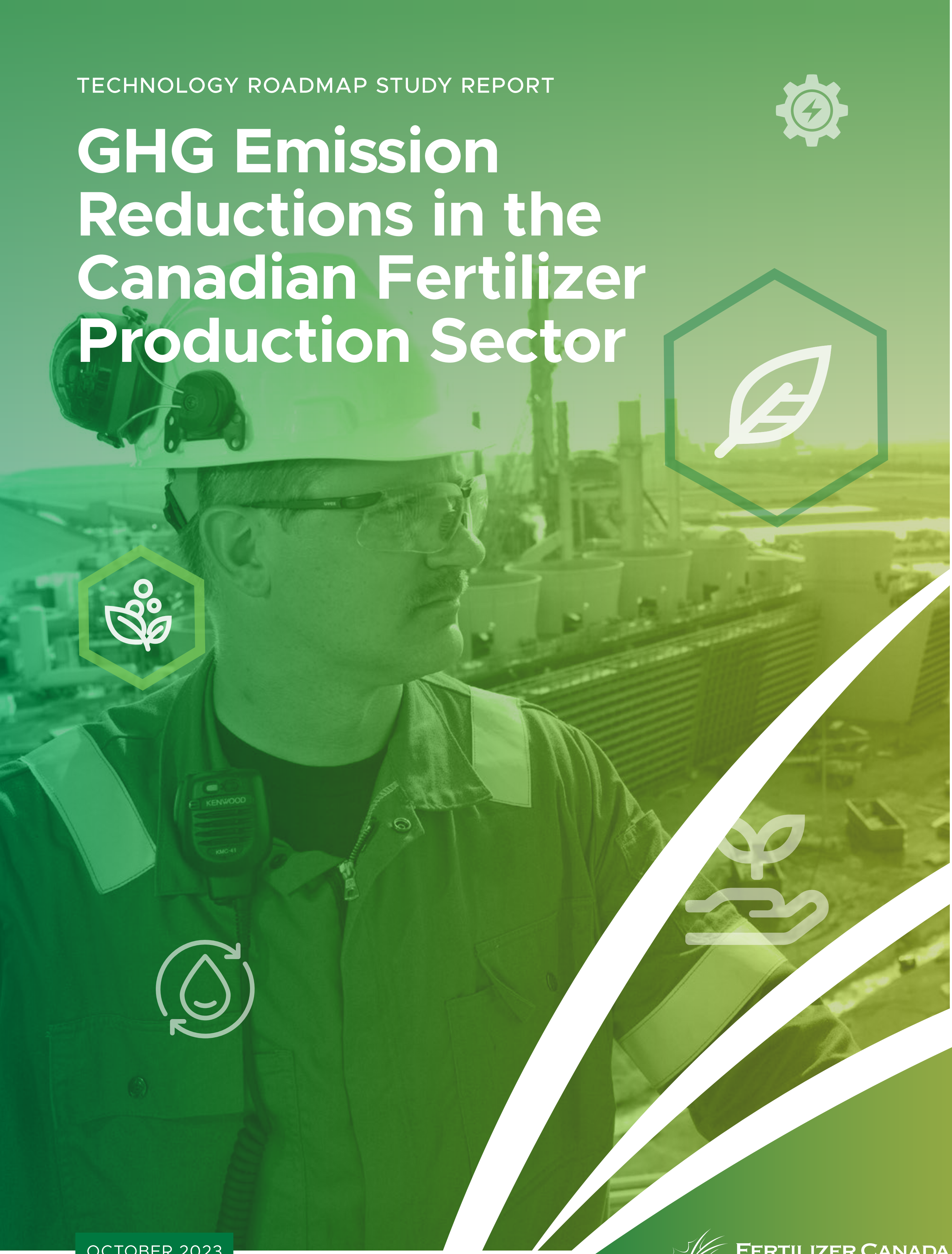
TECHNOLOGY ROADMAP STUDY REPORT

GHG Emission Reductions in the Canadian Fertilizer Production Sector



OCTOBER 2023

FERTILIZER CANADA

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User Note: This Table of Contents section acts as a reference point for the Record of Issue, Executive Summary and Study Limitations sections as and when they might be required.

Therefore, the structure of this section must not be altered in any way.

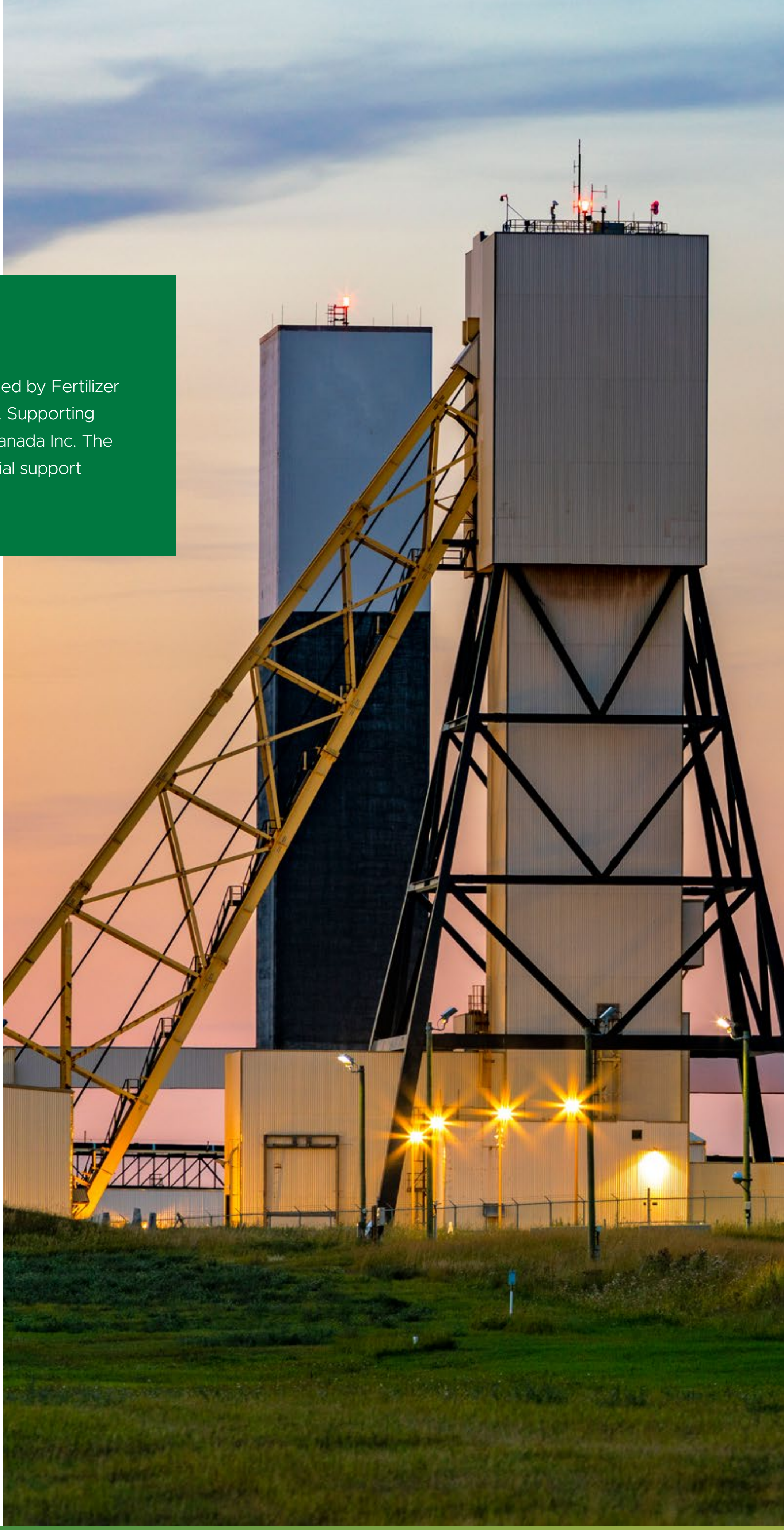
Executive Summary

Canada has a mature potash and nitrogen fertilizer sector that is a significant source of exports and contribution to the Canadian economy. As demonstrated in this study, when compared to other countries both the potash and nitrogen fertilizer sector are the best performing country globally with respect to greenhouse gas emissions intensity. At the same time carbon pricing and the demand for low carbon hydrogen and ammonia has the potential to disrupt the sector. This study outlines potential decarbonization technologies for the Canadian potash and nitrogen fertilizer production sector and discusses the implementation barriers and opportunities that are unique to the sector.

With the exception of the Jansen potash project there are currently no major sector projects planned. This demonstrates the lack of incentives in Canada for new projects that has resulted in no ammonia plants built in Canada over the last 30 years. Governments, financial institutions, and industry need to work together on how to de-risk investments in decarbonization technology projects in order to meet federal and provincial reduction objectives. New projects will need more regulatory certainties, especially for large-scale projects as an individual company is not able to absorb the risks like they could for small projects. Fixed prices, regulatory certainty and long-term commitment are tools that could help promote these investments.

There is not one clear technology to produce low carbon hydrogen to meet the projected demand. Electrolyzers and steam methane reformers coupled with carbon capture, utilization, and storage (CCUS) are different competitive technologies that both need to be developed at the same time. This study describes barriers, the tools, investments and timeline required to bring large scale projects on-line.

Canada is missing momentum for support of large scale decarbonization projects and the production of low carbon hydrogen and ammonia at scale. It's clear that we need more low carbon electricity supply, that we need the infrastructure to supply the energy needed for production and we need certainty to allow suppliers to make these investment decisions. It's clear that there is not one technology that can meet the demand and so we support both the expansion of our electrical systems and address other challenges such as a broader electrification and industrial decarbonization that have common solutions. We need to start to overcome these barriers now to meet the demand. It is hoped that the information contained in this study will help promote these discussions.



Acknowledgements

The study report was commissioned by Fertilizer Canada with input from members. Supporting work and analysis was by WSP Canada Inc. The report was developed with financial support from Natural Resources Canada.

Introduction

Fertilizer Canada represents manufacturers, wholesale and retail distributors of nitrogen, phosphate, potash and sulphur fertilizers. The fertilizer industry plays an essential role in Canada's economy, contributing over $23 billion annually and employs 76,000 workers throughout the supply chain. We take pride in advocating for sustainability, stewardship, safety and security through our industry-leading standards and Codes of Practice. As the foundation of Canada's agri-food sector, we apply innovative solutions that positively impact the environment, the economy, and the social fabrics of Canadian life.

Our industry is energy intensive. As such we are committed to high standards for environmental sustainability, and we support science-based policy that achieves environmental objectives while also maintaining our industry's global competitiveness. As part of our commitment, we proactively conducted a decarbonization technology scan for the Canadian fertilizer sector which explains current manufacturing processes, evaluates new and emerging technologies against their emission reduction potential, commercial scalability, economic viability, and regional considerations. This scan, along with key takeaways from the Sustainable Hydrogen and Ammonia Forum held in September 2022 in association with the Chemistry Industry Association of Canada forms the basis of this study.

Our industry is trade exposed. The potash industry continues to be a highly export driven industry and is a world leader in sustainable fertilizer manufacturing in Canada. Canadian potash is produced with an approximately 50 per cent lower Greenhouse Gas (GHG) intensity in comparison to global competitors (Cheminfo Services Inc. 2020)), with 95 per cent of Canadian potash production exported to global markets. Canadian nitrogen facilities primarily produce for the North American market and rank first as the most feed-and-fuel energy-efficient plants in the world (WSP 2023). However, they are competing in a global market and are subject to the prices and forces of supply and demand at work within that global market.

