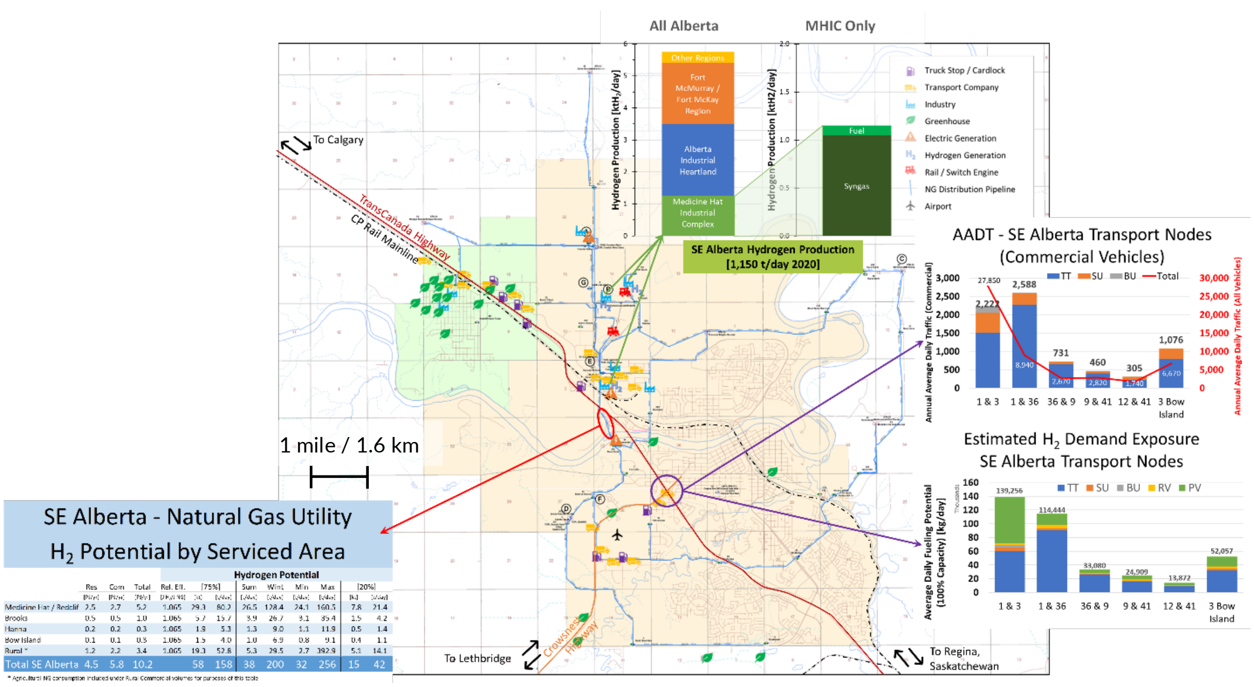
Figure 7.5 TransCanada Highway – Highway 36 Intersection

Intersection of two major transport highways situated west of the City of Brooks for potential establishment of a Partnership Rest Area, that could serve an ultimate hydrogen demand of upwards of 100 t/day. Location is proximal to complimentary supply and demand opportunities and could develop into a substantial hydrogen node.

7.5 Medicine Hat Industrial Complex

In addition to playing a meaningful role in the establishment of hydrogen fueling stations along the TransCanada Highway, the Medicine Hat Industrial Complex (**Figure 7.6**) could be a focus area for a variety of different hydrogen pilots, providing both the hydrogen supply and demand while minimizing the transportation and distribution requirements. Numerous opportunities are present to capitalize on the serendipity of having existing hydrogen and hydrogen carrier supply in proximity to numerous potential demand sources.

- The proximity of the complex to the TransCanada Highway as well as the CP Rail mainline, suggests an ease of access for hydrogen supply to the transportation corridor,
- within the complex, the City of Medicine Hat operates natural gas fired electrical generation and thus could have the potential to incorporate hydrogen into their fueling supply,
- the City of Medicine Hat natural gas distribution system runs through the complex and could provide the opportunity to introduce a hydrogen mixture,
- the abundance of greenhouses within Redcliff presents opportunities to supply hydrogen and possibly CO_2,
- both Redcliff and Medicine Hat municipal fleets could utilize hydrogen, and
- the Medicine Hat Industrial Complex is also the focus of the Project Clear Horizon CCUS project and thus provides long term benefits of focusing hydrogen related projects to this area.



	Res	Com	Total	Rel. Eff.	[75%]		Sum	Wint	Min	Max	[20%]	
	[PJ/yr]	[PJ/yr]	[PJ/yr]	[J H2/J NG]	[kt]	[t/day]	[t/day]	[t/day]	[t/day]	[t/day]	[kt]	[t/day]
Medicine Hat / Redclif	2.5	2.7	5.2	1.065	29.3	80.2	26.5	128.4	24.1	160.5	7.8	21.4
Brooks	0.5	0.5	1.0	1.065	5.7	15.7	3.9	26.7	3.1	35.4	1.5	4.2
Hanna	0.2	0.2	0.3	1.065	1.9	5.3	1.3	9.0	1.1	11.9	0.5	1.4
Bow Island	0.1	0.1	0.3	1.065	1.5	4.0	1.0	6.9	0.8	9.1	0.4	1.1
Rural *	1.2	2.2	3.4	1.065	19.3	52.8	5.3	29.5	2.7	392.9	5.1	14.1
Total SE Alberta	4.5	5.8	10.2		58	158	38	200	32	256	15	42

* Agricultural NG consumption included under Rural Commercial volumes for purposes of this table

Figure 7.6 The Medicine Hat Industrial Complex and Related Hydrogen Potential

Schematic illustrating potential for hydrogen access and demand for transportation (heavy truck and rail), natural gas utilities, electrical generation, and agriculture.

Currently, an estimate of 1,150 t/day of hydrogen is being generated within the complex by three industrial parties. Two of the entities, CF Industries and Methanex, are utilizing greater than 98% of their generated grey hydrogen as syngas for the creation of ammonia and methanol. The residual non-reacted hydrogen is captured and utilized as part of a low-pressure fuel stream. The third entity, CanCarb, is generating turquoise hydrogen as part of the company's pyrolysis process to produce carbon black. The by-product hydrogen generated, potentially merchant hydrogen, is utilized as a supplemental fuel for the heat requirements within the CanCarb operations.

The estimated 105 t/day of hydrogen that is consumed as fuel within the combined facilities represents an opportunity to be utilized as merchant hydrogen for purposes of early-stage hydrogen pilots. However, utilization of this hydrogen would require facility modification and process additions for the supplemental capture and purification. Additionally, as this hydrogen is being utilized as a fuel source, increased natural gas use would be required to replace the consumed hydrogen and result in increased CO_2 emissions at these facilities until such time as CCUS is operational and available to these companies.

However, from a net CO_2 emission perspective, if the merchant hydrogen from these facilities is replaced by natural gas and utilized to displace diesel use, net CO_2 emissions on a whole would be reduced. **Table 7.1** demonstrates that if 50t/day or 18.3 kt/year of hydrogen is recovered from the existing operations, an equivalent of 2.4 PJ of natural gas would be required to replace the fuel requirements and emit an incremental 121.6 kt of CO_2 emissions. However, 77.9 ML of diesel would be displaced if the hydrogen was utilized for heavy freight transition, which would have an associated 218.1 kt of CO_2 emissions. Thus, the net result of utilizing the hydrogen from the Medicine Hat producers to displace diesel usage while utilizing natural gas for fuel purposes, would result in a net CO_2 emission reduction of 96.5 kt/year.

Table 7.1 Net CO_2 Emission Reduction by Hydrogen Displacement of Diesel by Utilizing Natural Gas

Hydrogen			Natural Gas Replacement			Diesel Displacement				NET
t/day	kt/yr	TJ_{H2}	TJ_{H2}/TJ_{NG}	TJ_{NG}	kt CO_2 NG	TJ_{H2}/Tj_{Diesel}	TJ_{Diesel}	ML	Kt CO_2 Diesel	kt CO_2 NET
50	18.3	2,586.0	1.065	2,428.2	121.6	0.86	3,007.0	77.9	218.1	-96.5

A net reduction of CO_2 emissions would result by utilizing natural gas as the substitute fuel for existing hydrogen combustion and using the hydrogen to displace diesel use in heavy transport. For a given volume of hydrogen the relative efficiency of both natural gas and diesel can be utilized to determine the equivalent amount of natural gas required and the diesel displaced and the related emissions of those fuels.

From an economic perspective, based on an assumed value for diesel in 2024 of $2.00/L, inclusive of incremental carbon tax increases to $80/t CO_2, the total annual value for the diesel displaced would be $156 million. This would imply a value of $8.54/kg for the 18.3 kt of hydrogen if agreement was reached for payment of the hydrogen at a price equivalent to diesel. The incremental cost of the replacement natural gas, assuming a 2024 forecast price of $4.10/GJ plus the added carbon tax on the incremental emissions, would amount to $20 million. This would result in an annual net revenue stream of $136 million for purposes of covering the capital and operating expense of extracting the hydrogen and dispensing it within a pilot.

The full transition to the low carbon potential of hydrogen will likely occur as a gradual process with smaller quantities of hydrogen being initially required until full demand potential can be realized. This will result in the need to initially utilize some portion of grey hydrogen until CCUS is fully developed to generate blue hydrogen and green hydrogen generation is established. Hydrogen carriers, such as ammonia and methanol, could also play a critical role in establishing the initial hydrogen fueling station network, both as a means of addressing the initial smaller demand of the pilots but also by providing greater ease of transport to location and minimizing hydrogen storage requirements. SE Alberta can play an immediate role in being the supplier of initial hydrogen and hydrogen carrier requirements for initial stages of hydrogen piloting. As demand increases so too will the region's ability to expand its capability of generating low-cost blue, green and turquoise hydrogen, and establish SE Alberta as the supplier of choice for hydrogen and hydrogen carriers.

7.6 Public Engagement

To maximize the potential of initial pilots and projects, a concerted effort should be put forward by the municipalities, industrial associations, and institutions to disseminate information on energy transition and hydrogen. Public acceptance and participation will be critical for the timely expansion of transition.

A survey throughout the SE Alberta region should be undertaken to provide the necessary tools and information to gain public acceptance and to manage expectations, to identify challenges and negative perceptions, and to assist in the guidance of municipal policy decisions. A proactive approach to overcome NIMBYism, to establish an understanding of risk and reward, to create trust amongst industry, municipalities, and the public, and to determine the publics expectation for government support will have long term benefits for the advancement of the transition to hydrogen.

7.7 Long Term Pathways

Numerous other hydrogen pathways will become apparent once initial hydrogen supply and transportation logistics are better understood. These pathways can be evaluated for their own merits to contribute to the long-term expansion and optimization of a diverse hydrogen economy in SE Alberta. This would include opportunities to align renewable electrical generation with grid stabilization and optimization, green hydrogen production, expansion of fueling to secondary transportation corridors, establishing hydrogen "Last Mile" fueling infrastructure to address the site specific energy demand in rural and agricultural locations, integration of hydrogen into rural natural gas distribution systems, and capture of the emerging and expanding export markets for hydrogen and/or hydrogen carrier supply.

7.7.1 Renewable Generation: Line Stability & Hydrogen Production

As described in **Section 5.5**, the SE Alberta transmission grid could be at capacity with the in-service energizing of new renewable generation projects currently under construction. Incremental generation capacity of approximately 10,000 MW has been approved and / or announced for the region beyond the active projects (**Figure 7.7**). Increased renewable generation will challenge transmission line stability and capacity optimization. Introduction of this generation to the existing provincial electric grid and transmission system is likely to be delayed, until such time as further transmission construction can be carried out and addition of PFR devises are installed to secure transmission stability.

Utilization of off-peak generation for hydrogen generation could be piloted for use in fuel cells to act as battery reserve power and address the PFR issue. Additionally, some proposed projects could proceed as off-grid projects with the power utilized for hydrogen generation, with this hydrogen dedicated to other utilization.

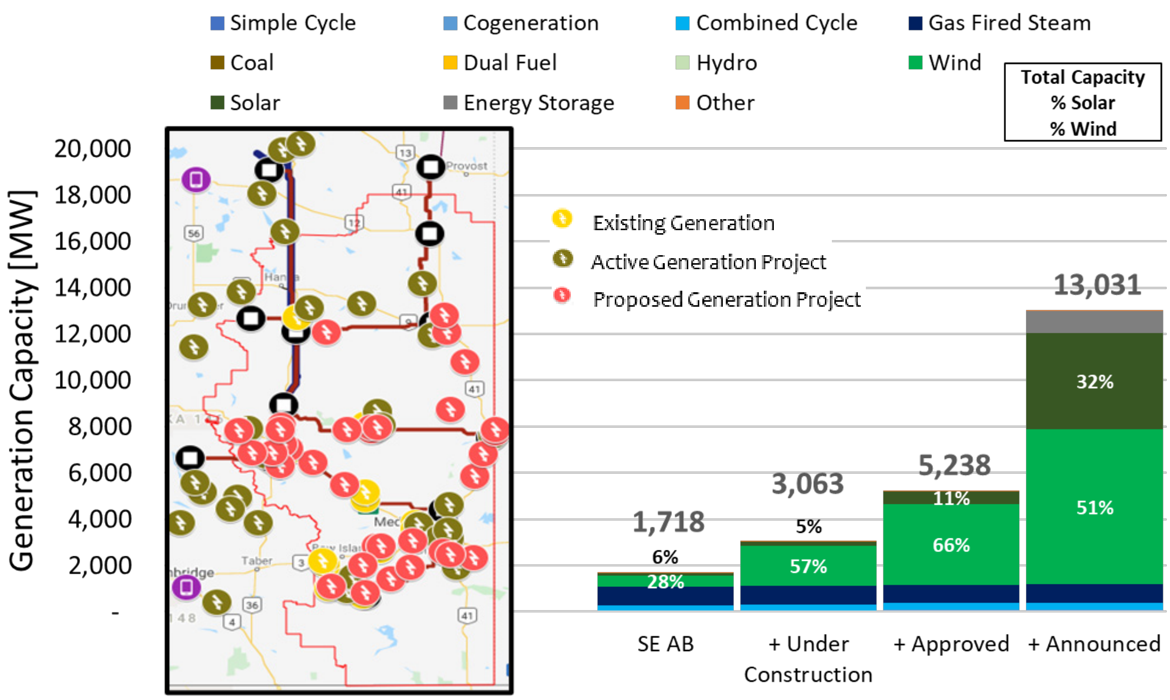


Figure 7.7 Potential Generation in SE Alberta Beyond Active Projects

7.7.2 Secondary Transportation

Successful integration of hydrogen into transport fleets will ultimately require the capability for that fleet to move past pilot projects focused on major transportation corridors and provide the flexibility for fleet operators to utilize hydrogen fueled trucks to deliver freight to any existing location, with much of that being in areas not directly connected with the corridor highway. This will drive expansion of fueling sites to less traveled locations and secondary transportation corridors, where economics of smaller scale fueling stations and delivery of hydrogen will pose the most significant economic hurdle. Pilot projects to lower the cost of fueling stations and delivery will be necessary to continue to drive the economic transition to hydrogen throughout the country. This could include the use of hydrogen carriers and on-site conversion to hydrogen, small scale reactors to generate hydrogen at site from natural gas supply, or off grid electrolysis to provide remote generation and supply.

7.7.3 "Last Mile" Fueling Depots

To accommodate hydrogen transition to off-road equipment, such as construction and agricultural equipment, hydrogen supply will be required to be delivered to the needed locations as opposed by having vehicles traveling to the fueling stations. In the same way that diesel is delivered to on site tanks or fueling trucks are used to directly fuel equipment, portable hydrogen fueling will require the ability to become mobile or easily set up for a period of time to satisfy the off-road fuel requirements, such as at a construction site or a field that is being harvested. This could be via truck or trailer mounted tank and compressor or portable reactors to convert hydrogen carriers to hydrogen on demand.

