Helium Liquefaction in Saskatchewan

Prepared for Saskatchewan Ministry of Energy and Resources

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Abstract:

A review and assessment of critical information pertinent to the helium landscape in Saskatchewan to support selection of a specific path forward. Logistical, environmental, and geographical aspects of helium liquefaction in Saskatchewan were reviewed.

Executive Summary

Producing 10% of the world demand for helium by 2030 will require new infrastructure in the form of helium production wells, crude helium transport, and purification/liquefaction facilities. A helium liquefaction plant could be instrumental in adding value to the provincial helium industry. Effective transportation and processing options will need to be selected based on the characteristics of the resource and of the technologies commercially available.

A survey of stakeholders (industry, local leadership groups, technology providers and liquid helium users) yielded positive responses to the prospect of helium liquefaction in Saskatchewan. In general, the group was interested in being involved in a project. One survey respondent expressed concern regarding the complexity of environmental approval processes. A detailed environmental roadmap (focusing on the area in Saskatchewan known as "south of the divide") was commissioned and is summarized in this report.

The capacity and location of liquefaction facilities will be greatly influenced by the potential location and volume of local helium production. Data was gathered related to the potential helium resources in Saskatchewan, Alberta, and Montana. Saskatchewan is centrally located and so, to further narrow siting options, Saskatchewan electrical, road and rail information was summarized.

Available information was compiled in order to complete an economic assessment of helium liquefaction in Saskatchewan. Liquefaction facility capital costs were calculated using engineering estimation techniques. Several scenarios were investigated, and all returned a positive net present value after 20 years at 15% discount rate. Pay-back periods varied between 5-13 years depending on the scenario analyzed. Details pertaining to the economic analysis can be found in Section 8 of this report.

The economic return of a large-scale facility was more attractive than that of the two smaller facilities, but the stage-gated approach of building two plants (or two trains in a single facility) at different times has several other advantages. Capital costs were dominated by the cost of the compressors, and operating costs were affected by both the cost of helium and the cost of electricity. A sensitivity analysis of the cash flows indicated that helium price and operating expenses were two of the largest sources of variability in the analysis and should be investigated with care before making any decisions.

Helium is a critical mineral, considered "critical for the sustainable economic success of Canada" The supply of helium is constrained, with the importance of the US strategic reserve and production to global helium supply lessening. Currently the largest helium producers in the world are Qatar, Algeria, and Russia. Helium was discovered in southern Saskatchewan as early as the 1940s, with production on and off since 1963. Liquifying helium can allow it to be transported longer distances economically, which could potentially provide access to larger markets world-wide. A Saskatchewan liquefaction hub could open broader helium markets, create jobs, and provide a positive financial return for its owners. Some risks remain; in particular, the full extent of recoverable reserves, the final cost of a liquefaction facility, and the price of liquid helium in the future should be investigated in more detail. Overall, a helium liquefaction facility is a promising opportunity for the Province of Saskatchewan that bears further scrutiny.

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1. INTRODUCTION

1.1 Background

Helium is included on the Government of Canada's list of critical minerals as "critical for the sustainable economic success of Canada".[1] The Government of Saskatchewan's 2020-30 Growth Plan[2] is committed to supporting the development of the Saskatchewan helium industry. In November 2021, the Government of Saskatchewan released the Helium Action Plan: From Exploration to Exports (HAP). The HAP "…has a vision of securing 10 per cent global market share in the helium sector, by 2030." Producing 10% of the world demand for helium will require new infrastructure in the form of helium production wells, crude helium transport, and purification/liquefaction facilities. SRC has been asked to provide a scope of work to support these goals.

Significant infrastructure for transportation and liquefaction will be required to produce large volumes of helium in the province. Effective transportation and processing options will need to be selected based on the characteristics of the resource and of the technologies commercially available. SRC has developed the work scope described here to provide a review and assessment of critical information pertinent to the helium landscape in Saskatchewan to support selection of a path forward.

A review of the processing technology will allow for a preliminary system design and a rough estimate of capital costs, and operating costs. A high-level assessment of the economics of Saskatchewan helium production will be used to highlight the options for a liquefaction facility/hub implementation and for industrial development supported by government.

1.2 Historical

The presence of helium was discovered during hydrocarbon exploration in southwest Saskatchewan, southeastern Alberta, and northern Montana beginning in the 1940's. Helium gas deposits are trapped in reservoirs under the same conditions that apply to hydrocarbons. However, the "carrier gas" for the helium in this area is unique when compared to other reserves throughout the world. In this instance the make-up of the gas is comprised mostly of nitrogen (e.g., > 95%) rather than methane and carbon dioxide gas. Figure 1 displays the areal extent of the exploration effort relative to the known basins of western North America.

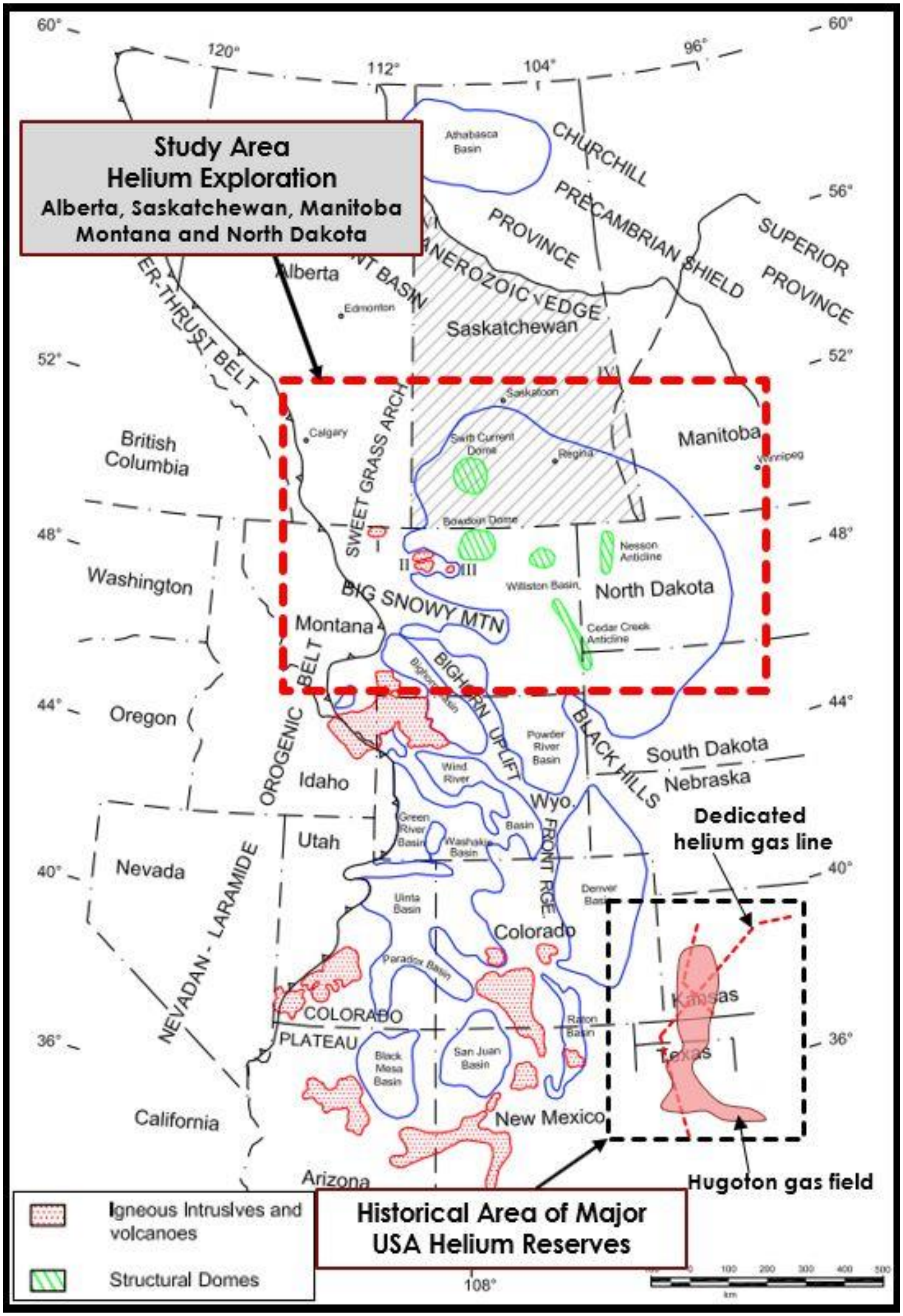


Figure 1 Study Area Relative to Basins in Western North America (Excerpt)[3]

Helium production in Saskatchewan began in 1963 when a facility owned and operated by Canadian Helium Ltd (a joint venture of British Oxygen Company and Air Liquide) was commissioned. The nitrogen-rich gas from the B.A. Wilhelm 1-9 well (drilled in 1958, northwest of Swift Current at 01-09-017-14 W3) contained 1.9% helium. The facility operated for 14 years until 1977. Well production was about 12 million cubic feet (mmscf) per year.

In 1914 the British government funded an investigation at the University of Toronto to identify sources of helium within the British empire, as well as to conceive of a purification process. There was concern that airships could be critical to war effort. Ontario natural gas reservoirs with 0.1 to 0.33% helium were found and Air Liquide was contracted to build a processing plant (a modified air separation plant design) in Hamilton. This became the world's first functional helium production plant - but it was not without problems. In 1918 helium was produced and 87% helium content was eventually achieved. By the time this achievement was reached, the Ontario fields were nearly depleted, and the plant was moved to Alberta to operate on Bow Island Field gas.

In 1917 the United States also became interested in helium for airships and the Norton-Jeffries Corporation was approached to design and build an extraction plant to run on Texan “Petrolia” gas. The path of helium production in the USA is complicated from this point, as Norton-Jeffries funding was cancelled at the same time funding was approved for Linde and Air Reduction Companies. The US National Research Council would eventually see to the restoration of funding to Norton-Jeffries.

In March 1918 Linde commissioned a five thousand cubic foot (mscf) per day plant in Fort Worth operating with the Joule-Thompson process. Helium purity of 70% was achieved but could be ultimately upgraded to 92% via reprocessing. The high compression costs made this an expensive process.

The Air Reduction plant (similar in size to Linde plant) was commissioned two months later based on the Claude process. This process used an expander and was cheaper but could only achieve 70% helium. The production from this plant was eventually sent to Linde in Fort Worth for reprocessing to achieve 92% purity.

The Norton-Jeffries plant was started later that year in October and was six times the size of the other two plants. This design used three expanders and much lower operating costs were expected. After much additional investment this plant would only ever produce 20% helium.

Underground storage of “excess” helium was tested successfully between 1918 and 1920. The use of helium in deep sea diving expanded the demand for helium, starting in about 1925. By 1929 three additional helium plants were built in the USA (Dexter, KS, Thatcher, CO, and Amarillo, TX). Two American airship disasters reduced the interest in lighter-than-air flight, and consequently helium demand.

World War II showed renewed interest in helium and military blimp uses. After the war helium production continued and reservoir storage increased dramatically. A breakthrough in 1949 occurred when 99.95% helium purity was achieved using activated carbon. This resulted in increasing demand for electric-arc welding.

2. METHODOLOGY

The scope of this work was separated into three tasks:

Task 1 Industry Consultation

- Engage with stakeholders (production, process licensors, local government, First Nations, environmental) to determine the needs for advancing liquefaction in Saskatchewan. It was felt that production stakeholders have the necessary information to make decisions regarding wellhead/raw gas helium purification, and therefore this was not considered for this report.

Task 2 Data Gathering

A facility siting assessment requires information from diverse sources. Guided by previous discussions with stakeholders, the following data will be gathered/developed:

- helium resource
  - location of current/future/potential helium production
  - estimation of reserves, and production rate
  - estimation of wellhead composition (water, helium, carbon dioxide, nitrogen, methane)
- provincial infrastructure
  - electrical
  - roadway
  - rail
- environmental
  - permitting
  - species at risk
  - other issues specific to the area known as "south of divide"
  - south of divide refers to all or part of the following rural municipalities:
    - Val Marie (17), Lone Tree (18), Frontier (19), Old Post (43), Waverley (44), Mankota (45), Glen McPherson (46), White Valley (49), Reno (51), Auvergne (76), Wise Creek (77), Grassy Creek (78), Arlington (79), Piapot (110), Maple Creek (111)
- economic information regarding helium will be sparse. Best efforts will be used to provide data for helium or proxies for:
  - cost of tube trailer operation (capex/opex)
  - cost of rail transport
  - pipeline costs
  - liquefaction plant costs

    - local labour availability
- potential sources of project funding
- ownership models

Task 3 Review of Helium Liquefaction

The data previously gathered will form the basis of an analysis to determine promising liquefaction hub configurations and locations.

SRC will perform a high-level analysis of helium processing costs for several scenarios (e.g., producer spacing, and facility arrangement). The effect of scale on purification and liquefaction economics will be estimated. Economics will be discussed relative to factors such as helium price and Saskatchewan helium reserves. Areas where government support could potentially be effective will be identified.

Task 4 Reporting

SRC will provide a report which will include all the information gathered and analysis completed in the tasks described above.

3. Confidential Industry Consultation

3.1 Helium Producers Summary

The helium producers and potential helium producers contacted are listed below. Responses were received from five entities from this list.

Table 1 Industry Survey Respondents

Surveyed Helium Industry Stakeholders	
Canadian Helium Inc.	*Global Helium Corp.*
Green Helium Corp.	*Helium Evolution Inc.*
North American Helium Inc.	*Royal Helium Exploration Ltd*
Thor Resources Inc.	*Weil Group Canada, Ltd*

In general, the responses from this group indicated an interest in pursuing the assessment of helium liquefaction in Saskatchewan, as well as a willingness to invest. One response indicated a concern regarding perceived difficulties with permitting and funding.

3.2 Process Licensors

Helium liquefaction technology providers that were contacted are listed below. One response was received.

Table 2 Liquefaction Technology Survey Respondents

Surveyed Helium Technology Stakeholders	
Air Liquide Helium America, Inc.	*Air Products and Chemicals Inc.*
Linde Canada Inc./Praxair Canada Inc.	

The response received indicated a belief that the helium industry in Saskatchewan would likely support a liquefaction facility if a multi-user/co-operative structure could be established. The concerns raised were related to the level of government support for a project, co-operation between producers and a desire to reduce gaseous helium trucking emissions (via liquid trucking).

3.3 Local Stakeholders

Local leadership organizations that were contacted are listed below.

Table 3 Local Leadership Survey Respondents

Surveyed Local Leadership Stakeholders
Saskatchewan First Nations Natural Resource Centre of Excellence
City of Swift Current

All groups contacted indicated an eagerness to participate in economic development projects such as helium liquefaction.

3.4 Other Stakeholders

The University of Alberta expressed an interest in being involved in this survey based on difficulties they have had related to obtaining helium for the operation of their nuclear magnetic resonance instrument.

3.5 Survey Questions

Table 4 Survey #1 Questions

Survey #1			
Scope			
Comments on the scope of information provided			
General			
Name of organization			
Name of survey respondent			
Industry			
How soon does your organization expect to be producing crude helium?			
From what locations (list) will crude helium be primarily produced?			
LSD, Lat/Long, town, or RM	*Expected Production*	*Expected Purity (%He)*	*Main Impurities*
What are your organization's pre-liquefaction purification requirements?			
Is your organization interested in financial involvement in a prospective liquefier project?			
What ownership models are attractive to your organization?			
Is your organization evaluating a prospective liquefier project?			
What is your organization's primary interest in this liquefaction study?			
Is any information provided in this survey considered confidential?			

Survey #1
Licensors
Does your organization offer helium liquefaction plant design?
What standard helium liquefaction plant design capacities are offered?
What pre-liquefaction purification processes are available?
Are any pre-liquefaction purification processes required?
Are approximate capital, operating costs, labour requirements available for helium liquefaction available for your typical plant designs?
What are the utility requirements for the typical plant design? How critical is the electrical grid reliability and the cooling (water/air) temperatures?
Transport
Does your organization have experience with operation or design of helium transport systems? If so, how?
Can your organization share information related to the pipeline, tube trailer or liquid helium transport? (pressure, volume, capital costs, operating costs)
Local Leadership
Whom do you represent?
What is your interest in this study? (environmental stewardship, economic development, local labour opportunities, potential owner or operator, …)
Do you have any concerns regarding helium liquefaction facilities that this study could address?
Are there other groups that you think may be interested in this project? If so, who?

4. HELIUM RESOURCE

4.1 Key Sources

The importance of the US strategic reserve and production to global helium supply is lessening. Qatar has become the largest exporter and the second-largest producer of helium gas in the world. The Qatari North Dome gas field represents nearly 30% of the globe's helium reserves.

4.1.1 United States

The Strategic Reserve and Hugoton Field

Going forward, the strategic helium reserve and the Hugoton field will play a minimal role in global helium supply[4].

The Wyoming LaBarge Field

The LaBarge field could continue to supply substantial amounts of helium; however, the LaBarge gas is carbon dioxide (CO_2) rich/methane lean and depends on local CO_2 enhanced oil recovery projects. A significant portion of the total CO_2 is being vented, which could conceivably impact the future viability of helium production at this location.

Big Piney

Matheson and Air Products built this plant to process gas from LaBarge via the Riley Ridge, WY, processing plant (Denbury Inc.). Helium production was expected to be 200 mmcf/y. After technical issues, Denbury shut the plant and then wrote it off in 2016.

Doe Canyon

An Air Products plant design to produce helium and CO_2 for EOR. Lack of demand for CO_2 has meant that the plant was running below 50% capacity in 2019.

Dineh-Bi-Keyah

Production was expanded in 2019 to about 140 mmscf/y. Production is gaseous.

4.1.2 Worldwide

Qatar

Production volumes are unknown but have been estimated at about 51 million m^3 in 2021[5].

Russia

Production volumes are unknown but have been estimated at about 9 million m^3 in 2021[5]. Development of the Amur gas field will have Russia rival Qatar by about 2030, eventually producing up to 60 million m^3 per year.

Algeria

Helium production is tied to LNG exports – feed gas helium concentration is low (0.17%). Production was estimated to be about 14 million m^3 in 2021. Gas exports to Europe reduce LNG (and helium) production.

Poland

The only European helium producer, Poland supplied only about 1 million m^3 in 2021. Production is expected to decline.

4.1.3 Potential Sources

South Africa

High helium concentrations (2-4%) have been found in natural gas fields in South Africa. A lack of infrastructure for gas will hamper potential helium development.

Iran

Iran is presently developing its South Pars field. Timelines are uncertain, especially with respect to LNG production and potential helium recovery.

Tanzania

Traces of helium found in the gas from geothermal springs has led to drilling discoveries reported to be between 4 and 10% helium[6]. Reservoir quality and remoteness may be factors affecting development.