As a mature energy intense and trade exposed (EITE) industry, these results show that the Canadian fertilizer industry has already assessed their operations to implement improvements to the energy profiles, otherwise known as "low-hanging fruit" measures, to reduce GHG emissions. This study therefore focussed on the decarbonization measures that had the potential to result in a significant reduction in GHG emissions, or commonly referred to as a 'step change' in GHG emissions. The study outlines potential decarbonization technologies for the fertilizer sector and discusses the implementation barriers and opportunities that are unique to the sector. Further emission reductions will require major investments of time and capital to develop and implement emerging low-carbon technologies, such as carbon capture, utilization, and storage (CCUS) or, in the long-term, electrolysis to produce clean hydrogen, and the possibility of small modular reactors to supply process heat, and electricity for direct use and to produce hydrogen through electrolysis. Implementation of these low-carbon technologies at our facilities also depends upon access to infrastructure (sequestration injection locations and pipelines, net-zero electricity, etc.,) and supply chains which do not currently exist in Canada and will take years, if not decades, to develop. Near term actions and government support that could facilitate the implementation of decarbonization technologies are discussed including regulatory approvals and policy, funding programs and initiatives, strategic planning and education infrastructure.

Overview of the Canadian Fertilizer Sector

There are nine nitrogen and ten potash fertilizer production facilities within Canada (Figure 1). Nitrogen based fertilizer production is concentrated in Western Canada with six facilities in Alberta, and one facility in each of Saskatchewan, Manitoba and Ontario. Potash based fertilizer production is focused in Saskatchewan.

Potash based fertilizer is mined. There are two distinct types of potash fertilizer production facilities—conventional mining and solution mining. In conventional mining ore is extracted from underground deposits using conventional mining equipment, and then is transferred to the surface for further processing. In solution mining a brine solution is heated and injected into the deposit. The brine dissolves the potash and the solution is returned to the surface for further processing.

Of the nine nitrogen fertilizer production facilities, eight produce ammonia from natural gas using steam methane reforming. One facility does not use steam methane reforming, instead it receives hydrogen and nitrogen from nearby petrochemical facilities, delivered by pipeline.

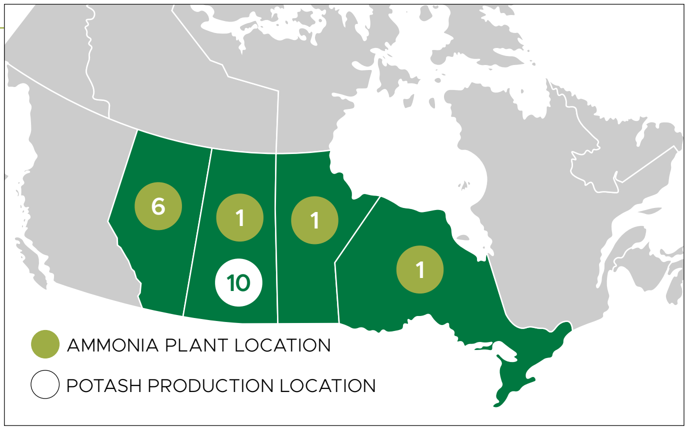
Annually, the sector produces approximately 4.8 million tonnes of ammonia, 61 per cent of which is further processed into other nitrogen-based products. This places Canada at approximately 10th in the world for production with approximately 35 per cent of production exported.

Approximately 22.5 million tonnes of potash-based fertilizer is produced annually making Canada the largest producer in the world with approximately 90 per cent of production exported. The United States (U.S.) is Canada's largest fertilizer export market: 34-38 per cent of total fertilizer exports were sold to the U.S. between July 2019 and June 2022.

The number of ammonia plants has not changed significantly over the past 20 years, with no new major production facilities becoming operational in that time and no new facilities in late-stage development. One ammonia plant in Kitimat closed in 2005. The age of current ammonia plants ranges from 30 and 67 years, with an average age of 48 years. Similarly, the potash sector has not changed significantly over the past 20 years with the same solution and conventional potash mines operational today as in 2002, with the exception of the opening of the Bethune mine in 2017, the closure of the Sussex mine in 2016 and the BHP Jansen mine planning to begin operation in 2026 (K+S 2023, CFI/CIPEC 2008, BHP 2023).

FIGURE 1: Fertilizer Production Facilities in Canada

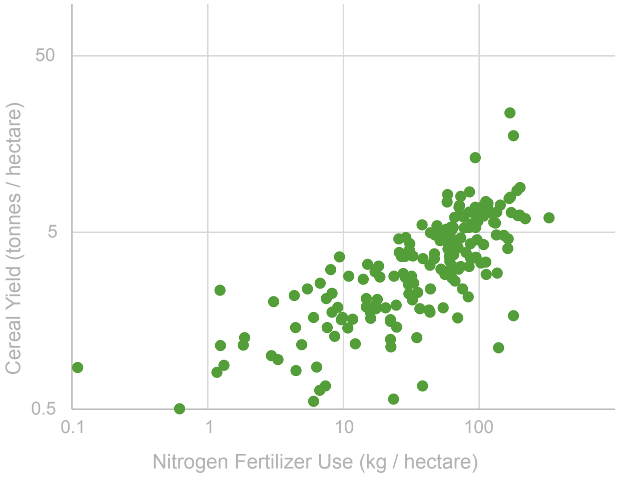
NITROGEN FERTILIZER PRODUCTION	POTASH FERTILIZER PRODUCTION
CF Industries—Courtright, ON	K+S—Bethune, SK (Solution)
CF Industries—Medicine Hat, AB	Nutrien—Allan, SK (Conventional)
Koch Fertilizer Canada—Brandon, MB	Nutrien—Cory, SK (Conventional)
Nutrien—Carseland, AB	Nutrien—Lanigan, SK (Conventional)
Nutrien—Fort Saskatchewan, AB	Nutrien—Patience Lake . SK (Solution)
Nutrien—Joffre, AB	Nutrien—Rocanville, SK (Conventional)
Nutrien—Redwater, AB	Nutrien—Vanscoy, SK (Conventional)
Sherritt Int. Corp.—Fort Saskatchewan, AB	Mosaic—Belle Plaine, SK (solution)
Yara Belle Plaine—Belle Plaine, SK	Mosaic—Esterhazy, SK (Conventional)
	Mosaic—Colonsay, SK (Conventional)



2.1 Production

Fertilizer provides essential nutrients for the production of food crops. It increases plant yields, prevents soil depletion and improves the nutritional values of crops, thereby assuring food security and improving human health. Figure 2 shows the relationship between cereal yield and nitrogen fertilizer application in 186 countries in 2019 (FAO 2023). The general trend showing increasing yields with increased fertilizer application underlines the importance of fertilizer production.

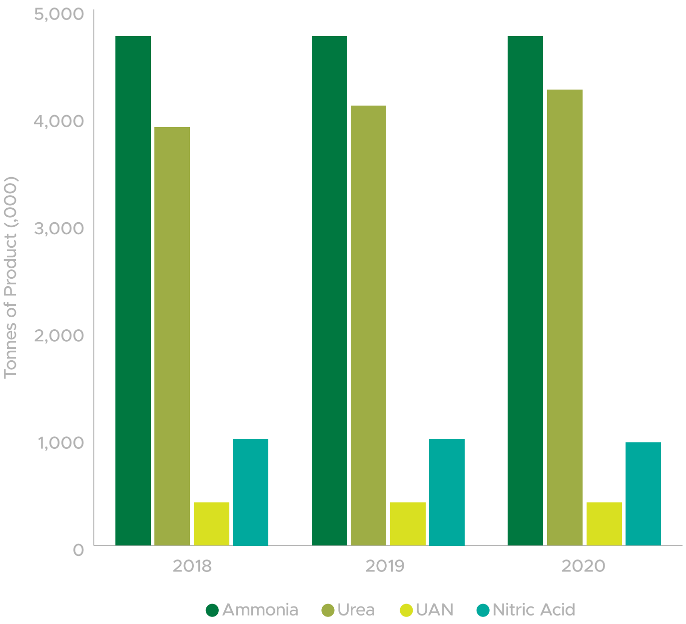
FIGURE 2: Cereal Yield and Nitrogen Fertilizer Use by Country in 2019



Source: FAO 2023

Annual nitrogen fertilizer production amounts were reported by the participating facilities for the three years of this study: 2018-2020. These were summed to calculate sector-wide production values for all of Canada and are presented in Figure 3. Ammonia is both sold for direct application as a fertilizer and it also acts as the precursor in the production of the other nitrogen fertilizer products, the main ones of which, urea, urea ammonium nitrate and nitric acid are also shown in Figure 3.

FIGURE 3: Total Annual Production of Nitrogen Fertilizer Products Reported by Canadian Facilities from 2018 to 2020

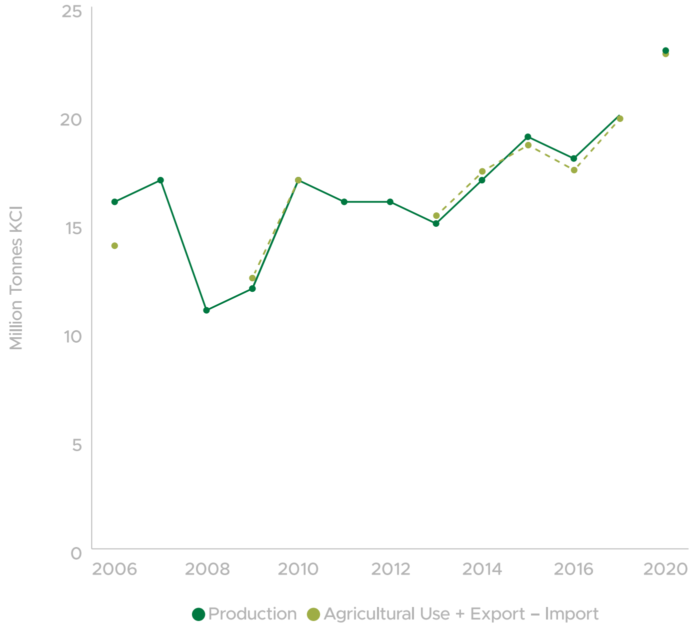


UAN: Urea Ammonium Nitrate

Ammonia production has increased slightly year-over-year from 2018 to 2020, with a 3-year average production of 4.8 million tonnes. Urea production has increased more rapidly over the same period with a 3-year average production of 4.1 million tonnes and a 9 per cent growth from 2018 to 2020. Annual production of urea ammonium nitrate has been somewhat stable over the period (average production of 420 thousand tonnes) and nitric acid production has declined from 2018 to 2020, showing a decrease of 18 per cent to 800 thousand tonnes in 2020.

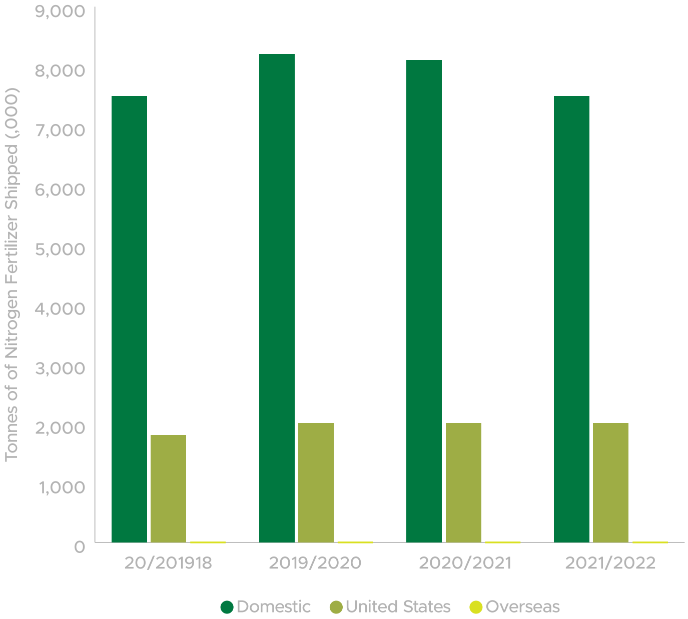
Canada produces the most potash in the world, accounting for 31 per cent of global production (NRCan 2022). Statistics regarding potash, including production, exports, imports and domestic use are available from the Food and Agriculture Organization of the United Nations (FAO) for over 245 countries and territories including Canada (FAO 2023). Canadian production and net use (agricultural use + exports—imports) of potash products from 2006 to 2020 are plotted in Figure 4. Gaps in the timeseries are where data was not available; net use was not calculated where any one of the three inputs was not available.