7.7.4 Rural Natural Gas Co-ops

Natural gas co-ops are typically non-profit, member owned organizations that were formed for the distribution of natural gas to rural customers. As a group, these utilities form the world's largest rural natural gas distribution network that services family farms, acreages, towns, villages, and both small and large industrial clients. The pipeline network is an accumulation of new and old vintage pipes and operated with a simple mandate to provide natural gas for the safe utilization of its customers. Significant potential exists to introduce hydrogen into the natural gas supply; however, these co-ops do not have the same technical support nor financial resources that large urban natural gas utilities have. Thus, transition for rural natural gas distribution systems will likely only proceed once proof of concept is established and the various codes, standards, and regulations are addressed. Determination of the suitability of the various pipeline networks as well as sourcing of hydrogen supply that the networks field nodes will be necessary.

7.7.5 Exports

Exports have been identified as a key pilar of each of the provincial and federal hydrogen roadmaps. SE Alberta is a current exporter of hydrogen and hydrogen related products based on the export of ammonia and methanol to the United States and carbon black globally. Existing utilization of the CP Rail mainline will allow for continued export of these products and would provide the opportunity for the region to increase the export of hydrogen and hydrogen carriers, whether it is to the United States or to tidewater on the west coast of British Columbia. Utilization of rail for export will have a capacity limitation and ultimate capture of export potential will rely on the establishment of pipeline infrastructure.

As discussed in **Section 6.7**, SE Alberta has the potential to establish itself as a low-cost hydrogen supplier of choice, both for domestic and international exports. With the establishment of incremental hydrogen generation for local demand requirements and a fully functioning CCUS and CO_2 distribution network, incremental export capacity in excess of 7,600 t/day could be realized by the area for supply to Calgary, Eastern Canada and the United States alone. This has the potential to be met by utilizing reformation, electrolysis, and pyrolysis processes for generation of low-carbon hydrogen and hydrogen carriers, and transported by an ultimate combination of road, rail and fit for purpose pipeline infrastructure.

8 KEY PARTNERS

8.1 Provincial / Federal Financial Support

It is imperative that all industry, municipality, and research organizations remain diligent in investigating and pursuing various funding and support organizations as Clean Technology and Energy Transition is a very dynamic area of interest and continues to see various programs being introduced and various funding and competitions opening and closing windows for applications. As of the timing of this report the following opportunities have been identified and could offer financial support to various transitional projects. As these programs may change or new programs or incentives may be introduced over time, it is advised that the reader completes their own updated research on this topic on an as current basis.

8.1.1 Emissions Reduction Alberta

Emissions Reduction Alberta was created in 2009 to address the Government of Alberta's environmental and economic goals. ERA invests in the pilot, demonstration and deployment of clean technology solutions that reduce GHGs, lower costs, attract investment, and create jobs in Alberta. ERA's Strategic Priorities: **Accelerate Technologies** that reduce GHG, **Drive Commercialization** for the adoption of widespread technology solutions that lead to growth and GHG reduction, and **Maximize Impact** through leveraged funding, communications, operational excellence and measurement and reporting on key performance metrics. [243]

Technology Projects Funding

ERA invests in a diverse portfolio of transformative and sustainable technologies that reduce GHG and positions Alberta for success in a lower emissions economy. Funding opportunities are posted on their site to address different areas of focus. Two of the four focus areas relate to hydrogen transition: Low Emitting Electricity System and Low-Carbon Industrial Processes & Products. ERA utilizes a twostep Call for Proposals process that includes an initial Expression of Interest submission and then Full Project Proposal stage for shortlisted projects. [244]

#746, 10104 103 Ave NW, Edmonton, AB T5J 0H8
780-498-2068 www.eralberta.ca/apply-for-funding/

8.1.2 Alberta Petrochemicals Incentive Program (APIP)

A key part of Alberta's Recovery Plan and the Natural Gas Vision and Strategy, APIP is intended to turn Alberta into a top global producer of petrochemicals. The program provides grants to companies to attract new or expanded investment in market-driven petrochemical facilities. A full Program Guideline is available for full program details. [245]

Key Features

- A 5 or 10-year program period during which time the eligible project must be built and operational,
- All projects submitted that meet the program's criteria will receive funding once built and operational,
- Grant's worth 12% of the project's capital cost will be issued once projects are operational, and
- Aligned with typical investment cycle by making funding available throughout the program's duration

Eligibility

- Project must be physically located within Alberta,
- Both new facilities, as well as brownfields and expansions on existing facilities, are eligible,
- Capital investment must be at least (CAD) $50 million,
- Facility must use natural gas, natural gas liquids, or petrochemical intermediaries such as ethylene, propylene, benzene, etc. in manufacturing its own products,
- Project must create permanent jobs in Alberta, and
- Not all capital costs are eligible for reimbursement as only costs related to manufacturing and processing capital expenditures qualify for reimbursement under APIP.

Application and Process

- Companies must first register for an APIP account through the Electronic Transfer System
- Three stage application and grant process:
    - Stage 1: Advance Notification
        - Submission of company information, project location, project type, and estimates of total costs, eligible capital costs, and job creation,
        - Allows interested parties to learn if their project is eligible under the program and to determine a high-level estimate of grant funding.
    - Stage 2: Qualification and grant agreement
        - Submission of incremental information; business plan, project timing, technology configuration, proponent's capability, economic benefit to Alberta, and environmental performance.
        - A minimum Class 3 capital cost estimate is required which would determine the maximum amount of the grant.
        - Government of Alberta would then enter into a grant agreement with the company.
    - Stage 3: Payment

- Smaller projects ($50 to $150 million) must be completed and operational within five years of opening of applications window (Oct 30, 2020) and would receive grant funds within one year of project completion,
- Larger projects (>$150 million) must be completed and operational within ten years of application window and would receive grant payments in equal instalments over 3 years.

8.1.3 Alberta Innovates

Alberta Innovates is Alberta's largest research and innovation agency, providing funding and commercialization programs to stimulate innovation across Alberta. They work closely with government, industry, academia, and other key partners to deliver 21st century solutions for the most compelling challenges facing Albertans. [246]

Bell Tower, 1500, 10104-103rd Ave, Edmonton, AB T5J 0H8
877-423-57272 www.albertainnovates.ca

Innovative Hydrocarbon Products

Three programs focused on diversifying Alberta's economy and add value to hydrocarbon resources to enable Alberta achieve prosperity in a low carbon, global economy. Two programs address bitumen but the third is Natural Gas Value-Add that supports the conversion of natural gas into higher value products such as liquid fuel and hydrogen.

CCUS and Emerging Technologies

Contributes to the decarbonization of energy systems, creates new end-user products, and achieves emissions reduction targets and net-zero goals. Consists of carbon capture, utilization, and storage (CCUS), hydrogen, critical minerals, and natural gas value add technology development through to systems-level integration.

Renewable and Alternative Energy

Focuses on grid modernization, energy storage and electricity generation. Positioned to ensure Alberta's future electricity system is safe, reliable, resilient, affordable, designed for growth, capable of incorporating decentralized energy resources and sustainable.

Clean Resources Continuous Intake Process
www.albertainnovates.ca/focus-areas/clean-resources/application-process/

Product Demonstration Program

Designed to de-risk the commercialization process by providing funding to commercialize products. Funding of up to $150,000 over a maximum of one-year term for purposes of piloting or demonstrating new products with a strategic partner who could be the first buyer towards commercialization.

Technology Development Advisors
403-210-5229 www.albertainnovates.ca/programs/product-demonstration-program/

InnoTech Alberta

A premiere applied research provider for unparalleled technology and scientific expertise, facilities, and knowledge to solve challenges for industry and government. Provide scaled services ranging from lab, pilot, demonstration, to field in the areas of agriculture, energy, environment, forestry, and manufacturing. Operates the Alberta Carbon Conversion Technology Centre in Calgary that was built to research, validate and demonstrate prototypes, and mitigate the risk of carbon capture and utilization technologies. Provides hydrogen services for production and conversion, infrastructure, and end use adoption.

Edmonton Research Park, 250 Karl Clark Road, Edmonton, AB T6N 1E4
780-450-5111 www.innotechalberta.ca

ACCTC – 9550-100 Street SE, Calgary, AB T3S 0A2
403-850-3753 www.innotechalberta.ca/facilities/alberta-carbon-conversion-technology-centre/

C-FER Technologies

Provides applied engineering services and testing to advance safety efficiency and environmental performance in partnership with the energy industry. Includes both technology push development and technology pull identification in addition to developing new standards for safety, reliability and implementation of new technologies.

200 Karl Clark Road, Edmonton, AB T6N 1H2
780-450-3300 www.cfertech.com

8.1.4 Prairies Economic Development Canada

PrairiesCan operates under the mandate to support economic growth and diversification in the Prairie provinces and advance interests of the region in national economic policy, programs, and projects in 4 key roles: [247]

- **Investor:** fund strategic and targeted initiatives to create jobs and growth
- **Convenor:** support collaboration and growth by connecting economic actors
- **Advisor:** advocate for Prairie interests and inform economic decision making
- **Pathfinder:** help people navigate federal economic programs and services

2022-2023 Priorities

- **Recovery:** equip communities, businesses, and organizations for a successful post-pandemic economic recovery.

- **Growth and Transformation:** invest in projects and help businesses and communities to grow and develop capacity in emerging sectors such as clean technology, digital technology, value-added agriculture, and precision healthcare.
- **Inclusivity:** increase economic participation by Indigenous people, black Canadians, women, and youth.

Funding Programs

- **Business Scale-up and Productivity (BSP):** open to high growth businesses that have operated in the Prairies for a minimum of 2 years and are seeking to scale and grow their businesses.
- **Regional Innovation Ecosystems (RIE):** open to not-for-profit organizations that support businesses, innovators and entrepreneurs for start-up, growth, productivity, technology commercialization, technology adoption, export and investment attraction. Applications must support either cluster growth or inclusiveness.
- **Economic Development Initiative (EDI):** funding to companies working in French to support projects that encourage economic diversification, business development, innovation, partnerships, and increased support in official language minority communities.
- **Community Economic Development and Diversification (CEDD):** supports economic development initiatives that contribute to economic growth and diversification of communities.
- **Strategic Partnerships Initiative (SPI):** helps Indigenous communities participate in complex economic opportunities.
- **Strategic Innovation Fund (SIF):** supports large-scale, transformative, and collaborative projects that help position Canada to prosper in the global knowledge-based economy. SIF projects promote the long-term competitiveness of Canadian industries, clean growth, and the advancement of Canada's strategic technology advantage. The Strategic Innovation Fund covers all sectors of the economy and is available to for-profit and not-for profit organizations with the goal of supporting the Canadian innovation ecosystem.

1500-9700 Jasper Ave, Edmonton, AB T5J 4H7
888-338-9378 www.prairiescan.gc.ca

8.1.5 Environment and Climate Change Canada (ECCC)

Clean Tech Funding opportunities include: [248]

Accelerated Investment Incentive

Provides enhanced first-year allowance for eligible machinery and equipment by allowing for upwards of three times the normal first-year deduction by applying a one and half times prescribed CCA rate for the year as well as suspending the CCA half-year rule. Eligible property must be utilized prior to 2028 with benefit decrease after 2023 and no benefit post 2028.

Agricultural Clean Technology Program

Research and Innovation Stream supports pre-market innovation, including research, development, demonstration, and commercialization activities that are transformative in clean technology in three priority areas: Green Energy, Precision Agriculture, and Bioeconomy. The Adoption Steam has been suspended pending review of current applications.

Jobs and Growth Fund

Delivered by PrairiesCan in Alberta, it supports regional job creation and positions local economies for long-term growth. Eligible businesses could receiver interest-free repayable contributions for up to 50% of authorized costs, and eligible not-for-profit organizations could receive non-repayable contributions for up to 90% of authorized costs. The fund supports the transition to a green economy, fosters inclusive recovery, enhances Canada's competitiveness through digital adoption, and strengthening capacity in sectors critical to Canada's recovery and growth.

8.1.6 Canada Infrastructure Bank

Purpose is to invest $35 billion in revenue-generating infrastructure which benefits Canadians and attracts private capital. Catalyst for private investment that supports economic growth in priority sectors – green infrastructure, clean power, public transit, trade and transportation, and broadband infrastructure. [249]

Zero-Emission Buses Initiative

Provides public transit and school bus operators financing to modernize fleets on an accelerated basis, in the form of direct loans to cover the higher upfront capital costs of ZEBs with repayments sourced solely from the actual savings generated by the lower cost of operating ZEBs compared to higher cost diesel buses. Investment target of $1.5 billion for an estimated 4,000 zero-emission buses.

150 King Street West, P.O. Box 15, Toronto, ON, M5H 1J9
833-551-5245 www.cib-bic.ca/en/sectors/public-transit/

Zero-Emission Vehicle Infrastructure Initiative

As part of the 2030 Emissions Reduction Plan issued in March 2022, CIB will provide support, in the form of an initial commitment of $500 million, for the federal government's objective to add 50,000 zero-emission vehicle (ZEV) charging infrastructure.

150 King Street West, P.O. Box 15, Toronto, ON, M5H 1J9
833-551-5245 www.cib-bic.ca/en/sectors/green-infrastructure/

Clean Power Initiative

Targeting infrastructure gaps to improve electricity interties and advance clean power generation, distribution and use of renewables and storage systems. Targeted investment of $2.5 billion and can provide low-cost and long-term capital for revenue streams not typically sufficient for traditional debt and equity investors.

150 King Street West, P.O. Box 15, Toronto, ON, M5H 1J9
833-551-5245 www.cib-bic.ca/en/sectors/clean-power/

8.1.7 Natural Resources Canada – Industrial Research Assistance Program

IRAP provides funding to support research and development projects at various stages of the innovation cycle. Funding threshold of up to $10 million. Targeted towards firms that can demonstrate the ability to achieve transformative growth within five years of completing their project and show a significant benefit to Canada's economy. [250]

1500-9700 Jasper Ave, Edmonton, AB T5J 4H7
877-994-4727 www.nrc.canada.ca/en/support-technology-innovation/financial-support-technology-innovation-through-nrc-irap

8.1.8 Natural Resources Canada (NRCan)

Zero Emission Vehicle Infrastructure Program

Objective is to address the lack of charging and refueling stations in Canada. Initial Request for Proposals closed Sept 8, 2021. A second RFP is targeting spring 2022. [251]

www.nrcan.gc.ca/energy-efficiency/transportation-alternative-fuels/zero-emission-vehicle-infrastructure-program/21876

Zero Emissions Vehicle Awareness Initiative

Supports projects that aim to increase awareness, knowledge and public confidence in ZEVs and public charging and fueling infrastructure. 2022 Call for Proposals anticipated for the summer of 2022.

www.nrcan.gc.ca/energy-efficiency/transportation-alternative-fuels/electric-and-alternative-fuel-infrastructure/zero-emission-vehicle-awareness-initiative/22209

8.1.9 Transport Canada – Incentives for Medium- and Heavy-Duty Zero Emission Vehicles Program (iMHZEV)

In April, the Government of Canada proposed an integrated strategy to reduce greenhouse gas (GHG) emissions from medium- and heavy-duty vehicles with an aim of reaching 35% of total medium- and heavy-duty truck sales being zero-emission vehicles (ZEVs) by 2030, by targeting the high up-front cost of ZEVs. The program is part of the 2030 Emissions Reduction Plan and Budget 2022, which committed $33.8 million over five years for Transport Canada to work with provinces and territories to develop and harmonize regulations and conduct safety testing for long-haul zero-emission trucks. [252][253][254]

Incentives for Medium- and Heavy-Duty Zero Emission Vehicle Program (iMHZEV)

- Purchase Incentives for MHZEVs - $547.5M starting in 2022-23 to reduce eligible ZEVs' price
- ZEV Infrastructure - $400M for ZEVIP and $500M for large-scale urban and commercial ZEV charging and refuelling infrastructure

- Green Freight Program - $199M to support assessments and retrofits to existing vehicles
- Zero-Emission Trucking Program (ZETP) – develop and harmonize regulations to address knowledge gaps, and conduct MHZEV safety testing
- Long-Term Targets and ZEV Regulations – aim for ZEVs to reach 35% of MHDV sales by 2030 and regulations to require 100% MHDV sales to be ZEVs by 2040 (subset of feasible vehicle types)

Eligible purchasers include Canadian organizations (profit and non-profit), provinces, territories, and municipalities, who buy or lease eligible MHZEVs. Medium- and heavy-duty vehicles include on-road vehicles with gross weight rating of 3,856 kg (8,500 lbs) or greater – Class 2B to 8, with amount of incentive varying by vehicle class and by purchase / length of lease. ZEVs includes battery electric vehicles (BEVs), plug in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FCEVs). Per vehicle incentives are to be in line with existing provincial / state incentives such as B.C., Quebec, and California.

