Decarbonizing the Canadian Chemical and Fertilizer Industry

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CLEAN ENERGY CANADA

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Executive summary

Canada's economy and the lives of Canadians are highly reliant on the materials and products produced by the chemical and fertilizer industry. Chemicals are heavily utilized in energy, healthcare, transportation, consumer goods, manufacturing, and food production.

The sector directly employs over 88,800 Canadians and supports hundreds of thousands more across the economy.[1,2] In 2020, Canada's chemical and fertilizer sector produced 21 Mt of GHGs, making it by far the largest emitter of the heavy industries (a category that does not include oil and gas). The sector accounts for almost the same as steel and cement combined, the second and third largest emitters respectively.

Given the sector's significant emissions and its importance in key supply chains, decarbonizing chemicals and fertilizers is a crucial step toward Canada's net-zero by 2050 goal. Equally, many chemicals, including some plastics and fertilizers, will play a significant role in a wide range of existing and future net-zero technologies and products.[3,4]

Currently, Canada does not have a net-zero pathway for chemicals and fertilizers (unlike cement, for example), nor is there an overarching government decarbonization strategy for heavy industry as exists in some other jurisdictions (e.g., the U.K.'s *Industrial Decarbonization & Energy Efficiency Roadmaps to 2050* and the U.S. Department of Energy's *Industrial Decarbonization Roadmap)*.[5,6] However, the Chemistry Industry Association of Canada has publicly committed to net-zero 2050 and is engaged with Canada's Net-Zero Advisory Body in finding effective solutions for Canada's chemistry industry.[7]

Canada has an opportunity to be a key global supplier of clean chemicals and fertilizers, with the ingredients to deliver both transitional, lower-carbon chemicals and a future of sustainable zero-carbon products. Private companies and international jurisdictions are already beginning to signal their preferences for such commodities.[8] But to deliver this, ambitious investment needs to be made in the coming years, supported by effective government policy to tackle the significant challenges presented in delivering cost-competitive commodity chemicals that are low- or zero-carbon.

KEY TAKEAWAYS

1. Canada should develop an overarching industrial strategy for chemicals and fertilizers that takes a holistic approach to decarbonization as we have seen in the U.K. and other jurisdictions.
2. The initial focus for decarbonization should be on industrial and agricultural chemicals as the largest source of emissions in the sector (e.g., ammonia) and the upstream source material for many consumer products (e.g., ethylene).
3. Governments and industry should work to evaluate and advance the best market opportunities for Canada in the clean chemicals sector.
4. Further research and strategic thinking is also required to fill the current knowledge gap around the type and scale of decarbonization pathways for the industry.

Introduction

Chemicals and fertilizers represent millions of different materials and products that are deeply integrated into our society and economy.

Chemicals and fertilizers (referenced in this paper as a subset of the chemicals sector referred to as agricultural chemicals, combined with mined fertilizer products) are heavily utilized in energy, healthcare, transportation, consumer goods, manufacturing, and food production. The sector generates $4.7 trillion in global annual revenues and directly employs over 15 million people.[3,9] Chemical production is the second largest manufacturing industry globally, and it is incredibly heterogenous compared to other heavy industry sectors such as steel or cement, with an estimated 350,000 different products traded in the global market.[10] Chemicals are also a market with substantial growth predictions: global production is set to triple by 2050 relative to 2010.[11]

Canada's economy and the everyday lives of Canadians are highly reliant on the chemical and fertilizer industry. The Chemistry Industry Association of Canada estimates that over 70,000 everyday consumer products in Canada involve chemicals (including plastics) in some way, with over 95% of all manufactured products reliant on chemistry.[7]

While the sector may have economic and social importance, the production of chemicals and fertilizers is emissions-intensive and was responsible for 1.4Gt CO_2e of direct emissions globally in 2019.[12] When Scope 2 and 3 emissions are also accounted for, the emissions profile of the chemical industry rises to slightly less than 4% of total global emissions.[3]

In 2020, Canada's chemical and fertilizer sector produced the most emissions of all heavy industry sectors: 29% of total heavy industry emissions (21 Mt), exceeding all other heavy industry sub-sectors, with almost twice as many emissions as the next most emissions-intensive sub-sector, steel (12 Mt), and far exceeding cement (10 Mt) and mining (9 Mt).[13]

Given the sector's significant emissions and its importance in key supply chains, decarbonizing chemicals and fertilizers is a crucial step toward Canada's net-zero by 2050 goal. Furthermore, many net-zero technologies and products are heavily reliant on chemical products (e.g., batteries for electric vehicles, various plastics and polymers for wind turbine blades). As a result, the International Energy Agency forecasts substantial growth in demand for products from the chemicals sector in its *Net-Zero by 2050* scenario, including a 25% increase in demand by 2030, assuming higher levels of plastic recycling.[4]

Chemicals also present a pathway for oil and gas products that are not combusted (e.g., natural gas as a feedstock for synthetic resins used to manufacture wind turbine blades, or for the production of blue hydrogen to manufacture ammonia for fertilizers), supporting economic growth and job creation in regions heavily reliant on fossil fuel industries as the world transitions to clean energy.

Defining chemicals and fertilizers

The Government of Canada categorizes chemicals and chemical products, including fertilizers, into four categories with a number of subcategories:

FOUR GENERAL CATEGORIES OF CHEMICALS

Industrial chemicals

Basic chemicals
Chemicals derived from organic hydrocarbons such as oil and natural gas. This category includes methanol and petrochemicals, which is further split into two classes:

- **Olefins:** Double-bonded hydrocarbons, which includes propylene and ethylene.
- **Aromatics:** Aromatic hydrocarbons, which includes benzene (a intermediate chemical used to produce other chemicals and plastics such as polystyrene), toluene (a solvent used in products including paint thinners and permanent markers), and xylene (a precursor to chemicals used to manufacture polyethylene terephthalate [PET] plastic bottles and polyester clothing). Together these are often referred to as BTX chemicals.[14]

Synthetic resins and fibres
Resins are liquid substances set into solid form through curing, such as epoxy or acrylic. Synthetic fibres include common clothing materials like nylon and polyester.

Polymerized petrochemicals and inorganic chemicals
This includes chloralkali process chemicals such as chlorine and the majority of plastics. For example, propylene and ethylene are polymerized into polypropylene and polyethylene, the most common plastic in the world.[15]

Formulated products

- Paints, adhesives and sealants.
- Soaps and toilet preparations (toiletries, e.g., after-shave, deodorant, moisturizer).
- Other chemical products.

Agricultural chemicals, including fertilizers and pesticides

- **Nitrogen fertilizers:** The largest group by volume includes ammonium nitrate and urea, both based on ammonia.
- **Phosphate fertilizers:** Obtained by mining phosphate rock, including various limestones and mudstone, which contain viable quantities of phosphate minerals.
- **Potassium fertilizers:** Obtained through the mining of potash—a mixture of potassium minerals found in evaporite deposits.