FIGURE 4: Canadian Production and Net Use of Potash from 2006 to 2020



Source: FAO 2023

FIGURE 5: Nitrogen Fertilizer Used Domestically and Exported to the United States.



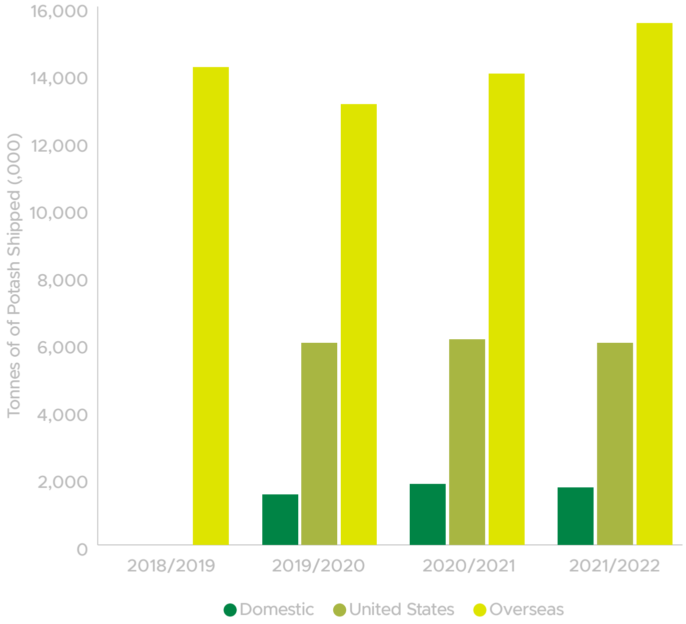
Note: periods shown are from July 1 to June 30 of the following calendar year; Source: Statistics Canada

Canadian potash production has seen an overall increase from 2006 to 2020 with year-to-year variability. Annual production in 2020 was estimated at 22.5 million tonnes. Domestic use in recent years has consumed 3–5 per cent of production while the majority is exported (90–95 per cent since 2015). Small amounts of potash (< 0.1 per cent of production) are also imported into Canada annually.

Statistics Canada collects data on the domestic use and exporting of fertilizer products in Canada (Statistics Canada [date unknown]). Figure 5 presents the amounts of nitrogen fertilizer (Ammonia, Urea, UAN, Ammonium nitrate, calcium ammonium nitrate, ammonium sulphate, monoammonium phosphate, diammonium phosphate) use within Canada and exported to the United States. Quantities include imports as well as Canadian production. No overseas exports of nitrogen fertilizers are reported, all nitrogen fertilizer shipped within or from Canada is sold within North America. Domestic consumption varies between 3.7 and 4.4 times more than quantities exported to the United States.

Figure 6 presents amounts of potash used domestically and exported to the United States and overseas. As the world's largest potash producing country with 31 per cent of global production in 2021, it is expected that exports would exceed domestic use significantly.

FIGURE 6: Potash Fertilizer Used Domestically and Exported to the United States and Overseas.



Note: periods shown are from July 1 to June 30 of the following calendar year; Source: Statistics Canada

2.2 GHG Emissions

Fertilizer production is energy intensive, **with ammonia production alone consuming approximately 2 per cent of the world's final energy consumption in 2020** (IEA 2021).

2.2.1 AMMONIA PRODUCTION EMISSIONS PROFILE

All nitrogen-based production facilities in Canada, with one exception, utilize natural gas with steam methane reforming to produce the hydrogen needed in the ammonia process. A schematic of the production of ammonia and associated products are shown in Figures 7 and 8.

Carbon dioxide is formed as a by-product of the steam methane reforming process and is:

- Utilized by many facilities downstream to produce **urea**
- Captured and sold or utilized where infrastructure exists, or
- Otherwise vented.

These emissions are referred to as ***Process* CO_2 emissions**. The second main source of carbon dioxide comes from the combustion of natural gas that provides heat for the steam methane reforming and other processes within the ammonia plant. These emissions are referred to as ***Combustion* CO_2 emissions**.

Carbon Dioxide Emissions from Ammonia Plants

Process CO_2 emissions are a byproduct formed during the ammonia production process. The resulting stream is nearly pure CO_2 (greater than 99%). Many facilities use this CO_2 stream as a feedstock for urea.

Combustion CO_2 emissions result from the combustion of natural gas in order to provide heat to the ammonia production process. This flue gas contains many other combustion products and is not pure CO_2 (less than 10%).

FIGURE 7: Schematic of Nitrogen Based Fertilizer Production and GHG Emissions

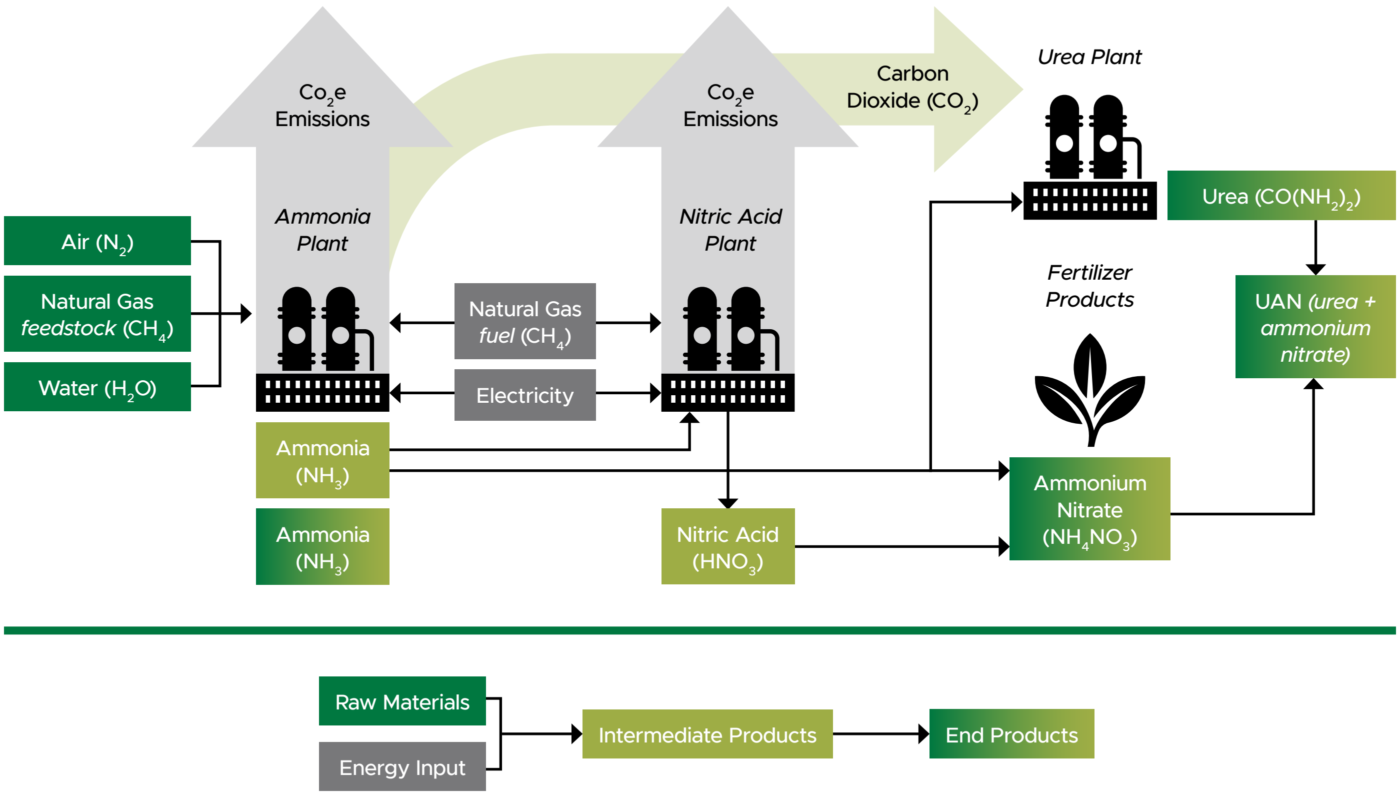
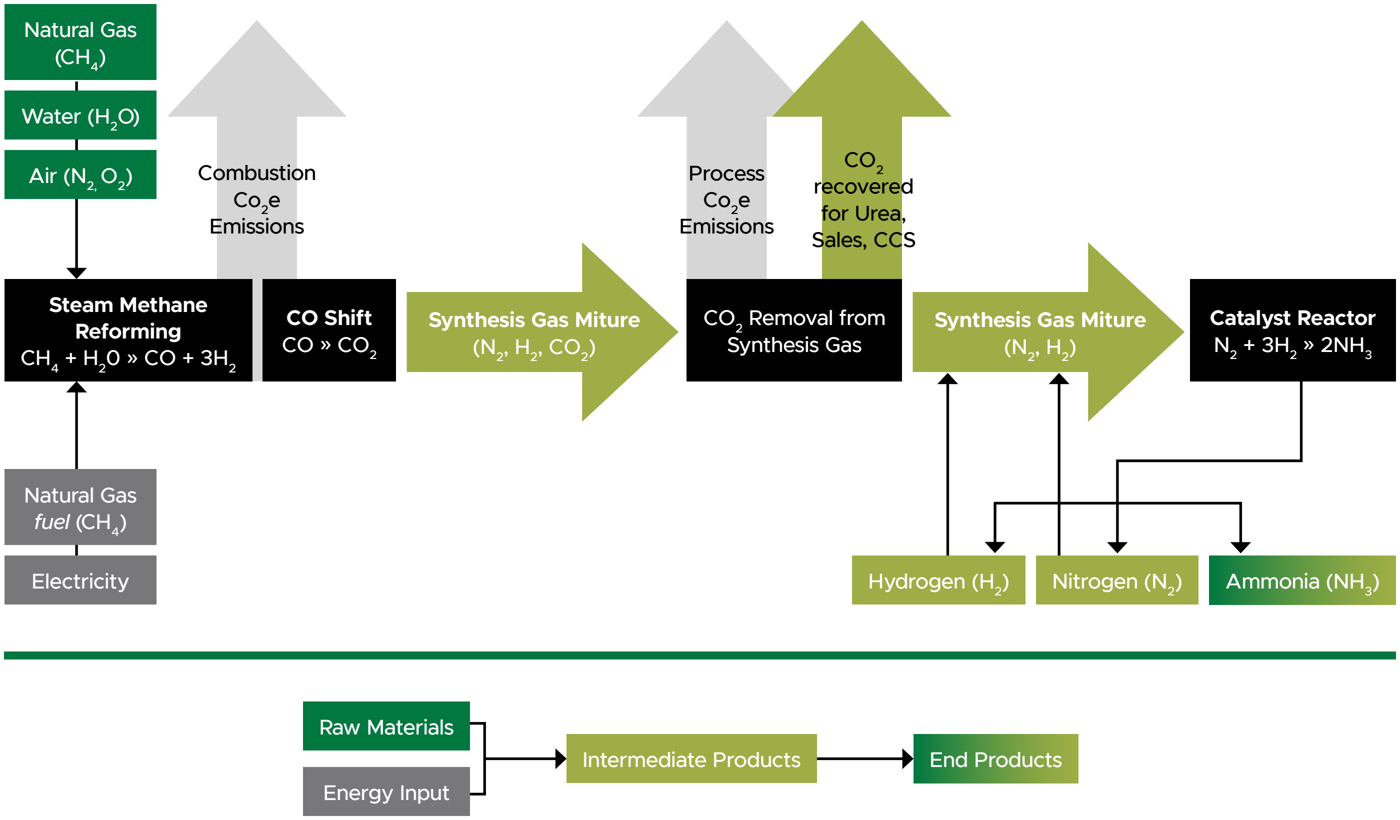