Transport Canada will provide further program details and procedures for enrolment in the proceeding months with the intent to launch as soon as feasible.

Contact: IncentivesMHZEV-IncitatifsVMLZE@tc.gc.ca
www.tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles

8.1.10 Scientific Research and Experimental Development Tax Incentive Program (SR&ED)

The program uses tax incentives to encourage research and development in Canada through three forms of tax incentives: income tax deduction, investment tax credit, and potential refunds. To be eligible, research must be conducted within Canada and be conducted to gain new knowledge that achieves an objective or resolves a problem as well as being conducted in a field of science or technology by means of experiment or analysis. [255]

10-9700 Jasper Ave, Edmonton, AB T5J 4C8
866-578-4538 www.canada.ca/en/revenue-agency/services/scientific-research-experimental-development-tax-incentive-program.html

8.1.11 Strategic Innovation Fund

The program supports a wide range of large-scale, transformative, and collaborative projects across all sectors of the economy. Current priority areas include **Net Zero Accelerator** – decarbonize domestic large emitters, adoption or commercialization of new low or zero carbon intensity products, processes, or methods of production, and development of battery ecosystem or other emerging clean technologies that enable decarbonization, and **Agri-food, Automotive, and Natural Resources** – projects promoting innovation through research, development, and technology adoption. [256]

C.D. Howe Building, 235 Queen Street, 1st floor, West Tower, Ottawa, ON K1A 0H5
800-328-6189 www. ic.gc.ca/eic/site/125.nsf/eng/home#a

8.1.12 Sustainable Development Technology Canada (SDTC)

Supporting Canadian companies who are leading in development of clean technologies. Fund businesses advancing innovative technologies that are pre-commercial and have potential for significant and quantifiable environmental and economic benefits. Seed – Start-up – Scale-Up [257]

45 O-Connor Street, Suite 1850, Ottawa, ON K1P 1A4
613-234-6313 ext. 0   www.sdtc.ca/en/

8.1.13 Foresight Canada

As Canada's cleantech accelerator, Foresight brings together innovators, industry, investors, government, and academia to support global transition to a green economy. Their accelerator cohorts include carbonNEXT – focused on deployment of CCUS technology, energyNEXT – focused on alternative non-combustion markets for hydrocarbons such as carbon fibre and graphene, Hydrogen, and other oil and gas emission reduction initiatives, and waterNEXT – focused on clean water technology, including desalinization. [258]

Suite 2200, 144-4th Ave SW Calgary, AB T2P 2N4
604-245-0042   www.foresightcac.com

8.2 Regional Economic Development Associations

8.2.1 Invest Medicine Hat

Invest Medicine Hat provides the connection between new and existing businesses with land development and real estate, incentives, and investment opportunities in the community.

City Hall, 580-1st Street, Medicine Hat, AB T1B 8E6
403-529-8148   www.investmedicinehat.ca

8.2.2 Brooks Newell Region Economic Development

Connecting residents and investors to the promise of the Brooks Newell Region through advocacy, support, and cooperation to attract, retain, and grow business. Municipal partners include Town of Bassano, Villages of Duchess and Rosemary, City of Brooks, and the County of Newell.

201 1st Ave W, Brooks, AB T1R 1B7
403-362-3333   www.brooksregion.ca

8.2.3 Palliser Economic Partnership

Palliser Economic Partnership connects southeast Alberta to markets and investments in Canada and abroad.

Box 1046 Medicine Hat, AB T1A 7H1
403-526-7552 www.palliseralberta.com

8.2.4 Community Futures Entre-Corp

Community Futures has been working with rural Alberta entrepreneurs for over 30 years providing guidance, business loans, training, and other free resources to facilitate Rural Economic Diversification. The organization supports priority sectors identified by Prairies Economic Development Canada, such as clean tech, and clean resources amongst others. The organization provides a bridge to financial institutions, Chamber of Commerce, and municipal economic development organizations.

#202, 556-4th Street SE, Medicine Hat, AB T1A 0K8
403-528-2824 www.albertacf.com

8.2.5 Other Economic Development Organizations

Special Areas Regional Economic Development

Special Areas Regional Economic Development provides the support to advance economic development in the Special Areas No. 3 & 4 regions.

Box 220, 4916-50th Street, Consort, AB T0C 1B0
403-577-3523 www.specialareas.ab.ca

Harvest Sky Economic Development Corporation

Harvest Sky Economic Development Corporation is a non-profit organization building economic development strategies for Special Area No. 2, Town of Hanna, and the Village of Youngstown.

Box 1255, 203-2nd Ave W, Hanna, AB T0J 1P0
403-577-3524 403-854-0589 www.harvestsky.ca

Verge Economic Development

Verge Economic Development provides economic development information and opportunities in the southeast corner of Alberta, building momentum in the economy by collaborating with community partners, working with government, and attracting and retaining investment in the region. Regional Partners with the County of Forty Mile, Cypress County and Town of Bow Island.

556 4th Street SE, #202, Medicine Hat, AB T1A 0K8
403-488-7015 www.verge-ed.ca

8.3 Associations and Institutions

8.3.1 APEX Alberta

APEX Alberta and its collaborative partners: Medicine Hat College, Community Futures Entre-Corp and Alberta Innovates, work towards providing services to Start, Grow, and Innovate businesses in southeast Alberta. This is through coaching, community networking, capital access and the provision of creative learning spaces.

#202, 556-4th Street SE, Medicine Hat, AB T1A 0K8
403-528-2824 www.apexalberta.ca

8.3.2 Medicine Hat College

Medicine Hat College (MHC) is dedicated to growing a vibrant future with learners and southeast Alberta. Proudly serving the communities in the region with its main campus located in Medicine Hat and a second campus in Brooks. With the renewal of the energy industry in Alberta, including the emergence of the hydrogen economy, the college has been busy creating new programming around sustainability and innovation. MHC's goal is to not only be prepared for the transition but play a role in driving it forward, being supportive to the region, serving as a conduit for initiatives, and enabling the workforce to drive forward meaningful energy transition and a hydrogen economy.

MHC's suite of existing hard skills programs includes Trades to ensure the region has the workers ready and willing to participate in on the ground transformation of existing and development of new purpose-built hydrogen infrastructure.

- Built Engineering Technology programming provides hands on training to ensure the region has workers ready to apply the engineering technology skills to support energy transition.
- Vehicle service technicians can assist with implementation of onboard technology related to transition of the transportation sector.
- Safety training courses including WHMIS, fall protection, confined space, and gas detection support safety in the workforce.
- UAV Drone advanced pilot training provides the ability for aerial support and monitoring for infrastructure and other industrial activities.
- Sustainable Energy Systems Professional certification will enhance the skillsets of existing trades to incorporate sustainability right into the hands of individuals in the field that can guide consumer and corporate choices.

Additionally, the Business, Entrepreneurship, Science, and Humanities programming supports the organizational, social, and economic transformation that will shape new environmentally centric organizations and demand trends. This programming includes degree collaboration and transfer programs, business management, entrepreneurship, and sustainable innovation. These programs drive research and policy in the region and the programs lead to degrees, professional credentials, and industry certifications.

MHC is fully integrated with the region but also has reach far beyond it with educational partnerships and consortium from across Alberta. Regional integration includes participating on the board of directors for the Palliser Economic Partnership helping to drive regional economic initiatives such as the Hydrogen HUB. Consortium participation includes programming focused on upskilling and reskilling individuals to transition to the new economy. All of the regional integration and Alberta-wide partnerships give MHC access to a broad range of programming combined with the ability to target it for specific regional needs. MHC has also begun its first Center for Innovation project in telehealth with plans to grow this capability to further support regional development which could include projects related to hydrogen and energy transition.

299 College Drive SE, Medicine Hat, AB T1A 3Y6
866-282-8394 www.mhc.ab.ca

8.3.3 Other Associations

Southern Alberta Alternative Energy Partnership

SAAEP is a partnership of southern Alberta's economic development organizations and associate member of Canadian Renewable Energy Association, focused on fostering various streams of alternative energy development: Solar, Wind, Bioenergy, Hydrogen, Battery Storage and Smart Grid Technology.

Lethbridge, AB
403-627-3373 www.saaep.ca

Southern Alberta Energy from Waste Association

SAEWA is a non-profit society developed through a coalition of over 60 municipal entities and waste management jurisdictions in southern Alberta, established to provide a collective voice to sustainable solutions that will provide viable alternatives to landfill waste and the associated environmental impact.

P.O. Box 792, Vulcan, AB T0L 2B0
www.saewa.ca

8.3.4 Chamber of Commerce

Business organizations located throughout southeast Alberta providing leadership, training and advocacy for regional businesses.

Medicine Hat & District Chamber of Commerce

Grassroots not-for-profit business network for the purpose of providing business to business support within the community and an advocacy for government policy. Business community representation for the City of Medicine Hat, Town of Redcliff and Cypress County. Priorities include agriculture, energy & environment, municipal affairs, trade and transportation, workforce development, and finance & taxation.

413-6th Ave SE, Medicine Hat, AB T1A 2S7
403-527-5214 www.medicinehatchamber.com

Brooks & District Chamber of Commerce

403-2nd Avenue West, Brooks, AB T1R 0S3
403-362-7641 www.brooksdistrictchamber.ca

Hanna & District Chamber of Commerce

Suite 4, 110-1st Avenue West, Hanna, AB T0J 1P0
403-854-5999 www.hannachamber.ca

Additional Chambers of Commerce in SE Alberta

Oyen & District Chamber of Commerce

Box 718 Oyen, AB T0J 2J0
403-664-1404 www.abchamber.ca

Consort & District Chamber of Commerce

244 Main Street, Sedalia, AB T0J 3C0
403-326-2251

Bow Island / Burdett & District Chamber of Commerce

116 North Railway Avenue W, Box 1001, Bow Island, AB T0K 0G0
403-545-6222 www.bowislandchamber.com

Foremost & District Chamber of Commerce

218 Main Street, Box 272, Foremost, AB T0K 0X0
403-867-3077 www.foremostalberta.ca

8.4 Indigenous Peoples and Groups

This report acknowledges that the people and industries of the southeast Alberta region live and work on treaty territory. The report pays respect to all Indigenous Peoples and honours their past, present and future, as it not only relates to their cultural heritages and relationships to the land but with respect to future business opportunities and the joint energy transition of the region.

Southeast Alberta is within the traditional lands of the Treaty 4, 6 and 7 First Nations and Métis Region 3 **(Figure 8.1).** Though no physical reservations fall within the region, the area represents the traditional lands of the Siksika (Blackfoot), Kainai (Blood), Piikani (Peigan), Stoney Nakoda, Tsuut'ina (Sarcee) as well as the Cree, Sioux, and the Saulteaux bands of the Ojibwa peoples. The area is also homelands of the Métis Nation within Region 3. [259][260]

8.4.1 Contact Information for First Nations and Associations

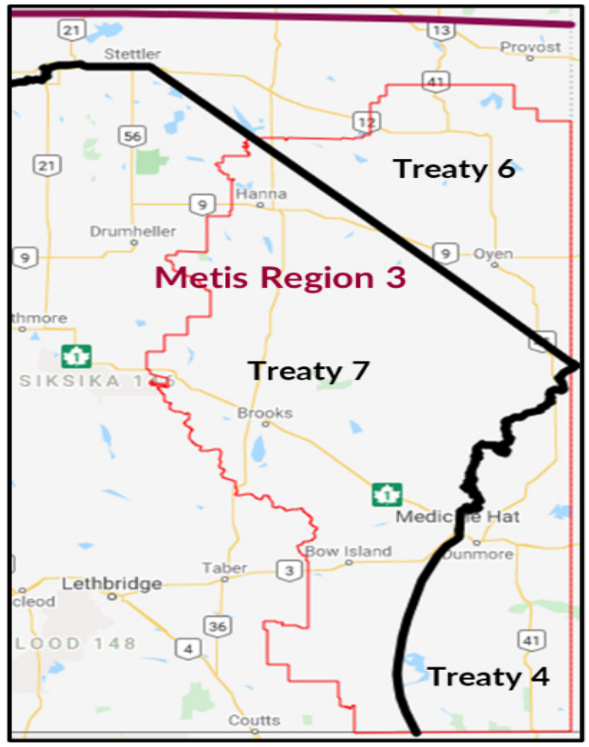


Figure 8.1 Indigenous Traditional Lands – SE Alberta

Métis Nation of Alberta (MNA)

100 Delia Gray Building, 11738 Kingsway Ave
Edmonton, AB T5G 0X5
800-252-7553 www.albertametis.com

MNA Region 3

1415-28 St. NE, Calgary, AB T2A 2P6
800-267-5844

Blackfoot Confederacy

7535 Flint Road SE, Calgary, AB T2H 1G3
587-287-1100 www.blackfootconfederacy.ca

Stoney Nakoda – Tsuut'ina Tribal Council Ltd.

Suite 200, 9911 Chiila Boulevard SW,
Tsuut'ina, AB T2W 6H6
403-685-2440

Stoney Nakoda Nation [Treaty 7]

P.O. Box 40, Morley, AB T0L 1N0
403-881-3770 www.stoneynation.com

Bearspaw First Nation [Treaty 7]

P.O. Box 40, Morley, AB T0L 1N0
403-881-2260 www.stoneynation.com

Chiniki First Nation [Treaty 7]

P.O. Box 40, Morley, AB T0L 1N0
403-881-2265 www.stoneynation.com

Wesley Nation [Treaty 7]

P.O. Box 40, Morley, AB T0L 1N0
403-881-2613 www.wesley-nation.ca

Tsuut'ina Nation [Treaty 7]

200, 9911 Chiila Boulevard, Tsuut'ina, AB T2W 6H6
403-281-4455 www.tsuutinanation.com

Blood Tribe (Kaini First Nation) [Treaty 7]

P.O. Box 60 Stand Off, AB T0L 1Y0
403-737-3753 www.bloodtribe.org

Piikani Nation [Treaty 7]

P.O. Box 70, Brocket, AB T0K 0H0
403-965-3940 www.piikanination.wix.com/piikanination

Siksika Nation [Treaty 7]

P.O. Box 1100, Siksika, AB T0J 3W0
403-734-5100 www.siksikanation.com

Confederacy of Treaty Six First Nations

17533-106 Ave, Edmonton, AB T5L 1E7
780-944-0346 www.treatysix.org

8.4.2 Alberta Indigenous Opportunities Corporation

The Alberta Indigenous Opportunities Corporation is a Crown corporation, that has been established to work with Indigenous communities across Alberta to invest in natural resources, agriculture, telecommunications, and transportation projects. The organization is intended to backstop up to $1 billion of loan guarantees for the investment by Indigenous communities. Loan guarantees range from $20 million to a $250 million.

Suite 2450, Calgary Place 1, 330-5th Ave SW, Calgary, AB T2P 0L4 www.theaioc.com

8.5 CFB Suffield

As part of Canada's commitment to reduce GHG emissions, the Department of National Defence has reaffirmed its commitments to reduce its CO_2 emissions by 40% of 2005 levels by 2030. This commitment was originally stated in 2017 saw a cumulative investment of $225 million by 2020 and resulted in an updated strategy in 2020 with the goals to achieve this vision appropriately adjusted. [261]

- Reduce GHG emissions in DND buildings and commercial vehicle fleet by 40% below 2005 levels (265 kt CO_2) by 2030 and achieve net-zero by 2050 – on track with 90% of electricity needs in Alberta being provided by renewable energy, looking to develop low-emission electric micro-grids for the High Artic to reduce reliance on fossil fuels.
- Use 100% clean electricity by 2022 where currently available and by 2025 in all locations. This will include utilizing the IDEaS challenge program to address challenges of renewable energy in the High Artic regions.
- 100% of DND commercial light-duty vehicle fleet purchases will be zero-emission vehicles with a procurement target of 50% by 2023. As of 2020, 33% of the Defence's commercial fleet were zero-emission vehicles with 84% of new purchases being green. Currently testing hydrogen vehicle at CFB Valcartier in collaboration with NRCan.