*Phosphate and potassium are mined products, and are therefore often categorized separately from chemicals when organizing the different heavy industry sectors, or for reporting emissions. For the purposes of this report, we have included them within the broader category of agricultural chemicals.

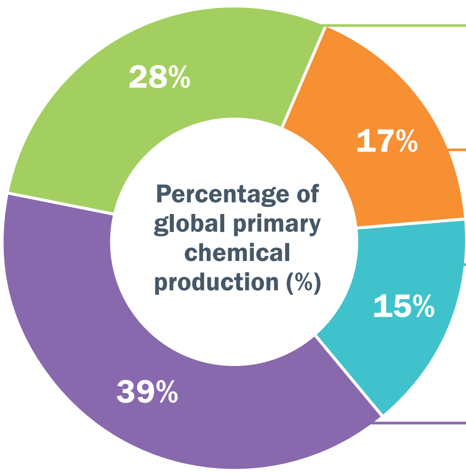
Pharmaceuticals and medicines

- Industry products are extremely heterogeneous, covering thousands of different medicines and compounds.
- Activity in the sector can be broadly split into two activities:
  - The research, development, and manufacturing of innovative new medicines and pharmaceutical products.
  - The production of existing medicines at scale, including brand-name, generic, and bio-pharmaceuticals.

BASIC AND AGRICULTURAL CHEMICALS

Basic and agricultural chemicals are the largest categories in term of production volume, and within this category the biggest is petrochemicals (chemical products derived from petroleum and other fossil fuels).[16] In Canada, these are predominantly derived from natural gas liquids. Despite the breadth and variety of the industry, the production of just seven chemicals make up two-thirds of the total energy requirements of the sector globally and underpin a huge variety of products further down the supply chain—these are also known as primary chemicals.[17] Figure 1 provides a summary of these chemicals and their global production levels.

Figure 1: Seven chemical building blocks and global production levels, 2018



Ammonia: the basis for all nitrogen fertilizers. Globally more than half of all ammonia is converted into urea.

Global Production: 185 Mt/Year

Aromatics: benzene, toluene and mixed xylenes: used in health, food production, transportation, and other sectors.

Global Production: 110 Mt/Year

Methanol: a precursor chemical used to synthesize other products; 40% is converted to formaldehyde and processed again into plastics, paints and textiles.

Global Production: 100 Mt/Year

Light olefins: ethylene and propylene: reactive compounds used to produce plastics and polymers, most commonly polyethylene and polypropylene.

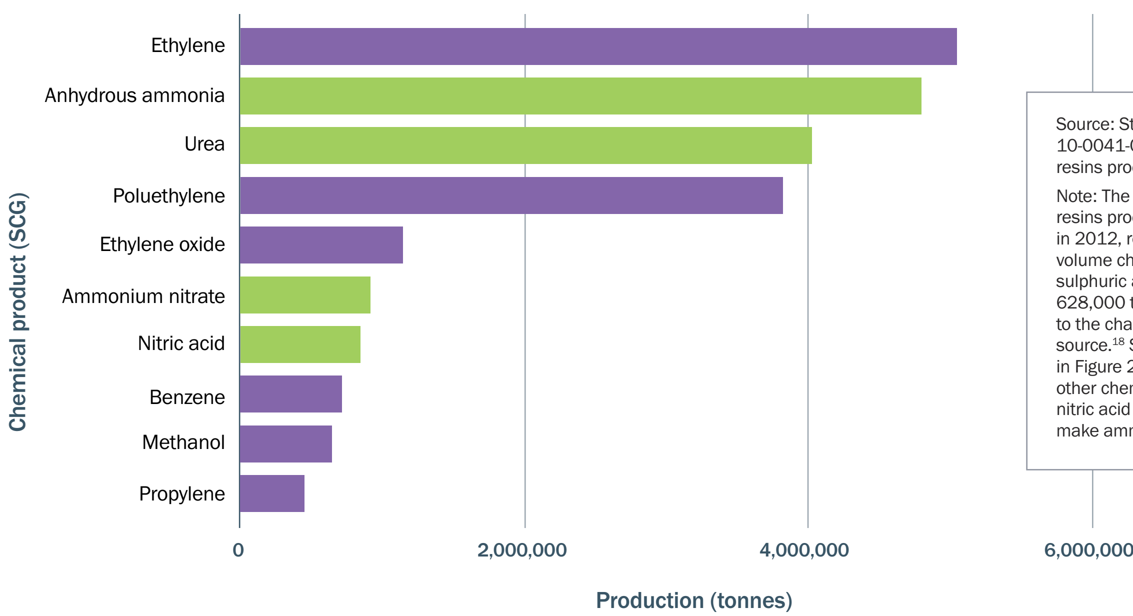
Global production: 255 Mt/Year

Note: Light olefins and aromatics are collectively referred to as high-value chemicals (HVCs). Total primary chemical production presented in source as 652 Mt/year. Percentages may not equal 100 due to rounding.

Source: IEA, *Future of Petrochemicals,* 2018.

Domestically, the chemicals industry is also dominated by the production of industrial and agricultural chemicals, specifically ammonia, ethylene, and propylene alongside urea (which itself is synthesized from ammonia).

Figure 2: Ten highest volume production chemicals in Canada, 2021



Source: Statistics Canada. Table 16-10-0041-01 Chemicals and synthetic resins production, annual.

Note: The chemicals and synthetic resins production survey was evaluated in 2012, removing a number of high-volume chemical commodities including sulphuric acid. Methanol production of 628,000 tonnes in 2021 is also added to the chart but is not present in the source.[18] Some of the chemicals listed in Figure 2 are downstream products of other chemicals in the same list (e.g., nitric acid and ammonia are used to make ammonium nitrate).

Emissions profile of chemical and fertilizer production

Emissions from the chemical and fertilizer sector are produced in two ways. **Energy-related emissions** arise from heat generation for chemical production (i.e. chemical cracking and steam generation) and **process emissions** are created when CO_2 is produced as a by-product of chemical reactions. Respectively, these two sources account for 85% and 15% of the sector's global emissions.[17]

When examined by chemical type, basic and agricultural chemicals make up 60% of total CO_2 emissions globally, of which ammonia is by far the largest contributor, accounting for 49%, followed by high-value chemicals (27%) and methanol (24%).