4.2 Study Area Geology

4.2.1 Introduction

SRC procured the services of geology consultant Larry Kovac to supply a high-level assessment of potential helium reserves. Recent helium exploration and development should begin with an examination of historical records (Figure 2) and the knowledge of structural features which provide trap mechanisms. Figure 3 displays the areal extent of the exploration effort relative to the known basins of western North America. The area for this study includes a major part of the Williston basin and extends westward to the Sweet Grass arch. Within the area major structural features such as the Swift Current Dome and Bowdoin Dome exist. Not surprisingly, this is where concentrations of helium greater than 0.3% have been recorded historically.

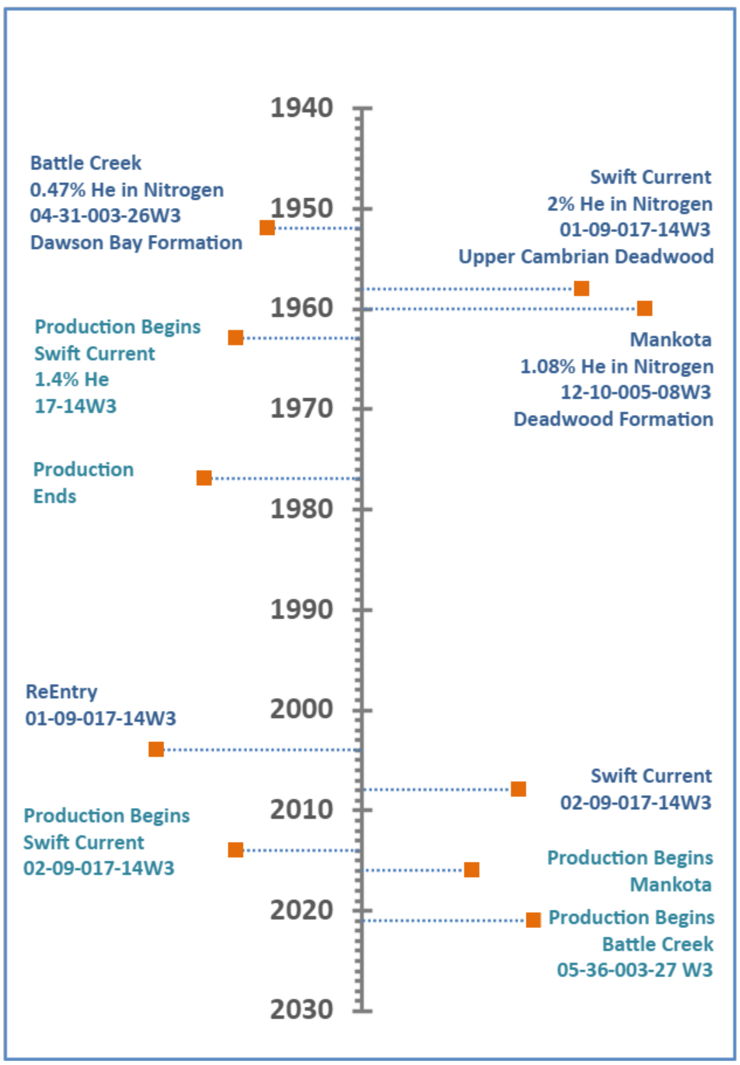


Figure 2 The History of Saskatchewan Helium Development

An important aspect for helium exploration in this area is provided in Figure 3, which displays a relevant view of the existing craton and tectonic elements. The variation in craton basement character (e.g., source rock for helium) and orogenic events (implying structural movement) shows the area to have good potential for the formation and build-up of helium reservoirs.

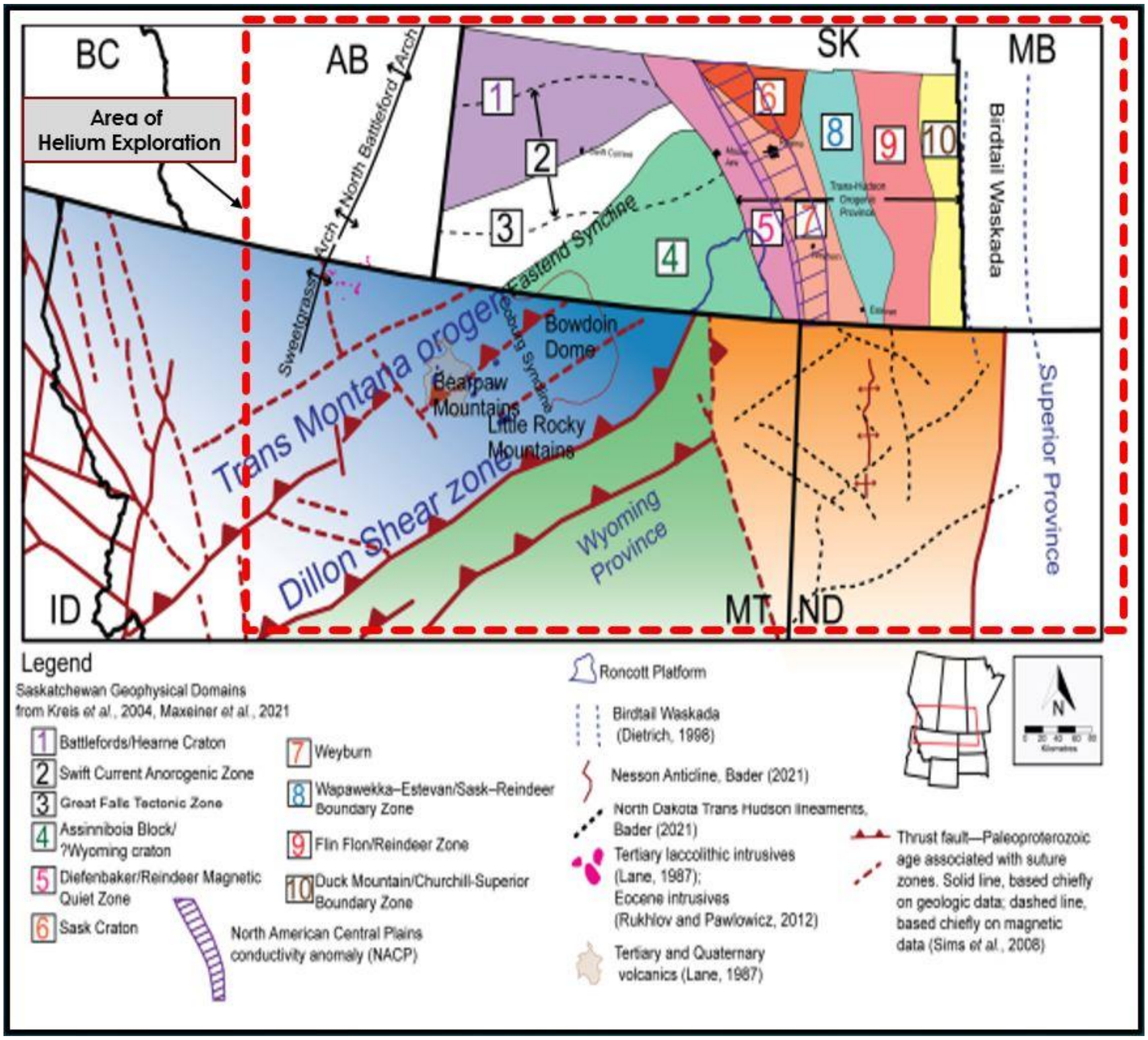


Figure 3 Craton and Tectonic Elements[7]

4.2.2 Geologic Setting

The primary targets for helium have been found in Paleozoic strata (Figure 4). The main producing horizon has been the sands that exist in the Cambrian Deadwood formation. Associated with the same stratigraphic level, a new zone has been recently drilled and tested for helium. It occurs below the Deadwood at the interface between the Deadwood and the underlying Precambrian basement. In some localities it exists as a thick sequence of igneous and metamorphic sediments and is often fractured yet characterized by low matrix permeabilities lending to the possibility of being a resource type reservoir for helium. Higher in the stratigraphic column helium has also been found in the Souris River (Beaverhill Lake) and the overlying Duperow carbonate formations. Both are comprised limestone and dolomite lithologies formed in marine shallow-water facies. These are usually capped by intervening evaporites that act as a caprock seal to a potential reservoir.

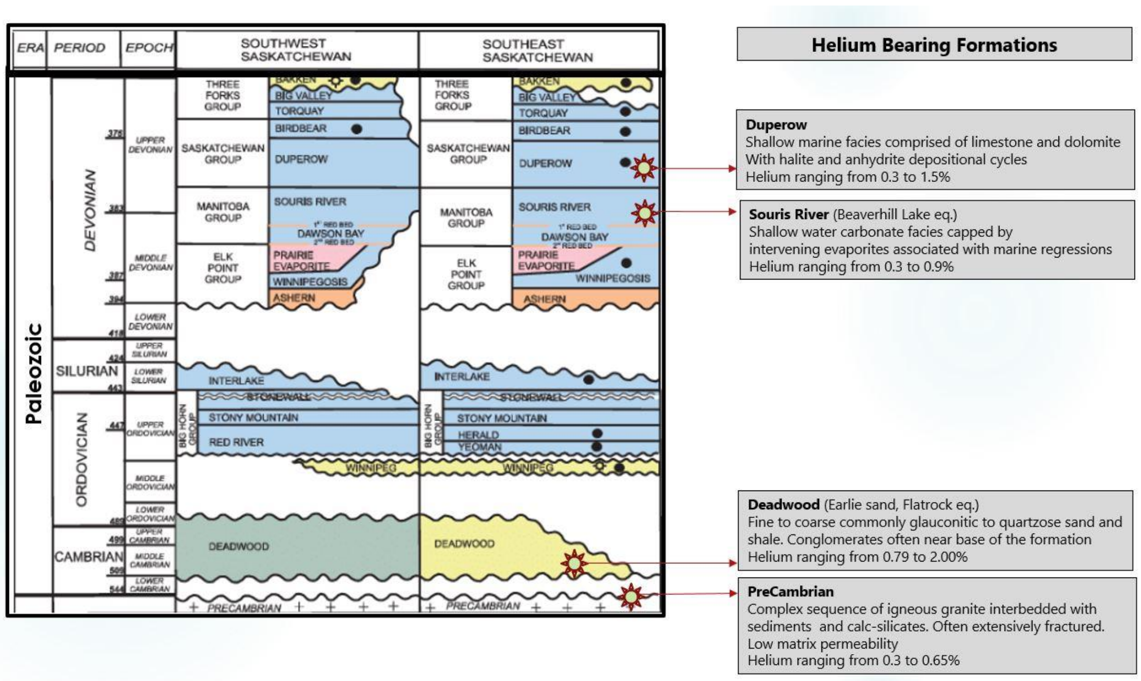


Figure 4 Stratigraphy – Paleozoic[8]

A detailed look at the Deadwood as the main producing formation is provided in Figure 5 where cross section A-A' spans roughly 30 kilometers in southwest Saskatchewan. Well logs are shown for three areas (Battle Creek, Swift Current – Wilhelm, Mankota) that were drilled over an eight-year time span (1952 to 1960). All three of the areas were originally targeted because of underlying structural features detected through 2D seismic programs. Hydrocarbons were not found at these locations, but helium was, and two locations, Swift Current (Wilhelm) and Mankota (Wood Mountain), were found to have helium concentrations sufficient for commercial production during that time period.

The average drill depth to the Deadwood formation ranges from 2000 to 2500 meters and recent drilling has gone further, to depths 100 meters deeper into the PreCambrian basement (source rock) itself. The gross thickness of the Deadwood can vary from 125 to 250 meters - the best reservoir quality occurring at the base as a conventional sandstone reservoir (e.g., conventional) that can be as thick 20 meters. These have been termed Earlie and Flatrock sands in some localities. The overlying shales are considered to be the caprock for the reservoir. In the Swift Current 1-9 well a much thinner Deadwood interval is found, due to the potential for deposition over a pre-existing PreCambrian basement erosional high (e.g., monadnock).

The Mankota area also has core information in addition to well logs that have been used to make reserves estimates for new field discoveries (Table 5).

Table 5 Mankota Resource Information

Pay	5 to 9 meters
Porosity	15 to 18%
Water saturation	30 to 35%
Recovery factor	75 to 80%

Areal extent has also been determined from historic field data and an average of 580 hectares - 1,440 acres (2.25 sections) can be used as a mean estimate. Gas concentrations and flow rate data are also shown and represent the same range that have been found in new field discoveries.

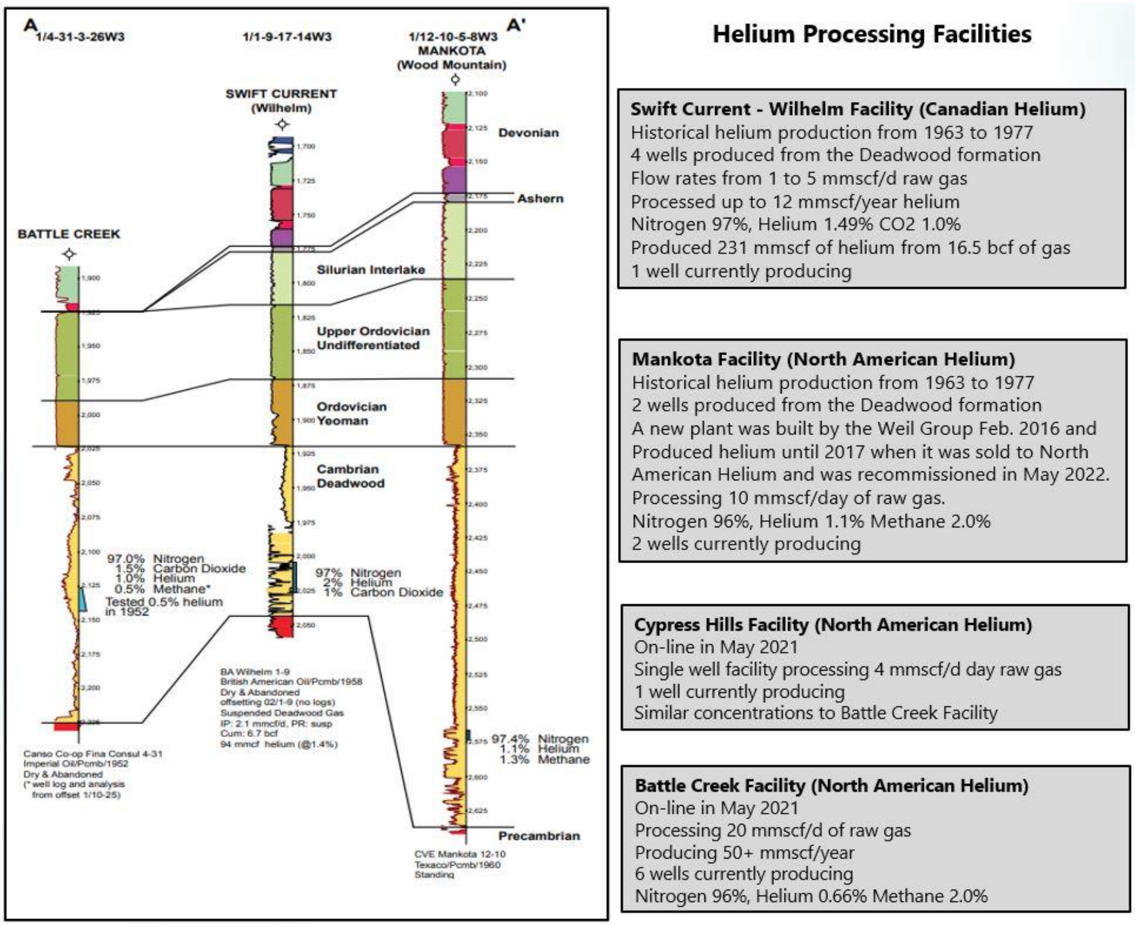


Figure 5 Cross-Section A-A', Southwest Saskatchewan[9]

4.2.3 Industry Activity

Activities by helium exploration and production companies in the study region are indicated in the area map shown in Figure 6. Triangle symbols represent locations where a prospect was tested for a potential new field discovery. Coloured circles represent the location and status of production facilities. The pink circles indicate a facility that is online and producing feed gas along with helium from a nearby field. A green symbol indicates the plant has been commissioned to be built and operation is pending.

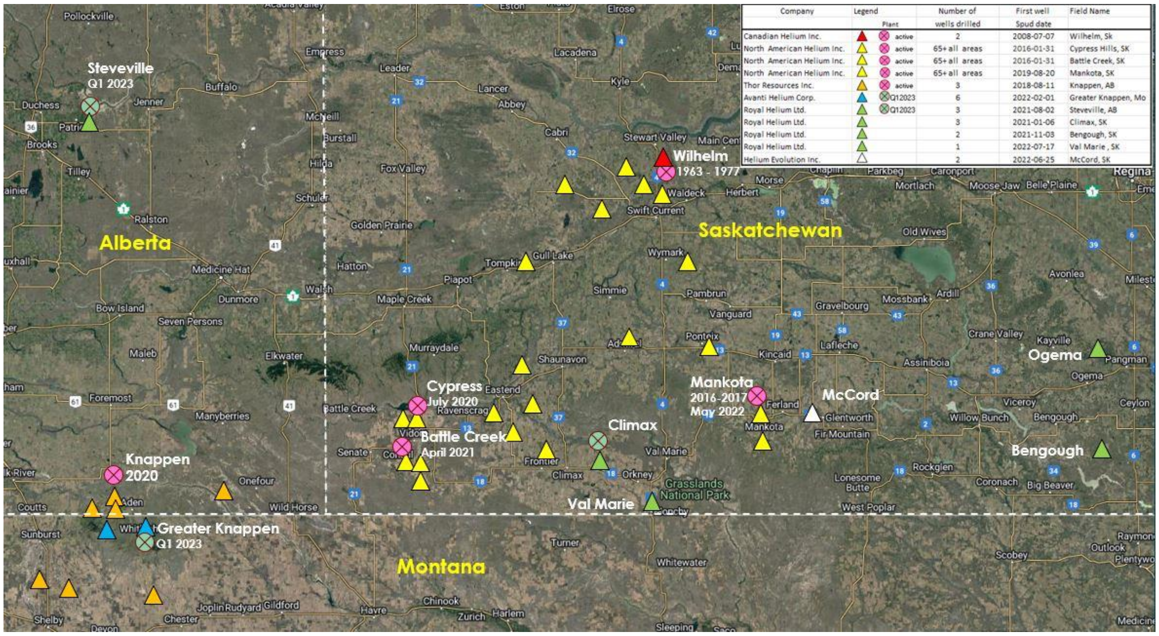


Figure 6 Industry Exploration Activity[10]

4.2.4 Cumulative Production to Date – Saskatchewan and Alberta

Cumulative production of helium in Saskatchewan, from historical data (e.g., 1960's) to the end of July 2022 is presented in Figure 7. The tally for helium production was made available from publicly available data collected by the Saskatchewan Energy and Resources (accessed via Petrinex) [11]. Excellent comprehensive information regarding the regional geology and reserves potential is also available from two recent government reports: Yurkowski Open File Report 2016-1[12] and Open File Report 2021-2[7].