- Develop a strategy for aviation and marine fuels that supports the net-zero GHG target for 2050. Encouraging industry to develop a sustainable aviation fuel supply that could use existing infrastructure – could be an opportunity to utilize hydrogen or hydrogen carriers as the fuel supply.
- Achieve 85% energy efficiency for fossil fuel electrical generation and distribution utilities in major deployed camps by 2023 – use of hydrogen and hydrogen carriers could play a meaningful role in achieving this target.

DND in conjunction with DRDC has formed the Innovation for Defence Excellence and Security (IDEaS) program to fund joint projects with private organization to help solve challenges faced by the Canadian Armed Forces (CAF). IDEaS program provides five funding mechanisms to assist Canadian innovators.

1. **Competitive Projects:** Up to $1.2M in phased development funding,
2. **Innovation Networks:** Up to $1.5M to stimulate free flow of ideas for purposes of innovation,
3. **Contests:** Competition to fuel innovative solutions,
4. **Sandboxes:** Combining military experts with private technology,
5. **Test Drives:** CAF providing joint collaboration and access to DND bases to test the technology.

CFB Suffield, P.O. Box 6000, Stn Main, Medicine Hat, AB T1A 8K8
403-544-4405 www.canada/ca/en/army/corporate/3-canadian-division/canadian-forces-basesuffield.html

8.5.1 Defence Research & Development Canada (DRDC)

DRDC has approximately 1,300 employees at seven research centres across Canada and works in partnership with more than 150 external groups which includes industry, academia, other government departments and international partners. DRDC – Suffield is the only centre west of Toronto and employs more than 300 full-time civilian employees, which is in addition to the over 100 stationed Canadian military personnel, upwards of 600 civilian employees, and permanent military staff associated with BATUS.

DRDC – Suffield specializes in weapon/blast effects, vehicles, autonomous systems, military engineering, and chemical, biological and radiological defence. As part of previous IDEaS competitions, CFB – Suffield has done extensive testing with UAV's. The Canadian Hydrogen Study identified use of hydrogen as a potential fuel for longer range and greater load bearing capacity UAVs for potential military use. Research and testing of hydrogen as it applies to potential weapons use, manned and unmanned vehicles, and GHG reductions by the military would be consistent with the mandates of the CAF and DND and could be a fit for partnership with the military. [262][263][264][265][266]

Industry forms a key component of the Canadian innovation system, is a major source of innovative ideas and an important partner for DRDC, to translate concepts into reality and provide equipment and systems that CAF and DND depend upon. DRDC facilities are available for use on a case-by-case basis on a cost-recovery basis as per existing science and technology requirements and federal government policies.

Defence and Security Science and Technology (DSST) program is another collaborative program administered by DRDC to harness innovation in eight strategic focus areas, with hydrogen potentially aligning with at least 2 of the focus areas.

- Advance Platforms and Weapons (Automation, AUV's – harnessing innovation),
- Evolution of Science and Technology (security challenges and technology advancement, modern capabilities.

Suffield Research Centre, P.O. Box 4000, Stn Main, Medicine Hat, AB T1A 8K6
www.canada.ca/en/department-national-defence/programs/defence-ideas.html

8.6 Environment, Water, and Stakeholder Relationships

8.6.1 Environmental

Various identified Wildlife Sensitivity areas and species have been listed in the Alberta Wildlife Sensitivity Data Sets and requires investigation to determine the impact these areas have on development specific to the area identified. [267]

A high-level summary of the sensitive species and the areas specific to southeast Alberta are as follows:

AMPHIBIANS AND REPTILES:

- The entirety of the Southeast Alberta region has been designated as a Sensitive Amphibian Range,
- Greater Short Horned Lizard Habitat has been identified near Bow Island and Medicine Hat along the South Saskatchewan River, near Foremost along Chin Coulee, and in the southern part of the region near Manyberries and Onefour in the Etzikom Coulee and Milk River waterways, and
- Sensitive Snake Habitat and Hibernacula Range throughout Newell, Cypress, and Forty Mile Counties proximal to the numerous river and creek watercourses.

MAMMALS:

- Ords Kangaroo Rat Habitat and Range northeast of the CFB Suffield range to the Saskatchewan border along the South Saskatchewan River, and
- Swift Fox Range in the southern portions of Cypress and Forty Mile Countries bordered by Saskatchewan and Montana.

BIRDS:

- Federal Emergency Order for the Protection of the Greater Sage-Grouse **(see Section 8.6.1.1)**,
- Provincial Game Bird Sanctuary around Many Island Lake east of Medicine Hat and Pakowki Lake near Manyberries,
- Colonial Nesting Birds Buffer in Newell, Cypress, and Forty Mile counties,

- Piping Plover Buffer around water bodies throughout region,
- Sharp-Tailed Grouse Survey area throughout the region,
- Burrowing Owl Range throughout the region, and
- Sensitive Raptor Range for Prairie Falcon, Feruginous Hawk, and Golden Eagle throughout the region.

FISH:

- Critical Habitat at risk for Western Silvery Minnow in the Milk River system.

PLANTS – ENDANGERED AND THREATENED PLANTS RANGE:

- Slender Mouse-Ear-Cress, northern Cypress County and northeastern County of Newell between South Saskatchewan and Red Deer Rivers,
- Small-flowered Sand Verbena and Tiny Cryptanthe, along South Saskatchewan River north of Burdett and northeast of Medicine Hat, and in Onefour area near the Montana border,
- Soapweed, in Onefour area along the Montana border, and
- Western Spiderwort, near Manyberries.

8.6.1.1 Federal Emergency Order – Greater Sage-Grouse

In February 2014, the federal government issued an Emergency Order under the Species at Risk Act for the protection of the Greater Sage-Grouse in the Manyberries area in the southern portion of Southeast Alberta **(Figure 8.2)**. The species is listed as endangered and believed to be near extirpation with an estimated population in 2014 of fewer than 50 birds. The Order covers 980 km2 of provincial Crown lands and

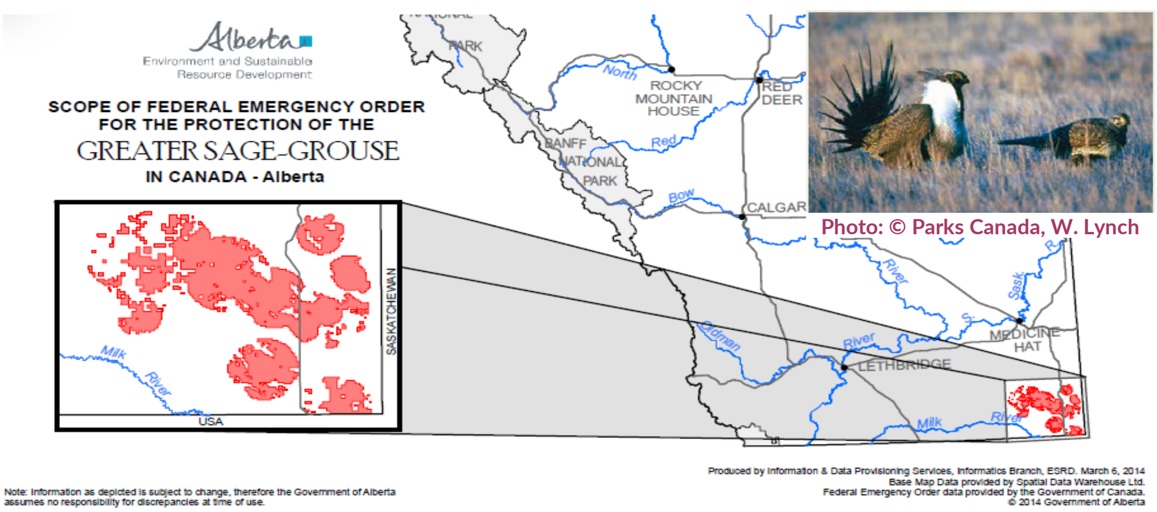


Figure 8.2 Area of Greater Sage-Grouse Protection Order

SOURCE: Government of Alberta

prohibits destruction of native plants, construction of new structures with specific height and noise thresholds, construction of roads and fences, and seasonal noise disturbance.

Emergency Order for the Protection of Greater Sage-Grouse
Canadian Wildlife Service – Prairie Region
Environment and Climate Change Canada - 9250-49th St, Edmonton, AB T6B 1K5
855-245-0331 www.sararegistry.gc.ca

8.6.2 Water

8.6.2.1 Irrigation Districts

Contact information for the three irrigation districts within southeast Alberta, as shown in **Figure 4.36**:

Eastern Irrigation District

Box 128, 550 Industrial Road, Brooks AB T1R 1B2
403-362-1400 www.eid.ca

Ross Creek Irrigation District

59 East 3 Ave, Dunmore, AB T1B 0L2
888-898-7082

St. Mary River Irrigation District

525-40 Street South, Lethbridge, AB T1J 4M1
403-328-4401 www.smrid.ab.ca

8.6.2.2 Watershed Planning & Advisory Councils

Alberta Environment and Parks have designated various independent, non-profit organizations to report on watershed, lead collaborative planning, and facilitate education and stewardship. These groups are intended to engage representatives of key stakeholders in the river basin area to seek consensus on land and water resource management strategies that support shared environmental, social, and economic outcomes within their watershed areas. [268]

Contact information for the four Watershed Planning & Advisory Councils that are part of the southeast Alberta region, as shown in **Figure 8.3:**

Battle River Watershed Alliance

5415 49th Ave, Box 3, Camrose, AB T4V 0N6
888-672-0276 www.battleriverwatershed.ca

Bow River Basin Council

P.O. Box 2100 Station M, Calgary, AB T2P 2M5
403-268-4597 www. brbc.ab.ca

Milk River Watershed Council Canada

Box 313, Milk River, AB T0K 1M0
403-647-3808 www.mrwcc.ca

South East Alberta Watershed Alliance

Rm 41 – 419 3rd St. SE, Medicine Hat, AB T1A 0G9
403-580-8980 www.seawa.ca

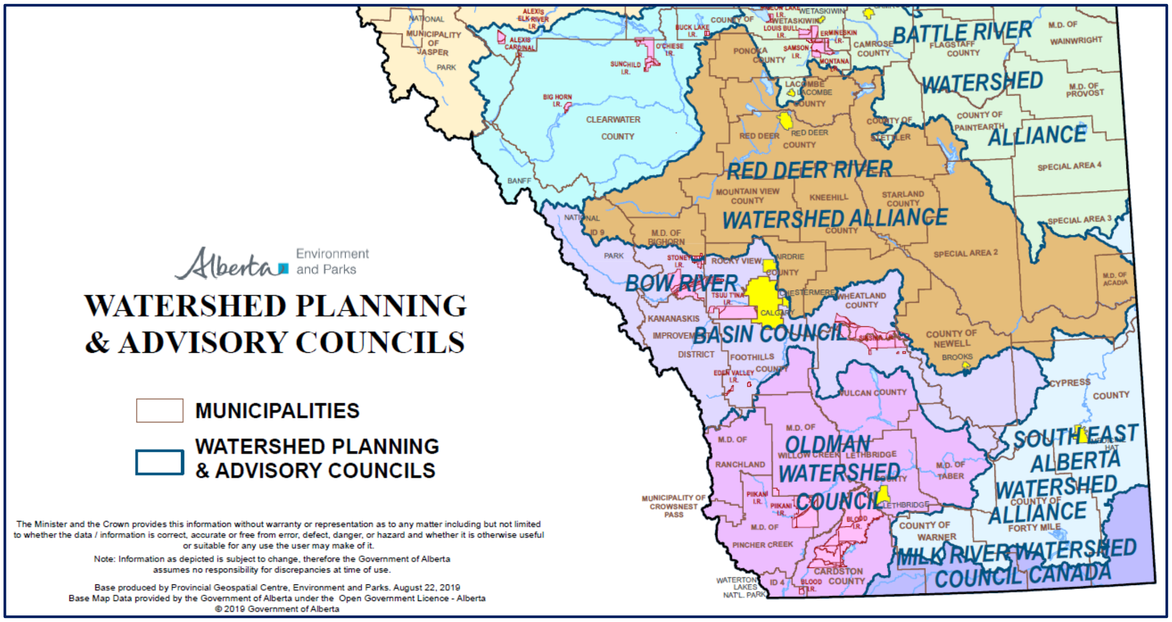


Figure 8.3 Southern Alberta's Watershed Planning Advisory Councils – Alberta Environment

SOURCE Government of Alberta, Watershed Planning and Advisory Councils

9 NEXT STEPS

9.1 Hydrogen HUB Launch

The intention of the Funding Partners is to move forward with the formal creation of a Southeast Alberta Hydrogen HUB and to promote engagement between various parties; municipal economic development organizations, existing and new industrial parties, provincial and federal regulatory bodies, academic and financial institutions, innovation networks, national defence, technical associations, and Indigenous, environmental and other public stakeholder groups, for the specific purpose of achieving mutually beneficial advancement of hydrogen transition and the establishment of a hydrogen economy for the region. The HUB would utilize a proactive approach to responsible development within the region, to capitalize on the existing resources, infrastructure, industrial capabilities, and regulatory support to become a leader in hydrogen transition and hydrogen supply, while maintaining the integrity of representing the interests and concerns of the region at large.

The HUB would work off the fundamental belief of recognizing the importance of cooperation and collaboration between various parties to achieve alignment in optimization and advancement of the hydrogen economy for the mutual benefits of industry, municipalities, and the public. The intent is to establish an inclusive and sustainable economic low carbon economy for southeast Alberta through planning and ultimate commercial development with the transitional acceptance of hydrogen. The HUB would promote hydrogen literacy and be an advocate for a low carbon economy and the strengths of the Southeast Alberta region.

9.1.1 Governance Structure

A potential governance structure **(Figure 9.1)** would include:

- **Steering Committee** and an integrating secretariate (an individual or group tasked with the responsibility to coordinate day to day operational duties and communications between the Steering Committee and other associated teams or groups).
- **Action Teams,** which are representatives of groups or interests embedded in a larger Ecosystem
- A **coalition** of economic development entities and coalition of philanthropic entities, embedded in the Ecosystem, will be formed to support the HUB. Coalitions will be self-organizing and governing, with two-way information exchange between the HUB and the coalitions. The HUB will benefit from advice for the coalitions, and the coalitions will benefit from understanding and being current to ongoing HUB progress.