Canada's chemical and fertilizer emissions sources

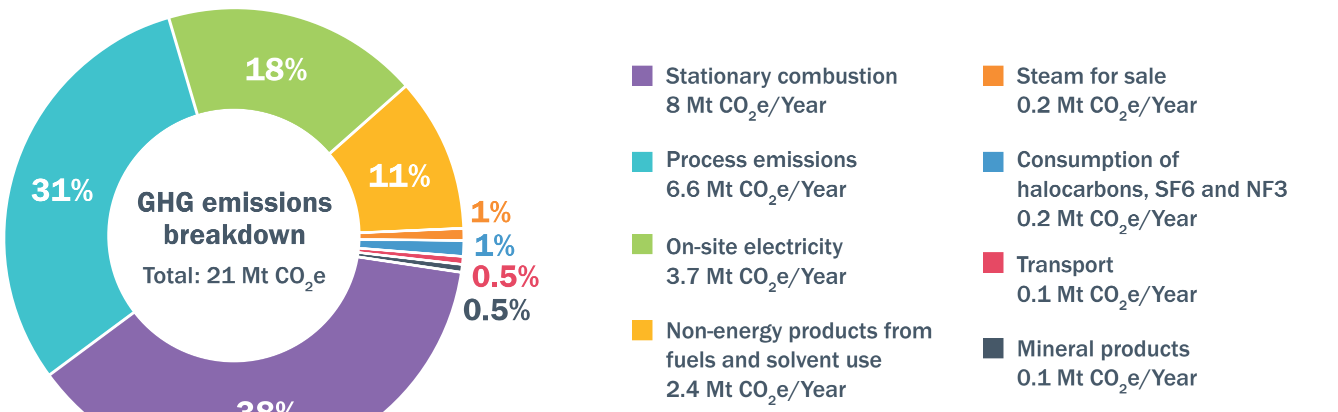
In 2020, Canada's chemical and fertilizer sector produced 21 Mt of GHGs, making it by far the largest emitter of the heavy industries—and nearly on par with steel and cement combined.* While emissions from the sector have dropped significantly since the 1990s due to the closure of heavily emitting facilities[20] and improvements across the sector (an estimated 35.8 Mt reduction for the chemical, fertilizer, and potash mining industries combined), less progress has been made over the last decade.[20] Since 2005, overall emissions reductions have been less significant, noting that the drop ending in 2010 was related to the 2008 global recession. While the data shown in Figure 4 accounts for total emissions and not emissions intensity, it remains clear that work by governments and industry is required if we are to return to a trend of significant emissions reductions.

Currently, Canada does not have a fully modelled pathway for net-zero chemicals and fertilizers, nor is there an overarching government strategy for the heavy industries as exists in some other jurisdictions (e.g., the U.K.'s *Industrial Decarbonization & Energy Efficiency Roadmaps to 2050* and the U.S. Department of Energy's *Industrial Decarbonization Roadmap*).[5,6] However, the Chemistry Industry Association of Canada has publicly committed to net-zero 2050, and is engaged with Canada's Net-Zero Advisory Body on finding effective solutions for Canada's chemistry industry.[7]

As Figure 3 on the following page highlights, in 2020, the largest slice of emissions come from the stationary combustion of fossil fuels to generate heat, followed by industrial processes and on-site electricity production.

* Defined in Canada as the production of chemicals and fertilizers, iron and steel, non-ferrous metals, cement, lime and gypsum, pulp and paper and mining.[19]

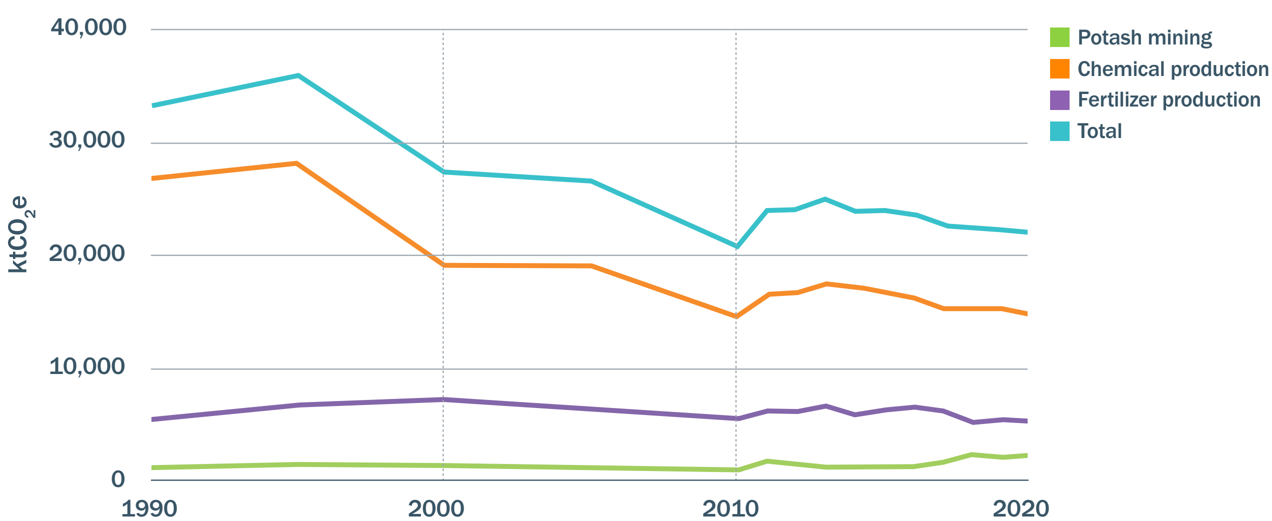
Figure 3: Canadian chemicals and fertilizers GHG emissions breakdown by source



Source: 2022NIR Part 3 (data for 2020). Note: Percentages total 101% due to rounding.

Note: Emissions sources as categorized by the Intergovernmental Panel on Climate Change

Figure 4: Emissions trends for chemicals and fertilizer production, Canada, 1990-2020



Source: The Canadian Energy and Emissions Data Centre database. Data combines National Inventory Report emissions records provided by Environment and Climate Change Canada, and estimates calculated by CEEDC

EMISSIONS INTENSITY OF CANADA'S CHEMICAL PRODUCTION

The choice of input feedstock, newness of technologies and facilities, and the regulatory environment all have a significant impact on the overall emissions intensity of a chemical product. As Canada's industrial chemicals sector primarily uses natural gas as a feedstock, has relatively modern facilities, and operates within Canada's industrial regulatory environment, our intensity compares favorably to international comparators.

The Chemical Industry Association of Canada estimates, based on data from 2005, that Canada's CO_2e per U.S. dollar of chemicals sold stood at 0.4Kg, compared to 2.17kg in China, which is more reliant on coal as a feedstock, and 2.34 in Eastern Europe.*

* International Council of Chemical Associations. Innovations for Greenhouse Gas Reductions: A life cycle quantification of carbon abatement solutions enabled by the chemical industry, 2009.