Production for the month of July 2022 was approximately 216,000 m^3 of helium (7,600 mcf/month) from 11 producing wells. Yearly production would be 91 mmcf. At the time of compiling this report the number of producing wells has grown to 13 with projected annual production closer to 100 mmcf. From recent government and company information (e.g., well licenses and news releases) it is speculated that this production number could double again over the next 12 months (Q3 2023).

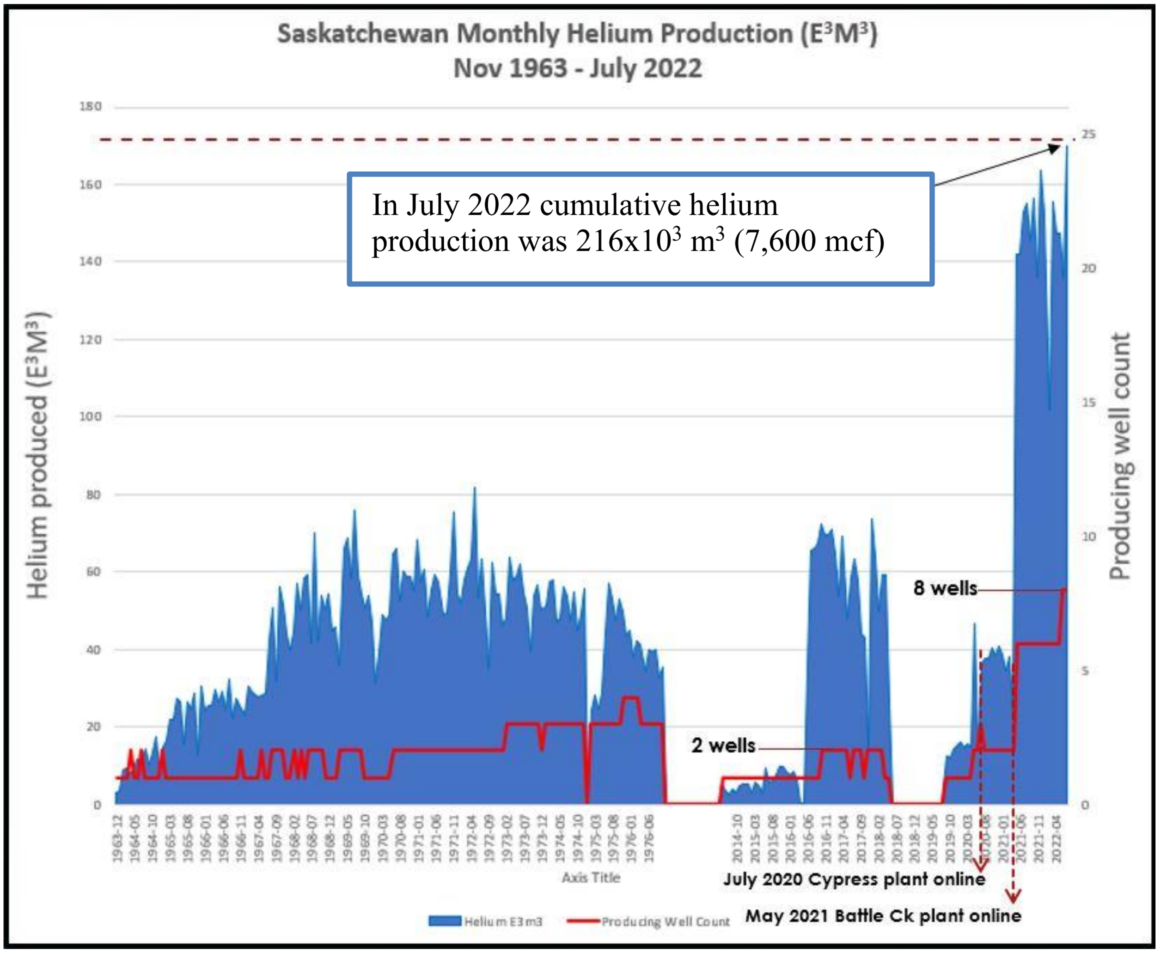


Figure 7 Monthly Helium Production, Southwest Saskatchewan

4.2.5 Reserve and Production Estimates

Publicly available information pertaining to reserves of gas found and helium production to date are summarized in Table 6 below. Table 7 contains an estimate of recoverable reserves based on the information in Table 6. Unfortunately, publicly available reserves estimates are extremely limited. Where confirmed reserve estimates were not available, current production was forecasted over 10 years based on the decline curve of the historic Mankota production wells. Information was only available for SK, AB, MT, and MO at this time. Table 7 predicts 3,128 mmscf of recoverable helium reserves, which is a conservative estimate. Ryder Scott Canada prepared a report in 2019 estimating 20 bcf of recoverable helium in the study area. If no other reserves are located, this amount of recoverable helium could be produced at a rate of 700 mmscf/y for between 4.5-28 years.

Table 6 Overview of Study-area Helium Production

Company	Location	Site	Plant type	Year online (Historic)	Producing Wells	Stand-by Wells	Plant capacity (mmcf/d)
Canadian Helium Ltd.							
	SK	Wilhelm	Multi-well	(1964-1977) July 2021	1		12
North American Helium							
	SK	Cypress Hills	Single-well	July 2020	1		8
	SK	Cypress West	Multi-well	Q4 2022		14	
	SK	Battle Creek	Multi-well	May 2021	6		20
	SK	Battle Creek				4	
(Formerly Weil Group Ltd.)	SK	Mankota	Multi-well	(Aug 2016)			10
	SK	Mankota West		May 2022	2	9	
	SK	Claydon	Multi-well	Q4 2022		6	
Royal Helium							
	AB	Steveville	Multi-well	Q1 2023		2	15
	SK	Climax 1	Multi-well	Q3 2023		2	
	SK	Climax 2	Single-well			1	
	SK	Val Marie	Single-well			1	
	SK	Bengough	Single-well	Q4 2023		1	
Thor Resources							
	AB	Knappen	Multi-well		2		6
	AB	Sapphire			1		
Avanti Helium							
	AB	Greater Knappen	Multi-well	Q1 2023		2	
	AB	Aden	Multi-well	2023		1	
	MT	Various					
	SK	Various					
Global Helium							
	MO	Rudyard	Multi-well	Q1 2023		1	

Table 7 Reserves Estimate

Site	Helium Produced to date (mmcf)	Estimated Helium Production (mmcf/y)	Estimated Recoverable Helium (mmcf)	He %	N2 %	Reserves Estimation Methodology
Wilhelm	231.5	35.7	357	1.78	96	Based on estimated 10-year plant
Cypress Hills		9	90	0.6	96	Ryder Scott 2019 – estimated 20 bcf recoverable Helium for all areas
Battle Creek		57	570	0.6	96	
Mankota	49.5	25	250	0.9	96	
Steveville		16.9	169	0.35-0.4	96	Based on estimated 10-year plant
Climax			1298	0.65	97	GLJ July 31, 2022, CPR (P50 unrisked)
Knappen		20	200	1.4	92.5	Based on estimated 10-year plant
Greater Knappen		18.7	187	1	98	McDaniels June 24, 2022
Rudyard		28.5	285	1.1		Based on estimated 10-year plant

4.3 Existing Helium Liquefaction Facilities

Available information on existing helium liquefaction facilities gas been provided below.

Table 8 Worldwide Helium Liquefaction Facilities

Country Location	Owner	Helium Source	Estimated Capacity mmscf/year
USA La Barge, WY	ExxonMobil	Natural gas	1610
USA Liberal, KS	Air Products and Chemicals	Natural gas	290
USA Cheyenne Wells, CO	Tumbleweed Midstream	Natural gas	520
USA Dolores County, CO	Air Products and Chemicals	CO_2 pipeline	190
USA Rush County, KS	Linde	Natural gas	Unknown
USA Cimarron County, OK	Midstream Energy Services	Natural gas	Unknown
USA Grant County, KS	Linde	Natural gas	210
Qatar Ras Laffan	RasGas, Qatar Gas	Liquefied natural gas plant	610
Qatar Ras Laffan	RasGas	Liquefied natural gas plant	1530
Algeria Skikda	Sonatrach, Linde	Liquefied natural gas plant	610
Algeria Arzew	Sonatrach, Air Liquide, Air Products	Liquefied natural gas plant	610
Australia Darwin	Linde	Liquefied natural gas plant	250
Russia Orenburg	GazProm	Natural gas	230
Poland Odolanow	Polskie Górnictwo Naftowe i Gazownictwo	Liquefied natural gas plant	100
USA Freeport, TX	Linde	Liquefied natural gas plant	Proposed

5. INFRASTRUCTURE

Details relating to the potential helium production area and Saskatchewan highways, rail lines, transmission lines, and generating stations is shown in Figure 8.

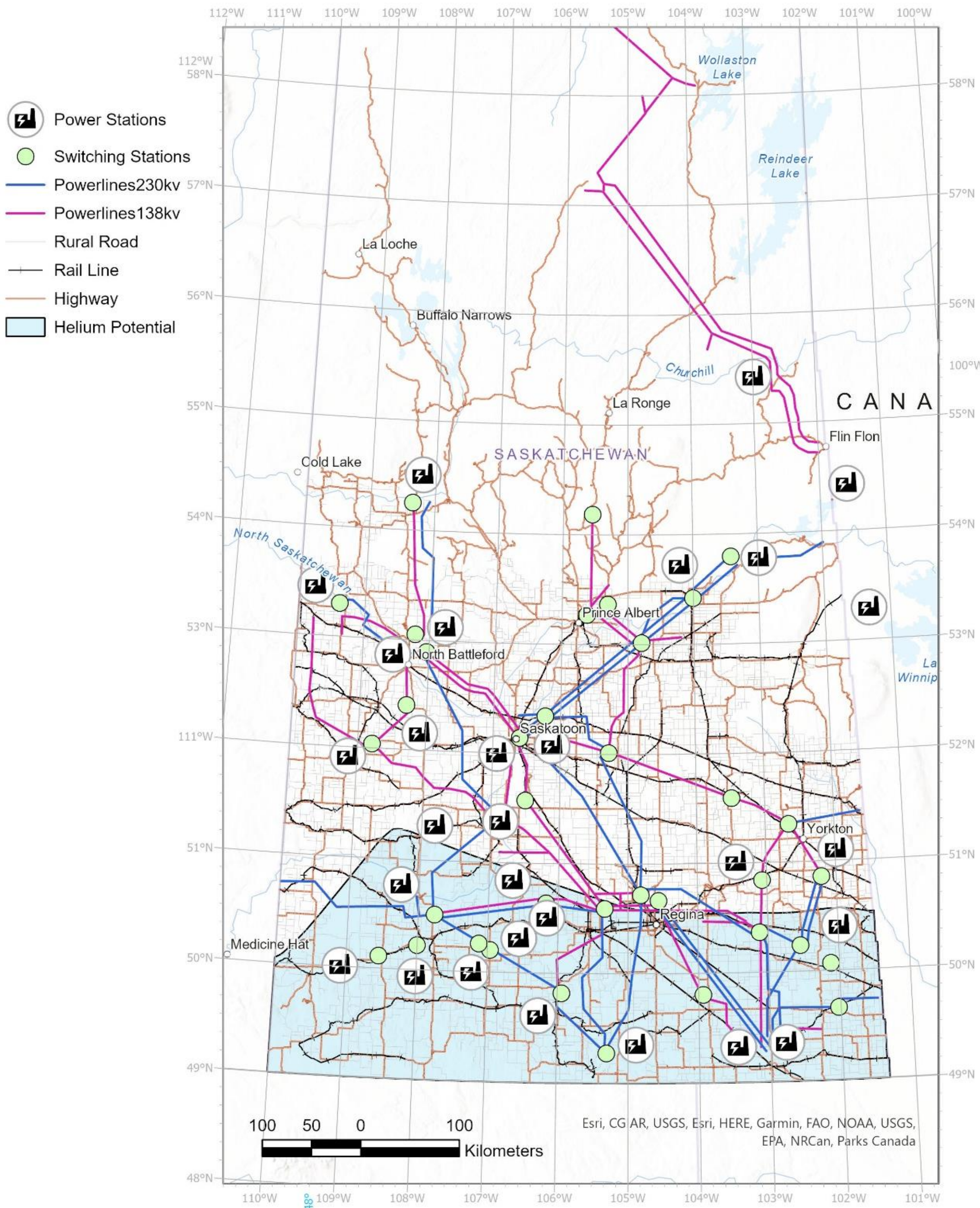


Figure 8 Saskatchewan Infrastructure

5.1 Electrical Infrastructure

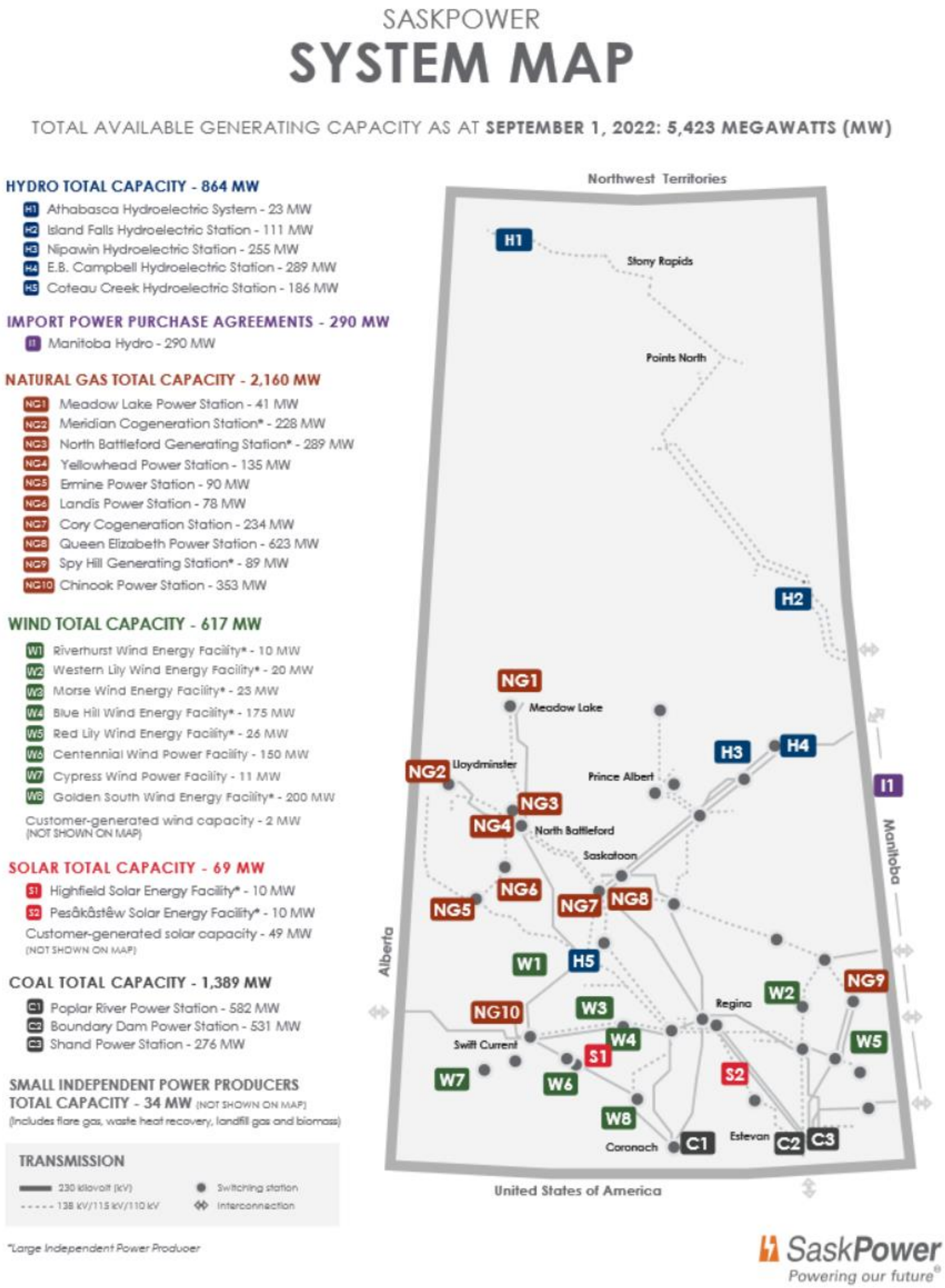


Figure 9 Electrical Generation and Transmission

It is apparent from Figure 9 that most of the potential helium production area is proximate to high voltage transmission lines. Locations significantly south of a line extended between Swift Current and Coronach should be evaluated with increased diligence. Estimated electrical power consumption for a 700 mmcf/y liquefier (described in greater detail in section 7), is approximately 5.2 MW (13.6 MWh/kg H_2).

Table 9 Electrical Requirements

Production		Power
mmcf/y	kg/y	MW
700	3 340 000	5.2
350	1 670 000	2.6

Most of the required power will be consumed by the compressor motors. Motors of this size (total of 6000 hp) can be custom built, but generally utilize electrical power between 4160 to 11000 volts. It is possible that the project (not the utility) will need to supply electrical transformers to produce the required motor supply voltage from the high voltage distribution system. Since the electrical load is primarily inductive it may be advantageous, or required, to install electrical gear design to improve the facility's power factor.

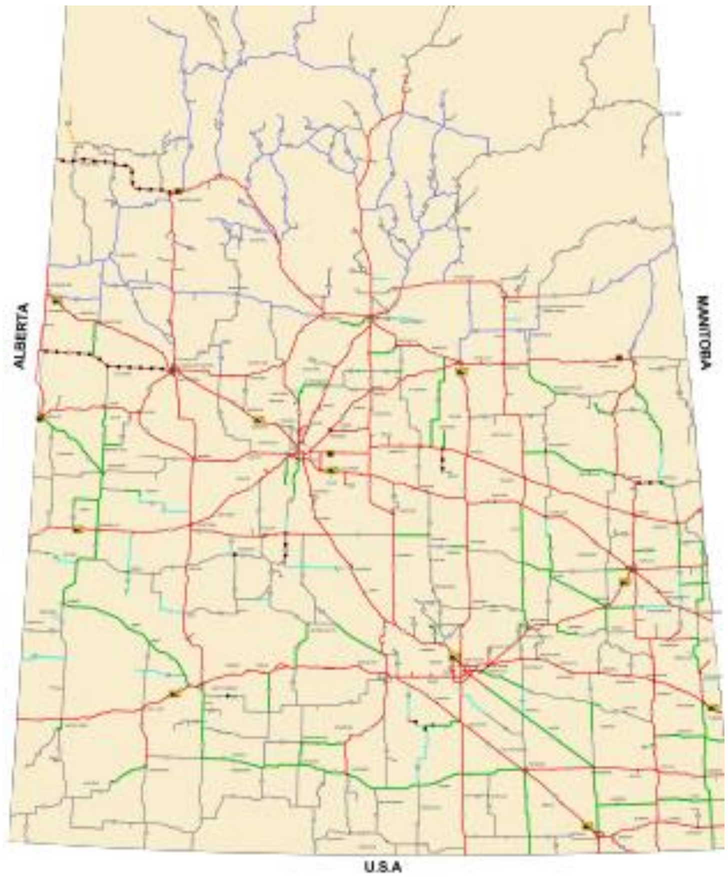
The Chinook Power Generating station (near Swift Current) added 353 MW of capacity to the grid in 2019. Helium liquefaction would require slightly more than 1% of this full capacity. The availability of reliable power is an important consideration when siting a liquefaction facility.