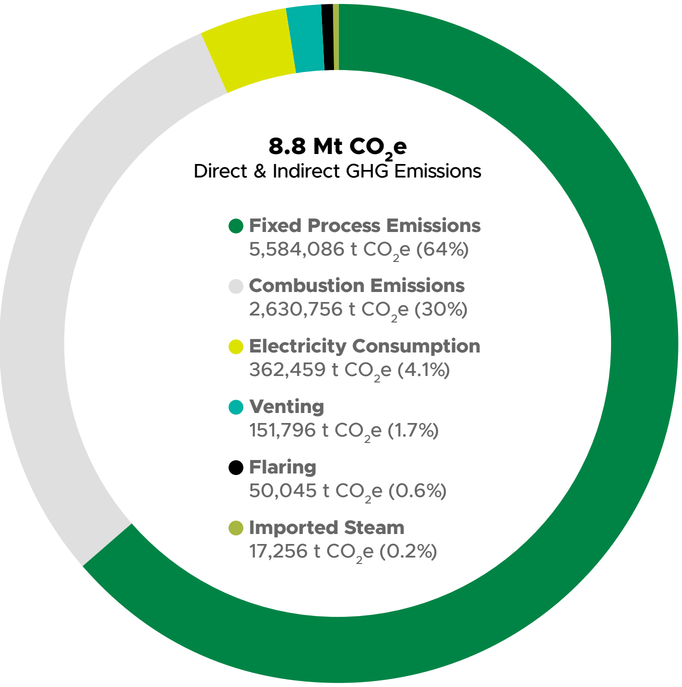
FIGURE 8: Schematic of Ammonia Production Using Steam Methane Reforming and the Haber-Bosch Process



Ammonia production is the most energy intensive nitrogen fertilizer product, and therefore the largest source of emissions. Data provided by the operators of the eight nitrogen ammonia production facilities using steam methane reformers was used to develop a profile of GHG emissions from ammonia production (Figure 9).

Data on fuel and energy use were provided for the three-year period of 2018 through 2020. The GHG emission calculations considered the energy balances into and out of the ammonia plant (specifically steam imports and exports) because the ammonia plant is usually part of a larger facility that undertakes other processes.

FIGURE 9: Ammonia Production GHG Emissions Profile—Steam Methane Reforming Facilities Only



Process CO_2 emissions are the largest emission source (prior to any emissions recovery and utilization), ranging from **50 per cent to 81 per cent at individual facilities**, with an **average of 64 per cent**. The second largest source is **combustion emissions, ranging from 18 per cent to 43 per cent, with an average of 30 per cent**. Venting and flaring combined comprise 2.3 per cent of emissions and imported steam and electricity make up 4.3 per cent. Emissions associated with vehicles use were reported by all facilities, however these were generally small (<1 per cent of facility wide emissions) and therefore have not been included in the sector wide totals.

All ammonia facilities operating using steam methane reformers capture a portion of the process CO_2 emissions for a beneficial use. Listed uses for captured CO_2 are:

- use as a feedstock in urea production, a valuable nitrogen-based fertilizer in Canada (CO_2 in urea will be released and emitted to atmosphere once applied for agricultural use).
- enriching the atmosphere in a neighbouring greenhouse,
- sale to specialty gas suppliers and third-party liquefaction facilities, and
- carbon capture and permanent sequestration via the Alberta Carbon Trunk Line (ACTL).

Carbon Dioxide Emissions Beneficial Use

In 2020, 61% of ammonia production process emissions were used for other beneficial purposes (approximately 55% for urea production and 6% for other uses).

2.2.2 POTASSIUM BASED FERTILIZER EMISSIONS PROFILE

The potash (potassium chloride) used to produce Canadian potash-based fertilizer is mined at 10 facilities in Saskatchewan. Conventional mining is used to extract potash from shallower deposits at depths ranging from approximately 950 to 1075 m (Figure 10) whereas solution mining is typically employed for deposits at depths greater than 1100 m (Figure 11).

The **largest source of GHG emissions in solution mining is the combustion of natural gas** to heat water which is pumped through the ore body to dissolve the potash. The resulting brine solution is pumped back up to surface pond(s) for extraction. During extraction, the potash is precipitated from solution, recovered, and sent to the mill facility where it is processed and dried. Product drying is another main source of GHG emissions.

In conventional mining, potash is extracted from underground deposits using electric powered continuous mining machines and conveyors, hoisted to the surface and then milled and refined. Saskatchewan has one of the highest electrical grid intensities in Canada. As a result, indirect emissions from electrical use are quite high. Once refined, the product must be dried. Combustion of natural gas to provide the heat required is the main source of direct emissions. The main sources of direct and indirect GHG emissions are crushing and grinding and product drying (Katta 2019).

The extracted and refined potash can be combined with nitric acid to produce potassium nitrate which requires further energy inputs in the form of process heat (combustion of natural gas).

FIGURE 10: Schematic of Potash Fertilizer Products Using Conventional Mining Extraction Methods

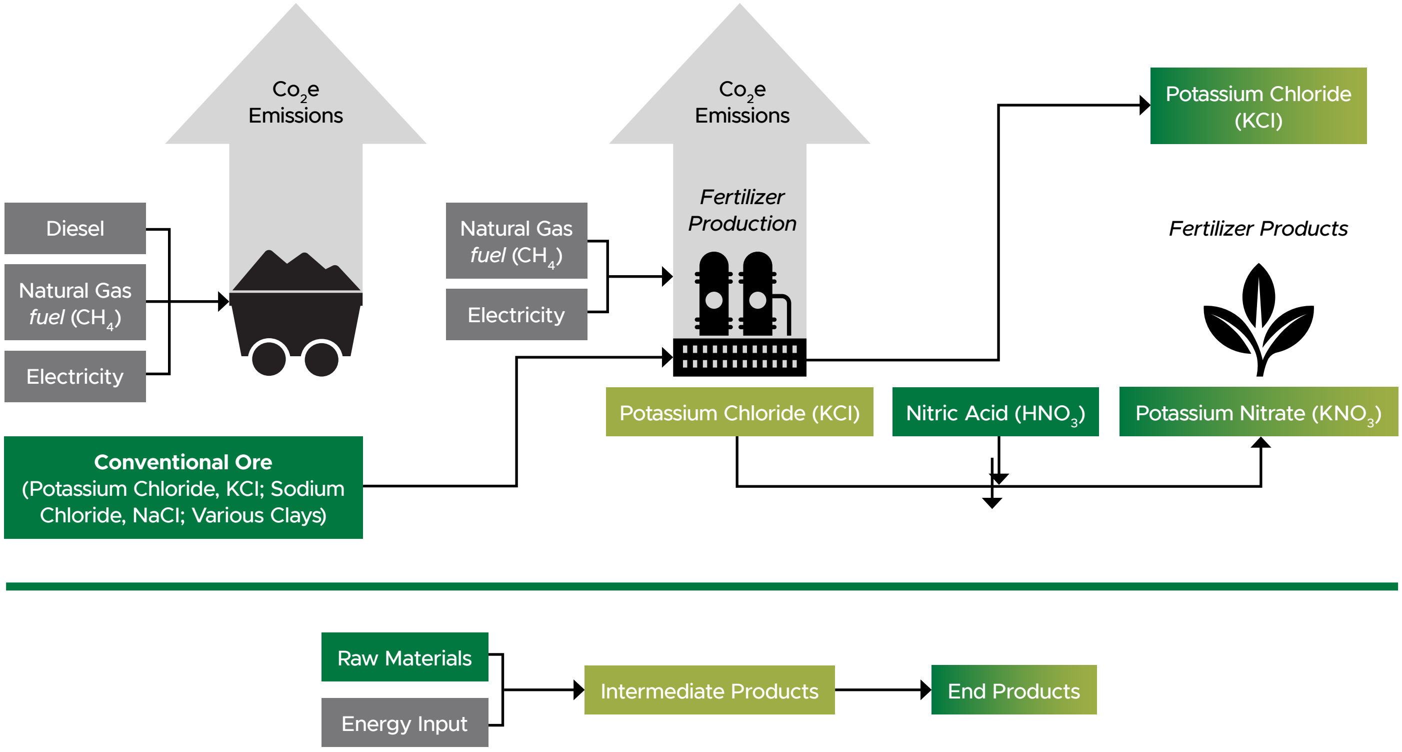
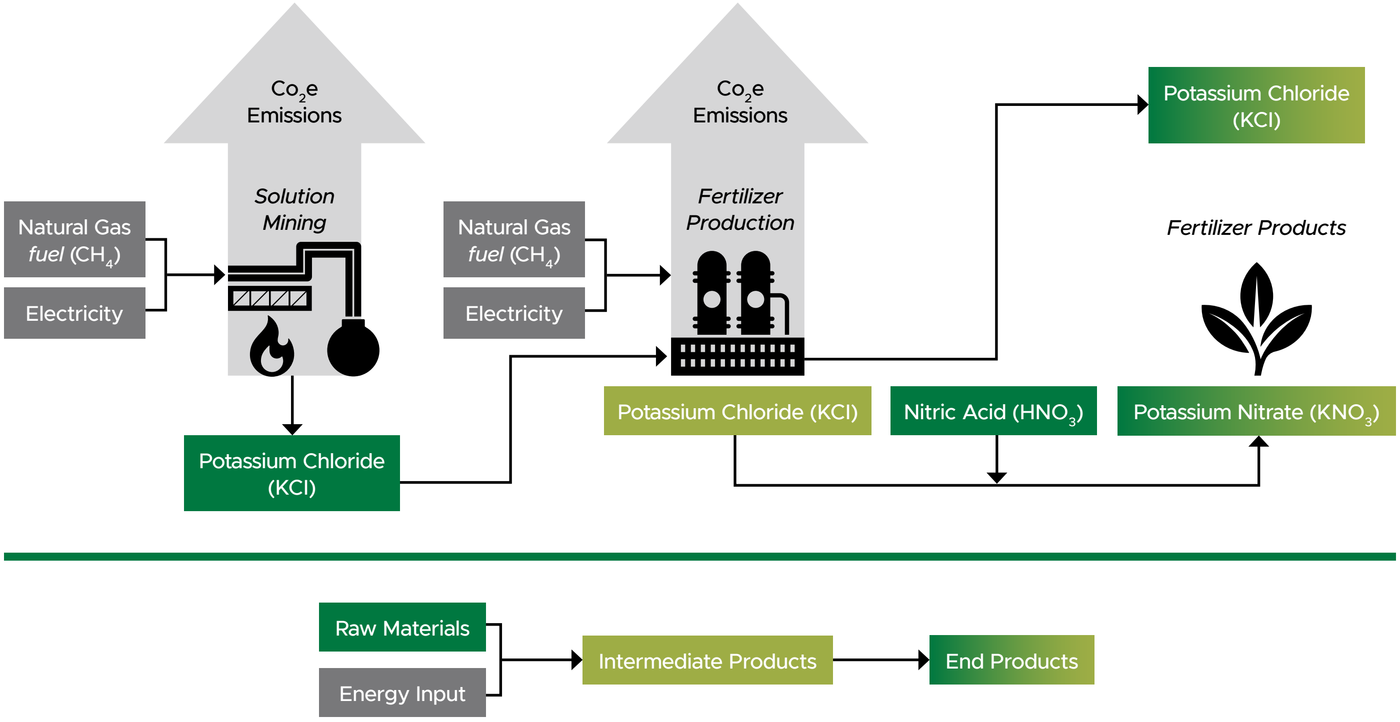