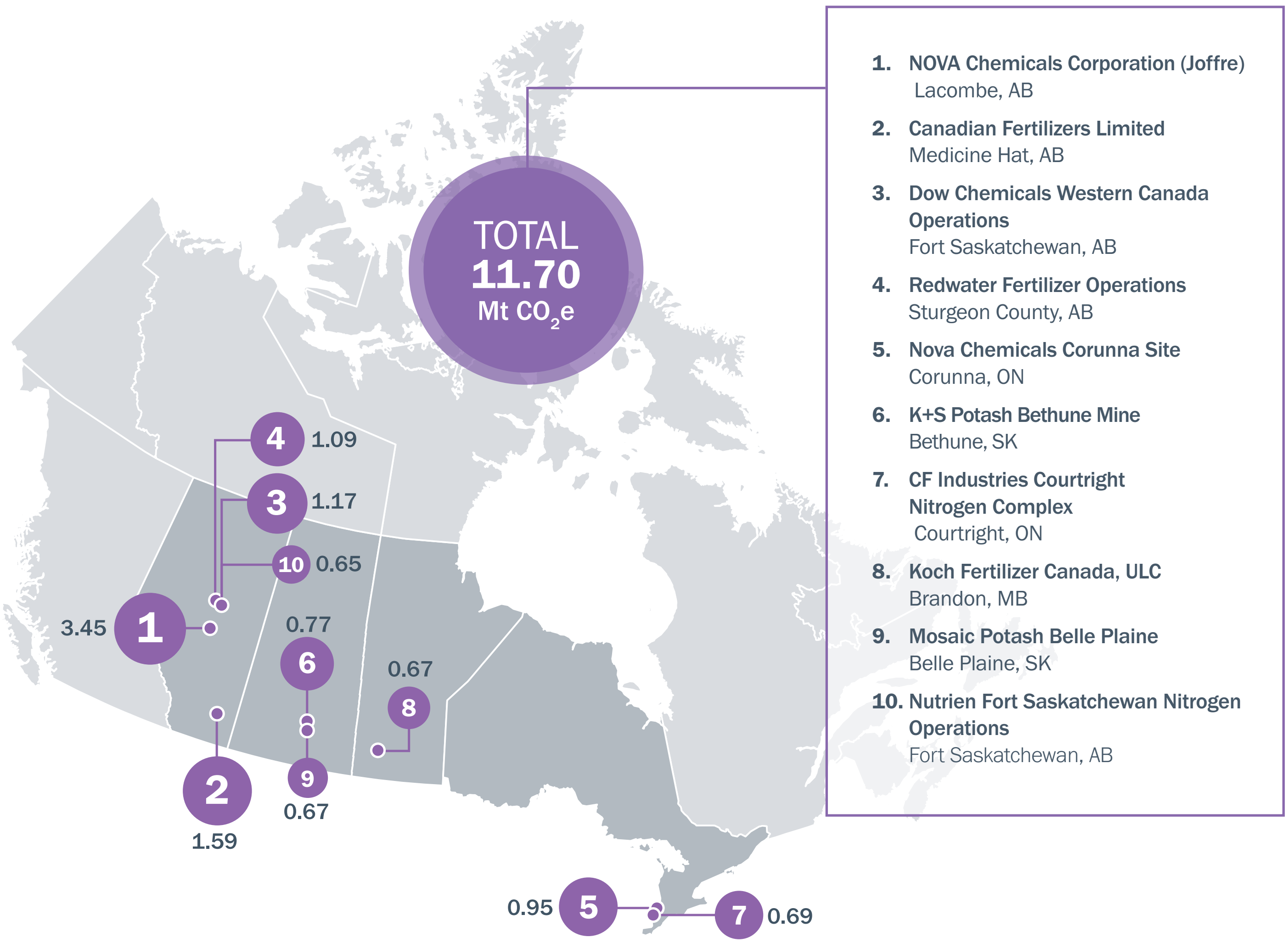
In terms of the geographic spread of emissions, over half (12.9 Mt) are produced in Alberta, with Ontario responsible for just under a quarter (5.0 Mt). The rest are shared between Quebec, Saskatchewan, Manitoba, and the Atlantic Provinces.[13]

Priority facilities

Overall, there are over 3,300 chemical manufacturers operating in Canada, reflective of the diversity of the sector.[21] However, in alignment with other heavy industries, the chemicals and fertilizer sector has a smaller number of large production sites that are responsible for significant emissions. Figure 5 below present the 10 highest-emitting Canadian chemical and fertilizer facilities. The highest-emitting facility in Canada is Nova Chemicals' ethylene and polyethylene complex (including a 475 MW cogeneration plant) in Joffre, Alberta, which produced over 3.4 Mt of CO_2e emissions in 2020.[22] The 10 highest-emitting chemical plants and fertilizer mines in Canada produce 11.7 Mt of emissions, approximately 56% of the sector's total.

Chemical facilities tend to be co-located, or located close to access to feedstock. Because a high percentage of chemicals are produced from natural gas liquids as feedstock, Canada's largest chemical facilities are located close to natural gas production and therefore are concentrated geographically, largely in Alberta, with facilities in Ontario located close to transit hubs for energy products such as Sarnia on Lake Huron, close to the U.S. border.

Figure 5: Highest-emitting chemical plants in Canada



Source: Government of Canada, Greenhouse Gas Reporting Program (GHGRP), 2020.

Note: Due to differences in cogeneration use at various facilities and how they are reported, some facilities in this list may or may not include cogeneration unit emissions in their total emissions.

Decarbonization pathways

While the sector is undeniably heterogenous with thousands of different product categories, the bulk of emissions come from a small number of large basic chemical and nitrogen fertilizer industries. As a result, the pathways to decarbonization currently focus on these areas.

The structure of the economies in which the chemical industry operates is also an important factor, given different jurisdictions have different regulatory environments, labour composition, access to trade markets, and energy infrastructure.

Ammonia has been an area of particular focus when modelling potential decarbonization pathways as the chemical product with the largest share of global emissions and one that underpins critical fertilizer production.[27–29] The International Energy Agency, World Economic Forum, and Low Carbon Emitting Technologies group have all presented analysis on the key technologies required and potential costs and timescales, which have crossover and application to other parts of the sector (e.g., Steam Methane Reforming/AutoThermal Reforming technologies, which are also used for the production of methanol).

The following section explores some of these critical pathways to decarbonization and the technical challenges they present. Broadly speaking, these can be placed into four buckets:

1. Shifting the underlying feedstock from fossil fuel sources such as natural gas and coal to cleaner alternatives such as hydrogen, which can be produced with zero-carbon emissions.
2. Increasing the efficiency of production processes and the use of feedstocks, including circularity and recycling.
3. Using carbon capture, utilization and storage (CCUS) technology to capture and store the carbon produced through existing chemical production processes and fossil fuel feedstock use.
4. Electrification and fuel switching to reduce or remove the carbon emissions from energy use and heat creation in the production of chemicals.