5.2 Road Infrastructure

The weight of helium transport tractor-trailers will be limited to 40 000 kg on primary routes and 35 000 kg on secondary routes. Some highways allow primary weight during the cooler months, but restriction to secondary weights during the spring/summer. Some tube trailers exceed secondary weights. Tube trailers can be commissioned with any number of "tubes", so trailers could be customized for local highway limits. Lighter trailers will transport less helium per trip.

Table 10 Tractor-Trailer Weights

Company	GWV		Capacity	
Praxair/Linde	81450 lbs.	37000 kg	178 mscf	5054 m^3



Primary Weight

9 Month Primary Weight, North Zone (15 km rule does not apply)

9 Month Primary Weight, South Zone (15 km rule does not apply)

Primary Weight Highway by Ministerial Order
(Refer to Ministerial Order for Specific Weight)

Figure 10 Saskatchewan Road Weight Restrictions[13]

6. Environmental

SRC procured the services of Canada North Environmental Services to supply a high-level assessment of potential environmental aspect related to industrial development in Saskatchewan. Canada North Environmental Services is a private environmental consulting company that is owned by the business arm of the Lac La Ronge Indian Band. They are one of the largest environmental service providers in western Canada.

Large areas of southwestern Saskatchewan, including the area known as "south of the divide", are environmentally sensitive. These critical habitats would require more reviews and more detailed reviews if they were selected as a potential project site. Other factors can also delay project development in the area; for example, migratory bird surveys can only be completed during migration. Selecting designated industrial parks, municipal land, or previously disturbed land could reduce the overall approval time.

6.1 Canada North Environmental Service Report Summary

This section provides a summary to a report *Helium Liquefaction Facility Regulatory Requirements and Environmentally Sensitive Area Mapping* (September 2022) commissioned from Canada North Environmental Services Limited Partnership for this purpose.

6.1.1 Regulatory Approval and Permitting

Development of the project would require environmental considerations and regulatory review at the federal, provincial, and municipal levels. Government agencies and legislation have been provided in the CanNorth report[14] as Table 2.

Table 11 Governmental Agency and Relevant Acts

Agency	Requirements
Federal	
Fisheries and Oceans Canada	Fisheries Act General project information including construction timing, desktop or field biophysical review. Mitigation/protection measures and site plan information.

Agency	**Requirements**
Environment and Climate Change Canada	Migratory Birds Convention/Species and Risk Acts General project information including construction timing, desktop or field biophysical review. Mitigation/protection measures and site plan information.
Provincial	
Ministry of Environment – Environmental Assessment and Stewardship Branch	Environmental Assessment Act Detailed project information including construction, and facility operation information. Desktop and field biophysical review, including effects evaluation. Stakeholder and Indigenous engagement and consultation.
Ministry of Environment – Fish and Wildlife Branch	The Wildlife Act Description of project and project area, including shapefile of project footprint.
	The Fisheries Act General project information including location and description of proposed project, information regarding the watercourse/waterbody (including figures/shapefiles), sampling methodology, and biophysical survey timing.
Parks, Culture and Sport –Heritage Conservation Branch	The Heritage Property Act Short description of project including construction method, size of development, baseline biophysical description.
Water Security Agency	Environmental Management and Protection Act General project information including location and description of proposed works, information regarding the watercourse/waterbody, mitigation/protection measures and site plan information.
	The Water Security Agency Act – Permit to Construct Checklist details the information to be submitted to obtain a Permit for Construction of Waterworks or Sewage Works for the construction, extension, or alteration of waterworks or sewage works within the province of Saskatchewan.
	The Water Security Agency Act – Permit to Operate Permits to operate lay out the operational requirements for waterworks owners including sampling and monitoring, and aid in the protection of public health and the environment.
	The Water Security Agency Act – Water License Rights Description of the works and how they are intended to be operated.

Agency	Requirements
Ministry of Agriculture	The Weed Control Act and Regulations General project information including construction timing, Desktop or field biophysical review. Mitigation/protection measures and site plan information.
Ministry of Highways and Infrastructure	The Highways and Transportation Act Description of project, location, site plans, specifications, profile detour plan, and written municipal consent.
Rural Municipalities	Development Policy Varies by RM.

Based on a preliminary understanding, it is anticipated that no federal Environmental Assessment will be necessary. In Saskatchewan, the Environmental Assessment and Stewardship Branch (EASB) requires the completion of an Environmental Assessment for any project that meets the definition of a development per Section 2(d) of The Environmental Assessment Act. An initial review of the project indicated that there will be a need to prepare a Technical Proposal for submission to the EASB. Following submission of the Technical Proposal, the EASB will determine whether the project constitutes a development that requires further assessment.

In addition to the regulatory agencies and approvals described above, engagement and approvals/permits/easements may also be required from the following agencies, organizations, or groups to inform preferred project siting and feasibility:

Table 12 Other Important Organizations

Organization	Consideration
SaskEnergy Incorporated & TransGas Limited	if the proposed Project location has potential to intercept one or more natural gas right of ways
SaskPower Corporation	the proposed Project location has potential to intercept one or more overhead or underground power line right of ways
Great Western Railway Limited	if the proposed Project location will intercept rail line right of way
First Nations groups	if the proposed Project location has the potential to intercept one or more reservations or First Nation community
Individual Landowners	if the proposed Project will disturb land owned by one or more private individuals

Engagement with these regulatory or stakeholder groups early in the design and project siting process is recommended. Where required, early engagement with regulatory groups or land holders to confirm requirements, identify constraints, and secure land access or easements is important to the furtherance of the project.

6.1.2 Screening

The region in southwest SK known as "south of the divide" (SoD) is critical habitat for several species covered by Canada's Species at Risk Act. The Species at Risk Act (SARA) protects endangered and at-risk species. SARA protects, in part, critical habitats necessary for the thriving of both of these groups. Environment and Climate Change Canada (ECCC) can issue (under SARA) Emergency Protection Orders to manage surface activity and protect land identified as critical habitat. These habitats in Saskatchewan are governed by a 2017 ECCC SoD Action Plan that was developed in collaboration with the provincial Ministry of Environment (ENV) (Action Plan for Multiple Species at Risk in Southwestern Saskatchewan: South of the Divide). The Action Plan focuses on a group of nine federally listed species and four species of special concern that inhabit the Milk River Drainage Basin of southwestern Saskatchewan, which is part of a corridor containing significant potential helium development. A large portion (40-45 per cent) of the land in the SoD region is considered critical habitat for at least one species.

Land Tenure

Federal and provincial parks within the SoD are protected areas which have been designated as such, and include the following:

- Grasslands National Park
- Fort Walsh National Historic Park
- Cypress Hills Provincial Park

Special management, permitting, and/or compensation land tenures identified within the SoD include the following:

- Lands protected under the provincial Wildlife Habitat Protection Act
- Conservation Easements
- Carry the Kettle Nakoda (IR 76-7)
- Little Pine (IR 116)
- Nekaneet Cree Nation IR
- Sturgeon Lake (IR 101c)
- Lands managed by the Government of Saskatchewan Fish and Wildlife Development Fund
- Lands managed by the Canadian Wildlife Service (CWS)

- Lands managed by the Nature Conservancy of Canada (NCC)
- Provincial community pastures, including:
- Arena (central)
- Dixon (east side of Grassland National Park west block)
- Mankota (west side of Grassland National Park east block)

Other than one rail line, the remaining land tenure areas (other specially managed areas) worthwhile noting include:

- A whooping crane migration corridor along the southeast corner of the SoD
- A Migratory Bird Sanctuary at the Val Marie Reservoir
- Designated Important Bird Areas (IBAs) (i.e., the areas within Govenlock-Nashlyn-Battle Creek Grasslands and the Grasslands National Park)

Habitat

Land Cover

A high proportion of this area has natural land cover, including native grassland, treed land, shrub land, wetland, and bare soil. Altered land covers include annual cropland and hayland/tame pasture.

Wetlands and Watercourses

Wetlands form a large proportion of the region, and there is a significant probability that any proposed facility would be in proximate to or within the boundary of one or more of these areas.

Documented Invasive Weeds and Soil-borne Diseases

Invasive weeds have been documented within small areas of the entire region. Additional screening will be required once specific site options are chosen.

Documented Rare, Endangered and Species of Conservation Concern

A total of 388 Species of Conservation Concern (SOCC) have been documented in the SoD area. An extensive list is provided in CanNorth report[14] as Table 5. This list includes plants, invertebrates, birds, fungi/lichen, mammals, reptiles, and amphibians. Additional screening will be required once specific site options are chosen.

Habitat Potential for Rare, Endangered, and Species of Conservation Concern

SoD features habitat and protected areas that have high habitat potential for a range of terrestrial wildlife and plants, including SOCC and breeding/nesting birds protected under the federal Migratory Birds Convention Act and species with federally and/or provincially recommended activity restrictions. SOCC that have been documented federally as having critical habitat in the SoD are provide in the CanNorth report[14] as Table 6.

Numerous wetlands within the SoD have moderate/high habitat potential for amphibians, breeding birds, and aquatic plant SOCC, particularly any wetlands where the surrounding upland habitat is primarily pasture and native grassland. The SoD area also contains several fish-bearing waterbodies and watercourses. Thirty-three fish species have been documented within the SoD.

6.1.3 Environmentally Sensitive Area Mapping

Some areas pose greater environmental, regulatory, or social challenges for development. Although it may be possible to mitigate disruption or destruction to these areas, it is strongly recommended that they be avoided for projects.

Parks, Wildlife Protection Areas, Conservation Easements, Community Pastures

National parks are protected under the Canada National Parks Act are not available for project development. There are two national parks, Grasslands National Park and the Fort Walsh National Historical Park, located in the region. One provincial park, Cypress Hills Provincial Park, is also located within the area.

Six types of special management areas were identified within the mapping study including:

- Wildlife Habitat Protection Areas (WHPA)
- Conservation Easements
- Fish and Wildlife Development Fund Lands (FWDFL)
- CWS land
- NCC land
- provincial community pasture areas

These special management areas are considered priority environmentally sensitive areas and should be avoided through Project siting wherever possible. For more details refer to the CanNorth report[14].

Archaeological Resources, Designated Heritage Sites, Churches, and Cemeteries

The provincial Heritage Property Act protects archaeological sites, paleontological resources, and significant heritage sites. Sites designated as Sites of Special Nature have special protection under the Act, in that no person shall destroy, remove, or excavate any pictograph, petroglyph, human skeletal material, burial object, burial place or mound, boulder, effigy, or medicine wheel. Cemeteries are protected by The Cemeteries Act, 1999. All archaeological resources and heritage sites should be considered highly constrained.

Environmentally Sensitive Areas

Although environmentally sensitive classification does not necessary prevent development, the extent of the classifications (number of sensitivities and the significance) could have significant impact.

Table 13 Existing Habitat and Considerations

Habitat	Consideration
Native Grassland	provide breeding and nesting areas for a variety of birds, valuable forage for livestock – also feeding, breeding, and cover habitat for SAR, SOCC, and other wildlife species. Certain species of songbirds, such as the Sprague's pipit (*Anthus spragueii*), which are endemic to North American grasslands, are found primarily within large, intact tracts of this relatively rare habitat (SARPR 2022). All native grassland areas should be considered sensitive and important; however, *the larger, contiguous areas of native dominant grasslands have greater conservation importance*.
Tree and Shrub	provide important wildlife habitat due to their structural diversity and high species richness.
Wetland	fulfill a wide range of ecological, hydrological, biochemical, and habitat functions such as maintaining water quality, regulating water flow on the landscape, and providing erosion control. Provide habitat for a variety of wildlife; an estimated one third of the wildlife SAR identified by COSEWIC are dependent on wetlands.

Waterbird Staging Areas	Hundreds of species use the Central Flyway during migration - Saskatchewan's habitats are very important for successful staging, migration, as well as breeding of wetland birds and shorebirds. Migratory Bird Sanctuaries, IBAs, and whooping crane migration corridors within the SoD are considered environmentally sensitive areas.
Known Rare Plants or Plants of Conservation Concern	often found to be associated with native grassland habitat. Locations of known rare and endangered plant species were identified using data obtained from the ENV (2022a). Plant species that have been listed by the federal government as SAR (as per the Species at Risk Act) or provincially defined as a rare plant ranked S1 through S3 (extremely rare to vulnerable at a provincial level) were buffered according to the distance prescribed in the High Disturbance category in the Activity Restriction Guidelines for Sensitive Species (ENV 2017).
Known Rare Wildlife or Habitats of Conservation Concern	Locations of known SAR and SOCC wildlife species were identified using data obtained from the ENV (2022a) and are presented in CanNorth[14] Figure 6, while critical habitat associated with those species are presented in Figure 7. Wildlife habitat and species may be protected under both provincial and federal legislation. Pertinent legislation includes the MBCA, SARA, The Wildlife Act, 1998 and The Wildlife Habitat Protection Act. A total of 388 SAR and SOCC have been observed in the SoD, and critical habitat for 12 of those species has also been documented (CanNorth Figure 7; Table 6).
Fish and Fish Habitat	The Fisheries Act (1985) prohibits the harmful alteration, disruption, or destruction of fish habitat through physical, chemical, or biological means. Fish bearing waterbodies have been acknowledged as an environmental constraint.

6.2 Next Steps

Once more details have been developed (candidate sites selected), the following activities are recommended.

Table 14 Potential Environmental Next Steps

Step	Description
Detailed Environmental Screening	Provide detailed results on a finer scale. Could include the use of tools such as HABISask, W.P. Fraser Herbarium, iMapInvasives, IBA of Canada database, National Soil Database, ISC for land tenure
Heritage Screening	Often requires site-specific project footprint information. Use of tools such as The Government of Saskatchewan's Parks, Culture and Sport Developers' online screening with results submitted to the Heritage Conservation Branch for a Heritage Resource Review
First Nations and Métis Consult	A duty to consult with Indigenous communities when contemplating decisions or actions with the potential to adversely impact the exercise of Treaty and Aboriginal rights and Traditional land and resource uses. The relevant ministry determines the need for consultation.
Stakeholders	Public meetings in local communities to receive feedback on potential issues, interests, or concerns.
Permits and Reporting	Species Detection Permits Department of Fisheries and Oceans Request for Review Aquatic Habitat Protection Permit Heritage Resource Impact Assessment and Heritage Clearance Technical Proposal for Environmental Assessment and Stewardship Branch

A simplified flowchart of the environmental permitting process for a liquefaction plant is provided in Figure 11 below. Some of the activities in the flowchart may have longer lead times than stated, as some critical habitat surveys can only be completed during certain times of the year (e.g., migratory bird surveys). Note that this flowchart is for information only and working directly with an environmental consultant is highly recommended.

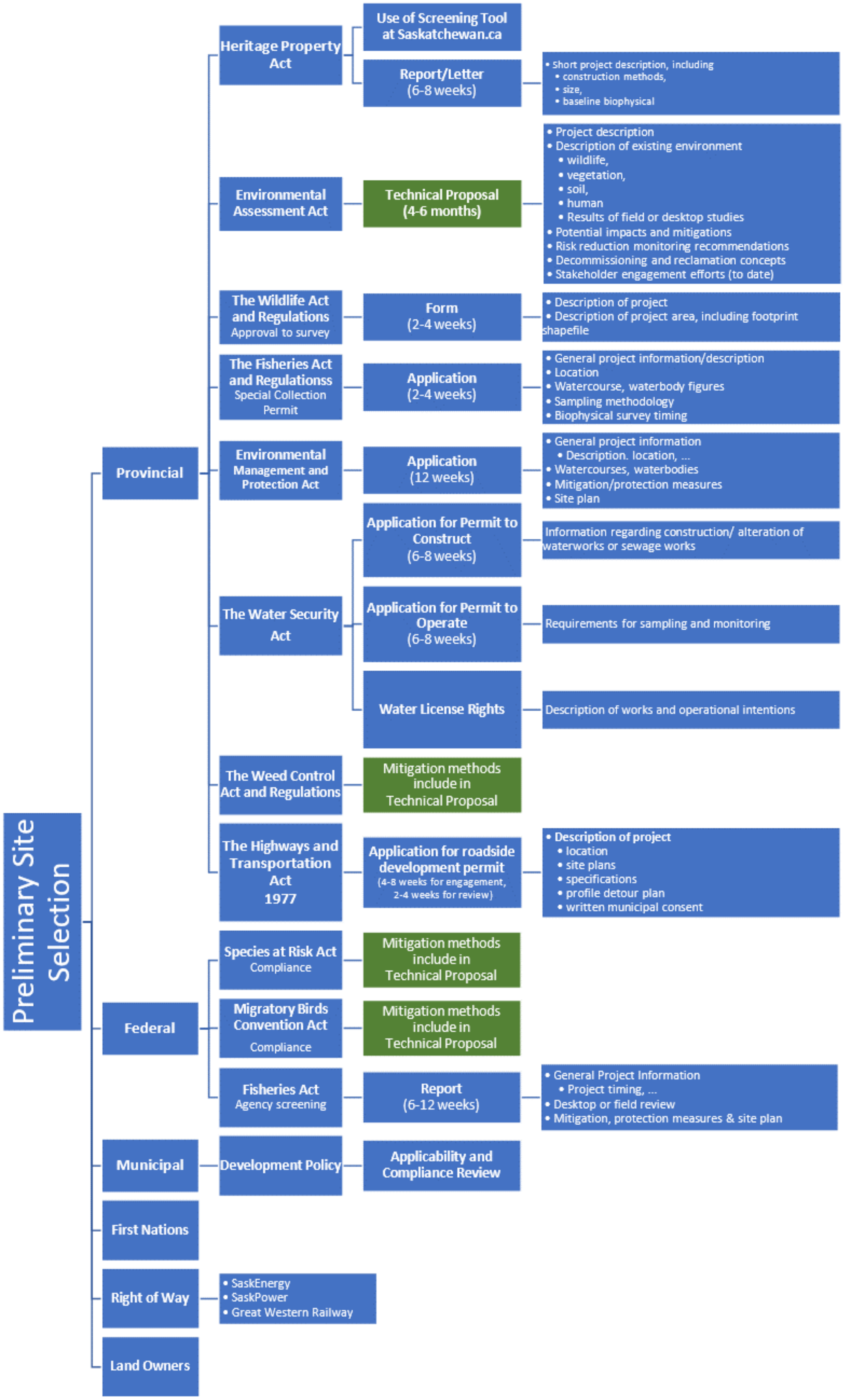


Figure 11 Illustrative Environmental Process

7. Review of Helium Liquefaction

7.1 Introduction

Helium liquefies at a few degrees above absolute zero and is one of the coldest substances on Earth. This makes it impossible to liquify helium through the evaporation of a lower-boiling point liquid. Hence, technical options to create liquid helium commercially are extremely limited. Helium liquefaction plants are available from three major technology providers, each of which has their own subtle design differences. Helium technology providers Air Liquide, Air Products, and Linde were contacted during the stakeholder engagement portion of the project but were unable to provide details regarding their designs. Instead, general process information has been gathered from patents, publications, and other publicly available sources[15].