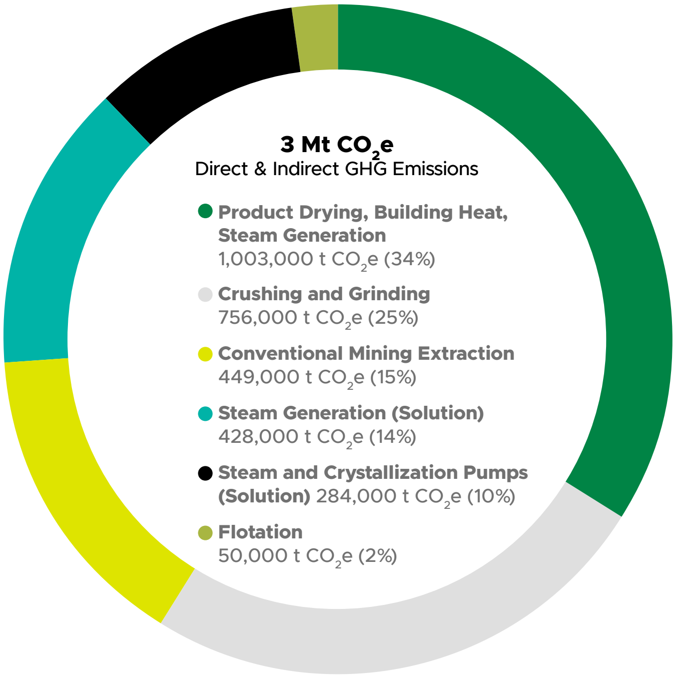
FIGURE 11: Schematic of Potash Fertilizer Products Using Solution Mining Extraction Methods



Katta (2019) provides a disaggregation of the GHG emissions sources in potash mining (conventional and solution mining combined) in 2015 and it is presented in Figure 12. Product drying is the single largest source of GHG emissions, comprising 34 per cent of the sector-wide total followed by crushing and grinding at 25 per cent. Solution mining is energy-intensive. Even though only three of the ten potash mines are solution mines, the energy required for the extraction process (steam generation and pump operation) accounts for 24 per cent of sector-wide emissions. Extraction of the potash by conventional mining methods accounts for 15 per cent of sector-wide emissions.

In terms of energy sources, natural gas accounts for 50 per cent of emissions in the combined conventional and solution mining extraction of potash, electricity accounts for 49 per cent and Diesel, 1 per cent. All Canadian potash is extracted in the province of Saskatchewan where the very high electrical grid intensity greatly increases indirect emissions associated with electrical consumption.

FIGURE 12: Potash Production GHG Emissions Profile



Decarbonization Technology Solutions

Fertilizer Canada has proactively conducted a GHG Reduction Technology Scan for the Canadian fertilizer industry. This section evaluates new and emerging technologies against their emission reduction potential, commercial scalability, economic viability, and regional considerations. These mature facilities have already implemented improvements to the energy profiles, otherwise known as "low-hanging fruit" measures, to reduce GHG emissions. Examples of these measures include additional heat exchangers for waste heat recovery, use of waste heat for electrical generation thereby reducing grid electricity consumption, upgrading motors/turbines and other major process equipment with more efficient technology, steam trap surveys and repairs, use of insultation, improvements to start-up and operating procedures, replacement of large utility boilers with higher efficiency boilers. Accordingly, this study focussed on "step-change" technologies that could meaningfully reduce sector emissions, the most promising of which are describes in the following tables:

- **Carbon Capture and Storage**—Process CO_2 and Flue Gas (Combustion) CO_2
- **Hydrogen Production through Electrolysis**
- **Small Modular Reactors**
- **Cogeneration**
- **Electrification of Mine Fleet**

Decarbonization Solutions are *Facility Specific*

Solutions are dependent on:

- The emissions profile and fertilizer products produced at each facility. At ammonia plants process CO_2 emissions are already partially captured for beneficial use at many facilities
- Policy and regulatory environment differences between jurisdictions
- Access to a lower carbon intensity power grid
- Proximity to other industry that can use captured CO_2
- Proximity to infrastructure such as hydrogen and CO_2 pipelines

CARBON CAPTURE, UTILIZATION AND STORAGE—PROCESS CO_2 AND FLUE GAS CO_2

Technology Description: Carbon Capture and Storage (CCS) is the process of capturing the carbon dioxide emissions generated during the production of a product, transporting, and then storing the CO_2, usually underground. Carbon Capture and Utilization (CCU) is the capture and beneficial use of the carbon to make new products.

In fertilizer production there are two main sources of CO_2. It is generated during ammonia production as a result of the reactions in the manufacturing process (Process CO_2). It is also generated through the combustion of fuel for energy (Combustion or flue gas CO_2). Currently, CCUS has focused on capturing the excess Process CO_2 from ammonia production not needed for use in urea production. For existing facilities, the IEA Ammonia Technology Roadmap states that CCUS will play a critical role in near-zero ammonia production (IEA 2021).

In order to successfully sequester or utilize process CO_2 that is not used in urea production, it is typically compressed and dehydrated prior to injection into a pipeline for transportation to a permanent sequestration reservoir (Shell Quest and Boundary Dam) or enhanced oil recovery reservoir (Enhance Energy's ACTL and Estevan).

Application—Types of Plant	Ammonia (process CO_2 and flue gas CO_2) Potash solution and conventional mines (flue gas CO_2)
Location Specific Considerations	Western Canada has largest storage resource potential for CO_2 storage sedimentary basins, while Canada as a whole has great storage capacity. Most CCS pilot projects are within Western Canada (NRCan 2013). Requires a pipeline (or connector to a carbon trunk line) to transport the captured CO_2; and either storage capacity or an end user, so this is location specific.
Technology Stage of Development	**Process CO_2 Capture:** Commercially available, widespread within the Canadian Nitrogen fertilizer sector. **Flue gas CO_2 Capture:** Commercially available, but not widespread. Not in use in the Canadian fertilizer sector. Technology Readiness Level for Process CO_2[Note 1]: 9 Technology Readiness Level for Flue Gas CO_2: 7
Implementation Timeline to Wide Commercial Implementation	See Section 4.2.3.

Capital Cost	High Implemented CCU initiative on steam methane reformers in Alberta to capture process emissions had a capital cost of $790 million with $573.3 million in Government funding (Shell International 2017). **The $790 million capital costs was broken down into $623 million for capture, $127 million for transportation and $40 million for storage** (Shell International 2017). Shell noted in 2020 that if Quest were to be built today it would cost approximately 30% less (Shell Canada 2023). **Capturing flue gas CO_2 would require additional capital expenditures (CAPEX)**, above those required for capturing process emissions, for **gas cooling, conditioning, scrubbing, compression and liquefaction, and clean up at existing facilities**. Additional operating expenses (OPEX) (e.g., amine scrubbing is energy-intensive) are also required for flue gas capture, which would impact the cost competitiveness of fertilizer products. High cost supporting infrastructure, costs are also location-specific (i.e., proximity to existing pipeline infrastructure). Noted that this approach will generally require a partnership, and therefore the CCUS infrastructure will not be directly developed by fertilizer producers. Capital costs of the ACTL were approximately $1.2 billion dollars (Labine 2020), funded partially by the federal government ($63 million) and Alberta Government ($495 million) (MIT CC&ST 2016).
Operating Costs	Medium to high The Shell Quest CCS project had operating costs of between **$26 million and $33 million** annually for the calendar years from 2017 through 2019 (Alberta Department of Energy, 2019). This equates **to between $24 and $29/t Process CO_2 captured**.
GHG Reduction Potential	High Dependent on capacity of pipeline and capture/usage infrastructure (e.g., ACTL has a capacity of **14 megatonnes per year**) (RIAS Inc. 2019). Although CCUS results in a high proportion of emissions being captured, it does not result in a 100 per cent capture rate because of the operational energy requirements for the capture process. Sector wide, ammonia production process emissions generally are greater than 60 per cent of facility emissions. However, 61% of these process emissions are already recovered (sector-wide) and are therefore unavailable for CCUS. **The vast majority of recovered process emissions are used for the production of urea**.

Barriers to implementation

High cost for projects.

Alberta Carbon Trunk Line (ACTL) project required **$495 million from Government** (RIAS Inc. 2019).

High CAPEX/OPEX is a barrier to capturing flue gas CO_2 emissions which may need partners or government support for CCUS.

Location is important for transportation to sequestration/use site requires the infrastructure to be in place.

Other barriers include **technology readiness, brownfield land acquisition and usage constraints, and stakeholder approvals**.

Examples of Implementation

PROCESS CO_2

ACTL (Canada)—CCU system captures process CO_2 at the North West Redwater Partnership (NWR) Sturgeon Refinery and Nutrien's Redwater fertilizer facility for permanent sequestration through enhanced oil recovery (ACTL [Date unknown]) (IEA 2021).

Nutrien Geismar and Denbury partnership (USA)—Process CO_2 from Nutrien's Geismar fertilizer facility is compressed/dehydrated and injected into Denbury's CO_2 pipeline network for permanent sequestration via enhanced oil recovery (EOR)

Coffeyville Resources Nitrogen Fertilizers and Chaparral partnership (USA) capture of process CO_2 from fertilizer plant, compression facility onsite, transport for use in the oil and gas sector (Charparral Energy 2021).

Quest CCS Project (Canada):, this project captures process CO_2 from a refinery and stores it underground in a saline aquifer. It can capture up to one million tons of carbon dioxide annually.

FLUE GAS CO_2

A number of small-scale applications and demonstration projects exist across Canada (NRCan 2020).

Large scale:

Petra Nova CCS Facility: Located in Texas, this project captures carbon dioxide from a coal-fired power plant and stores it underground in a depleted oil reservoir. It can capture up to 1.6 million tons of carbon dioxide annually. The project was shut down in 2020 because low oil prices made the captured CO_2 use for enhanced oil recovery uneconomical. The project also reportedly struggled to meet operational and capture targets. Current owners report plans to bring the project back online in 2023 (IEEFA 2021).

Boundary Dam CCS Project: This project, located in Saskatchewan, Canada, captures carbon dioxide from a coal-fired power plant and stores it underground in a saline aquifer. It has a capacity to capture one million tonnes of carbon dioxide annually (IEEFA 2021). This project has also had challenges in meeting design CO_2 capture targets.

Both of these examples are capture of flue gas CO_2 from coal combustion.

Note 1: Technology Readiness Level for this study were based on the Government of Canada definitions (Government of Canada, 2018).

HYDROGEN PRODUCTION THROUGH ELECTROLYSIS AND ALTERNATIVE THIRD-PARTY SOURCES OF HYDROGEN

Technology Description: North American ammonia production typically uses natural gas (CH_4) as a feedstock, requiring the use of steam-methane reforming to generate the hydrogen required. Carbon dioxide is produced as a by-product due to the carbon content of the natural gas. Hydrogen production through electrolysis is an alternative way of producing hydrogen that does not use natural gas as a feedstock.

Electrolysis is the process of splitting water into oxygen and hydrogen, using electricity. The hydrogen can then be combined with atmospheric nitrogen through a separation unit or supplied concentrated nitrogen to produce ammonia, through the Haber Bosch Process. The process has high electricity needs, and the carbon intensity of the ammonia produced is dependant on the carbon intensity of the electricity source.

The hydrogen through electrolysis can be produced on site or alternative third party hydrogen can be procured.

Application—Types of Plant	Ammonia (for electrolysis and third party).
Location Specific Considerations	Regions with low-cost renewable/nuclear energy are optimal - expected to see costs decrease by 2030 (Hydrogen Council 2020). Access to water is necessary, certain locations have water resources fully allocated already whereas others have abundant access to water. Proximity to deep water ports for shipping (if products are targeting the international market). Potential carbon reduction for H_2 produced by electrolysis is lower in jurisdictions that have a relatively high grid intensity. Proximity to hydrogen source or distributor to minimize transportation costs and emissions.
Technology Stage of Development	Feasibility Not in commercial operation at a scale that can support fertilizer facility energy needs (Reuters News Service 2021). Feasibility/small scale commercial for 3rd party sources. Technology Readiness Level: 8
Implementation Timeline to Wide Commercial Implementation	Medium to long term for on-site large scale hydrogen production The CF Donaldsonville plant (USA) is expected to be operational by 2023. Funding dependent, the Yara Norway plant could be operational by 2023 (Yara 2022). Medium to long term for third party hydrogen Nutrien Joffre plant is a current operational example (Nutrien 2019). Requires availability of alternative third party hydrogen for widespread adoption.