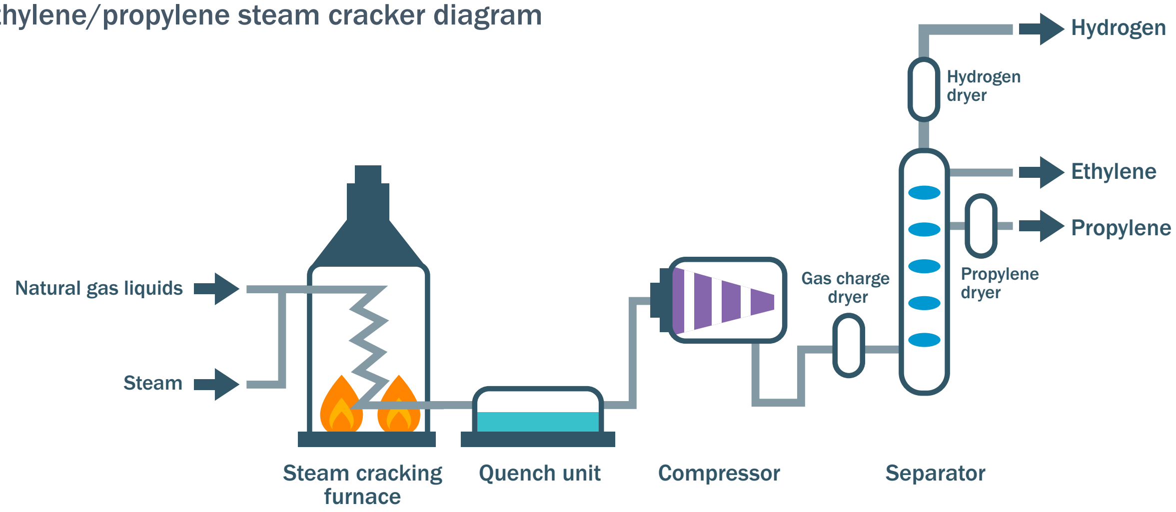
CHEMICAL AND NITROGEN FERTILIZER PRODUCTION

Industrial chemicals, synthetic resins and fibers, formulated chemical products and nitrogen fertilizers—which together make up the vast majority of chemicals manufactured in Canada and globally—share similar upstream production processes (that are also responsible for the majority of greenhouse gas emissions).[4,23]

The raw input materials for creating chemicals and nitrogen fertilizers are categorized as feedstock, and these are split into organic and inorganic categories. Fossil-fuel-based feedstocks are produced through a process of fractionation and purification from raw crude oil or natural gas extracted from wells. Fractionation leverages the different boiling points of the various compounds that make up raw natural gas and oil.[24]

This transformation of these fractionated feedstocks into chemicals is achieved through cracking. For the production of the bulk volume of industrial chemicals, the process used is steam cracking. Here, the input feedstock is diluted with steam and briefly heated to a high temperature (~850 °C). Depending on the temperature used to crack the feedstock, the amount of steam used, and the initial chemical makeup of the feedstock, various different chemicals are produced.[25]

Ethylene/propylene steam cracker diagram



Both methanol and ammonia, Canada's second largest chemical output by volume, utilize the Steam Methane Reforming (SMR) or AutoThermal Reforming (ATR) process in their production. These are multistep processes that begin with purified natural gas (methane), which is then reacted with steam to produce syngas, consisting of carbon monoxide (CO) and molecular hydrogen (H_2), with the addition of CO_2 in the case of ATR.

Ammonia is then created through the Haber–Bosch process, which produces ammonia through the catalytic reaction of hydrogen and nitrogen. The nitrogen is derived from atmospheric air, and the hydrogen is converted from syngas.[26]

SPOTLIGHT Canadian decarbonization projects

Dow Chemicals Net Carbon Zero Circular Hydrogen Cracker and CCUS Project

In 2021, Dow Chemicals announced the world's first net-zero carbon emissions integrated ethylene cracker and derivatives site at their Fort Saskatchewan facility in Alberta. The project also extends to retrofitting CCUS to the existing facilities on site in order to capture CO_2 emissions. The investment will also triple Dow's ethylene and polyethylene capacity from the existing site.[95]

Feedstock transition

Feedstocks with high carbon content are the most potent contributor to the emissions of chemical production. In Canada, the Canadian Energy and Emissions Data Centre database shows 7.7Mt of emissions coming from natural gas alone.[30] Natural gas is the dominant feedstock for Canada's basic chemicals industry, due to abundant availability and low cost. Feedstock prices and availability are driving economic factors for the chemical industry in a given jurisdiction (e.g., the boom in natural gas extraction through hydraulic fracturing leading to increased chemical production in the U.S.).

There are currently limited viable feedstock alternatives for most chemicals. Feedstock switching is most promising as a pathway for ammonia and methanol. In lieu of current high-intensity feedstocks, two approaches could be applied to reduce emissions in the production of these materials: 1) utilizing low-carbon bio-gas (or renewable natural gas, as the bio-gas is upgraded to pipeline specification) as a feedstock in SMR/ATRs combined with CCUS, and 2) replacing existing hydrogen produced using natural gas and coal with blue or green hydrogen (made using CCUS technology or electrolysis).* In both cases, carbon is still required (carbon monoxide to create syngas for methanol and to convert ammonia to urea), but there is potential to reduce this carbon footprint by using a secondary source: captured CO_2 from another facility or activity.

The International Energy Agency analyzed the technological readiness of hydrogen in the chemical sector and categorized fossil-fuel-based ammonia production with CCUS as the only mature technology, with fossil-fuel-based methanol production with CCUS in the early adoption phase, and clean hydrogen produced via electrolysis for both ammonia and methanol production still in the demonstration phase.[31] Biomass gasification is a relatively mature technology, while methane pyrolysis for turquoise hydrogen is perhaps the least viable currently, with recent analysis scoring it between Technology Readiness Level 3 and 5 (proof of concept and validated in a simulated environment, respectively).[32,33] For the remainder of the chemical sector, the feedstock picture becomes more complex with varying technology maturity and viability. There are a huge range of approaches being tested, which can be grouped into the following categories:

- **Municipal solid waste:** Using thermal reactions to convert consumer and industrial waste products into syngas, methanol, and other products.
- **Algae proteins:** Farming algae that can produce proteins and olefins through biocatalysis.
- **Biomass (2nd generation):** Using biomass from crops or waste to produce butanol, solvents, resins and other high-value chemicals through fermentation and thermal conversion.
- **Recycled plastics:** Recycling plastics back into constituent feedstocks (light olefins and aromatics) through thermal conversion, electrochemistry, and with chemical catalysis.[34]

* Globally 75% of ammonia feedstock is natural gas, and 25% coal.[27]

Downstream impacts of feedstock transition

Cost and scalability of feedstock technologies remains a significant barrier when accounting for the downstream cost implications in product supply chains. Basic and agricultural chemicals are, after all, low-cost bulk commodities. In the case of ammonia, without any policy interventions or cost-reductions, replacing existing feedstock with green hydrogen could result in a 55% increase in the cost of production, which would have knock-on effects down the supply chain, with a corresponding 25% increase in nitrogen fertilizer costs and a 15% increase in per-tonne food costs.[35]

Increasing efficiencies and material recycling

Improving resource and energy efficiency and reducing the use of primary materials as a feedstock presents significant opportunities to reduce the overall carbon intensity of the chemical sector. Efficiency involves the use of best available technology in all elements of the production processes where the most modern and energy- and resource-efficient technologies are utilized. The overall emissions reduction potential of greater efficiency varies significantly depending on the process or product.