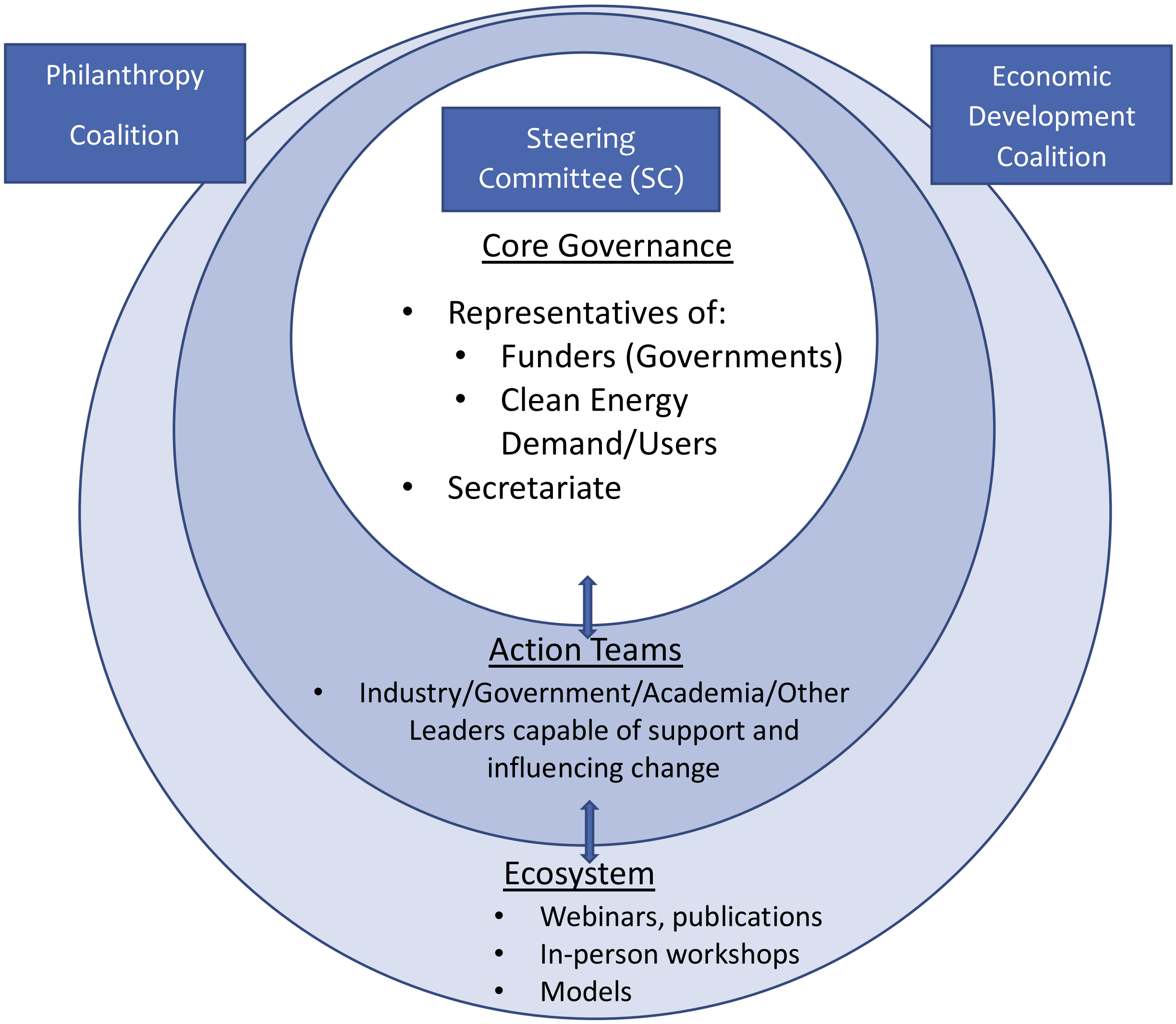


Figure 9.1 HUB's Governance Structure

SOURCE: The Transition Accelerator – HUB Governance Structure

9.1.2 Action Teams - Subcommittees

To promote and support a coordinated approach to achieving economic success while maintaining appropriate standards with regards to public stakeholders and environmental quality for the Southeast Alberta region, various subcommittees would be created within the association. These Action Teams would be comprised of members from industry, government, academia and other associations or stakeholders, and work with the Steering Committee and Secretariate to address specific transitional issues, such as infrastructure, regulations & codes, incentives & funding, region specific initiatives, exports, carbon capture, utilization, and storage, as well as the various transitional sectors such as transportation, electrical generation, natural gas utilities, agriculture, and industrial, innovation & technology, etc. The subcommittees would not have any direct authority to direct association commitments or activity but would ensure regular and considerate communication and opportunities for involvement with both industrial and non-industrial stakeholders of the region with respect to its planning and development.

9.2 Inter-HUB Communications

The Southeast Alberta Hydrogen HUB Association would welcome the opportunity to become a member of a nationwide Hydrogen HUB community and work within that group to ensure the interests of Southeast Alberta are represented and that the strengths of the various HUBs can be accentuated across the country to ensure Canada becomes a successful example of nationwide Hydrogen transition.

APPENDIX A Units, Constants, and Conversions

[269][270]

Variable	Value
PREFIXES	
deca (da)	10^1
kilo (k)	10^3
mega (M)	10^6
giga (G)	10^9
tera (T)	10^{12}
peta (P)	10^{15}
STANDARD CONDITIONS	
Pressure	1 bar
Temperature	0 °C
VOLUME	
1 m^3	6.2898 bbl
1 m^3	35.315 ft^3 (scf)
1 m^3	1000 L
1 dam^3	0.810713 acre-ft
1 dam^3	1000 m3

Variable	Value
1 Mcf	1000 scf (ft^3)
1 MMcf	1000 Mcf
1 Bcf	1000 MMcf
MASS	
1 t (ton)	1000 kg
1 tonne	1016 kg
1 t (ton)	0.91 tonne
LENGTH	
1 m	3.281 ft (')
1 ft (')	12 in (")
1 in (")	2.54 cm
1 m	100 cm
1 km	0.6214 miles
AREA	
1 ha	0.01 km^2
1 ha	2.47 acre
1 mi^2	640 acres
1 mi^2	2.6 km^2
PRESSURE	
1 bar	14.504 psi
1 bar	100 kPa
1 kPa	1000 Pa

Variable	Value
1 MPa	1000 kPa
1 MPa	145.04 psi
1 atm	101.325 kPa
1 atm	14.696 psi
ENERGY	
1 kWh	3.6 MJ
1 MWh	3.6 GJ
1 MMBtu	1.055 GJ
FUEL DENSITY / ENERGY CONTENT	
Hydrogen	
Density	0.09 kg/m3
HHV	141.7 MJ/kg
HHV	12.7 MJ/m3
LHV	120 MJ/kg
LHV	10.8 MJ/m3
Methane	
Density	0.689 kg/m3
HHV	54.281 MJ/kg
HHV	37.414 MJ/m3
LHV	48.989 MJ/kg
LHV	33.766 MJ/m3

Variable	Value
Diesel	
Density	846 kg/m3
HHV	45.6 MJ/kg
HHV	38,600 MJ/m3
LHV	42.6 MJ/kg
LHV	36,000 MJ/m3
Gasoline	
Density	737 kg/m3
HHV	46.4 MJ/kg
HHV	34,200 MJ/m3
LHV	43.4 MJ/kg
LHV	32,000 MJ/m3
Kerosene	
Density	821 kg/m3
HHV	46.2 MJ/kg
HHV	37,900 MJ/m3
LHV	43.0 MJ/kg
LHV	35,300 MJ/m3
Methanol	
Density	791 kg/m3
HHV	23.0 MJ/kg

Variable	Value
HHV	18,200 MJ/m3
LHV	19.9 MJ/kg
LHV	15,800 MJ/m3
Ammonia	
Density	0.763 kg/m3
HHV	22.5 MJ/kg
HHV	16.2 MJ/m3
LHV	18.9 MJ/kg
LHV	13.6 MJ/m3

REFERENCES

[1] Government of Canada, *Budget 2022: A Plan to Grow Our Economy and make Life More Affordable*, **07-Apr 2022**, [Online], Available: https://budget.gc.ca/2022/home-accueil-en.html

[2] Government of Canada, *2030 Emissions Reduction Plan: Clean Air, Strong Economy*, **29-Mar 2022,** [Online], Available: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030.html

[3] Government of Canada, Environment and Climate Change Canada. *Achieving a Sustainable Future: Draft federal sustainable development strategy 2022 to 2026*. **2021**, [Online], Available: https://www.fsds-sfdd.ca/en#/en/goals/

[4] Layzell, D.B., Young, C., Lof, J., Leary, J., Sit, S. *Towards Net-Zero Energy Systems in Canada: A Key Role for Hydrogen*. **2020**, [Online], Available: https://transitionaccelerator.ca/wp-content/uploads/2020/09/Net-zero-energy-systems_role-for-hydrogen_200909-Final-print-1.pdf

[5] Layzell, D.B., Lof, J., Young, C., Leary, J. *Building a Transition Pathway to a Vibrant Hydrogen Economy in the Alberta Industrial Heartland.* **Nov 2020**, [Online], Available: https://transitionaccelerator.ca/building-a-transition-pathway-to-a-vibrant-hydrogen-economy/

[6] Natural Resources Canada, Government of Canada. *Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen*. **Dec 2020**, [Online], Available: https://www.nrcan.gc.ca/climate-change-adapting-impacts-and-reducing-emissions/canadas-green-future/the-hydrogen-strategy/23080

[7] British Columbia Government. *B.C. Hydrogen Strategy: A sustainable pathway for B.C.'s energy transition*. **Jul 2021**, [Online], Available: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/electricity/bc-hydro-review/bc_hydrogen_strategy_final.pdf

[8] Government of Alberta. *Alberta Hydrogen Roadmap*. **2021**, [Online], Available: https://www.alberta.ca/hydrogen-roadmap.aspx

[9] Ontario Government. *Ontario's Low-Carbon Hydrogen Strategy: A Path Forward*. **Apr 2022**, [Online], Available: https://www.ontario.ca/page/ontarios-low-carbon-hydrogen-strategy

[10] Manitoba Government. *Focused on What Matters Most: Manitoba's Clean Energy Strategy*. **2012**, [Online], Available: https://www.gov.mb.ca/sd/environment_and_biodiversity/energy/pubs/energy_strategy_2012.pdf

[11] Manitoba Government. *Preliminary Hydrogen Opportunities Report: Setting the Direction for Hydrogen Development in Manitoba*. **Apr 2003**, [Online], Available: https://www.manitoba.ca/sd/environment_and_biodiversity/energy/pubs/hydrogen.pdf

[12] Allan, B., Eaton, D., Goldman, J., Islam, A., Augustine, T., Elgie, S., and Meadowcroft, J. *Canada's Future in a Net-Zero World: Securing Canada's Place in the Global Green Economy*. Smart Prosperity Institute, Transition Accelerator and Pacific Institute for Climate Solutions. **Mar 2022**, [Online], Available: https://pics.uvic.ca/research/canadas-future-net-zero-world-securing-canadas-position-global-green-economy

[13] Hamelin, P., Dubé, N., Cajvan, P., Stano, M., Rochon, Q., Hobbs, E., Van Soelen, L. *The Frontier Comes into View: Canadian Governments' Hydrogen Strategies*. Gowling WLG. **08-Jun 2021**, [Online], Available: https://www.mondaq.com/canada/oil-gas-electricity/1078248/the-frontier-comes-into-view-canadian-governments39-hydrogen-strategies-

[14] United States Department of Energy. *Hydrogen Program*. [Online], Available: https://www.hydrogen.energy.gov/ (Accessed 2022)

[15] United States Department of Energy. *Hydrogen Strategy: Enabling a Low-Carbon Economy*. Office of Fossil Energy. **Jul 2020**, [Online], Available: https://www.energy.gov/sites/prod/files/2020/07/f76/USDOE_FE_Hydrogen_Strategy_July2020.pdf

[16] United States Department of State. *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*. United States Executive Office of the President. **Nov 2021**, [Online], Available: https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf

[17] Hydrogen Council. *Hydrogen scaling up: A sustainable pathway for the global energy transition*. **Nov 2017**, [Online], Available: https://hydrogencouncil.com/en/study-hydrogen-scaling-up/

[18] International Energy Agency. *Global Hydrogen Review 2021*. **Oct 2021**, [Online], Available: https://www.iea.org/reports/global-hydrogen-review-2021

[19] Griffiths, S., Sovacool, B.K., Kim, J., Bazilian, M., Uratani, J.M. *Industrial decarbonization via hydrogen: A critical and systematic review of developments, social-technical systems and policy options*. **08-Jul 2021**, [Online], Available: https://doi.org/10.1016/j.erss.2021.102208

[20] Government of Alberta. *Getting Alberta Back to Work: Natural Gas Vision and Strategy*. **Oct 2020**, [Online], Available: https://open.alberta.ca/publications/getting-alberta-back-to-work-natural-gas-vision-and-strategy

[21] Mortlock, L., Milia, D., Denhamer, T., Kim, A. *Canada's hydrogen future – risks and rewards*. The Canadian Energy Climate Nexus, EY. **2021**, [Online], Available: https://www.ey.com/en_ca/energy-resources/canadas-hydrogen-future-risks-and-rewards-ey

[22] IEA. *Hydrogen*. [Online], Available: https://www.iea.org/reports/hydrogen (Accessed 2021)

[23] Gorski, J., Tahra, J., Tam Wu, K. *Carbon intensity of blue hydrogen production*. **Aug-2021**, [Online], Available: https://www.pembina.org/pub/carbon-intensity-blue-hydrogen-production

[24] Eversheds Sutherland. *Clearing up the colours: The hydrogen colour spectrum*. **2021**, [Online], Available: https://www.eversheds-sutherland.com/documents/sectors/energy/hydrogen-hub/Clearing%20up%20the%20colours-%20Hydrogen%20colour%20wheel.pdf

[25] Methanol Institute. *Carbon Footprint of Methanol*. **Feb 2022**, [Online], Available: https://energycentral.com/c/og/carbon-footprint-methanol

[26] IPHE. *Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen*. **Oct 2021**, [Online], Available: https://www.iphe.net/iphe-working-paper-methodology-doc-oct-2021

[27] CertifHy. *CertifHy Scheme*. [Online], Available: https://www.certifhy.eu/certifhy-documents/ (Accessed 2022)

[28] Mazloomi, K. and Gomes, C. *Hydrogen as an energy carrier: Prospects and challenges*. **10-Feb 2012**, [Online], Available: https://doi.org/10.1016/j.rser.2012.02.028

[29] Van Hoecke, L., Laffineaur, L., Campe, R., Perreault, P., Verbruggen, S.W., Lenaerts, S. *Challenges in the use of hydrogen for maritime applications*. **08-Dec 2020**, [Online], Available: DOI: 10.1039/d0ee01545h, http://rsc.li/ees

[30] Murray, S. *The Potential and Challenges of Hydrogen as an Alternative Fuel*, **Dec 2021**

[31] Asia Pacific Energy Research Centre. *Perspectives on Hydrogen in the APEC Region*. **Jun 2018**, [Online], Available: https://aperc.or.jp/file/2018/9/12/Perspectives+on+Hydrogen+in+the+APEC+Region.pdf

[32] RIX Industries, *Solving the Hydrogen Storage Challenge*, **2022**, [Online], Available: https://www.rixindustries.com/request---solving-the-hydrogen-storage-challenge-white-paper

[33] California Air Resources Board. *CA-GREET 3.0 Lookup Table Pathways Technical Support Documentation*. **13-08-2018**, [Online], Available: https://ww2.arb.ca.gov/sites/default/files/classic//fuels/lcfs/ca-greet/lut-doc.pdf

[34] Hydrogen Council, McKinsey & Company. *Hydrogen for Net-Zero: A critical cost-competitive energy vector*. **Nov 2021**, [Online], Available: https://hydrogencouncil.com/wp-content/uploads/2021/11/Hydrogen-for-Net-Zero_Full-Report.pdf

[35] Hydrogen Council, McKinsey & Company. *Hydrogen Insights: A perspective on hydrogen investment, market development and cost competitiveness*. **Feb 2021**, [Online], Available: https://hydrogencouncil.com/en/hydrogen-insights-2021/

[36] Ewing, M. Israel, B. Jutt, T. Talebian, H. Stepanik, L., *Hydrogen on the path to net-zero emissions: Costs and climate benefits*, **Jul 2020**, [Online], Available: https://www.pembina.org/pub/hydrogen-primer

[37] Taibi, E., Blanco, H., Miranda, R., Carmo, M. *Green Hydrogen Cost Reduction: Scaling Up Electrolysers to Meet the 1.5C Climate Goal.* IRENA (2020). **2020**, [Online], Available: https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf

[38] UK Department for Business, Energy & Industrial Strategy. *Hydrogen Production Costs 2021*. **Aug 2021**, [Online], Available: https://www.gov.uk/government/publications/hydrogen-production-costs-2021

[39] Hafner, M. and Luciani, G. *The Palgrave Handbook of International Energy Economics*. **2022**, [Online], Available: https://doi.org/10.1007/978-3-030-86884-0

[40] GLJ Ltd, Apr 1st 2022 – *3 Consultant Average*, **Apr 2022**, [Online], Available: https://www.gljpc.com/historical-forecasts

[41] IEA, Hydrogen *Projects Database 2021 (revised)*, **2022**, [Online}. Available: https://www.iea.org/reports/hydrogen-projects-database

[42] Martino, M., Ruocco, C., Meloni, E., Pullumbi, P., Palma, V. *Main Hydrogen Production Process: An Overview*. **25-Apr 2021**, [Online], Available: https://doi.org/10.3390/catal11050547

[43] Ji, M. and Wang, J. *Review and comparison of various hydrogen production methods based on costs and life cycle impact assessment indicators*. **16-Sep 2021**, [Online], Available: https://doi.org/10.1016/j.ijhydene.2021.09.142