A simplified helium liquefaction process is described in Figure 12.

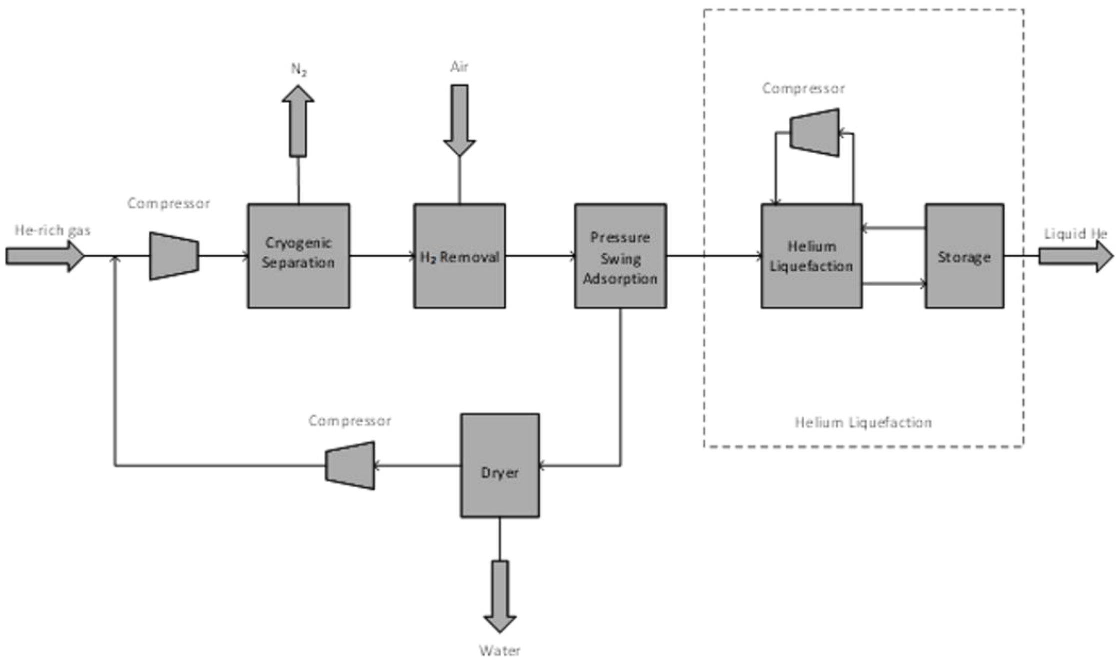


Figure 12 Helium Liquefaction Process

The liquefaction process follows these general steps:

- Helium is purified from source gas, either through cryogenic separation, pressure or temperature swing adsorption, membrane separation, or some combination, prior to entering the liquefaction plant

- At the liquefaction facility, purified helium is compressed and then cooled
- A portion of the helium is expanded through a turbine which removes energy from the helium, causing the temperature to go down
- Cold, low-pressure helium from the turbine exit is used to cool the remaining helium
- Liquid helium is separated, and un-liquefied helium is recycled to the start of the process

7.2 Market Summary

7.2.1 Liquefaction Plant Costs

Although costs have not been provided by the technology providers at this time, capital costs can be estimated using engineering estimation techniques. The estimates depend on the size and number of pieces of equipment and have been performed for three scenarios in Section 8.

7.2.2 Helium Price

Helium is a privately traded commodity, which means there is no "open market" price. Until recently, the US Bureau of Land Management was auctioning off the helium previously held in reserve by the US government. This gives us at least one published sales price for helium.

According to the United States Geological Survey (USGS)[5],

> *"In fiscal year (FY) 2021, the price for crude helium to Government users was $3.61 per cubic meter ($100.00 per thousand cubic feet). The BLM does not post a conservation helium price; conservation helium prices were last posted by the Federal Government in 2018. The estimated price for private industry's Grade-A helium was about $7.57 per cubic meter ($210 per thousand cubic feet), with some producers posting surcharges to this price."*

Figure 13 was produced by combining the USGS price with the few prices published in journals and news articles. The price of gaseous helium used for economic analysis in this report was \$7/m^3. Liquid helium prices are equally difficult to obtain; the price used in this report was \$13/m^3.

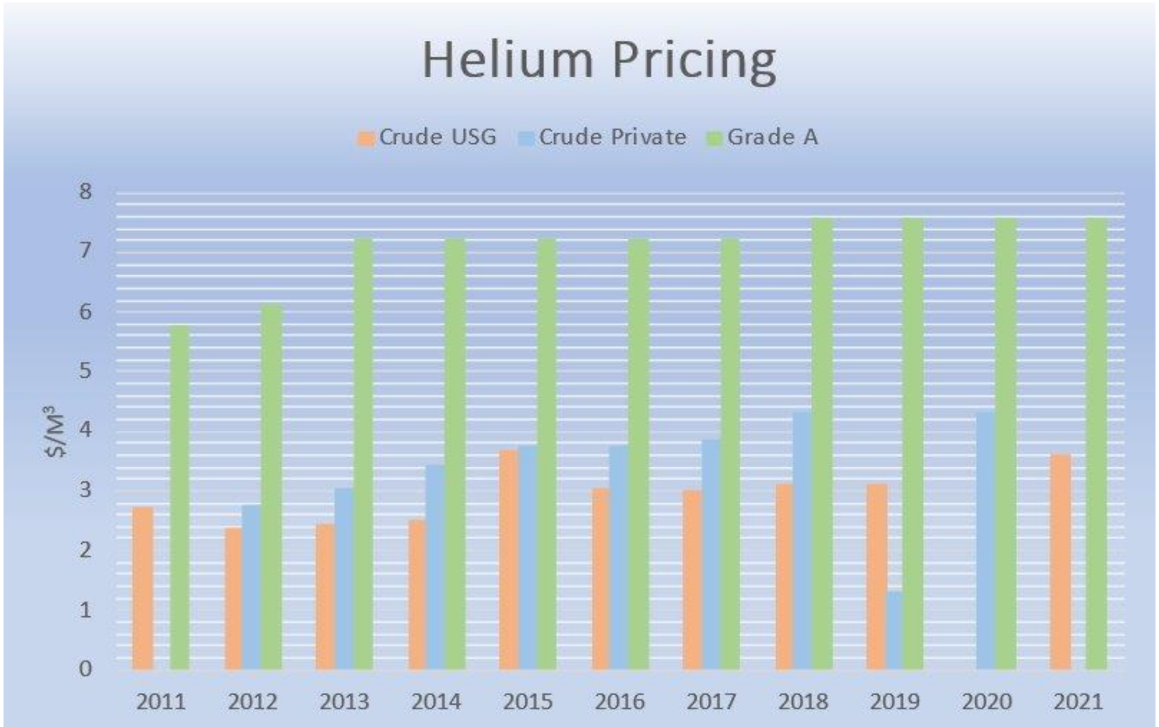


Figure 13 Helium Pricing

It is also important to note that the price of helium gas depends on its purity. As is the case with helium prices, the required helium purity is negotiated between the seller and the buyer. Generally, it will fall into one of three broad categories:

- Crude: 60 to 80%
- Near pure: 95 to 98%
- Grade A: 99.996%+

From conversations with stakeholders, most Saskatchewan production is currently being purified to Grade A.

7.2.3 Transportation

Helium can be transported as a compressed gas or as a liquid. Helium is much denser when in the liquid phase, which makes it much cheaper to ship on a volume basis. However, liquid helium needs to be kept at extremely low temperatures to prevent it from boiling back into a gas, so specialized cryogenic containers are required. Liquifying helium can allow it to be transported longer distances economically, which could potentially provide access to larger markets world-wide.

One of the largest current users of liquid helium is the US space industry, which is located in continental North America and therefore accessible to road transport. A map from Sask. Interactive Mapping shows major and primary highways (red lines) and railroads (dashed red lines) in southern Saskatchewan in Figure 14. Transportation of gaseous and liquid helium by truck, rail, and pipeline are discussed briefly in the sections following.

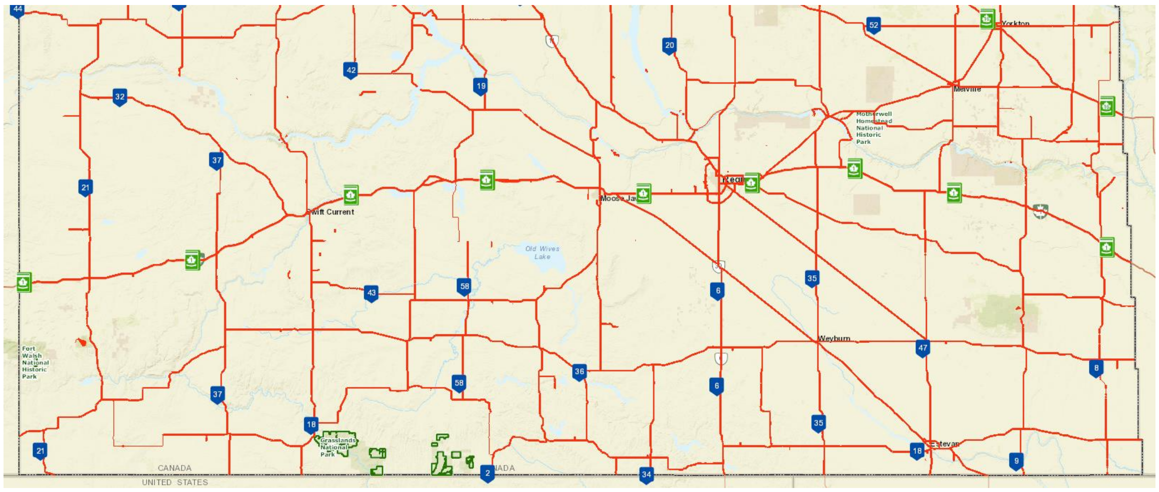


Figure 14 Major and primary highways and railroads in southern SK[16]

Truck Transport:

Compressed gas is typically transported in tube trailers. Trailer capacity will depend on the number of tubes, which will in turn determine its weight; 10 tubes per trailer is a typical configuration. Tubes trailers are available in one of four types[17]:

- Type 1: These trailers are an older style and use a stack of steel tubes. They can hold 3,200 psi of pressure and need to be re-certified every 10 years. Lifespan for this type of trailer is indefinite, so long as it continues to pass re-certification. Costs are in the range of $300K USD for Type 1 trailers.
- Type 2: Type 2 trailers have tubes with a steel core wrapped in carbon fibre for reduced weight. These trailers are less frequently used, and no cost estimate was available as of the writing of this report.
- Type 3: The tubes in this trailer type have an aluminum core wrapped in carbon fibre. They have a higher capacity at 4,000 psi, and a lifespan of approximately 15 years. They cost in the range of $700 000 USD each. These trailers are often used in Western Canada for natural gas transport.
- Type 4: These trailers have tubes with a plastic core wrapped in carbon fibre. They can hold up to 4,000 psi, and have a 15-year lifespan, as with the Type 3 trailers. Due to the plastic construction, these are the lightest weight trailer type. However, the permeation

rate through plastic is much higher than for steel, which is especially an issue for small helium molecules. No costs were collected for this type of trailer as they are not suitable for helium transportation.

Tube trailers filled with compressed gas often exceed road weight limits, and liquid helium trailers are even heavier. On most major roads in the United States, the max allowable weight is 36 000 kg (with some exceptions). In Canada, major roads have a weight allowance of 40 000 kg for 3-axle trailers and 35 000 kg on primary routes. Section 5.2 discusses road transportation limits in more detail. Due to the weight of liquid helium transport containers, locating a facility on a primary road, such as Highway No.1, is recommended.

When trucking helium to the United States it's also important to note that the border crossing south of Swift Current at Monchy, SK is not available for commercial export, and transporters should plan for a longer distance drive to one of the other, larger, border crossings. Feedback from producers has indicated that helium exports from Saskatchewan are occurring through Coutts, AB for this reason.

Rail Transport

Railroad transportation of helium was considered a possibility in the United States during the late 1960s. At the time, railway tank cars cost $100 000 USD and could hold 240-345 mcf of helium compressed to 2200-4000 psi. By 2002, a 40 000-litre liquid helium tank costs over half a million dollars (USD)[15]. However, these tanks could not be transported by rail. The 2002 UN portable tanks working group recommended an exemption to the 4 g rail impact test requirement as, in their words,

> *"Refrigerated liquefied helium portable tanks have been safely used for long distance (international) transportation and are not transported on railroads due to the unpredictability of rail impact loads on a worldwide basis and the possibility of high economic losses due to structural or insulation failures of these containers if transported by rail."*[18]

Recent stakeholder discussions have confirmed ISO tanks cannot be used on rail, and the trailers currently used by the industry are not rail certified. In light of this information, the Saskatchewan liquefaction hub should not consider transportation by rail as a viable option in the near term, though it might be an area of development in the future.

Pipeline Transport

Although there are no current helium pipelines in Canada, other compressed gases are commonly transported via pipeline. In a recent publication SRC compared pipeline costs from several sources[19,20,21], and calculated an average cost of $220 000 per km of CO_2 pipeline. Using the distance from Swift Current to the US border as an example, pipeline capital costs could be in the range of $33M dollars. Helium transportation by pipeline is technically possible, but not likely an economical choice in the near-term.

7.2.4 Local Labour Availability

Introduction

As Saskatchewan looks for opportunities to build the helium value chain, a range of workers will be required to support its development. A key component of the added-value processing — the liquefaction plants — could be instrumental in adding value to the provincial helium industry. Initially, the focus will be on workers with skills in the design, engineering, and construction of these liquefaction facilities, then transitioning to workers with operational and maintenance capabilities. Other services essential to the successful functioning of a helium hub in the region would include trades and physical services, support workers, and technicians.

National Labour Context

The Canadian job market can provide a broader context for labour market trends and future outlooks. The Mining Industry Human Resources Council (MiHR) estimated, in 2019, the potential labour gaps in mining in Canada for 2020 to 2030. It states that the mining industry regularly faces tight labour markets and competes with other industries for new hires.[22]

For the period from 2020 to 2030, MiHR estimates that only the extraction and milling sub-sector will experience hiring gaps. It also sees a “slack” labour market (higher unemployment) for primary metal manufacturing.

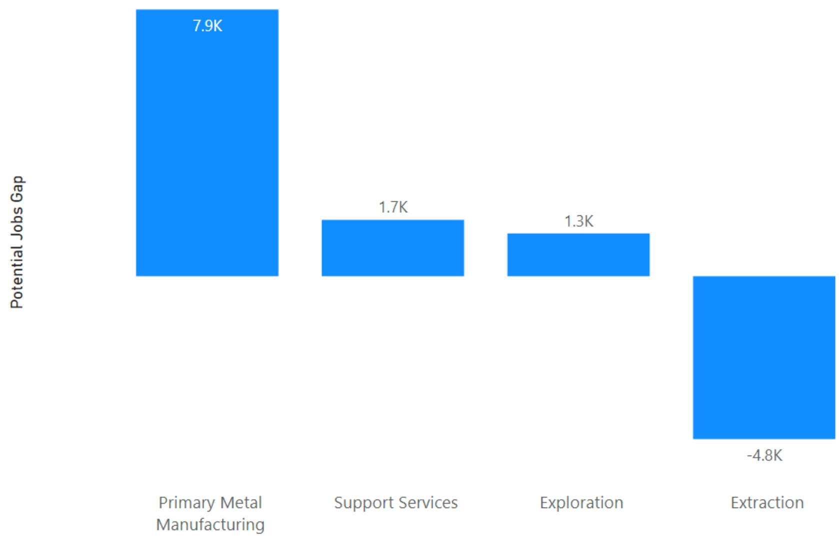


Figure 15 Potential Job Gaps by Sub-Sector (2020 to 2030)

In terms of occupation type, the largest gaps are anticipated for supervisors and support workers: both could see deficits of approximately 300 workers over this ten-year period.

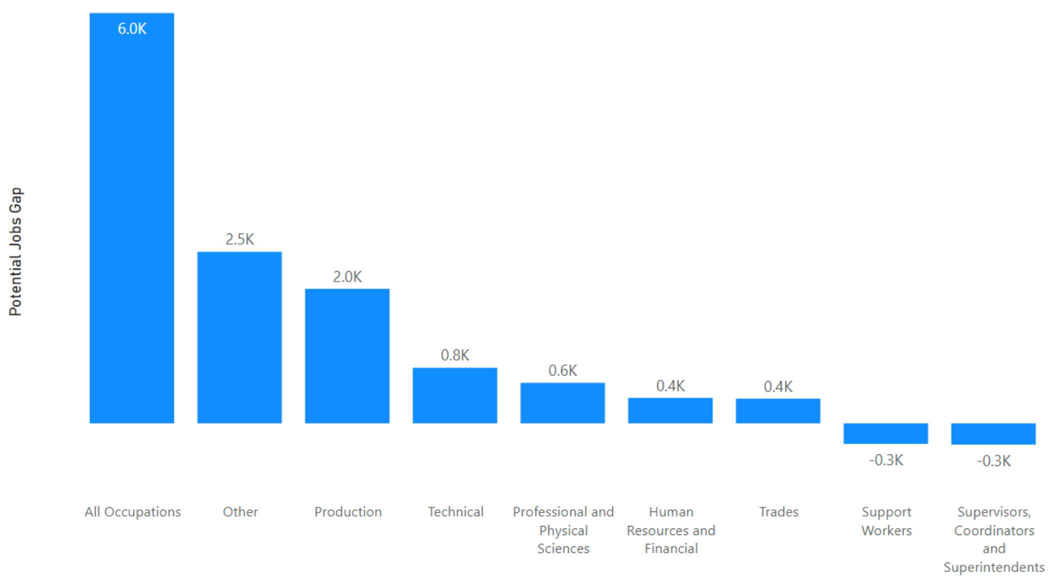


Figure 16: Potential Jobs Gap by Occupation Type (2020-2030)

Given that the helium industry is burgeoning in Canada, companies will need to attract workers across all the general occupations above, most likely from the mining sector or from the oil and gas sector. Figure 16 offers potentially good news, in that for the next ten years, it is anticipated that there should be no serious shortage of most of these workers—at least from a country-wide perspective.