Reusing materials (primarily plastics) as recycled feedstock (also known as circularity) has relevance in chemicals, but it will not be a relevant pathway for the production of mined fertilizers (e.g., potash). Successful recycling is complex, and its viability broadly depends on four factors:

1. **The collection rate:** The proportion of plastic waste that is recycled in society, which therefore determines the potential volume of feedstock material available.
2. **The recycling yield:** The amount of material that remains after accounting for losses in the processing and recycling of the material.
3. **The displacement rate:** The volume of plastic products that can be recycled into a product of the same type or quality.
4. **The cost differential:** The difference in costs between final recycled material compared to the primary material it is aiming to replace. [36,37]

In many cases, products cannot be reused to create a product of the same type or quality and the process involves downcycling. For example, currently, a PET plastic bottle cannot be recycled to create another bottle, but it can be recycled into PET fibers. All of these factors need to be considered, and improved, in order to realize the potential of a circular economy in the chemical industry.[17] As a result, it is also important to combine these recycling approaches with a reduction in overall usage. Policies such as Canada's ban on single-use plastics is one example of this in action.[38]

Carbon capture, utilization, and storage

CCUS encompasses a range of different technologies and approaches to reduce CO_2 emissions. The International Energy Agency has highlighted the chemical industry as one of the most promising applications for CCUS technology, as in many chemical production processes, including ammonia and methanol, the CO_2 is chemically separated and purified.[17] CCUS presents a particularly viable option in jurisdictions such as Canada where low-cost natural gas will remain competitive as a chemical feedstock in the foreseeable future, and where geological carbon storage is easily accessible (e.g., Alberta).[27,39,40]

CCUS has been modelled by the IEA and others as a critical intermediary technology given the gulf in price between current feedstocks and future alternatives.[35] In their 2023 Energy Technology Perspectives report, the IEA highlighted that for ammonia and methanol production, CCUS was at mature or early adoption levels for at least one approach (e.g., chemical absorption) and in the demonstration phase for high-value chemicals.[31] However, according to the report, just two chemical facilities have utilized CCUS technology to date—both in China and operated by Yangchang Petroleum and Sinopec respectively.[41]

There are several reasons why CCUS may not yet have been adopted en masse by the chemical industry. Broad application of CCUS for producing blue hydrogen feedstock or for decarbonizing chemical and fertilizer facilities requires significant investment. Successful deployment requires access to external resources including natural gas and carbon transportation and storage infrastructure. As a result, these are defined as site-tailored technologies, requiring bespoke engineering and construction. These factors mean projects often rely on public support and private sector collaboration.[41] Additionally, in many chemical production facilities, there are often a high number of emissions sources, with no single one providing a high concentration of CO_2 flue gas, which presents a challenge to the economics of a CCUS installation.

Electrification and fuel switching

Electrification of manufacturing processes that currently use fossil fuels (e.g., coal, natural gas) can provide significant emissions reductions. But in order to use electricity, the manufacturing approach for some chemicals will require further innovation or process changes, such as transitioning to clean methanol as a feedstock.[42] In many cases, electrification will require innovation in the use of catalysts at lower temperatures as a replacement for the high-heat fossil-fuel-based approaches that are currently mainstream.[43]

Approaches to replace fossil fuels with electrical energy in steam cracking are now reaching the demonstration phase of TRL. In Belgium, six chemical companies (BASF, Borealis, BP, LyondellBasell, SABIC and Total) have come together in the Cracker of the Future Consortium to explore how natural gas and naphtha-fed steam crackers could be operated on clean electricity (noting that the cracking process itself still produces CO_2 that will require abatement).[44] In all these cases, the use of electrification as a route to decarbonization is predicated on access to low-cost, abundant, reliable clean electricity.

Basic chemical facilities also tend to have a lot of heated or fired equipment (e.g., furnaces, heaters, boilers, gas turbines). This equipment is often large in scale, which requires significant investment and additional infrastructure to replace, including energy transmission and storage, in addition to reliable access to clean electricity. As a result, in some instances fuel switching may be a more viable interim alternative: transitioning from unabated fossil fuels such as coal and natural gas to low to zero-carbon fuels such as clean hydrogen or renewable natural gas for fired equipment.[45] As noted in the introduction, in the case of the chemistry sector, many fossil fuels currently provide a duel function in a chemical facility: as the feedstock for the chemicals themselves, and also as the fuel used for the generation of electricity and process heat.

Critical pathways for G7 nations

The IEA's 2022 paper, *Achieving Net Zero Heavy Industry Sectors in G7 Members,* provides a framework to achieve the decarbonization of the sector by 2050, including key milestones that are considered achievable by G7 nations.[46] Table 1 outlines the milestones for the use of each of these pathways by 2020, 2030, and 2050.

Table 1: Key milestones for the chemical industry in the G7

Key milestones for the chemical industry in the G7		2020	2030	2050
Plastic recycling	Share of waste collected for recycling (%)	25%	35%	62%
	Share of secondary plastic production (%)	15%	21%	49%
On-site hydrogen	Overall production (Mt H_2)	8	10	11
	Production with electrolyzer capacity (GW)	0	8	34
Share of production via innovative routes (%)		1%	18%	94%
CO_2 captured (Mt CO_2)		2	23	78