[44] Nikolaidis, P. and Poullikkas, A. *A comparative overview of hydrogen production processes*. **18-Sept 2016**, [Online], Available: http://dx.doi.org/10.1016/j.rser.2016.09.044 1364-0321/© 2016 Elsevier Ltd

[45] Von Keitz, M. *Methane Pyrolysis for Hydrogen – Opportunities and Challenges*. **31-Aug 2021**, [Online], Available: https://www.energy.gov/sites/default/files/2021-09/h2-shot-summit-panel2-methane-pyrolysis.pdf

[46] Dors, M., Nowakowska, H., Jasinski, M., Mizeraczyk, J. *Chemical Kinetics of Methane Pyrolysis in Microwave Plasma at Atmospheric Pressure*. **24-Nov 2013**, [Online], Available: DOI 10.1007/s11090-013-9510-4, https://link.springer.com/article/10.1007/s11090-013-9510-4

[47] Schneider, S., Bajohr, S., Graf, F., Kolb, T. *State of the Art of Hydrogen Production via Pyrolysis of Natural Gas*, **15-Jul 2020**, [Online], Available: DOI: 10.1002/cben.202000014, www.ChemBioEngRev.de

[48] Von Keitz, M. *Methane Pyrolysis for Hydrogen – Opportunities and Challenges*. **31-Aug 2021**, [Online], Available: https://www.energy.gov/sites/default/files/2021-09/h2-shot-summit-panel2-methane-pyrolysis.pdf

[49] Srilatha, K., Bhagawan, D., Shiva Kumar, S., Himabindu, V. *Sustainable fuel production by thermocatalytic decomposition of methane – A review*. **01-Oct 2017**, [Online], Available: https://doi.org/10.1016/j.sajce.2017.10.002

[50] Hume, D. *Ammonia as Maritime Fuel*. Pacific Northwest National Laboratory. **07-May 2021**, [Online], Available: https://www.energy.gov/sites/default/files/2021-08/9-nh3-maritime-fuel.pdf

[51] Cheddie, D. *Ammonia as a Hydrogen Source for Fuel Cells: A Review*. (Chapter 13). **2012**, [Online], Available: http://dx.doi.org/10.5772/47759

[52] Autrey, T. and Ahluvalia, R. *Hydrogen Carriers for Bulk Storage and Transport of Hydrogen*. **06-Dec 2018**, [Online], Available: https://www.energy.gov/sites/prod/files/2018/12/f58/fcto-webinarslides-hydrogen-carriers-120618.pdf

[53] Nordvang, E. *Hydrogen Production from Ammonia for Next Generation Carbon-Free Energy Technologies*. **05-May 2017**, [Online], Available: https://www.azocleantech.com/article.aspx?ArticleID=656

[54] Shen, Y., Zhan, Y., Shuping, L., Ning, F., Du, Y., Huang, Y., He, T., Zhou, X. *Hydrogen generation from methanol at near-room temperature*. **06-Sep 2017**, [Online], Available: DOI: 10.1039/c7sc01778b, https://pubs.rsc.org/en/content/articlelanding/2017/sc/c7sc01778b

[55] Aurora Hydrogen *Website*. [Online], Available: https://aurorahydrogen.com/ (Accessed 2022)

[56] Methanol Institute, *Methanol as a Hydrogen Carrier*, **2022**, [Online], Available: https://www.methanol.org/wp-content/uploads/2021/11/M2H2-Final.pdf

[57] Edlund, D. Lim, D. *The Renewable Methanol Pathway to Green Hydrogen*, **Apr 2021**, [Online], Available: https://www.methanol.org/wp-content/uploads/2020/04/Renewable-methanol-to-Green-Hydrogen-final-1.pdf#:~:text=Renewable%20Methanol%20to%20Support%20A%20Low%20Carbon%20Economy,offers%20the%20near-term%20potential%20of%20being%20carbon%20neutral.

[58] Chiyoda Corporation, *SPERA Hydrogen™ Chiyoda's Hydrogen Supply Chain Business*, **2020**, [Online], Available: https://www.chiyodacorp.com/en/service/spera-hydrogen/innovations/

[59] National Grid ESO. *UK, Future Energy Scenarios*. **Jul 2021**, [Online], Available: https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021

[60] Qin, Z., Yang, Z., Jia, C., Duan, J., and Wang, L. *Experimental study on combustion characteristics of diesel–hydrogen dual-fuel engine*. J. Therm. Anal. Calorim. doi: 10.1007/s10973-019-09147-y. **Jan. 2020**, [Online], Available: https://doi.org/10.1007/s10973-019-09147-y

[61] Tsujimura, T. and Suzuki, Y. *The utilization of hydrogen in hydrogen/diesel dual fuel engine*. Int. J. Hydrog. Energy. Volume 42, No. 19 (Page 14019–14029). **May 2017**, [Online], Available: doi: 10.1016/j.ijhydene.2017.01.152

[62] Vavra, J., Bortel, I., and Takats, M. *A Dual Fuel Hydrogen - Diesel Compression Ignition Engine and Its Potential Application in Road Transport*. SAE International, Warrendale, PA. SAE Technical Paper 2019-01-0564. **Apr. 2019**, [Online], Available: https://www.sae.org/publications/technical-papers/content/2019-01-0564/

[63] Mission Innovation. *Dual Fuel Hydrogen-Diesel Combustion System*. [Online], Available: http://mission-innovation.net/our-work/mission-innovation-breakthroughs/dual-fuel-hydrogen-diesel-combustion-system/

[64] Hygear, Hy.Gen *On-Site Hydrogen Generation System*, **Jun 2019**, [Online], Available: https://hygear.com/wp-content/uploads/2019/06/HYGEAR_HyGen_May19.pdf

[65] Natural Resources Canada. *Comprehensive Energy Use Database*. **15-Dec-2004**, [Online], Available: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

[66] Canada Energy Regulator. *Provincial and Territorial Energy Profiles – Alberta*. [Online], Available: https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-alberta.html (Accessed 2022)

[67] Statistics Canada (2021). *Table 25-10-0029-01. Supply and demand of primary and secondary energy in terajoules, annual*. **13-Dec 2021**, [Online], Available: https://doi.org/10.25318/2510002901-eng

[68] Statistics Canada (2021). *Table 25-10-0030-01. Supply and demand of primary and secondary energy in natural units*. **13-Dec 2021**, [Online], Available: https://doi.org/10.25318/2510003001-eng

[69] Government of Alberta. *Regional Dashboard*. [Online], Available: https://regionaldashboard.alberta.ca/#/ (Accessed 2022)

[70] EDC Associates Ltd., *A Review of Cogeneration in Alberta*, **15-Sep 2015**, [Online], Available: https://www.oscaalberta.ca/wp-content/uploads/2015/08/A-Review-of-Cogeneration-in-Alberta.pdf

[71] Government of Canada, Environment and Climate Change Canada, *Greenhouse Gas Reporting Program (GHGRP) – Facility Greenhouse Gas (GHG) Data*, [online], https://open.canada.ca/data/en/dataset/a8ba14b7-7f23-462a-bdbb-83b0ef629823 (accessed 2022)

[72] Government of Canada, Environment and Climate Change Canada, *Greenhouse gas emissions from large facilities*, [Online], Available: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions/large-facilities.html (accessed 2021)

[73] Palliser Economic Partnership, *Explore the Palliser Region Map*, **2021**, [Online], Available: https://palliseralberta.com/map/

[74] Alberta Municipal Affairs. *2019 Municipal Affairs Population List.* **Nov 2019**, [Online], Available: ISBN: 9781460146231, https://open.alberta.ca/publications/2368-7320

[75] Government of Alberta. *Alberta Major Projects*. [Online], Available: https://majorprojects.alberta.ca/#map/?includeNoEstimates=1&budgetmin=5&budgetmax=1020 (Accessed 2021)

[76] Outlook Market Research & Consulting Ltd. *BREWD Research Report*. **05-Jun 2020**, [Online], Available: https://www.investsoutheastalberta.ca/post/brewd-finalresearchreport

[77] Government of Alberta, *High Load Corridor*, **Apr 2015**, [Online], Available: https://www.alberta.ca/high-load-corridor.aspx

[78] University of Calgary, Digital Collections, *Gas Well 'Old Glory', Medicine Hat area, Alberta,* **1909**, [Online], Available: https://digitalcollections.ucalgary.ca/Browse/Collections?#/SearchResult&VBID=2R3BXZ7KDDTTU&PN=1&WS=PackagePres

[79] Government of Alberta, *Alberta energy history up to 1999.* [Online], Available: https://www.alberta.ca/alberta-energy-history-up-to-1999.aspx (Accessed 2022)

[80] Alberta Culture and Tourism. *Natural Gas – Accidental Industry*. [Online], Available: http://history.alberta.ca/energyheritage/gas/creation-of-an-industry/accidental-industry (Accessed 2022)

[81] Alberta Energy Regulatory. *Building it Old School: Alberta's First Pipeline. Resource Stories with Energy*. **23-Apr 2017**, [Online], Available: https://resource.aer.ca/stories/building-it-old-school-albertas-first-pipeline

[82] Eideard. *Alberta Energy Revolution begins with Largest Solar Project in Western Canada*. **24-Dec 2017**, [Online], Available: https://eideard.com/2017/12/24/alberta-energy-revolution-begins-with-largest-solar-project-in-western-canada/

[83] Capital Power. *Media and government stakeholders get firsthand look at construction progress of Whitla Wind*. **15-Aug 2019**, [Online], Available: https://www.capitalpower.com/media-and-government-stakeholders-get-firsthand-look-at-construction-progress-of-whitla-wind/

[84] Statistics Canada, Population growth in Canada's rural areas, 2016 to 2021, 09-Feb 2022, [Online], Available: https://www12.statcan.gc.ca/census-recensement/2021/as-sa/98-200-x/2021002/98-200-x2021002-eng.cfm

[85] Government of Alberta. *Economics of Production and Marketing Greenhouse Crops in Alberta*. **Oct 2018**, [Online], Available: https://open.alberta.ca/publications/1927-5714

[86] Government of Canada, *National Highway System,* **03-Sep 2020**, [Online], Available: https://tc.canada.ca/en/corporate-services/policies/national-highway-system

[87] Our Airports. *Map of airports in Alberta, Canada*. [Online], Available: https://ourairports.com/countries/CA/AB/ (Accessed 2022)

[88] Pryde Schropp McComb Inc. *Inventory of Alberta Regional and Local Airports*. **18-Feb 2003**, [Online], Available: https://www.alberta.ca/inventory-of-alberta-regional-and-local-airports-assessment-of-facilities.aspx

[89] TC Energy, *NGTL System and Foothills Pipelines Ltd. Customer Operations Meeting,* **10-Mar 2022**, [Online], Available: http://www.tccustomerexpress.com/docs/20220310_Customer%20Ops%20-%20NGTL.pdf

[90] TC Energy. *Customer Express*. [Online], Available: http://www.tccustomerexpress.com/index.html (Accessed 2022)

[91] CAPP, *Canadian and US Crude Oil Pipelines and Refineries – 2020,* **01-Jul 2020**, [Online], Available: https://www.capp.ca/wp-content/uploads/2022/05/2020-CAPP-Pipeline-and-Refinery-Map-scaled.jpg

[92] Canada Energy Regulator. *Interactive Pipeline Map*. [Online], Available: https://www.cer-rec.gc.ca/en/safety-environment/industry-performance/interactive-pipeline/index.html (Accessed 2022)

[93] Keystone XL, *Terminated Keystone XL Project – Keystone Pipeline*, **2021**, [Online}, Available: https://www.keystonexl.com/maps/

[94] AESO. *2022 Long-term Transmission Plan*. **24-Feb 2022**, [Online], Available: https://www.aeso.ca/grid/long-term-transmission-plan/

[95] Government of Alberta, Rural Electrification Associations Service Areas, Jan 2019, [Online], Available: http://www.afrea.ab.ca/filesaf/afrea/rea_January_2019.pdf

[96] Government of Alberta. *Rural Gas Utility Franchise Areas*. **Feb 2022**, [Online], Available: https://open.alberta.ca/publications/rural-gas-utility-franchise-areas-map

[97] AESO, Market Reports, 2022, [Online], Available: http://ets.aeso.ca/ets_web/ip/Market/Reports/CSDReportServlet, (Accessed 2021, 2022)

[98] BIC Magazine, *Plains Midstream Canada to expand ownership in North America's largest natural gas processing center*, **30-Oct 2020**, [Online], Available: https://www.bicmagazine.com/industry/pipelines/plains-midstream-canada-enters-into-an-agreement-to-expand-o/

[99] Blanke, J. Drumheller Online, Sheerness Power Plant Conversion to Natural Gas Complete, 10-Nov 2021, [Online], Available: https://drumhelleronline.com/local/sheerness-power-plant-conversion-to-natural-gas-complete

[100] JBS Foods – Canada, *Website*, **2022**, [Online], Available: https://jbsfoodsgroup.com/locations/Canada

[101] Alberta Energy Regulator. *Maps, Map Viewers, and Shapefiles*. Alberta Energy Regulator. **2022**, [Online], Available: https://www.aer.ca/providing-information/data-and-reports/maps-mapviewers-and-shapefiles

[102] Hutterite directory. *Website*. [Online], https://hutterite.directory/Hutterite.Directory.pdf (Accessed 2021)

[103] Government of Alberta, Alberta Agriculture and Forestry. *Agriculture*. [Online], Available: https://www.alberta.ca/agriculture.aspx (Accessed 2021)

[104] Meadowcroft, J. *Disruptive forces influencing the sustainability of Canada's agri-food sector: A scoping report*. The Transition Accelerator. **Nov 2021**, [Online], Available: https://transitionaccelerator.ca/wp-content/uploads/2021/11/TA-Report-3.6-Agri-food-Report-PUBLISH.pdf

[105] Government of Alberta. *Alberta Farm Input Prices*. [Online], Available: https://www.agric.gov.ab.ca/app21/farminputprices (Accessed 2021)

[106] Government of Alberta. *Profile of the Greenhouse Industry in Alberta 2019*. **Sep 2020**, [Online], Available: https://open.alberta.ca/publications/9781460148273

[107] Canadian Forces Base, Suffield, Website, 2022, [Online], Available: https://www.canada.ca/en/army/corporate/3-canadian-division/204anadian-forces-base-suffield.html

[108] Government of Canada. *Canadian Environmental Sustainability Indicators: Greenhouse Gas Emissions*. Environment and Climate Change Canada. **2022**, [Online], Available: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html

[109] Environment and Climate Change Canada (2022). *Canadian Environmental Sustainability Indicators: Greenhouse gas emissions*. **2022**, [Online], Available: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html

[110] Government of Canada, Environment and Climate Change Canada, *Emission Factors and Reference Values*, [Online], Available: https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system/federal-greenhouse-gas-offset-system/emission-factors-reference-values.html (accessed 2021)

[111] Government of Canada, Environment and Climate Change Canada, *Canada's Official Greenhouse Gas Inventory*, [Online], Available: https://data.ec.gc.ca/data/substances/monitor/canada-s-official-greenhouse-gas-inventory/A-IPCC-Sector/?lang=en (accessed 2022)

[112] Gómez, D.R., Watterson, J.D., Americano, B.B., Ha, C., Marland, G., Matsika, E., Nenge Namayanga, L., Osman-Elasha, B., Kalenga Saka, J.D., Treanton, K. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* (Chapter 2 Stationary Combustion). **2006**, [Online], Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

[113] Government of Alberta. *Alberta Emission Offset System*. [Online], https://www.alberta.ca/alberta-emission-offset-system.aspx (Accessed 2022)

[114] Government of Alberta. *Technology Innovation and Emissions Reduction Regulation*. [Online], Available: https://www.alberta.ca/technology-innovation-and-emissions-reduction-regulation.aspx (Accessed 2022)

[115] Alberta Carbon Registries. *Website*. [Online], https://alberta.csaregistries.ca/ (Accessed 2022)

[116] Westlaw, *Generating and Calculating Credits and Deficits Using Fuel Pathways,* **2022,** [Online], Available: https://govt.westlaw.com/calregs/Document/ICE25B5523F704BB0885DBB0678E75944?transitionType=Default&contextData=%28sc.Default%29