Capital Cost	High Electrolyzer unit has a high capital cost. Plant reconfiguration—CF Donaldsonville Louisiana example costing $100 million USD for a facility that will produce approximately 20,000 tonnes of ammonia (Reuters News Service 2021). Cost of alkaline electrolyzer dropped 40 per cent between 2014–2019 in North America (Bloomberg NEF 2020).
Operating Costs	High Very high electricity consumption for hydrolysis, electrolyzer requires 55 kWh of electricity to produce 1 kg of hydrogen. The devices today require as much as **55 kWh/kg Hydrogen** (NREL 2009). Cost of hydrogen production is sensitive to electricity costs (National Renewable Energy Laboratory [NREL] 2004). The hydrogen strategy for Canada provides estimated bulk hydrogen production costs (not including distribution) by 2030 for different production pathways of the following: ~$1.00–2.00/kg hydrogen for production through steam methane reforming and CCUS, and $3.20/kg hydrogen for production using electrolysis from dedicated renewable energy (NRCan 2020).
GHG Reduction Potential	Medium to high Lowest carbon intensity hydrogen: 0–0.6kg CO_2e/kg H2 (Pembina Institute 2020). Lower carbon intensity hydrogen: 2.3–4.1kg CO_2e/kg H2 (Pembina Institute 2020). Current method (Haber-Bosch Steam Methane Reforming): 11.3–12.1 kg CO_2e/kg H2 (Pembina Institute 2020). The carbon intensity of hydrogen produced by electrolysis **is dependent on the carbon intensity of the electricity grid**.
Barriers to implementation	Needs an electricity infrastructure grid that **is capable of supplying reliable power at the high power demands, at a relatively low carbon intensity and at a low enough price**. Currently the technology is only available on a small scale, whereas to support fertilizer production the technology would need to be commercially available on a much larger scale. Cost, especially high capital cost of smaller scale electrolysis systems (NREL 2004).
Examples of Implementation	Yara partnership for development of Norway facility. CF Donaldsonville plant in Louisiana USA is under construction. A grid connected 20 MW electrolyser for 20 kilotonnes/year ammonia (IEA 2021).

SMALL MODULAR REACTORS

Technology Description: Small Modular Reactors are nuclear fission reactors that are smaller than traditional nuclear power plants and offer potential benefits for sites that are located off-grid or in high carbon intensity grids, such as Saskatchewan.

Potassium fertilizer production, including solution mines, could use Small Modular Reactors to generate low carbon intensity electricity to displace higher carbon intensity electricity and offset natural gas combustion by using the cooling water from the Small Modular Reactor to provide heat to the process.

Application—Types of Plant	All types of facilities.
Location Specific Considerations	Potential carbon reductions are lower for higher grid carbon intensity jurisdictions (e.g., SK/AB).
Technology Stage of Development	Demonstration projects (Canadian Small Modular Reactor Roadmap Steering Committee 2018). Technology Readiness Level: 6
Implementation Timeline to Wide Commercial Implementation	Long term Pilot Project could be operational at Ontario Power Generation's Darlington site by 2028 (CANDU 2021) but commercialization could take longer.
Capital Cost	High Small Modular Reactor under construction in Argentina is experiencing increasing costs as it develops (Green 2019). 2014 estimate: $446 million USD for a 25 MW reactor. 2017: $700 million USD for a 25–32 MW reactor (Green 2019). NRCAN: $270 million dollars for 20MWe system (NRCan 2021).
Operating Costs	Low to medium NRCAN: Fuel cost $64 million dollars for fuel replacement every 10 years—$6,400,000 per year (NRCan 2021). Comparison to current operating costs are dependent on whether the facility is on or off-grid, electricity purchase costs and carbon tax costs (Economic and Finance Working Group [EFWG] 2018). Compared to the existing grid, Small Modular Reactors could be competitive on a $/MWh basis (EFWG 2018).

GHG Reduction Potential	Medium Small Modular Reactors do not have direct GHG emissions. Life cycle GHG emissions of 5.9–13.2 g CO_2e/kWh due to mining of fuels required for reactor operation (Carless et al 2016). Magnitude of reduction depends on carbon intensity of existing electricity and energy supply.
Barriers to implementation	Public and stakeholder acceptance can become a challenge, with concern over safety aspects. Regulatory licensing process at provincial and federal levels.
Examples of Implementation	Global First Power micro modular reactor at Chalk River Laboratories in Ontario. Currently undergoing environmental assessment and has started the licensing process for Canadian Nuclear Safety Commission's License to Prepare Site (Ontario Power Generation [Date unknown]).

COGENERATION

Technology Description: Cogeneration, or combined heat and power (CHP), is the process of generating electricity and useful heat simultaneously through the use of one engine. There are fuel efficiency gains by using cogeneration if the waste heat from the combustion turbine is also utilized. In jurisdictions where the electricity grid has a higher carbon intensity, the use of cogeneration can potentially generate lower carbon intensity power.

Application—Types of Plant	Applicable to all facilities with a large energy requirement, including Nitrogen fertilizer production, Potash solution mines and Potash conventional mines.
Location Specific Considerations	Regional legislation may influence feasibility (e.g., rules on who can generate power in Saskatchewan).
Technology Stage of Development	Commercially available. Technology Readiness Level: 9
Implementation Timeline to Wide Commercial Implementation	Short term Technology is commercially available and implemented at 12 fertilizer facilities across the United States (Energy Star 2017) and examples in Canada including in Saskatchewan (Government of Saskatchewan 2003), and Alberta (TC Energy date unknown).
Capital Cost	Medium to high CHP systems CAPEX range from $670–3300/kW depending on the type of CHP prime mover (gas turbine= $1200–3300/kW; reciprocating engine= $1500–1900/kW; steam turbine= $670–1100/kW) (Whole Building Design Guide [WBDG] 2016). CHP systems installed in fertilizer plants range from 2MW to 225 MW, with the average being ~40MW (Energy Star 2017). CAPEX could range from $1.3 million to $742 million, average estimated to be $79 million (based on $1985/kW and 40MW system). Example: 1MW reciprocating engine system has a CAPEX of $1.6 million (WBDG 2016).
Operating Costs	Low to medium CHP can save money for facilities (Verde Solutions 2019). Savings on operating costs are dependent on whether the facility is currently on or off-grid, costs of current energy supply and carbon tax prices.

GHG Reduction Potential	Low to medium Cogeneration units can achieve efficiencies of over 80 per cent, compared to 50 per cent for conventional technologies (such as grid supplied electricity and an on-site boiler) (Energy Star 2017). Cogeneration is viewed as a 'transitional technology', that needs to be paired with CCUS to maximize carbon reductions.
Barriers to implementation	Power Producing Agreements and Feed in Tariffs potentially need to be negotiated with multiple parties. Regulatory barriers in some provinces about who can buy/sell power (i.e., restriction in Saskatchewan on CHP plants).
Examples of Implementation	Cory Cogeneration Station in Saskatchewan—power plant and steam production (SaskPower 2021). Carseland Cogeneration Plant in Alberta—power plant and steam production (TC Energy, date unknown). Various examples provided Appendix H (CHP Installations at Fertilizer Plants) of the Energy Star Energy Efficiency and Cost Saving Opportunities document (Energy Star 2017).

ELECTRIFICATION OF MINE FLEET

Technology Description: Mine fleet vehicles and equipment are used in Potash mining, the majority of which are diesel powered. Conversion to an electric battery-powered fleet is an emerging technology. There are certain pieces of equipment that are more easily replaced with their electric counterparts, whereas certain large, heavy duty equipment do not currently have an electric counterpart.

Application—Types of Plant	Most applicable to potash conventional mines. Applicable to the mining fleet.
Location Specific Considerations	The magnitude of GHG reductions is dependant on the carbon intensity of the electricity grid which replaces the diesel equipment.
Technology Stage of Development	Some classes of vehicles at the early stage of being commercially available. Technology Readiness Level: 8 for underground vehicles, 6 for large surface vehicles.
Implementation Timeline to Wide Commercial Implementation	Medium term Technology is available for some vehicles (e.g., electric miners), however other heavy-duty vehicles do not currently have an electric option. Mining companies predicting electrification of fleet in the next 10 years (Nouveau Monde Graphite 2020; Moore 2020).
Capital Cost	Capital cost depends on size of mine fleet. One study cites 20–30 per cent higher capital costs for electric fleet versus diesel (Varaschin & De Souza 2015).
Operating Costs	Operating costs for electric mine vehicles versus diesel have been reported as both higher and lower, depending on diesel and local electricity price.
GHG Reduction Potential	Low Ranking in consideration of both mine and fertilizer production emissions (i.e., mine fleet emissions represents a relatively small fraction of total production emissions).
Barriers to implementation	New fleet and charging infrastructure required. Higher carbon reductions need a lower carbon intensity electricity grid for maximum benefits.
Examples of Implementation	Goldcorp Borden mine (Jamasmie 2016).

Decarbonization Technology Implementation

Of the technologies listed in Section 4, both the use of electrolysis and steam methane reformers equipped with CCUS to produce hydrogen have the greatest potential for GHG reductions from the nitrogen sector. Although these are different competitive technologies there is no clear production pathway, and implementation is influenced by location specific considerations. These technologies therefore need to be developed at the same time. For the potash sector Small Modular Reactors have the greatest potential for GHG reductions.

Potential roadmaps to bring projects to scale are needed covering the investments, barriers, and timeline required including:

- Regulatory Approvals/Policy
- Funding Programs and Incentives
- Strategic Planning
- Education Infrastructure

4.1 Regulatory Approvals and Policy

Two decarbonization technologies, CCUS and Small Modular Reactors, face challenges in obtaining regulatory approvals. Both are novel technologies that will require approval from multiple government bodies and extensive stakeholder engagement. There is significant uncertainty in the timelines for these approvals and engagement processes.

4.1.1 REGULATORY APPROVAL TIMELINES

CCUS faces timeline challenges to implementation due to the different components required: capture, transportation and sequestration (Figure 13), each have separate regulatory approval process.

FIGURE 13: Implementation Timeline Challenges for CCUS

CAPTURE:

Process to separate CO_2 from flue/process gas, compress the CO_2, so it can be transported and stored.

Timeline: Requires multiple stages of design. Technology is still emerging and there are competing processes that complicate Front End Engineering Design (FEED).

TRANSPORTATION:

Moving compressed CO_2 from the site to the sequestration area. Requires pipeline infrastructure.

Timeline: Pipelines are controversial and land acquisition and access is complex

SEQUESTRATION:

Injection of supercritical CO_2 in geological formations, such as deep saline aquifers, to permanently store in liquid form.

Timeline: Permitting and access process is developing and varies province to province. No standards on Public engagement and Monitoring. Measurement and Validation requirements.