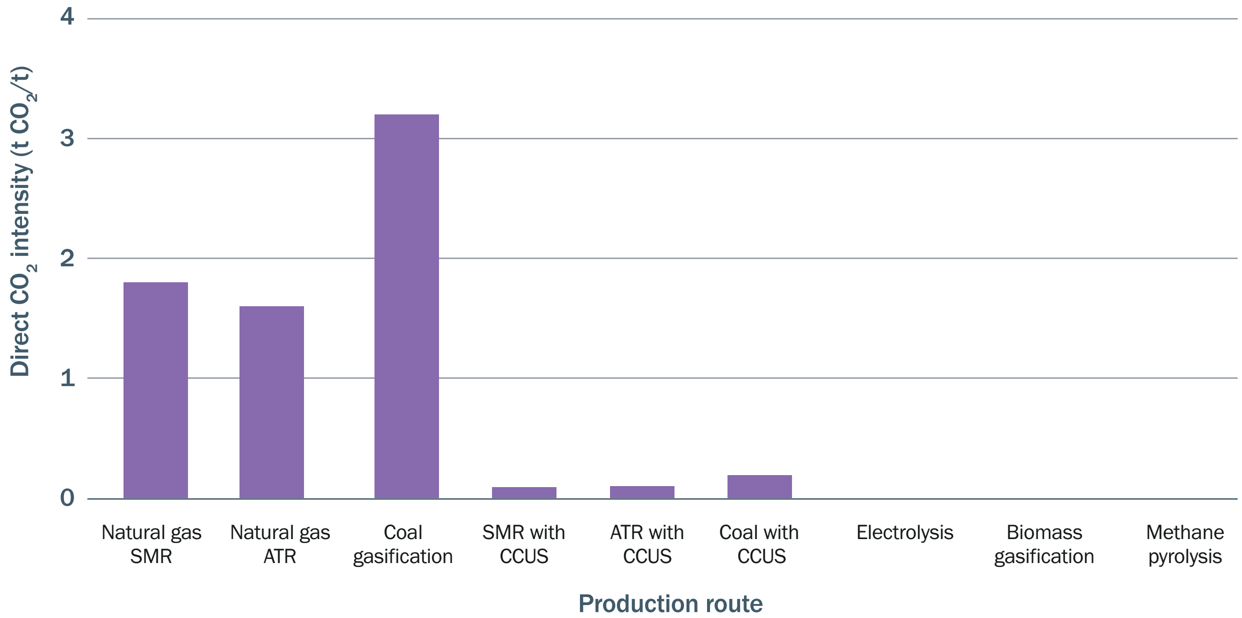
Reproduced from IEA, Achieving Net Zero Heavy Industry Sectors in G7 Members, Table 1.1. Pg. 37

Net-zero pathways illustrated: ammonia

Ammonia production is currently heavily dependent on fossil fuels. Approximately 75% of production is via steam-reforming, which predominantly relies on natural gas, while the remainder is produced via coal gasification. Ammonia facilities have a long lifespan, between 20-50 years, and therefore we are only one investment cycle away from 2050 in most cases.[27]

Figure 6 below outlines the energy and direct CO_2 intensity of the various technology pathways, some of which were explored in this section. As expected, using coal as an initial feedstock produces the most GHG-intense product, but many of the other options present a more complex picture, with trade-offs in energy efficiency and intensity in different areas, even when total CO_2 intensity is approximately the same (0 or 0.1). In reality, the decisions around which option is best will depend on technological viability, costs, and regional external factors (e.g., is carbon storage or transport readily available to a given site).

Figure 6: Direct CO_2 intensity (t CO_2/t) of one tonne of ammonia for each production route (best available technology)



Source: IEA Ammonia Technology Roadmap, 2021.

SPOTLIGHT Canadian decarbonization projects

Shell Polaris CCS

Shell is planning to add a large-scale CCS installation to its existing refinery and chemical production site in Scotford, Alberta. If built, the Polaris CCS system could reduce scope 1 and 2 emissions from the chemical plant by 30%—removing 750,000 tonnes of CO_2 across the site each year. Polaris could serve as a CO_2 storage hub for more than 10 million tonnes of CO_2 annually. It will also serve as a hub for blue hydrogen, utilizing the existing hydrogen production facility onsite combined with the addition of CCS technology. A final investment decision is planned for 2023.[97]

The economic opportunity of a decarbonized chemical and fertilizer sector

Chemicals, including plastics and fertilizers, have a significant role to play in a net-zero world through a wide range of existing and future net-zero technologies and products.[3,4]

Federal and provincial policy makers therefore need to think strategically about what Canada's role will be. Given that over 140 countries have also committed to net-zero emissions, it is safe to assume there will be a significant market for chemicals and chemical products that can meet low-carbon requirements.[47]

The Chemistry Industry Association of Canada valued the chemical and fertilizer manufacturing sector at $52 billion in 2021. The sector directly employs over 88,800 people across Canada and is estimated to support a further 410,000 jobs across the economy. This is similar in size to Canada's forestry industry (91,636) and notably larger than other heavy industries such as primary metal manufacturing (56,463).[2,48] The economic activity of the chemical and fertilizer industry has clear regionality in Canada: Ontario, Alberta, and Quebec represent 86% of all industry production by value.[2]

Today, Canada's chemical and fertilizer industry is dominated by a relatively small number of chemical and oil and gas companies (the latter primarily in basic chemicals that rely on the extraction of natural gas and oil). The largest of these operating in Canada is BASF, which employs over 117,000 people worldwide, having posted revenues of US$78.6 billion in 2021.[49]

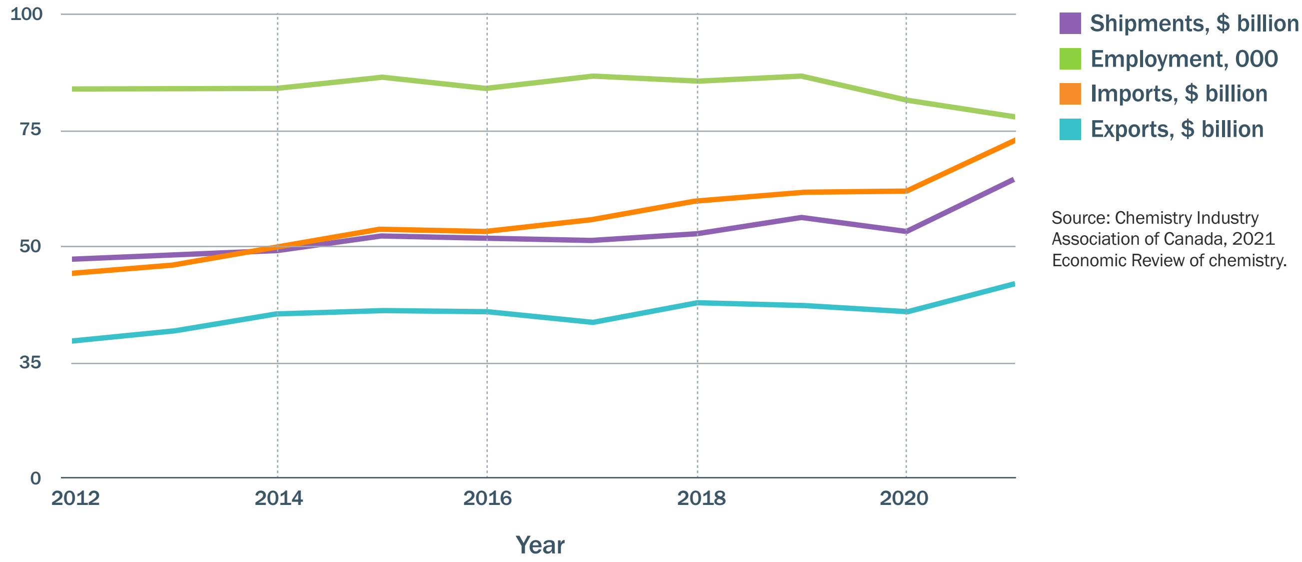
In recent years, there has also been a reduction in the number of companies due to mergers and acquisitions. For example, Nutrien, a fertilizer producer, was created in 2008 through the merger of Agrium and PotashCorp.[50] The company is now responsible for 2.7 Mt of emissions from five of its largest facilities across both nitrogen fertilizer production and potash mining.