[117] SAEWA, *Website*, **2022**, [Online], Available: https://www.saewa.ca/

[118] Lamb, J.J. and Pollet, B.G. *Hydrogen, Biomass, and Bioenergy, Integration Pathways for Renewable Energy Applications*. **2020**, [Online], Available: ISBN: 978-0-08-102629-8

[119] Government of Alberta, Alberta Environment, *Water Act*, **02-Jun 2021**, [Online], Available: https://open.alberta.ca/publications/w03

[120] Government of Alberta, Alberta Environment, *Water Act: Facts at your Fingertips*, **Jan 2010**, [Online], Available: https://open.alberta.ca/publications/alberta-water-act-facts-at-your-fingertips

[121] Government of Alberta, *Water for life: Alberta's strategy for sustainability*, **Nov 2003**, [Online], Available: https://open.alberta.ca/publications/0778530582

[122] Government of Alberta, Alberta Environment, *Water for life: a renewal*, **Nov 2008**, [Online], Available: https://open.alberta.ca/publications/9780778576709

[123] Government of Alberta, Alberta Environment, *Water for life: action plan*, **Nov 2009**, [Online], Available: https://open.alberta.ca/publications/9780778576723

[124] Government of Alberta, Alberta Environment, *Water for life: Facts at your Fingertips*, **01-Jan 2011**, [Online], Available: https://open.alberta.ca/publications/water-for-life-facts-at-your-fingertips

[125] Government of Alberta, Alberta Environment, *Water for life: Progress Report*, **01-Jan 2012**, [Online], Available: https://open.alberta.ca/publications/9780778589754

[126] Flow North, *Website: Info on Northwestern Alberta*, **2022**, [Online], Available: https://flownorth.ca/where-we-paddle/

[127] Government of Alberta, Alberta Environment, *South Saskatchewan River Basin Water Management Plan*, **Apr 2002**, [Online], Available: https://www.alberta.ca/south-saskatchewan-river-basin-water-management-plan.aspx

[128] Government of Alberta, Alberta Environment, *Approved Water Management Plan for the South Saskatchewan River Basin (Alberta)*, **Aug 2006**, [Online], Available: https://open.alberta.ca/publications/0778546209

[129] The Bow River Project Research Consortium, *Bow River Project: Final Report*, **Dec 2010**, [online], Available: https://albertawater.com/bow-river-project/

[130] Government of Alberta, Environment and Parks, *Watershed Planning & Advisory Councils Map*, **22-Aug 2019**, [Online], Available: https://www.alberta.ca/watershed-planning-and-advisory-councils.aspx

[131] SEAWA, *The State of the Saskatchewan River Basin, Chapter Nine: The South Saskatchewan River Sub-Basin*, accessed 2021, Available: https://seawa.ca/assets/media/documents/SSaskReport.pdf

[132] AMEC Earth & Environmental, *South Saskatchewan River Basin in Alberta: Water Supply Study*, **Dec 2009**, [Online], Available: https://open.alberta.ca/publications/south-saskatchewan-river-basin-in-alberta-water-supply-study-summary

[133] Bow River Basin Council, *State of the Watershed: Summary Booklet*, **2010**, [Online], Available: https://www.brbc.ab.ca/ecr/

[134] Alberta Irrigation District Association, *About AIDA*, **2022**, [Online], Available: https://www.albertairrigation.ca/?page_id=59

[135] Government of Alberta, Alberta Environment, South Saskatchewan River Basin Water Management Plan: Phase one Water allocation transfers, Jun 2002, [Online], Available: https://www.qp.alberta.ca/documents/orders/Orders_in_Council/2002/602/2002_321.html

[136] Government of Alberta, Alberta Agriculture and Forestry, *Alberta Irrigation Information 2019*, **Sep 2020,** [Online], Available: https://open.alberta.ca/publications/3295832

[137] Various Data Providers, *Proprietary energy data for Southeast Alberta from local industrial, municipal, and regulatory organizations: see Acknowledgements*, **Nov 2021 to Jun 2022**, provided via verbal and written correspondence under confidentiality

[138] Hunter, C and Deligiannis, G. *Canadian hydrogen survey 2004-2005: capacity, production and surplus update*. Canada: N. **2005**, [Online], Available: http://www.h2.ca/en/PDF/CANADIANHYDROGENSURVEY2005.pdf

[139] Natural Resources Canada, *2020 Fuel Consumption Guide*, **Jan 2020**, [Online], Available: https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/oee/pdf/transportation/tools/fuelratings/2020%20Fuel%20Consumption%20Guide.pdf

[140] Alberta Transportation. *Traffic Data Mapping*, **2022** [Online], Available: http://www.transportation.alberta.ca/mapping/

[141] Government of Alberta. *Traffic volumes at points on the highway*. [Online], Available: https://open.alberta.ca/opendata/traffic-volumes-at-points-on-the-highway (Accessed 2022)

[142] Government of Alberta, *Alberta highway historical ESAL report*, **10-Mar 2021,** [Online], Available: https://open.alberta.ca/publications/alberta-highway-historical-esal-report

[143] Government of Alberta, *Alberta highways 1 to 986: traffic volume, vehicle class, travel & ESAL statistics report*, **25-Feb 2021**, [Online], Available: https://open.alberta.ca/publications/alberta-highways-1-to-986-traffic-volume-vehicle-class-travel-esal-report

[144] Statistics Canada. *Table 23-10-0067-01 Road Motor Vehicle Registrations, by Type of Vehicle*. **27-Dec-2017**, [Online], Available: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310006701

[145] Government of Alberta, *Motorized Vehicle Registrations: by Vehicle Body Style*, **31-Mar 2021**, [Online], Available: https://open.alberta.ca/dataset/553f5a93-0032-484a-b5d3-bcfd8c47bc11/resource/00d8cdde-2177-4a29-9e04-f6f8b93fc3d1/download/trans-motorized-vehicle-registrations-by-vehicle-body-style-2021.pdf

[146] Government of Alberta, *Expression of Interest ("EOI") Number 2022-2: Commercial Safety Rest Areas Alberta Transportation*, **14-Feb 2022**, [Online], Available: https://www.alberta.ca/release.cfm?xID=81889BF483877-F646-42A1-41E4002E14451FE5

[147] Hyundai Motor Company, *XCIENT Fuel Cell brochure*, **2022**, [Online], Available: https://trucknbus.hyundai.com/hydrogen/en

[148] Transport & Environment, *Comparison of hydrogen and battery electric trucks: Methodology and underlying assumptions*, **Jun 2020**, [Online], Available: https://www.transportenvironment.org/wp-content/uploads/2021/07/2020_06_TE_comparison_hydrogen_battery_electric_trucks_methodology.pdf

[149] CP Rail, *CP announces hydrogen-powered locomotive pilot project*, **18-Dec 2020**, [Online], Available: https://www.cpr.ca/en/media/cp-announces-hydrogen-powered-locomotive-pilot-project

[150] CP Rail, *Canadian Pacific expands Hydrogen Locomotive Program to include additional locomotives, fueling stations with Emissions Reduction Alberta grant,* **01-Nov 2021,** [Online], Available: https://www.cpr.ca/en/media/Canadian-pacific-expands-hydrogen-locomotive-program-to-include-additional-locomotives-fueling-stations-with-emissions-red

[151] Transport Canada. *Rail Traffic Database*. [Online], Available: https://tc.canada.ca/en/corporate-services/policies/rail-transportation-0 (Accessed 2022)

[152] Railway Association of Canada. *Canadian Rail Atlas*. [Online], Available: https://rac.jmaponline.net/canadianrailatlas/ (Accessed 2022)

[153] Railway Association of Canada, *Rail Trends: 2021*, **23-Dec 2021**, [Online], Available: https://www.railcan.ca/wp-content/uploads/2021/12/RAC-RAIL-TRENDS-2021-Web-1.pdf

[154] CP Rail, *CP Weekly TRMs and Carloads,* [Online], Available: https://investor.cpr.ca/key-metrics/default.aspx (Accessed 2022)

[155] CN Rail, *CN 2022 Business Units Carloads and RTMs by AAR Weeks,* [Online], Available: *https://www.cn.ca/en/investors/key-weekly-metrics/*, (Accessed 2022)

[156] CN Rail, *CN AAR Websummary,* [Online], Available: https://www.cn.ca/-/media/Files/Investors/Investor-Performance-Measures/CN-AAR-WEBSUMMARY.xlsx?la=en&hash=B45CF24FE40477D08F902D8E3E2B28CB4ECB70B4, (Accessed 2022)

[157] CN Rail, *Week 52 2021: Carloads by AAR Commodity Groupings*, [Online], Available: https://www.cn.ca/en/investors/key-weekly-metrics/ (Accessed 2022)

[158] Statistics Canada, *Rail industry origin and destination of transported commodities,* **08-Apr 2022**, [Online], Available: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310006201

[159] Berger, R. *Hydrogen, A future fuel for aviation?* **Mar 2020**, [Online], Available: https://www.rolandberger.com/en/Insights/Publications/Hydrogen-A-future-fuel-for-aviation.html

[160] Utilities Consumer Advocate. *Electricity & Natural Gas*. [Online], Available: https://ucahelps.alberta.ca/default.aspx (Accessed 2022)

[161] Gas Alberta Inc, *Website*, **2022**, [Online], Available: https://www.gasalberta.com/

[162] AESO. *Hourly Load by Area and by Region 2017-2020*. [Online], Available: https://www.aeso.ca/market/market-and-system-reporting/data-requests/hourly-load-by-area-and-region/

[163] AESO. *Hourly Load by Area and by Region 2020-2022*. [Online], Available: https://www.aeso.ca/market/market-and-system-reporting/data-requests/hourly-load-by-area-and-region/

[164] AESO. *Hourly Metered Volumes and Pool Price and AIL Data 2010 to 2022*. **2022**, [Online], Available: https://www.aeso.ca/market/market-and-system-reporting/data-requests/hourly-metered-volumes-and-pool-price-and-ail-data-2010-to-2022/

[165] Government of Alberta, *Renewable Electricity Program*, **2021**, [Online], Available: https://www.alberta.ca/renewable-electricity-program.aspx

[166] AESO. *Market Statistics*. **2022**, [Online], Available: https://public.tableau.com/app/profile/market.analytics/viz/AnnualStatistics_16161854228350/Introduction

[167] AESO. *Connection Project List Details*. **2022**, [Online], Available: https://www.aeso.ca/grid/projects/connection-project-reporting/

[168] AESO. *Needs Identification Document for Central East Transfer-out Transmission Development*. **12-Aug 2020**, [Online], Available: https://www.aeso.ca/assets/Uploads/AESO-CETO-NID.pdf

[169] AESO. *Transmission planning areas*. **26-Nov 2021**, [Online], Available: https://www.aeso.ca/assets/Uploads/PlanningRegions-Nov26-PRINT.pdf

[170] AESO. *2021 Long-term Transmission Plan*. **Jan 2021**, [Online], Available: https://www.aeso.ca/grid/long-term-transmission-plan/

[171] AESO. *2021 Long-term Outlook*. **Jun 2021**, [Online], Available: https://www.aeso.ca/assets/Uploads/grid/lto/2021-Long-term-Outlook.pdf

[172] Alberta Utilities Commission. *Reports*. [Online], Available: https://www.auc.ab.ca/reports/ (Accessed 2022)

[173] Government of Canada. *Businesses – Canadian Industry Statistics*. [Online], Available: https://strategis.ic.gc.ca/app/scr/app/cis/businesses-entreprises (Accessed 2022)

[174] Alberta Energy Regulator. *ST3: Alberta Energy Resource Industries Monthly Statistics*. [Online], Available: https://www.aer.ca/providing-information/data-and-reports/statistical-reports/st3

[175] Alberta Energy Regulator. *Natural Gas Data*. **2018**, [Online], Available: http://www1.aer.ca/st98/data/reserves/ST98-2018_NaturalGas_Reserves.xlsx

[176] Alberta Energy Regulator. *ST98: Alberta Energy Outlook: Reserves*. [Online], Available: https://www.aer.ca/providing-information/data-and-reports/statistical-reports/st98/reserves (Accessed 2022)

[177] Alberta Energy Regulator, Alberta Energy Outlook: Executive Summary 2021, 2021, [Online}, Available: https://static.aer.ca/prd/documents/sts/ST98/2021/st98-2021-executivesummary.pdf

[178] Sjödin, A. and Ekberg, E., *Hydrogen – The future fuel for construction equipment?* **04-Jun 2020**, [Online], Available: http://www.diva-portal.org/smash/get/diva2:1440721/FULLTEXT01.pdf

[179] Moreda, G.P., Muñoz-García, M.A., Barreiro, P. *High voltage electrification of tractor and agricultural machinery – A review*. **07-Feb 2016**, [Online], Available: https://doi.org/10.1016/j.enconman.2016.02.018

[180] Phillips, C. and Leachman, J. *The hydrogen fueled farm of the future*. **08-Apr 2021**, [Online], Available: https://hydrogen.wsu.edu/2021/08/04/the-hydrogen-fueled-farm-of-the-future/

[181] Baur, D., Emmerich, P., Baumann, M.J., Well, M. *Assessing the social acceptance of key technologies for the German energy transition*. **2022**, [Online], Available: https://doi.org/10.1186/s13705-021-00329-x

[182] Hyacinth Project. *Hydrogen Acceptance in the Transition Phase*. **May 2017**, [Online], Available: https://hyacinthproject.eu/results/presentations/

[183] Graphene-info. *Graphene-Info's top 10 graphene applications of 2021*. **30-Dec 2021**, Available: https://www.graphene-info.com/graphene-infos-top-10-graphene-applications-2021

[184] Government of Alberta, *Environmental Quality Guidelines for Alberta Surface Waters,* **28-Mar 2018,** [Online], Available: https://open.alberta.ca/publications/9781460138731

[185] Government of Alberta. *Carbon capture, utilization and storage – Overview*. [Online], https://www.alberta.ca/carbon-capture-utilization-and-storage-overview.aspx (Accessed 2022)

[186] Government of Alberta. *Carbon capture and storage (CCS) factsheet*. [Online], Available: https://open.alberta.ca/publications/carbon-capture-and-storage (Accessed 2022)

[187] Government of Canada. *CO2 Capture, Utilization and Storage (CCUS)*. [Online], Available: https://www.nrcan.gc.ca/energy/offices-labs/canmet/ottawa-research-centre/co2-capture-utilization-and-storage-ccus/23320 (Accessed 2021)

[188] AFRY & Gaffney Cline. *CCUS deployment challenges and opportunities for the GCC*. **Jan 2022**, [Online], Available: https://www.ogci.com/portfolio/ccus-deployment-challenges-and-opportunities-for-the-gcc/

[189] University of North Dakota Energy & Environmental Research Center, *PCOR Partnership Atlas*. 6th Edition. **2021**, [Online], Available: https://undeerc.org/PCOR/Resources.aspx

[190] Gorecki, C.D., *Plains CO2 Reduction Partnership (PCOR) Phase III Final Report*, **Dec 2019**, [Online], Available: https://www.osti.gov/biblio/1580755

[191] International CCS Knowledge Centre, *Website – BD3 CCS Facility*, **2022**, [Online], Available: https://ccsknowledge.com/bd3-ccs-facility

[192] Whitecap Resources Inc., *Website – Sustainability, CO2 Sequestration*, **2022**, [Online], Available: https://www.wcap.ca/sustainability/co2-sequestration

[193] Cardinal Energy Ltd., *Website – Sustainability*, **2022**, [Online], Available: https://cardinalenergy.ca/sustainability/sustainability-overview/

[194] Peck, W.D., Liu, G., Klenner, R.C.L., Grove, M.M., Gorecki, C.D., Steadman, E.N., and Harju, J.A. *Storage capacity and regional implications for large-scale storage in the basal Cambrian system: Plains CO2 Reduction (PCOR) Partnership Phase III Task 16 Deliverable D92 for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FC26-05NT42592*. EERC Publication 2014-EERC-05-12, Grand Forks, North Dakota, Energy & Environmental Research Center. **Mar 2014**, [Online], Available: https://edx.netl.doe.gov/dataset/storage-capacity-and-regional-implications-for-large-scale-storage-in-the-basal-cambrian-system

[195] Energy & Environmental Research Center, University of North Dakota. *Basal Cambrian - GIS raster layers*. **2018**, https://edx.netl.doe.gov/dataset/basal-cambrian-gis-raster-layers