To illustrate the timeline challenges, schedule estimates for potential CCUS permitting processes were developed. Key factors driving potential timelines include:

- Capture system design complexity
- Pipeline routing and length
- Right of way agreements and land acquisitions
- Advancement of sequestration site development (e.g., greenfield sites versus established sites or hubs)
- Provincial and federal impact assessment and approval requirements
- Stakeholder engagement

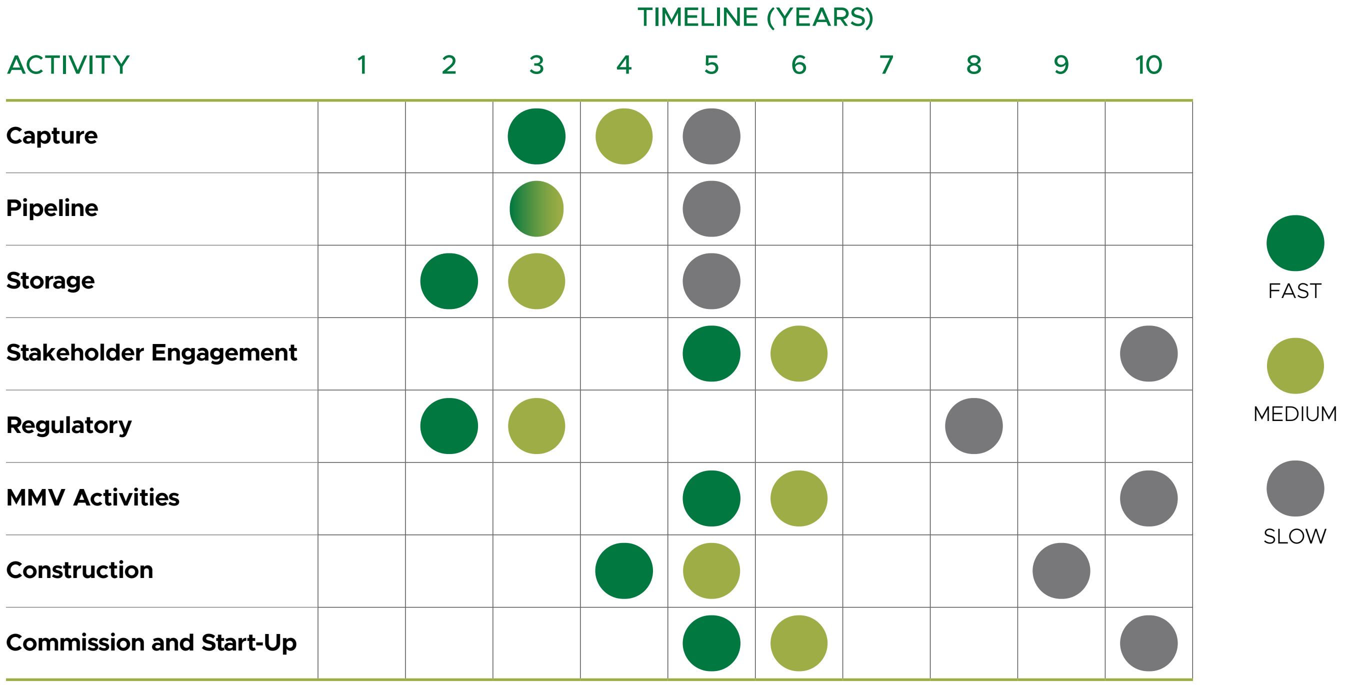
Schedule estimates were developed for different potential scenarios, categorized as fast, medium, and slow, and consider initial project conception, regulatory approvals, engineering design, construction, and commissioning as described in Table 1. The key driving factor is the local provincial approval process and if a Federal Impact Assessment is required and therefore the estimates have been based on the location of the project as further described in the Section below. It is important to note several provinces do not have a path for facilities to permit and implement CCUS. In those provinces, the path to implementation for any facility will require regulatory changes by the province and, in some provinces, both legislative and regulatory changes. These changes add approximately 1.5–2 years for regulatory changes to be implemented by the province and an additional approximately four years where legislative changes must be implemented first. This is assumed to be an additional delay and not done in parallel with engineering and design work and is not reflected in the approximate timelines notes below.

TABLE 1: Scenario Definition and Estimated Regulatory Approval Timelines

SCENARIO	FAST	MEDIUM	SLOW
Example Provincial Approval Process	Saskatchewan	Alberta	Alberta
Federal Approval Process	Not required	Not required	Required
Stakeholder Concern	Little to none	Moderate	Moderate to high
Pipeline Length	< 40 km	40 – 75 km	> 75 km
Natural Gas Usage	Low	Moderate	Moderate to high
Estimated Schedule Length (Years)	5	6	10

The estimated timeline for implementation can ranges from five to 10 years. These estimates are based on experience with CCUS projects and other development projects that have undergone, or are undergoing, provincial and/or federal permitting processes. The timeline estimates are further summarized in Figure 14.

FIGURE 14: Timelines for Implementation of a CCUS Project (Fast, Medium and Slow Scenarios)



Regulatory Timelines for Decarbonization Solutions — CCS Case Studies

- **Permitting timelines:** Boundary Dam and Shell Quest stakeholder engagement and impact assessments took more than five years 2008 to 2012.
- **Heritage considerations:** Alberta Trunk Line's application to Alberta Historical Resources Foundation was submitted in May 2009 and approved July 2015 as ongoing routing changes delayed application process (Alberta 2021).
- **Stakeholder considerations:** For the Boundary Dam CCS project SaskPower had predicted much greater capture rates than what has been achieved so far, which poses significant reputational risk for subsequent individual company applications.

4.1.2 ADDITIONAL REGULATORY BARRIERS

Within each province where members operate, there are different provincial processes to developing geologic carbon storage locations and obtaining injection approval. The issues of cumulative impacts and pore space rights to inject the CO_2 are areas of emerging practices. For example:

- Until recently, injection of CO_2 was specifically prohibited in Ontario. The government of Ontario has taken initial steps towards addressing the barriers, the first step of which is proposed changes to the Oil, Gas and Salt Resources Act to remove the current prohibition (Government of Ontario 2023). However, the approval process and guidance on how to apply for an injection permit is not available.
- In Alberta, pore space leases have been awarded to several consortia who are permitted to apply for and develop injection hubs. Companies not already in an approved consortia may be disadvantage compared to others who have been approved.
- In Saskatchewan, injection approvals are issued by the Ministry of Energy and Resources. An injection well application form is available, and the contents of the application package is described by the ministry. The issue of cumulative effects and if the project is considered to be designated under the provincial environment assessment process is conducted by the Ministry of Environment and no guidance is available for these considerations.

As noted above, there are several pilot projects of Small Modular Reactors and the regulatory approvals (and licensing) process has yet to be streamlined. However, Small Modular Reactors are currently treated as Class 1 Nuclear Facilities and could have a timing similar to the slow implementation schedule in Section 4.1.1.

4.2 Funding Programs and Incentives

Fertilizer production is a global market. Canadian facilities are not only competing globally, but for members with multiple production facilities this can mean competing against other international facilities within their own company for capital investment to implement decarbonization technologies. Various jurisdictions globally are putting in place policies and funding programs to accelerate reductions in GHG emissions therefore Canadian policies and commitments can impact the flow of capital to Canadian facilities.

4.2.1 THE EFFECTS ON CANADIAN FERTILIZER PRODUCTION

Future policies (and funding mechanisms) in Canada have the potential to impact domestic competitiveness, which includes considerations of policies and funding programs in other jurisdictions where fertilizer production occurs. This is particularly true in the U.S. which is Canada's largest fertilizer market, accounting for well over half of total fertilizer exports each year (Fertilizer Canada, 2023). If the impact on the Canadian fertilizer sector is not carefully considered, this can result in companies moving their production from Canada to a jurisdiction with more favorable policies.

A second consideration are the policies, incentives and fundings being offered in other jurisdictions to support the development or implementation of decarbonization technologies and associated infrastructure. Such programs can have the effect of companies relocating Canadian production to these jurisdictions.

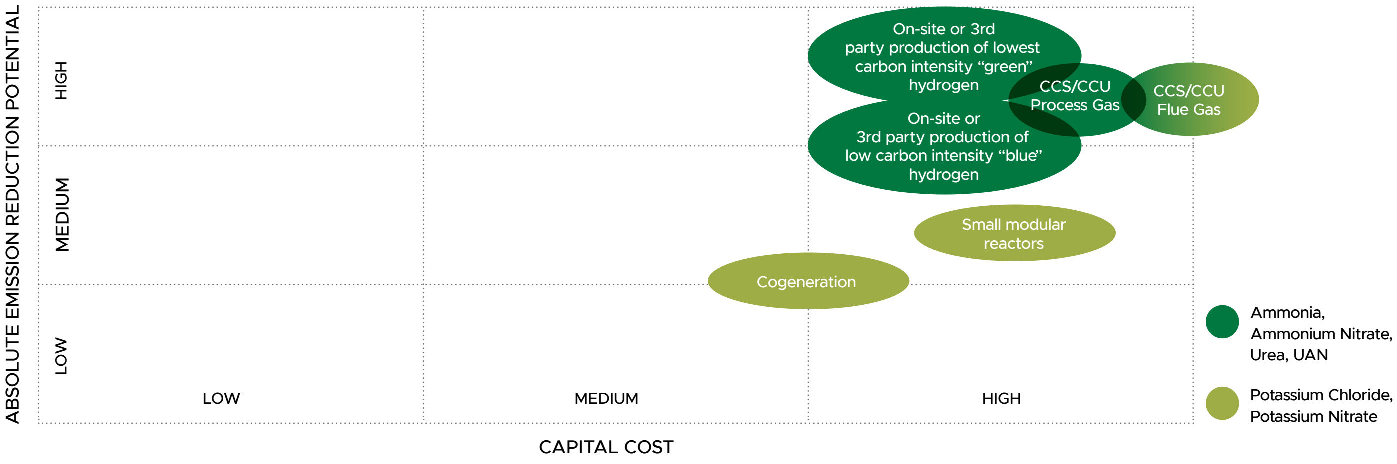
Example of Incentives and Funding to Support Adoption of Decarbonization Technologies and the Potential to Impact Canadian Production

- CCS projects in the U.S are eligible for a tax credit (investment- and production- based) under the Section 45Q policy. The policy was first introduced in 2008 and was expanded and extended in 2022 under the U.S Inflation Reduction Act.
- The policy provides between $60 and $85 USD/tonne CO_2 captured, depending on the type of CCS/CCU project (IEA 2023).
- A similar policy to incentivise the adoption of CCS/CCU does not exist in Canada.

4.2.2 TECHNOLOGY COSTS

The cost barrier of technology implementation can be driven by capital cost, operating cost, or both. Figure 15 provides the capital cost of the technologies and the associated GHG emissions reduction potential, which shows that the technologies with the highest GHG emissions reduction potential have capital costs in excess of $50 million dollars.

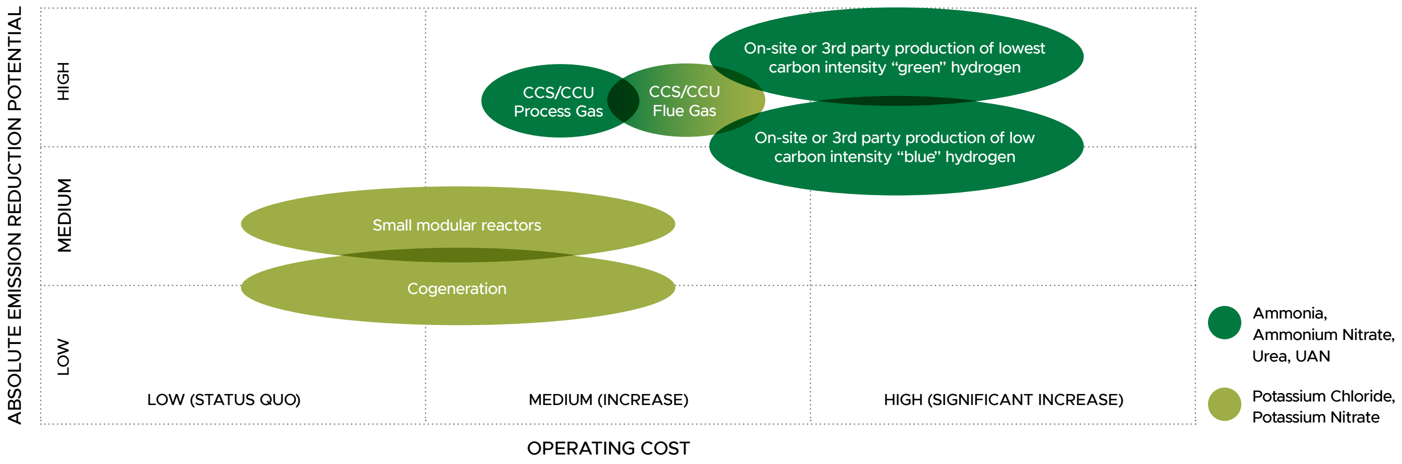
FIGURE 15: Technology Capital Cost Versus Absolute Emission Reduction Potential



Capital Cost: Low = <$5 million dollars, Medium = $5–$50 million dollars, High = >$50 million dollars.
Absolute Emissions Reduction Potential: Low = <10 per cent reduction in production emission, Medium = 10–50 per cent reduction in production emissions, High = >50 per cent reduction in production emissions.