Saskatchewan

According to the latest labour market bulletin from the Government of Saskatchewan, the total number of workers employed in the province in August 2022 was 574,200 - up slightly from the previous year when 562,000 were employed.[23] The largest segment of the workforce employed was in trades, with 96,000.

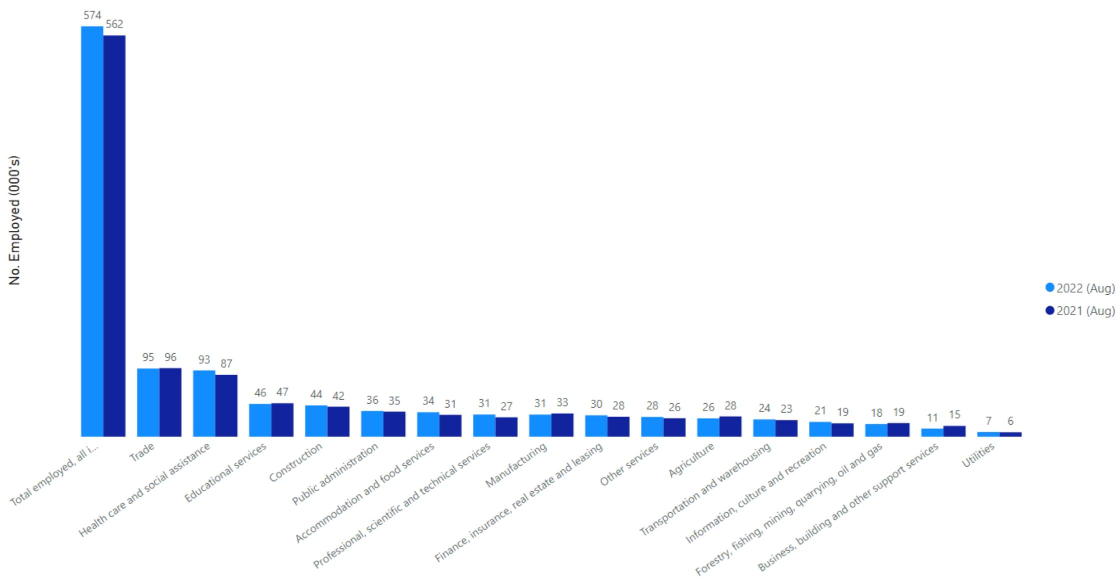


Figure 17: Saskatchewan Employment by Sector

Source: Labour Market Bulletin - Saskatchewan: August 2022.

Those professions most likely needed in the helium industry are highlighted in Figure 18.

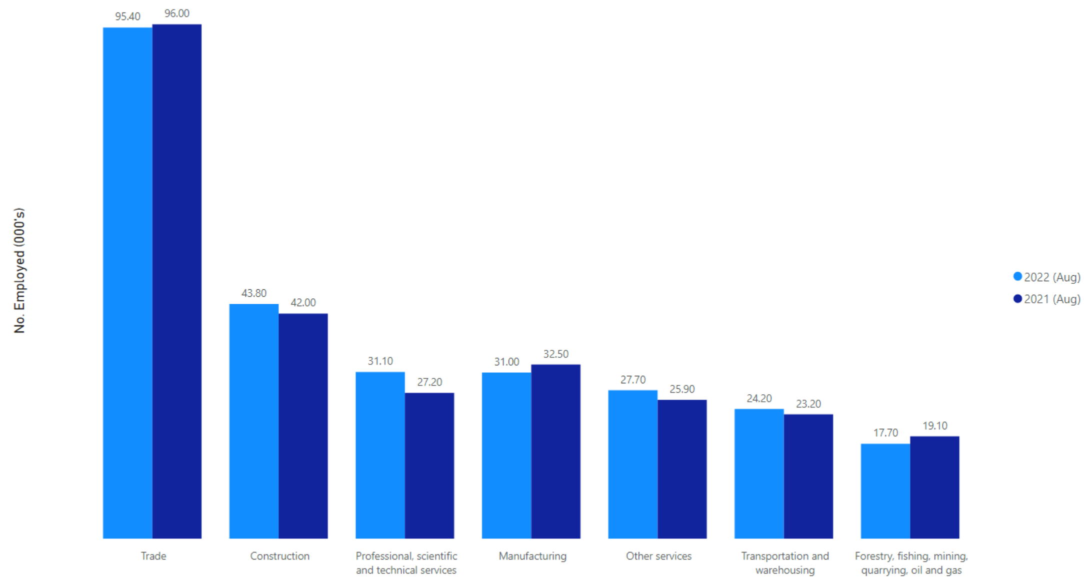


Figure 18: Key Sectors for Helium Industry in Saskatchewan

In August 2022, the resource industry, which includes forestry, fishing, mining, quarrying and oil and gas, has approximately 1,400 fewer jobs compared to 2021. There were 17,700 working in the sector in August of this year.

Construction is another key sector. It has seen an increase, from 2021, in the number of workers employed. In August 2022 there were approximately 43,800 employed while in August 2021 there were just over 42,000, an increase of 1,800 jobs.

Mining

The last Saskatchewan Mining Association Labour Outlook report was published in 2014.[24] Although the data is somewhat older, there are some take-aways from the analysis.

- The province is a net exporter of mine workers, with approximately 1,400 workers commuting from Saskatchewan to Manitoba or Alberta.

- For the ten-year period (2014-2024) it was forecasted that the mining sector would have to hire nearly 13,000 workers for the baseline scenario of mining activity. Retirement in the industry is a key driver of this prediction.

- For occupations, the largest potential job gaps were forecasted for technical at just under 950. All occupations except designated trades were assessed to have a hiring deficit from 2014-2024. The hiring requirements and talent availability comparisons are provided in Table 15.

Table 15 Labour Availability Gaps

Occupation	Hiring Requirements	Talent Availability	Potential Gap
Technical Occupations	1,330	384	-946
Professional and Physical Science	1,111	742	-370
Supervisors, Coordinators, and Foremen	995	679	-316
Support Workers	515	314	-201
Human Resources and Financial	315	227	-85
Production Occupations	2,950	2,890	-60
Designated Trades	1,440	1,660	220

Construction

BuildForce Canada analyzed the Saskatchewan construction industry and provided an outlook for 2020-2030.[25] The current distribution of construction workers based on subsectors is seen in Figure 19. In 2020, approximately a third of the workers were in engineering, followed by approximately 20 per cent each in residential, industrial, commercial, and institutional (ICI) and non-residential maintenance.

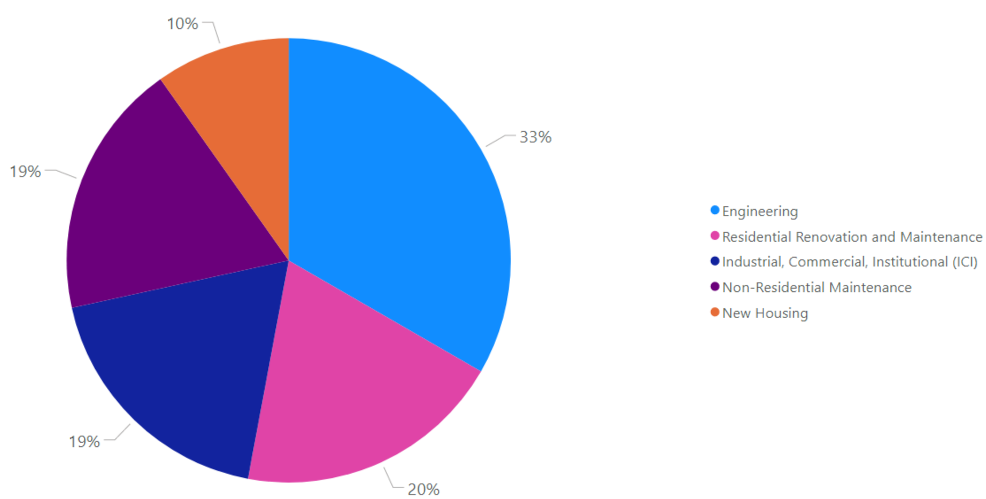


Figure 19 Saskatchewan Construction Workers by Sub-sector

Retirement in the Saskatchewan construction industry will have the largest impact on this industry over the coming years. It is anticipated that over 9,000 workers will retire between now and 2030. In addition to retirement, BuildForce also anticipates that new mine developments in the next decade in Saskatchewan will tighten labour markets even more. For these new mines, more than 2,400 workers could be needed between 2022-24. In total, the Saskatchewan construction industry could need to hire approximately 11,400 people within the next few years.

Economic Region – Swift Current-Moose Jaw

The economic region of Swift-Current-Moose Jaw (SC-MJ) is the primary region of focus as it captures the majority of the current helium development in the province.

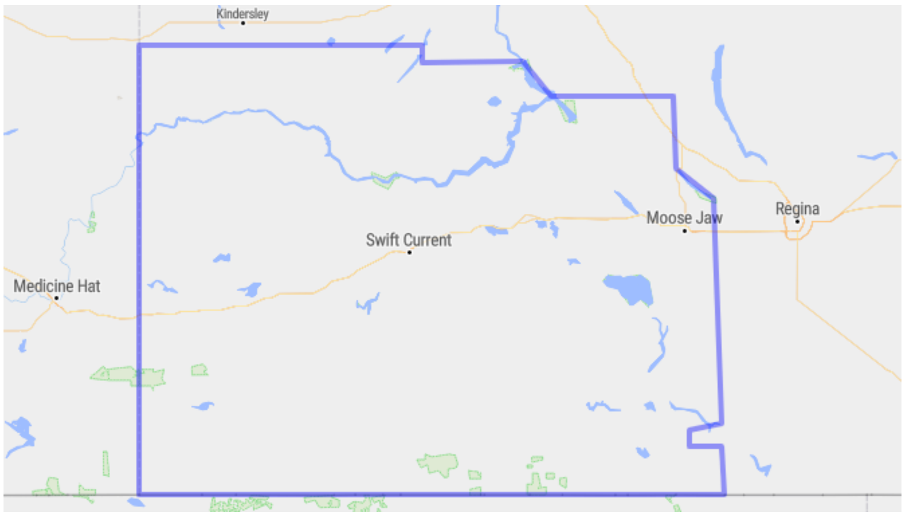


Figure 20 Swift Current-Moose Jaw Economic Region

Unemployment Rate

The unemployment rate in the SC-MJ for August 2022 was just over 5 per cent.[26] The rate is considerably lower than in the COVID-impacted years of 2020 and 2021 when the unemployment rate was over 7 per cent.

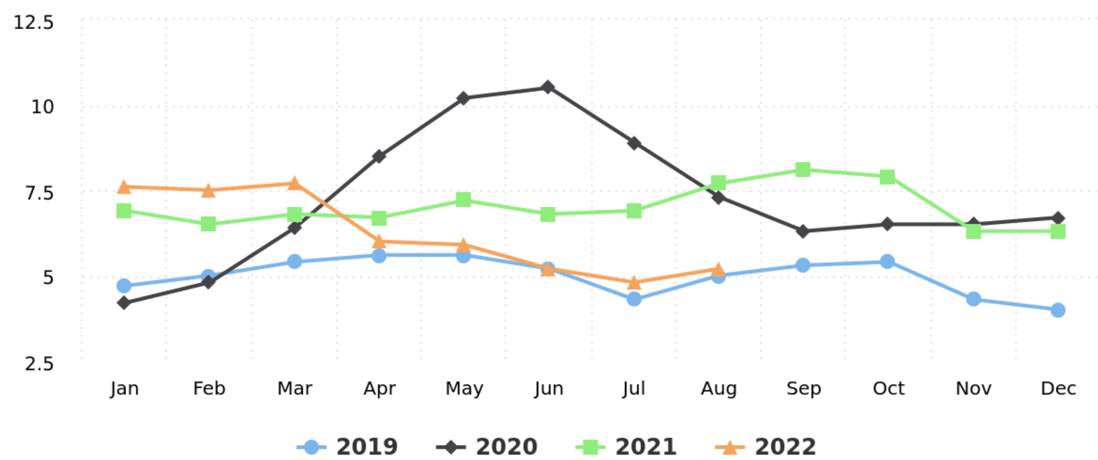


Figure 21 Unemployment Rate (SC-MJ)

Participation Rates for Swift Current-Moose Jaw

Comparing labour force participation rates from 2019 to 2022 (to August), 2022 has had some of the lowest numbers. The participation rate was approximately 65 percent for most of 2022. An increase in the participation rate indicates more people are entering the labour force.

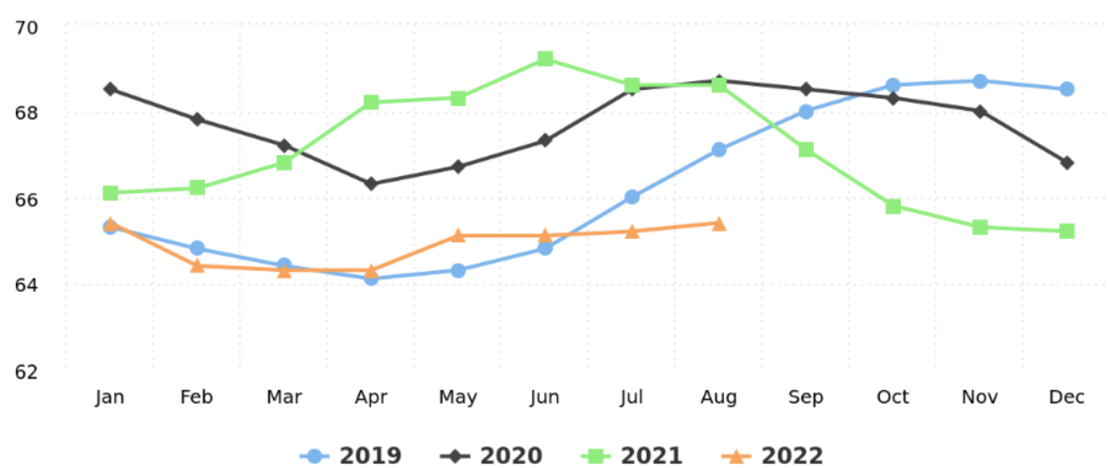


Figure 22 Participation Rates for Swift Current-Moose Jaw

The 2022 employment rate in the SC-MJ has been increasing since March and reached its high in August of 65.4 percent.

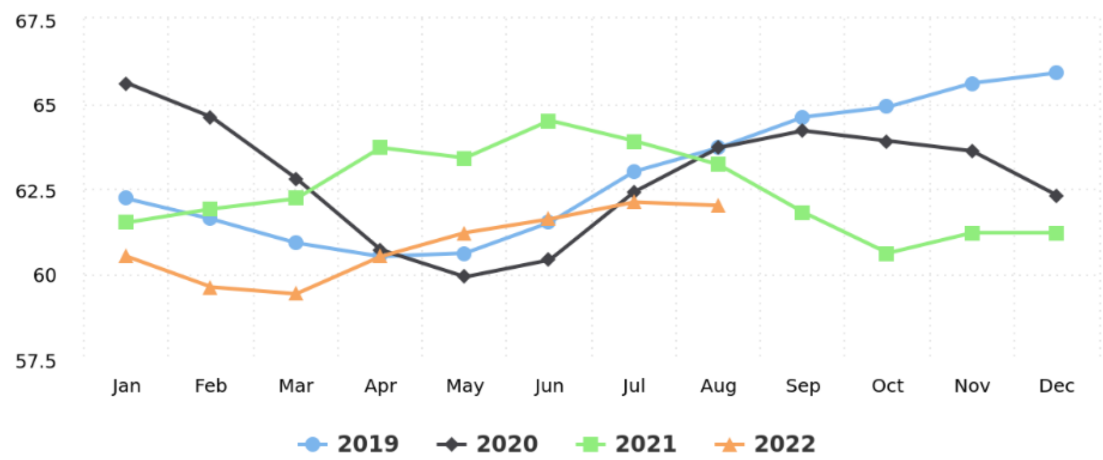


Figure 23 Employment Rates for the Swift Current-Moose Jaw EC
Source: Swift Current, SK - Labour Force | Townfolio.

Considerations for the Labour Markets and the Helium Industry

- Other mining projects in southern Saskatchewan will have an impact on available labour. Several large, announced potash mines are at various stages of development. Some are anticipated to begin construction within the next decade.
- Saskatchewan is starting to emerge as a key location for the processing of Rare Earth Elements (REEs). This is another sector that could draw skilled workers and add more competition for labour over the next decade.
- Lithium extraction from brines is a similar industry to helium, in that there are skills that could be drawn from both mining and oil and gas sector. In southern Saskatchewan, companies are evaluating the potential of extracting lithium from brines in abandoned oil wells.
- Saskatchewan is also looking to establish a hydrogen economy and developments in the sector could pull workers from the oil and gas and mining sectors.

Potential List of Occupations Required

The following list is derived from the Mining Industry Human Resources Council (MiHR) list of occupations relevant to the mining sector.[27]

Production Occupations

- Transport truck drivers
- Construction trades helpers and labourers
- Central control and process operators, mineral and metal processing
- Labourers in mineral and metal processing
- Other trades helpers and labourers
- Power engineers and power systems operators

Trades Occupations

- Heavy-duty equipment mechanics
- Carpenters
- Steamfitters, pipefitters and sprinkler system installers
- Construction millwrights and industrial mechanics
- Industrial electricians
- Welders and related machine operators

Professional and Physical Sciences

- Mechanical engineers
- Electrical and electronics engineers
- Civil engineers
- Chemical engineers
- Metallurgical and materials engineers
- Industrial and manufacturing engineers

Support Workers

- Inspectors in public and environmental health, and occupational health and safety
- Production logistics coordinators
- Engineering inspectors and regulatory officers
- Transportation route and crew schedulers
- Construction estimators

Technical Occupations

- Drafting technologists and technicians
- Civil engineering technologists and technicians
- Electrical and electronics engineering technologists and technicians
- Land surveyors
- Industrial instrument technicians and mechanics
- Chemical technologists and technicians
- Land survey technologists and technicians
- Mechanical engineering technologists and technicians
- Information systems analysts and consultants
- Industrial engineering and manufacturing technologists and technicians

Supervisors, Coordinators and Foremen

- Supervisors
- Construction managers
- Contractors and supervisors, pipefitting trades
- Engineering managers
- Contractors and supervisors, mechanic trades

8. LIQUEFACTION HUB CONCEPT DEVELOPMENT

A helium liquefaction plant could be instrumental in adding value to the provincial helium industry. As discussed in earlier sections, liquefying helium reduces its density, allowing it to be transported longer distances for lower cost. Liquid helium is higher value than gaseous, and there is a growing market for its use. Saskatchewan has helium resources and is currently producing grade A purity helium, with more production wells planned for the near future. A liquefaction facility or a "hub" of several facilities would allow Saskatchewan to participate in the full value of its helium resource.