[196] Energy & Environmental Research Center, University of North Dakota. *Basal Cambrian boundary GIS*. **2018**, https://edx.netl.doe.gov/dataset/basal-cambrian-boundary-gis

[197] Weides, S. Moeck, I. Majorowicz, J. Grobe, M. *The Cambrian Basal Sandstone Unit in central Alberta – an investigation of temperature distribution, petrography and hydraulic and geomechanical properties of a deep saline aquifer*, **Jul 2014**, [Online], Available: https://www.researchgate.net/publication/263965388

[198] Government of Alberta. *Quest Carbon Capture and Storage Project: Annual Report 2011*. **Mar-2012**, [Online], Available: https://open.alberta.ca/publications/quest-carbon-capture-and-storage-project-report-2011

[199] Alberta Department of Energy, *Quest Carbon Capture and Storage Project: Annual Summary Report 2020*, **Aug 2021**, [online], Available: https://open.alberta.ca/publications/quest-carbon-capture-and-storage-project-annual-report-2020

[200] Wolf Midstream, *Website – Carbon*, **2021**, [Online], Available: https://wolfmidstream.com/carbon/

[201] Enhance Energy, *Website – ACTL*, **2022,** [Online], Available: https://enhanceenergy.com/actl/

[202] North West Redwater Partnership. *Refinery Units / Sturgeon Refinery*. [Online], Available: https://nwrsturgeonrefinery.com/project/technologies/

[203] Enhance Energy Inc. and North West Redwater Partnership. *Alberta Carbon Trunk Line Knowledge Sharing Report: Appendices i-viii*. **Mar. 2019,** [Online], Available: https://open.alberta.ca/dataset/e61e2157-9260-4fc4-b5fd-e206de00f7b5/resource/0e8724c8-f3d5-49d2-9a00-868567a45935/download/apps-i-viii-2018.pdf

[204] Enhance Energy, *Fact Sheet, Low-Carbon Oil: A New Concept Using Proven Technology*, [Online], Available: https://enhanceenergy.com/about-the-carbon/ (Accessed 2022)

[205] Alberta Economic Development Authority, *Enhanced Oil Recovery (EOR) through Carbon Capture and Storage (CCS) – An Opportunity for Alberta*, **Jan 2009**, [Online], Available: https://open.alberta.ca/dataset/d1cd3d1b-ec50-4c43-ab0c-32b0f2d780b5/resource/f58c2967-b2de-42fa-9c19-83975ed3b3d2/download/enhanced-oil-recovery-carbon-capture-storage.pdf

[206] Godec, M. *Role of CO2 EOR for Carbon Management*, **24-Jan 2020**, [Online], Available: https://usea.org/sites/default/files/event-/Mike%20Godec%20-%20JAF2020_004%20Godec%20USEA%202020%20EOR%20101.pdf#:~:text=Role%20of%20CO%202EOR%20for%20Carbon%20Management%20The,Dome%2C%20etc.%29%20established%20the%20foundation%20for%20the%20CO

[207] AESO. *Energy Storage Roadmap*. **Aug 2019**, [Online], Available: https://www.aeso.ca/grid/grid-related-initiatives/energy-storage/

[208] Global Solar Atlas. Information obtained from: *Global Solar Atlas 2.0*, a free, web-based application developed and operated by the company Solargis s.r.o., on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info

[209] Global Wind Atlas. Information obtained from: *Global Wind Atlas 3.0*, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

[210] Government of Alberta, *Prevailing Wind Direction*. [Online], Available: https://acis.alberta.ca/wind-rose.jsp (Accessed 2022)

[211] AESO. *Technology Forward Report 2021*. **Nov 2021**, [Online], Available: https://www.aeso.ca/assets/Technology-Forward_Report-2021-Nov30.pdf

[212] AESO. *2021 Annual Market Stats Final*. **Mar 2022**, [Online], Available: https://www.aeso.ca/market/market-and-system-reporting/annual-market-statistic-reports/

[213] AESO. *2020 Annual Market Stats Final*. **Mar 2021**, [Online], Available: https://www.aeso.ca/market/market-and-system-reporting/annual-market-statistic-reports/

[214] AESO. *2019 Transmission Capability Assessment for Renewables Integration*. **Mar 2019**, [Online], Available: https://www.aeso.ca/assets/Uploads/2019-Transmission-Capability-Assessment-Final-18Apr2019.pdf

[215] Bowen, T., Chernyakhovskiy, I., Denholm, P. *Grid-Scale Battery Storage*. National Renewable Energy Laboratory. **Sep 2019**, [Online], Available: https://www.nrel.gov/docs/fy19osti/74426.pdf

[216] GPA Engineering Pty Ltd. *Final Report - Pipelines vs Powerlines - A Technoeconomic Analysis in the Australian Context*. **2022**, [Online], Available: https://www.apga.org.au/sites/default/files/uploaded-content/field_f_content_file/pipelines_vs_powerlines_-_a_technoeconomic_analysis_in_the_australian_context.pdf

[217] Khan, M.A., Young, C., Layzell, D.B. *The Techno-Economics of Hydrogen Pipelines: Technical Brief*. **Nov 2021**, [Online], Available: https://transitionaccelerator.ca/techbrief-techno-economics-hydrogenpipelines/

[218] Government of Alberta. *Export Alberta*. [Online], Available: https://export.alberta.ca/ (Accessed 2022)

[219] ACIL Allen Consulting for ARENA. *Opportunities for Australia from Hydrogen Exports*. **2018**, [Online], Available: https://arena.gov.au/knowledge-bank/opportunities-for-australia-from-hydrogen-exports/

[220] Zen and the Art of Clean Energy Solutions. *British Columbia Hydrogen Study*. **Jun 2019**, [Online], Available: https://www2.gov.bc.ca/assets/gov/government/ministries-organizations/zen-bcbn-hydrogen-study-final-v6.pdf

[221] ITM Power, Chiyoda Corp, Mitsui & Co., G&S Budd Consulting. *Centralized renewable hydrogen production in B.C.* **2020**, [Online], Available: https://www2.gov.bc.ca/assets/gov/business/natural-resource-industries/reports/centralised_renewable_hydrogen_production_in_bc_final_report.pdf

[222] Malanima, P. *World Energy Consumption, A Database 1820-2018 (2020 revision)*. **2020**, [Online], Available: https://histecon.fas.harvard.edu/energyhistory/DATABASE%20World%20Energy%20Consumption.pdf

[223] Yaku, F. Nikkei Asia, *Itochu's 'blue' ammonia from Canada to power Japan's green future*, **03-Aug 2021**, [Online], Available: https://asia.nikkei.com/Business/Energy/Itochu-s-blue-ammonia-from-Canada-to-power-Japan-s-green-future

[224] Itochu Corporation, *Press Release – ITOCHU Announces Project to Manufacture and Sell Blue Ammonia and Blue Methanol in Canada, Aiming to Realize a Decarbonized Society,* **24-May 2022**, [Online], Available: https://www.itochu.co.jp/en/news/press/2022/220524.html

[225] Mitsubishi Corporation, Press Release – *Mitsubishi Corporation and Shell sign MoU to collaborate on hydrogen plans in Alberta*, **08-Sep 2021**, [Online], Available: https://www.mitsubishicorp.com/jp/en/pr/archive/2021/html/0000047710.html

[226] Okunlola, A., Giwa, T., Di Lullo, G., Davis, M., Gemechu, E., Kumar, A. *Techno-economic assessment of low-carbon hydrogen export from Western Canada to Eastern Canada, the USA, the Asia-Pacific, and Europe*. **03-Dec 2021**, [Online], Available: https://doi.org/10.1016/j.ijhydene.2021.12.025

[227] Department for Business, Energy & Industrial Strategy. *Hy4Heat*. [Online], Available: https://www.hy4heat.info/about-us

[228] Emissions Reduction Alberta. *ATCO project blends hydrogen with natural gas to reduce emissions*. [Online], Available: https://eralberta.ca/story/atco-project-blends-hydrogen-with-natural-gas-to-reduce-emissions/

[229] Alberta Utilities Commission, Bulletin 2022-05, 25-Mar, 2022, [Online], Available: https://media.www.auc.ab.ca/prd-wp-uploads/News/2022/Bulletin%202022-05.pdf

[230] CSA Group. *CSA Communities – Hydrogen*. [Online], Available: https://community.csagroup.org/ (Accessed 2022)

[231] Hydra Energy. *Website*, **2022**, [Online], Available: https://hydraenergy.com/

[232] ULEMCo Ltd. *Website*, **2022**, [Online], Available: https://ulemco.com/

[233] University of Alberta. *Bob Koch: Main page*. [Online], Available: https://sites.ualberta.ca/~ckoch/

[234] Kalyanaraman, M. *Tug project leads the way for 1 MW+ hydrogen-burning engines*. DNV GL. **Nov-2019,** [Online], Available: https://www.rivieramm.com/news-content-hub/news-content-hub/tug-project-leads-the-way-for-hydrogen-burning-mw-engines-56680

[235] Yanmar Holdings Co. Ltd. *Yanmar Develops Hydrogen Fuel Cell System for Maritime Applications | 2020 | News | YANMAR*. **04-Jun-2020**, [Online], Available: https://www.yanmar.com/global/news/2020/06/04/75041.html

[236] IEPS Canada, *Kitsim Hydrogen (H_2) Project Overview*, **2021**, [Online] Available: https://ieps.ca/kitsim-hydrogen-h2-project-overview/

[237] Rockpoint Gas Storage, *Press Release – Rockpoint Gas Storage Canada Ltd. Partners with Plug, Certarus and FortisBC in first of its kind Hydrogen Storage Transaction,* **05-May 2022**, [Online], Available: https://www.prnewswire.com/news-releases/rockpoint-gas-storage-canada-ltd-partners-with-plug-certarus-and-fortisbc-in-first-of-its-kind-hydrogen-storage-transaction-301539711.html

[238] Gallant, C. *Carbon Capture plan starting to take shape,* **03-Dec, 2021**, [online], Available: https://medicinehatnews.com/news/local-news/2021/12/03/carbon-capture-plan-starting-to-take-shape/

[239] City of Medicine Hat, *City accepting proposals for Carbon Capture project for the Power Generation Plan*, **07-Feb, 2022**, [online], Available: https://www.medicinehat.ca/en/news/city-accepting-proposals-for-carbon-capture-project-for-the-power-generation-plan.aspx

[240] Canadian Energy Systems Analysis Research, *$15-million project to test hydrogen fuel in Alberta's freight transportation sector*, **03-Dec 2019**, [Online], Available: https://www.cesarnet.ca/blog/15-million-project-test-hydrogen-fuel-alberta-s-freight-transportation-sector

[241] ATCO, *ATCO Group to Contstruct Two Hydrogen Production & Fueling Stations in Alberta for Canadian Pacific's Hydrogen Locomotive Program*, **04-May 2022**, [Online], Available: https://www.atco.com/en-ca/about-us/news/2022/122954-atco-group-to-construct-two-hydrogen-production-fuelling-station.html

[242] Luczak, M. Railway Age, *First Look: CP's Hydrogen Zero Emissions Locomotive*, **05-Oct 2021**, [Online], Available: https://www.railwayage.com/news/first-look-cps-h20el/

[243] Emissions Reduction Alberta, *Website*, **2022**, [Online], Available: https://www.eralberta.ca/

[244] Emissions Reduction Alberta. *Technology Roadmap*. **Dec 2019**, [Online], Available: https://www.eralberta.ca/about-era/technology-roadmap/

[245] Government of Alberta. *Alberta Petrochemicals Incentive Program*. **28-Oct 2020**, Available: https://www.alberta.ca/alberta-petrochemicals-incentive-program.aspx

[246] Alberta Innovates, *Website*, **2022**, [Online], Available: https://albertainnovates.ca/

[247] Government of Canada, *Prairies Economic Development Canada,* **2022,** [Online], Available: https://www.canada.ca/en/prairies-economic-development.html

[248] Government of Canada, *Climate change funding programs*, **2022**, [Online], Available: https://www.canada.ca/en/services/environment/weather/climatechange/funding-programs.html

[249] Canada Infrastructure Bank, Website, 2022, [Online], Available: https://cib-bic.ca/en/

[250] Government of Canada, IRAP: *Support for technology innovation*, **2022,** [Online], Available: https://nrc.canada.ca/en/support-technology-innovation

[251] Government of Canada, *Natural Resources Canada, Funding, Grants and Incentives*, **2022,** [Online], Available: https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/funding-grants-incentives/4943

[252] Transport Canada. *Incentives for Medium- and Heavy-duty Zero Emissions Vehicles Program (iMHZEV)*. **26-Apr 2022**

[253] Transport Canada, *Minister of Transport announces the expansion of the Incentives for Zero-Emission Vehicles Program*, **22-Apr 2022**, [Online], Available: https://www.canada.ca/en/transport-canada/news/2022/04/minister-of-transport-announces-the-expansion-of-the-incentives-for-zero-emission-vehicles-program.html

[254] Government of Canada, *Transport Canada, Zero-emission vehicles*, **2022**, [Online], Available: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles

[255] Government of Canada, *Scientific Research and Experimental Development (SR&ED) tax incentives,* **2022**, [Online], Available: https://www.canada.ca/en/revenue-agency/services/scientific-research-experimental-development-tax-incentive-program.html

[256] Government of Canada, *Strategic Innovation Fund,* **2022**, [Online], Available: https://www.ic.gc.ca/eic/site/125.nsf/eng/home

[257] Sustainable Development Technology Canada, *Website*, **2022**, [Online], Available: https://www.sdtc.ca/en/

[258] Foresight Canada, *Website*, **2022**, [Online], Available: https://foresightcac.com/

[259] Government of Alberta. *First Nation Reserves and Metis Settlements map*. **08-Apr 2021**, [Online], Available: https://www.alberta.ca/map-of-first-nations-reserves-and-metis-settlements.aspx

[260] Alberta Teacher's Association. *Acknowledging Land and People*. **2019**, [Online], Available: https://www.teachers.ab.ca/SiteCollectionDocuments/ATA/For%20Members/ProfessionalDevelopment/Walking%20Together/PD-WT-17c-TreatyMap.pdf

[261] Government of Canada. *Canadian Forces Base, Suffield*. [Online], Available: https://www.canada.ca/en/army/corporate/3-canadian-division/canadian-forces-base-suffield.html (Accessed 2022)

[262] Government of Canada. *Defence Research and Development Canada*. [Online], Available: https://www.canada.ca/en/defence-research-development.html (Accessed 2022)

[263] Government of Canada. *IDEaS – Innovation for Defence Excellence and Security* [Online], Available: https://www.canada.ca/en/department-national-defence/programs/defence-ideas.html (Accessed 2022)

[264] Government of Canada. IDEaS – Innovation for Defence Excellence and Security: Annual Report 2019-2020 **2020**, [Online], Available: https://www.canada.ca/en/department-national-defence/corporate/reports-publications/ideas-2019-2020-annual-report.html (Accessed 2022)

[265] Government of Canada. National Defence, Canadian Armed Forces. *Defence Energy and Environment Strategy 2020-2023*. **2020**, [Online], Available: https://www.canada.ca/en/department-national-defence/corporate/reports-publications/dees.html

[266] Government of Canada, National Defence, Canadian Armed Forces. *Defence Energy and Environment Strategy*. **2017**, [Online], Available: https://www.canada.ca/content/dam/dnd-mdn/documents/reports/2017/20171004-dees-en.pdf

[267] Government of Alberta. *Wildlife Sensitivity Maps*. [Online], Available: https://www.alberta.ca/wildlife-sensitivity-maps.aspx (Accessed 2022)

[268] Government of Alberta, Watershed Planning and Advisory Councils, 2022, [Online], Available: https://www.alberta.ca/watershed-planning-and-advisory-councils.aspx#:~:text=Overview%20Watershed%20Planning%20and%20Advisory%20Councils%20%28WPACs%29%20are,collaborative%20planning%2C%20and%20facilitate%20education%20and%20stewardship%20activities.

[269] Supple, D. *Units & Conversions Fact Sheet*. Massachusetts Institute of Technology. [Online], Available: http://web.mit.edu/mit_energy (Accessed 2022)

[270] The Engineering Toolbox, **2022**, [Online], Available: https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html

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