Figure 16 provides the operating cost of the technologies and the associated GHG emissions reduction potential, which shows that the technologies with the highest GHG emissions reduction potential have operating costs that are a significant increase in operating costs over the status quo. It should be noted that the operating costs should be considered approximate due to the limited amount of publicly available information on operating costs, this information was supplemented through confidential interviews with operators.

FIGURE 16: TECHNOLOGY OPERATING COST VERSUS ABSOLUTE EMISSION REDUCTION POTENTIAL



Operating Cost: Low = Similar to operating costs to status quo, Medium = Expected increase in operating costs over status quo, High = Significant increase in operating costs over status quo.
Absolute Emissions Reduction Potential: Low = <10 per cent reduction in production emission, Medium = 10–50 per cent reduction in production emissions, High = >50 per cent reduction in production emissions.

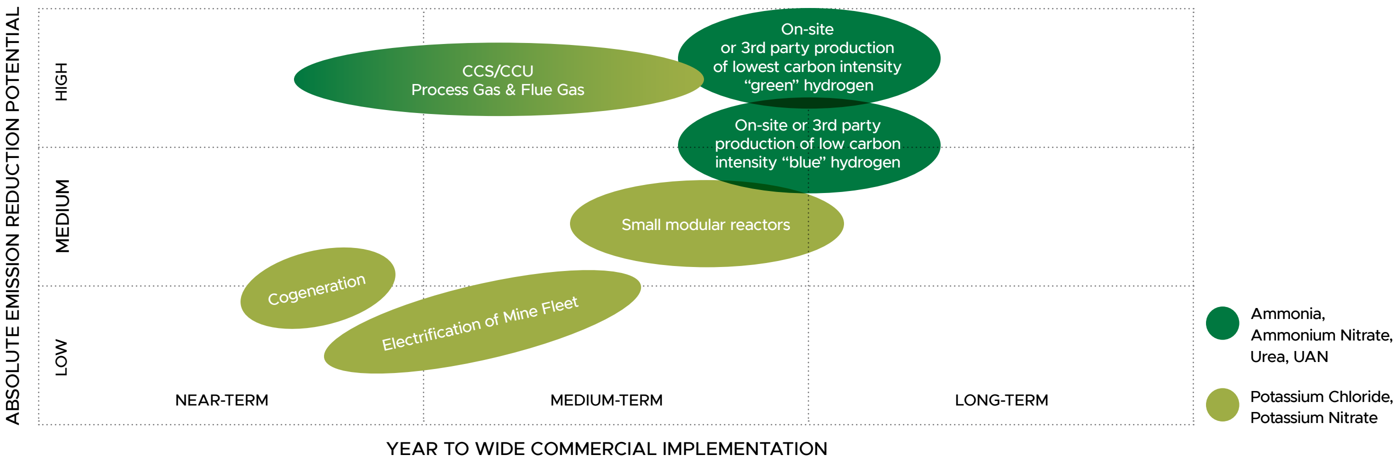
Example of Incentives and Funding to Partially Address Capital and Operating Cost Barriers

- To support capital costs for the ACTL, partial government funding of the approximate $1.2 billion capital cost was provided, $63 million by the Federal Government and $495 million by the Alberta Government (Labine 2020, MIT CCS Technologies 2016).
- To support operating costs, the U.S Section 45Q policy provides between $60 and $85 USD / tonne CO_2 captured, depending on the type of CCS/CCU project (IEA 2023).
- In Canada, the planned investment tax credit for CCUS projects will contain provisions a 50 per cent tax credit for investment in equipment to capture CO_2 (excluding direct air capture) and 37.5 per cent for investment in equipment for transportation, storage and use (IEA 2022).

4.2.3 IMPLEMENTATION TIMELINES

In the decarbonization technology solutions review, no feasible technologies were identified for near-term (i.e., < 5 years) implementation that will result in significant GHG reduction. Although CCUS was considered to be a commercially available technology, with commercial scale examples of implementation, there are other barriers (e.g., regulatory approval timelines, financial barriers) that mean the timeline for implementation is near-medium term. Estimated years to wide commercial implementation for different technologies is shown in Figure 17.

FIGURE 17: YEARS TO WIDE COMMERCIAL IMPLEMENTATION



Near term = 1–5 years, Medium-term = 5–10 years, Long-term = > 10 years.
Absolute Emissions Reduction Potential: Low = <10 per cent reduction in production emission, Medium = 10–50 per cent reduction in production emissions, High = >50 per cent reduction in production emissions.

4.3 Strategic Planning

4.3.1 TECHNOLOGY READINESS

A number of the technology solutions require further development in order for them to be ready for commercial implementation. Depending on the current technology readiness levels (TRL) of the solutions this can mean undertaking further research and development and pilot studies (in some cases this requires partnerships with vendors). Funding programs and incentives typically target support for the implementation/operation of commercially ready technologies, whereas some technologies require support at early stages of development such as feasibility level studies at a particular facility. One example of a funding mechanism providing support to GHG reduction projects is the Government of BC Innovation Accelerator funding which supports projects that involve the demonstration, pilot or trial of clean technologies or processes with the potential to reduce emissions for industry in B.C. (Government of B.C 2023).

4.3.2 ACCESS TO CLEAN ELECTRICITY

Technology solutions such as hydrogen production through electrolysis requires access to an electricity infrastructure grid that is capable of supplying the high power demands at a low carbon intensity. The carbon intensity of the hydrogen produced is very dependant on the carbon intensity of the electricity given that up to 55 kilowatt hours is needed to produce 1 kg of hydrogen by electrolysis (NREL 2009).

4.3.3 EXISTING CAPTURE OF CO_2 EMISSIONS

Ammonia plants in Canada already recover on average 61 per cent of the relatively pure CO_2 process emissions, the majority of which is used to produce other fertilizer products such as urea. Some facilities **recover up to 90 per cent of their process CO_2 emissions**. These recovered emissions are not available for CCUS, and are therefore a barrier to the implementation of that technology. **At facilities with already high recovery rates of CO_2, the application of CCUS to these facilities is limited to the more difficult to capture flue gas CO_2**.

4.4 Education and Training

With the implementation of new technologies there is also a requirement for training employees to adapt to these new systems. For example, there will be a need for training on the **operation and maintenance of Small Modular Reactors, a skillset that is not currently available in the fertilizer (or other) sectors**. Training current operational personnel or hiring additional qualified personnel will be a barrier to overcome to implement these technologies.

Solutions for Workforce Readiness from the Mining Sector

- Cambrian College and Collège Boréal recently partnered with Epiroc to ensure training programs on Battery Electric Vehicles were up-to-date.
- British Columbia Institute of Technology (BCIT) have various course offerings designed to provide the skills to operate and maintain zero-emission vehicles.

4.5 Life of Mine/Facility

For potash fertilizer production, both conventional and solution mines, with a longer defined mine life will have more certainty to implement large capital decarbonization solutions. Conversely, shorter defined mine life may limit an operation's ability to invest in large capital projects or operational changes, particularly if the mine is close (i.e., within 10 years) to the end of life.

For nitrogen fertilizer production all facilities in Canada are relatively old, with the average age of **48 years**, which provide uncertainty over the **remaining useful life of the facilities**. A new facility could reasonably expect to have a significant **lifespan of 30–50 years**, however no new nitrogen fertilizer production facilities have been developed in the past 30 years, and no facilities are in late-stage development such as the permitting stage. Similar to a mine a facility may be more limited to make a long-term capital investment in decarbonization technologies if they are nearing the end of the facility life.

Government Support Required for Sector Decarbonization

A key topic during the Sustainable Hydrogen and Ammonia Forum held in September 2022 was how government and industry could work together to meet the demand for low carbon hydrogen and ammonia. The key takeaways from the forum are summarized in Appendix A.

The following provides a breakdown of near-term actions that target the key barriers associated with reducing emissions and ultimately reaching net-zero emissions. The action recommendations aimed to achieve the largest emissions reductions have been classified into five categories: funding programs and incentives, regulatory approvals and policy, strategic planning, education infrastructure and additional study.

- **Funding Programs and Incentives:** Re-evaluate incentive programs or establish new funding programs to encourage operations to be early adopters of emerging technologies.
- **Regulatory Approvals and Policy:** Work with regulators to communicate specific regulatory challenges to implementing decarbonization technologies in the fertilizer sector.
- **Strategic Planning:** Collaborate with key suppliers and other stakeholders to communicate long-term outlooks with facility operators on low carbon business models and policies to de-risk investments.
- **Educational Infrastructure:** Identify and establish partnerships with educational institutions to advance research and development and provide training for mine technicians.
- **Further Study:** Areas that require additional study to increase certainty in the sector decarbonization options.

The actions have been categorized as near term actions or medium to long term actions, where near term is defined as the next five years and medium to long term have been defined as beyond five years from present day.

REGULATORY APPROVALS AND POLICY

BARRIERS	NEAR TERM ACTIONS
Regulatory approval timelines are long (federal/provincial approvals)	Ensure available funding and accessible application process for funding programs for the fertilizer production sector. Implementation of technologies in other sectors has been reliant on receiving funding.
Regulatory barriers to CCS/CCU in certain jurisdictions	Regulatory change to allow CCS/CCU
Uncertainty in regulatory approvals process	Clarify regulatory approvals for Small Modular Reactors (both federal and provincial) Simplify approvals

BARRIERS	MEDIUM TO LONG TERM ACTIONS
Uncertainty in/federal provincial carbon pricing beyond 2030 leading to regulatory uncertainty for facilities	Engage industry early in developing carbon pricing to avoid unintended impacts on global competitiveness. Publication of carbon pricing at least five years prior to implementation to reflect the planning timeframes for industry.
More favorable regulations/policies support in other international jurisdictions	For globally trade-exposed industries such as Fertilizer manufacturing consider the impacts of regulations/policies in other jurisdictions on Canadian operations when developing regulatory processes.
Future availability of high-quality offsets (to balance any remaining emissions to zero)	Support the development of offset programs that will provide sufficient high-quality offsets that can be used by industry to balance any remaining emissions to zero.

FUNDING PROGRAMS AND INCENTIVES

BARRIERS	NEAR TERM ACTIONS
Production moves to a less carbon regulated jurisdiction	All policies must consider their impact on domestic competitiveness and potential for carbon leakage.
Technology costs (capital and operating costs)	Ensure available funding and accessible application process for funding programs for the fertilizer production sector. Implementation of technologies in other sectors reliant on receiving funding.
Projects constrained by longer lead times making them ineligible for some short-term Industrial Funding Program.	Adjusting funding programs to allow for projects with longer lead times to accommodate technologies that are commercially limited.

BARRIERS	MEDIUM TO LONG TERM ACTIONS
Technology costs (capital and operating costs)	Ensure available funding and accessible application process for funding programs for the fertilizer production sector, many projects will take multiple years from design through to implementation.

STRATEGIC PLANNING

BARRIERS	NEAR TERM ACTIONS
Technologies are not commercially available at this time	Funding programs targeted to the early development of technologies and activities such as pilot and demonstration studies.
Some technologies need access to abundant low carbon electricity sources	Decarbonization of the provincial electricity grids.

BARRIERS	MEDIUM TO LONG TERM ACTIONS
Workforce availability	Evaluate planned course offerings from relevant education institutions, to understand whether there will be sufficient workforce capacity that is suitably trained to implement decarbonization solutions.

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