Section 8.1 summarizes the criteria for selecting a location for the liquefaction hub. The following sections (8.2 through 8.6) explore the economics of three potential liquefaction scenarios: a single large-scale facility, a single smaller facility, and a "hub" consisting of two smaller facilities (or a single facility with dual trains).

8.1 Site Selection

Industrial facility siting is normally an iterative process whereby the characteristics of a number of locations are quantitatively and qualitatively compared. Several constraints that should be considered when selecting a potential location for a liquefaction hub in Saskatchewan are summarized below.

- Helium is currently being produced in both south-central and southwestern Saskatchewan. Although the liquefaction hub doesn't need to be co-located with production facilities, proximity to existing and future production should be considered.
- There are special environmental considerations in the area known as "south of the divide". Options like designated industrial parks, municipal land, or previously disturbed land could reduce the required number of reviews.
- Transportation of gaseous and liquid helium is likely restricted to trucking, at least in the near-term. Helium transport trucks are heavy and due to the weight restrictions on secondary highways, the liquefaction facility should likely be located as closely as possible to primary roadways (Figure 10).
- Helium liquefaction requires significant electrical power to operate. The availability of reliable power and proximity to high voltage transmission lines are considerations.
- A nearby source of skilled labour would be beneficial.

8.2 Scenario 1: 10% of world demand

Global demand for helium is projected to reach 7,000 mmcf/y by 2030[28]. To meet Saskatchewan's goal of providing 10% of world demand, the province will need to process 700 mmcf/y. Liquefaction at that scale can be achieved in one of several ways. This scenario examines the cost to build a single large-scale facility capable of liquefying all 700 mmcf/y (~370 kg/h) of helium.

Detailed plant designs had not been made available from process licensors at the time of this report. Helium liquefaction processes have been in use since the 1960's and are well-understood in patents and public literature (see section 6 of this report). Therefore, SRC has based the economic assessment on a Joule-Thomson cryogenic helium liquefaction process. The liquefaction plant was modelled using commercially available chemical process simulation software (ChemCAD NXT). Note that this design is conceptual – for discussion purposes only, and not for construction.

A diagram of the flowsheet used in the simulation is presented as Figure 24.

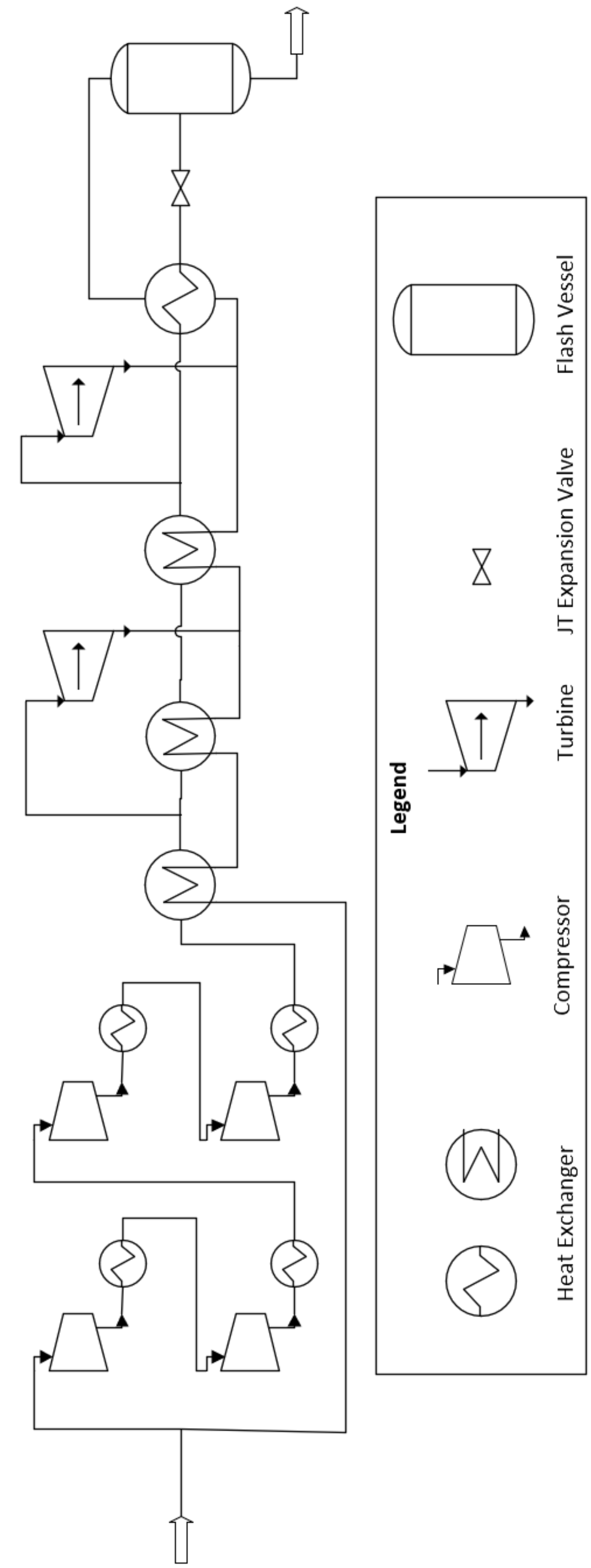


Figure 24 Helium liquefaction process model

The cost of a facility like that in Figure 24 can be developed using engineering estimation methods[29]. The capacity of each major piece of equipment is determined and then the cost of that equipment is established from published sources. The main pieces of equipment are:

- a four-stage intercooled compressor (air-cooled)
- cryogenic heat exchangers
- gas expansion turbines
- a gas-liquid separator
- a Joule-Thomson expansion valve
- remainder of plant (e.g., buildings, storage tanks, control system, etc.)

In order to be able to process helium from anywhere in the province, a liquefier will need to have some flexibility to deal with potential contaminants. A pre-liquefaction purification process is recommended before the main liquefier stage. This section will remove any remaining nitrogen, carbon dioxide, methane, water, or hydrogen in the feed gas. A purification process was designed in ChemCAD based on "near pure" helium feed at 95%. The main pieces of equipment in the pre-treatment section are:

- a four-stage intercooled compressor (air-cooled)
- a hydrogen removal reactor
- a carbon dioxide and water pressure swing adsorption system (PSA)
- a nitrogen and methane PSA system
- knock-out vessels
- a methane combustor
- an activated carbon bed
- heat exchangers (non-cryogenic)

Given the equipment lists and capacity described above, the fixed capital cost of a liquefaction plant of capacity 700 mmcf/y (370 kg/h) (i.e., Scenario 1) is calculated to be $45M. The largest contributor to capital expense is the cost of the compressor. For a second data point, a recent publication by the Canadian Helium Advocacy group estimated capital costs for a smaller 182.5 mmcf/y liquefaction plant to be in the range of $80M-90M. This data can be used to develop a range of capital costs for use in the economic analysis.

Because of economies of scale, building a plant with twice the capacity does not mean it will cost twice as much. As a rule of thumb, capital costs for chemical plants are typically scaled at an exponent of 0.6[29], as shown in the calculation below:

$$C_2 = C_1 \left(\frac{size\ 2}{size\ 1}\right)^{0.6} = \$90M \left(\frac{700 mmcf/y}{182.5\ mmcf/y}\right)^{0.6} = \$202\text{M}$$

The capitol cost calculated from engineering estimates and the scaled industry cost provides us with range of $45M to $202M for capital costs for the 700 mmcf/y facility investigated in Scenario 1.

Operating costs are calculated from a sum of direct manufacturing expenses, such as raw materials (in this case, gaseous helium at 95% purity), utilities (electricity)[30], operating labour (five shifts of three operators each), supervisory labour, maintenance &supplies, operating supplies, and laboratory fees, as well as indirect manufacturing expenses such as overhead, admin, and insurance costs. Estimated total operating expenses (OPEX) for this scenario are in the range of $158M-$168M/y. Note that these costs are "flat costs", and inflation was not taken into account. The largest contributor to the operating expense is the cost of gaseous helium at $7/m^3. The prices of gaseous and liquid helium are likely correlated and are not able to be independently manipulated. The second largest operating expense is the electricity required to operate the facility; the major electricity user in the plant is the compressor.

A theoretical cash flow profile for a 700 mmcf/y (370 kg/h) facility is given in Figure 25. With a discount rate of 15%, the net present value (NPV) at 20 years is $72M - $203M. Payback period is 5-10 years after project start, or 2-7 years after facility start-up. A sensitivity analysis illustrating how the cash flow analysis depends on the input assumptions follows in Section 8.5.

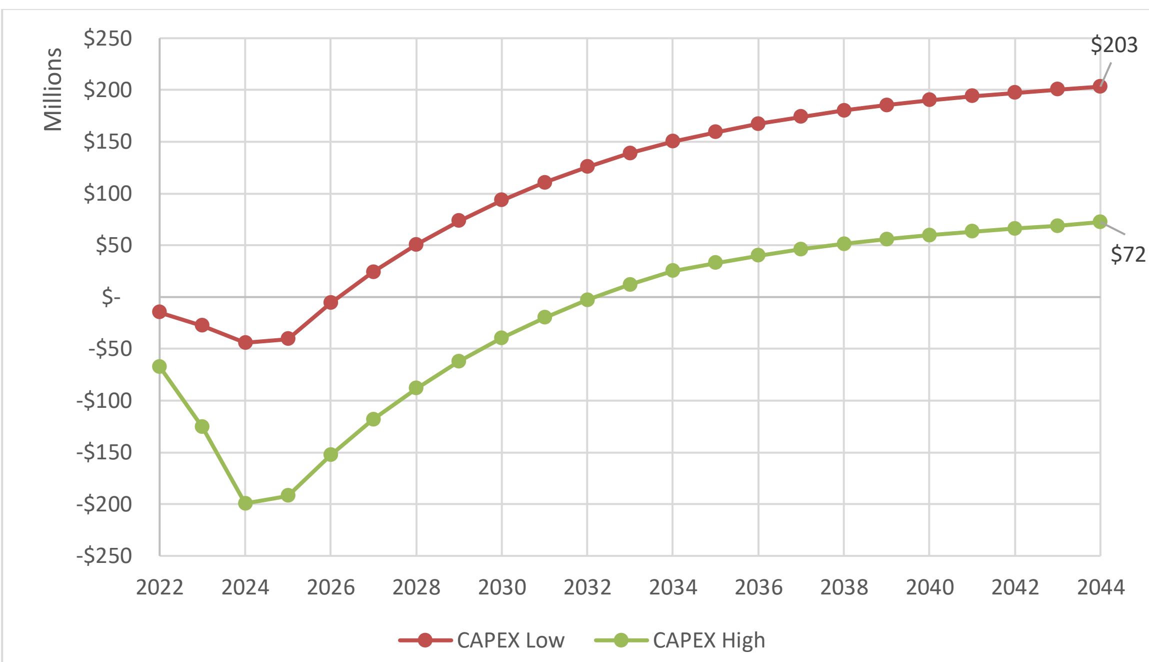


Figure 25 Cash flow profile for a single large helium liquefier in Southern Saskatchewan

8.3 Scenario 2: Single mid-size liquefier in Southern Saskatchewan

In this scenario a single liquefier capable of processing half the province's 2030 helium production goal is built in southern Saskatchewan, near Swift Current. SRC has modelled a liquefaction facility based on a capacity of 350 mmcf/y (190 kg/h) helium using the chemical process simulator ChemCAD NXT. The flowsheet used in the simulation is the same as that presented in Figure 24.

As before, the cost of the liquefaction facility can be approximated using engineering estimation methods. Each major piece of equipment is re-sized based on its new capacity and the cost of that equipment is compiled from published sources. The main components of the system remain the same, i.e.:

- a four-stage intercooled compressor (air-cooled)
- a hydrogen removal reactor
- a carbon dioxide and water pressure swing adsorption system (PSA)
- a nitrogen and methane PSA system
- knock-out vessels
- a methane combustor
- an activated carbon bed
- heat exchangers (non-cryogenic)
- a four-stage intercooled compressor (air-cooled)
- cryogenic heat exchangers
- gas expansion turbines
- a gas-liquid separator
- a Joule-Thomson expansion valve
- Remainder of plant (e.g., buildings, storage tanks, control system, etc.)

Given the equipment and capacity described above, and the estimate provided by the Canadian Helium Advocacy group, Scenario 2 has a fixed capital cost of $37M-$133M. The largest contributor to capital expense is once again the cost of the compressor.

Operating costs are calculated from a sum of direct manufacturing expenses, such as raw materials (in this case, gaseous helium at 95% purity), utilities (electricity), operating labour (5 shifts of 3 operators each), supervisory labour, maintenance & supplies, operating supplies, and laboratory fees, as well as indirect manufacturing expenses such as overhead, administration, and insurance costs. Raw material requirements and utilities scale with the reduced capacity of the plant, but operating labour does not. Modern plants use data acquisition and digital control systems which allow operators to control equipment almost regardless of its size.

Estimated total operating expenses (OPEX) for this scenario are \$83M-\$89M/y. The largest contributor to the operating expense is the cost of gaseous helium at \$7/m^3. As in the previous scenario, the analysis assumes purchasing gaseous helium at full price to account for the opportunity cost of selling to a third party.

A theoretical cash flow profile for a 350 mmcf/y (190 kg/h) facility is given in Figure 26. With a discount rate of 15%, the net present value (NPV) at 20 years is \$9M - \$89M.

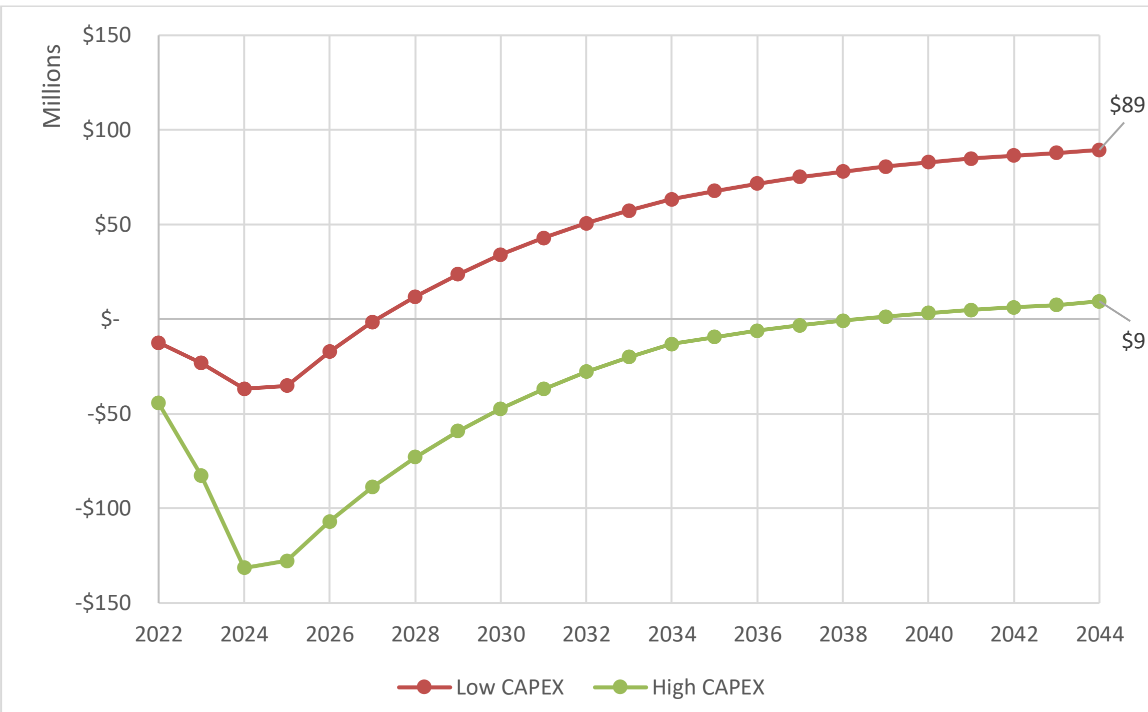


Figure 26 Cash flow profile for a single mid-sized helium liquefier in Southern Saskatchewan

8.4 Scenario 3: Liquefaction Hub

Another option worth considering is building two liquefiers, either as a dual train facility or at two different locations in the province. Although no two plants are ever exactly alike, the economics of this scenario can be estimated by doubling those of Scenario 2. For simplicity, the flowsheet, CAPEX, and OPEX are algebraically doubled, resulting in the cash flow profile in Figure

27. The NPV_{20} discounted at 15% is $54M-$179M, approximately double that of a single plant, and the payback period varies from 6-13 years.

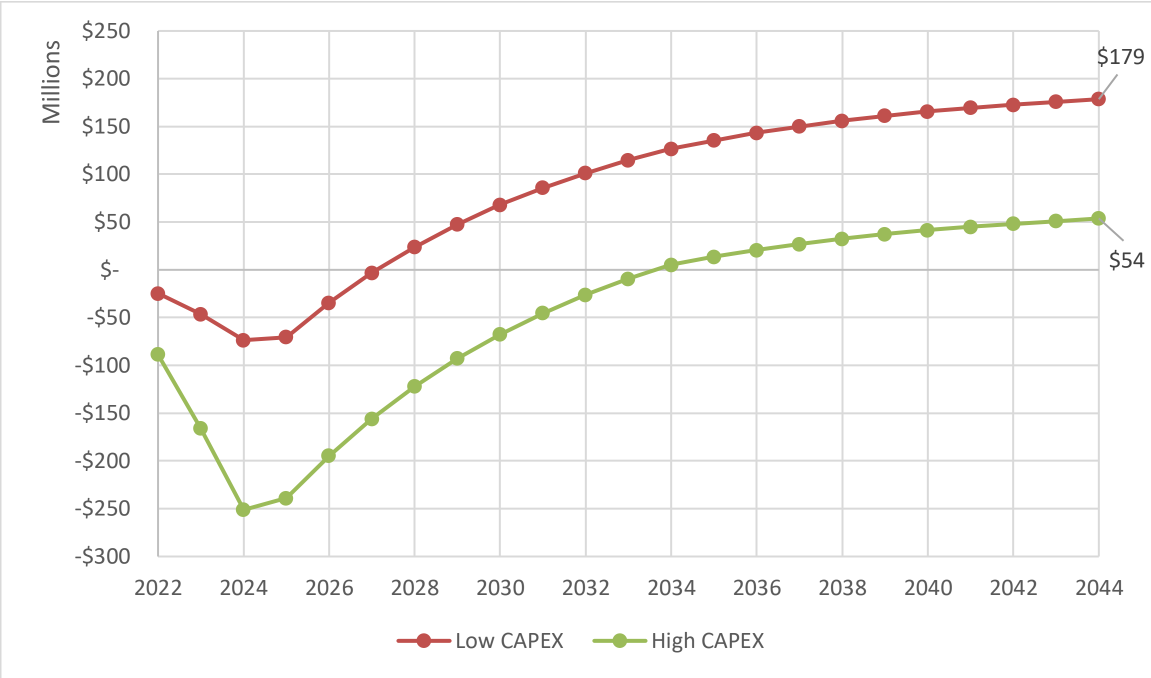


Figure 27 Cash flow profile for two mid-sized helium liquefiers built at the same time

If the province were to support two liquefiers, there's no reason they would need to be built at the same time. In fact, there are many advantages to building them in a stage-gated fashion. If a second plant were built 10 years after start-up of the first plant, the cash flow profile in Figure 28 results. Construction on the second plant begins ten years after start-up of the first plant and takes three years to complete. Each plant is operated for its 20-year life and then shut down. The 15% discounted NPV in this case is between $32M-$104M with payback period of 6-13 years. Note that inflationary effects on future capital expenditures for the second plant are unknown, which could impact the accuracy of this analysis.

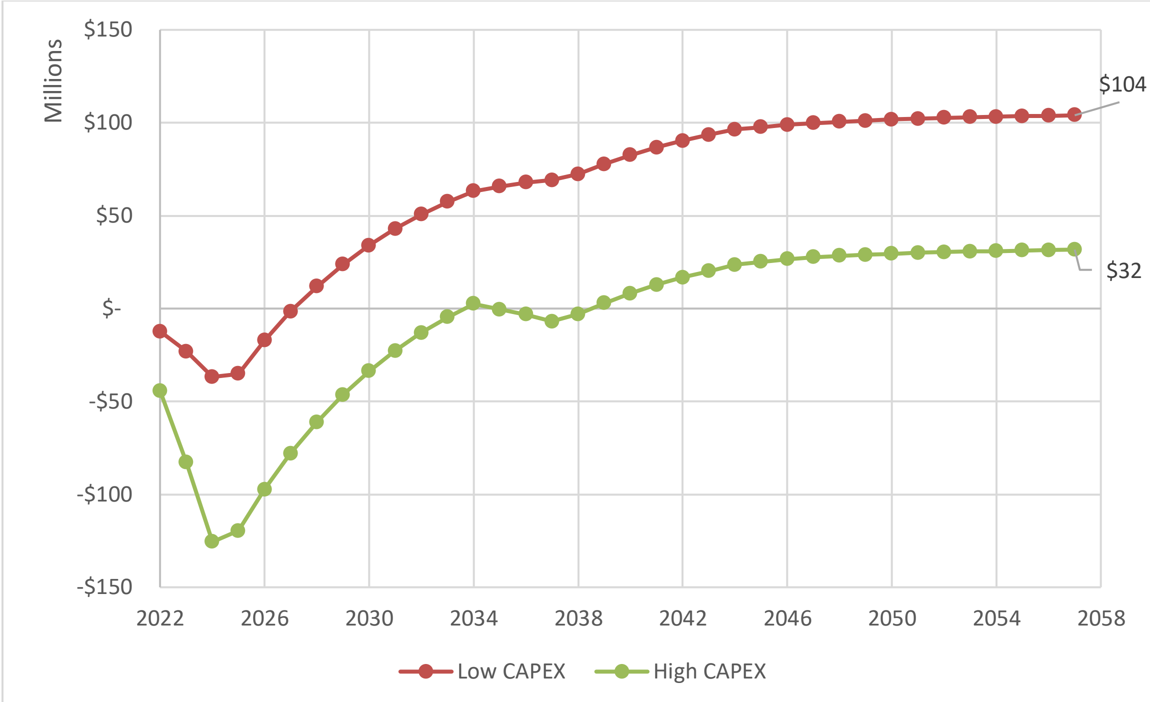


Figure 28 Cash flow profile for two mid-sized helium liquefiers built 10 years apart

8.5 Comparison

Cash flow parameters for the three scenarios are compared in Table 16. The undiscounted cash flow profiles of the three scenarios discussed in this section are compared in Figure 29.

Table 16 Comparison of Cash Flow Parameters

	Scenario	1 - Low	1 - High	2 - Low	2 - High	3 - Low	3 - High
Throughput	mmcf/y	700	700	350	350	2 x 350	2 x 350
	kg/h	370	370	190	190	2 x 190	2 x 190
Capital Cost		$45M	$202M	$37M	$133M	$74M	$266M
Operating Costs		$158M	$168M	$83M	$89M	$166M	$178M
NPV		$203M	$72M	$89M	$9M	$104M	$32M
Payback Period		5	10	5	16	6	13

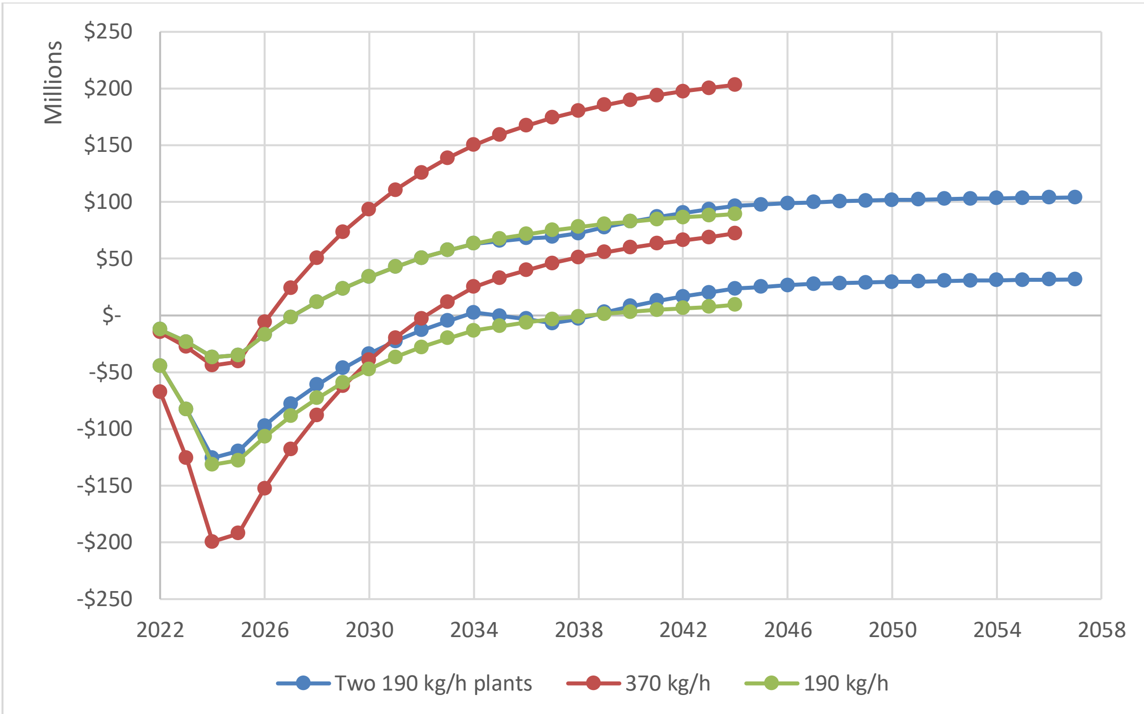


Figure 29 Cash flow profile comparison

As can be inferred from Equation 1 and demonstrated by Figure 29, a larger plant will almost always be more cost effective than multiple smaller ones. However, there are non-financial advantages to building two facilities such as:

- Capital expenditures are spread out over a longer period, which may make it easier to raise the required capital.
- Capacity can be brought onstream in a stage-gated manner as the market develops, rather than all at once. Current Saskatchewan helium production has been estimated at 91 mmcf/y (50 kg/h) based on the monthly production peak in summer 2022.
- Knowledge gained from the first plant can be applied to the second.
- Engineering costs may be reduced as plant design can be reused.
- Having plants in separate locations may create access to different markets, though this is less likely to be a consideration since both plants would be located in southern Saskatchewan.
- Two plants provide redundancy in case of unforeseen shutdown or other complications.
- Scalable capacity – compressors are a major part of the process for helium liquefaction and although a variable frequency drive can allow for turn-down, there are efficiency and economic penalties to operating too far outside their design range. Splitting production into two trains creates the option of operating at reduced capacity. This may not be feasible if the plants are owned by two different entities.

8.6 Sensitivity Analysis

A sensitivity analysis allows one to investigate the impact of changes to various assumed or calculated variables. For example, what is the impact on the profitability of the facility if revenue is lower than predicted? It can also be used to find the variables with the highest impact on the economics of the facility. The project can then be de-risked by investing more time and effort into researching those variables. For example, if the largest impact on profitability came from changes to capital costs, more accurate equipment prices could be obtained through discussion with vendors, rather than relying on the engineering estimates used here. A sensitivity analysis of the cash flow for Scenario 1 (370 kg/h) is given in Figure 30.

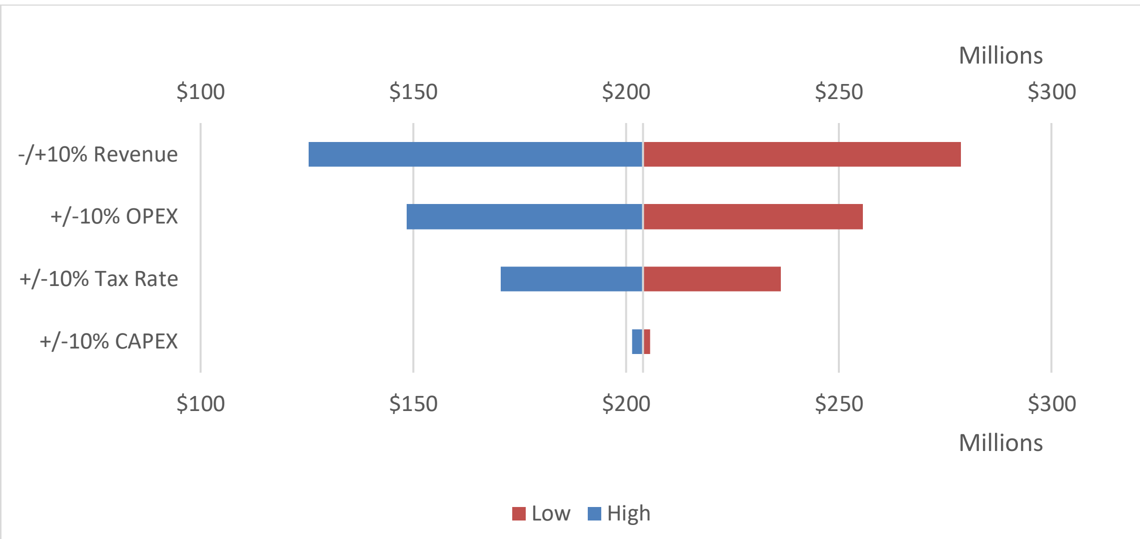


Figure 30 Sensitivity analysis for 370 kg/h liquefaction plant

According to the sensitivity analysis in Figure 30, the most impactful variables for NPV are revenue and operating expenses. Revenue is dominated by the margin between gaseous and liquid helium. The largest contributor to operating expenses is the cost of gaseous helium, as discussed in Section 7.2. Therefore, we can surmise that the variable with the largest impact on profitability is the price of helium. Unfortunately, due to the private nature of helium sales contracts, this is also one of the variables in which the authors have the least confidence. Helium producers who are interested in liquefaction will have more details on current and projected helium prices; it may be in their best interest to lock in long-term purchase contracts to reduce the risks of price volatility.

Changes to taxation rate (which may take the form of government tax breaks or royalty incentives) and changes to the capital cost have much smaller impacts, as shown in Figure 30. Note that while the impact of capital costs on NPV can be reduced by the ability to write-down the depreciation of the asset, large capital costs can have a major impact on whether a project goes ahead, due to the difficulty of raising capital.

8.6.1 Project funding sources

Saskatchewan – Policy Overview

In 2021, Saskatchewan released its Helium Action Plan which focuses on five key areas: exploration, production, innovation, processing, and export infrastructure, with the overarching goal of producing 10 per cent of the world's helium by 2030.

The Government of Saskatchewan has two key incentive programs that are applicable to helium processing facilities:

Oil and Gas Processing Investment Incentive (OGPII)

OGPII is administered by the Ministry of Energy and Resources (MER) and offers a 15 per cent transferable oil and gas royalty/freehold production tax credit for eligible costs of the program.[31] Helium processing and liquefaction facilities are listed as eligible projects.

The cap for projects is set at $75 million (i.e., $500 million project) for oil, gas, and helium projects.

Saskatchewan Petroleum Innovation Incentive (SPII)

SPII is also administered by MER. The program offers transferable oil and gas royalty/freehold production tax credits for commercialization projects at a rate of 25 per cent of eligible project costs.[32] The credit cap is $5 million (i.e., $20 million in eligible costs per project).

SPII includes pilot projects and commercial scaling projects in the oil, gas and helium industries which are at a 7 or higher on the Technology Readiness Level (TRL) Scale. Eligible activities include improving helium recovery, managing adverse environmental issues, increasing processing capacity or commercializing helium production byproducts or waste.

Government of Canada

Currently there are no active helium-specific funding programs. The primary source of funding for helium development is expected to be linked to Canada's critical minerals strategy.[33] The government closed consultations about the discussion paper in September 2022 and the strategy will be published by the end of the year. Canada's current list of critical minerals includes helium.[34]

The Federal Budget of 2022 proposed to provide up $3.8 billion over eight years to implement the strategy.[35] Allocations that could be relevant for helium processing include:

- $1.5 billion for new infrastructure investment for mineral projects in critical regions (note that in this strategy Saskatchewan is highlighted for its opportunities in helium production; see map below)
- $144 million for critical mineral R&D to support extraction and processing of critical minerals

It is anticipated that specific funding will begin to be announced in early 2023 and roll out over the length of the 8-year program.

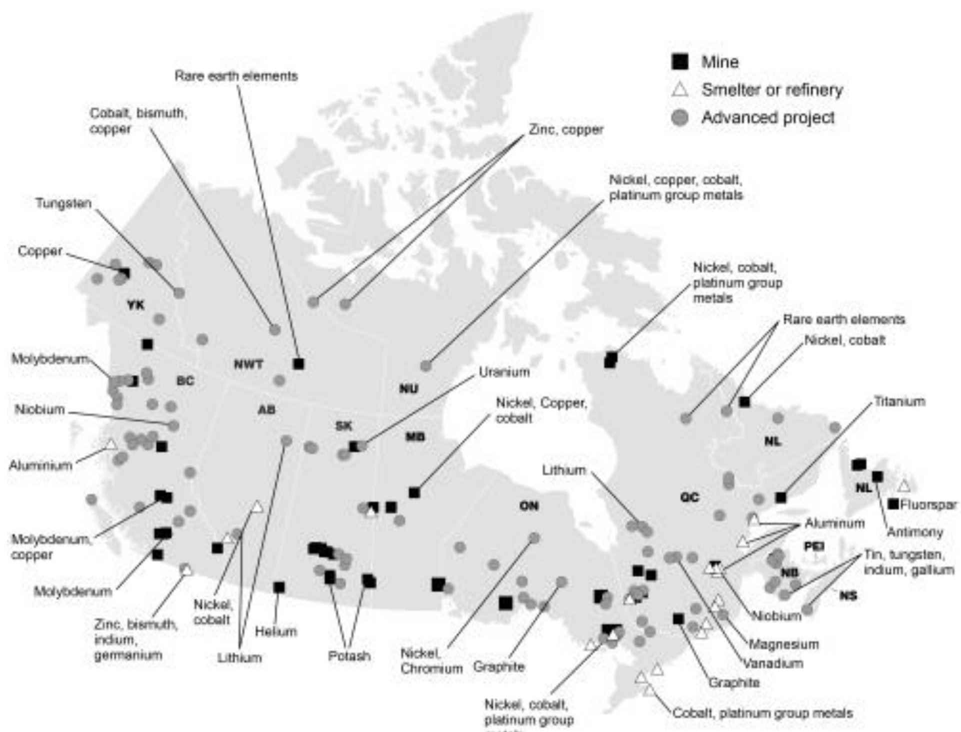


Figure 31 Critical Mineral Opportunities in Canada (Source: Federal Budget 2022)

PrairiesCan

Business Scale-up and Productivity (BSP) in the Prairie Provinces

PrairiesCan accepts expressions of interest on an ongoing basis for the BSP program.[36] It gives special consideration for companies working in the critical minerals processing space. The program provides up to 50 percent of eligible costs up to a maximum of $5 million.

8.6.2 Ownership models

Although the stakeholder survey response was somewhat lower than anticipated, the responses that were received indicated an interest in further exploring a liquefaction project, potentially with partners and a willingness to invest. A stakeholder suggested that they believed that there will be enough production to justify a facility, but that a cooperative ownership model is likely necessary. The same stakeholder suggested that local support may be particularly important to the success of this project.

9. Summary

Helium is a critical mineral with applications in healthcare, scientific research, microchip manufacture, and space exploration, among other industries. The era of the US Strategic Reserve has come to an end, and sources from further afield will be playing a larger role in supply. Saskatchewan has an opportunity to be a significant source of helium for the world; the goal of the Government of Saskatchewan's Helium Action Plan is to provide 10% of the world market by 2030. Canadian liquefaction facilities would help broaden liquid helium supply options. Most stakeholders surveyed provided positive feedback for the prospect of a helium liquefier in Saskatchewan.

A brief review of the geology of helium producing areas, including an estimate of production and reserves, was provided. Readers searching for a more in-depth discussion of geology are referred to Melinda Yurkowski's 2021 report on helium in southern Saskatchewan[7]. The environmental process has been outlined and summarized in this report. A focus on the special area south of the divide provided additional insight into the concerns of this unique area.

Section 7 summarized the current market conditions for helium. Helium prices were estimated at $7/m^3 for gaseous helium and $13/m^3 for liquid helium. Transportation by truck, rail, and pipeline were discussed in brief, with truck transportation the most likely option for a Saskatchewan liquefier. Developments in potash mines, rare earths, and lithium will continue to put pressure on labour availability but will also provide a source of skilled workers along with existing local Oil and Gas operators.

The economics of a potential liquefaction facility or hub were discussed in Section 8. Several scenarios were investigated, all anticipated to return a positive net present value after 20 years at 15% discount rate. Pay-back periods varied between 5-13 years depending on the scenario analyzed. The economic return of a large-scale facility was more attractive than that of the two smaller facilities, but the stage-gated approach of building two plants (or two trains in a single facility) at different times has several other advantages. A sensitivity analysis of the cash flows indicated that helium price and operating expenses were two of the largest sources of variability in the analysis, and they should be investigated with care before making any decisions. Some potential funding sources were listed.

A Saskatchewan liquefaction hub could open broader helium markets, create jobs, and provide a positive financial return for its owners. Some risks remain; in particular, the full extent of recoverable reserves, the final cost of a liquefaction facility, and the price of liquid helium in the future should be investigated in more detail. Overall, a helium liquefaction facility is a promising opportunity for the Province of Saskatchewan that bears further examination.

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