Current economic trends

Figure 7 presents the last decade of chemical industry trends for overall production, employment levels, imports, and exports. Prior to the economic and social impacts of the COVID-19 pandemic, all of these markers of economic performance had been trending positively, and 2021 saw an economic recovery to new heights for all data points other than employment.

When it comes to fertilizers specifically, we see similar trends with shipments and imports trending positively in the last decade. However, exports have not seen the growth that we see in the sector overall, experiencing a modest decline since 2016.

Figure 7: Statistical trends in the chemical sector (2012-2021)



Source: Chemistry Industry Association of Canada, 2021 Economic Review of chemistry.

There are signs that fertilizer exports may see significant growth in the coming years, particularly in potash, due to Russia's invasion of Ukraine influencing the world's other key producers, Russia and Belarus. Nutrien, Canada's largest fertilizer company, is increasing potash production by 20% in 2022 in response to these factors.[59]

Looking at recent and planned investments in Canada's chemical and fertilizer sector, we see two clear trends: the expansion of industrial chemicals and potash mining. Most recently, two new Canadian operators entered the chemical sector with proposed polypropylene production facilities in Alberta. These industries are underpinned by access to the feedstock inputs that are the basis of these products, in particular natural gas liquids. The price and availability of natural gas feedstock in Alberta in particular has drawn increased investment into the sector.[60,61]

But it is important to note that the price volatility of fossil fuels means that this investment can also rapidly shrink or be diverted unless we transition to more sustainable feedstocks. Methanol is one example of this, between 2001 and 2006, four methanol facilities were shut down in Alberta due to the price of natural gas at the time, and only recently has investment returned to the sector.[62]

Canada is not unique in this trend. Countries tend to lead and grow production in chemical products for which they have abundant feedstock. For example, the U.S. is forecast to grow its proportion of global ethylene production from 17% in 2017 to 22% by 2025 due to the boom in natural gas production from hydraulic fracturing.[17] Similarly, China is forecast to grow its methanol (and downstream olefins) production resulting from abundant coal feedstock.[17]

The importance of chemicals in a net-zero world

Electric vehicles

Most cars, including EVs, are approximately 50% plastic by volume but only 8% by total weight.[51] Their low weight makes plastics a desirable material for building EVs as electric vehicles are, on average, 19% heavier than their gas-powered equivalents.[52] Chemical and plastic/polymer technologies also have a significant role in advancing battery performance and durability in EVs as technologies advance and mature.[53]

Clean electricity generation

The production of photovoltaic solar power cells is heavily reliant on chemicals and plastics. This includes processing the silicon used in the majority of PV cells worldwide.[54] Resins and plastics make up between 11% to 16% of wind turbines,[55] and advances are being made in new types or resins with high recyclability for a future net-zero world that could produce two million tonnes of waste turbine blade material each year as parts wear out and need replacement.[56]

Food production

While the over-application of nitrogen fertilizers presents an environmental and emissions challenge, the requirement of fertilizers to meet our food production needs is expected to grow over the coming decades. Global population levels will in part dictate this need,[57] with the United Nations forecasting a 50% increase in global use by 2050.[58]

Imports and exports

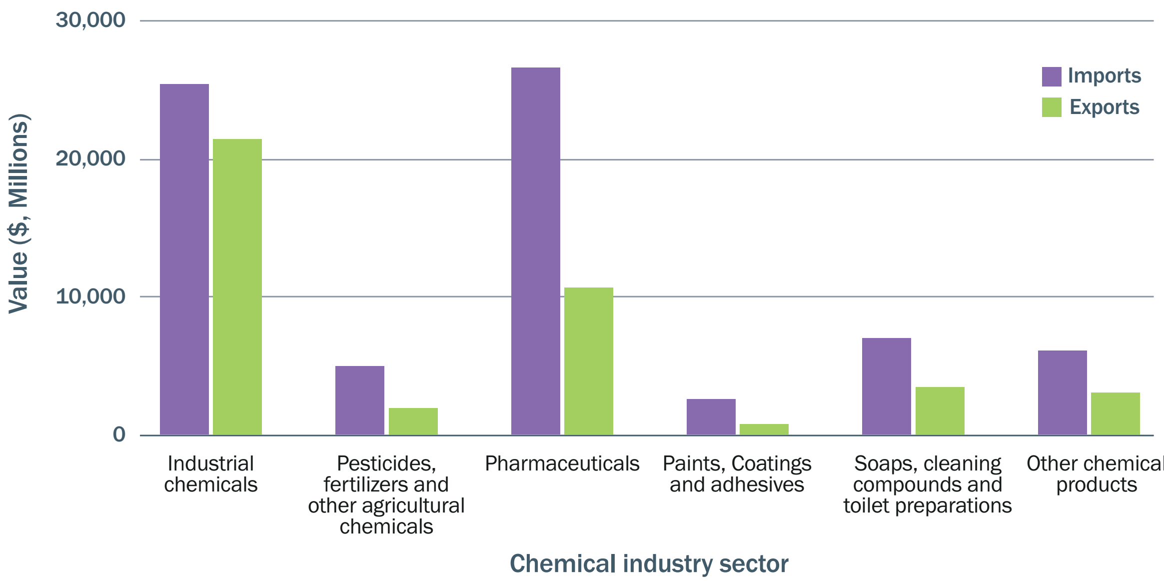
In total, Canada exported $41.7 billion worth of chemicals in 2021 and imported $72.9 billion. Exports grew 15.8% over 2020. Across every sub-category of chemicals, Canada imported more products by overall value, with the difference most significant in pharmaceuticals and closest in parity for industrial chemicals.

Currently, 77% of all Canada's chemical exports end up in the United States, with the next largest export markets being China (3.6%) and Japan (2.4%).

At a product level, export markets present greater variety: 64% of ethylene glycol exports (used primarily for creating polyester fibers and as a component of antifreeze) go to China, 54% of butadiene (a precursor of synthetic rubber) is exported to South Korea, and 99% of methanol is sold to the United States.[2]

Canada is a major player in the chemical and fertilizer sector and is globally competitive in a number of areas.[63–65] Canada leads the world in potash fertilizer production and chlorine exports as well as ranking fifth worldwide for ammonia exports in 2021, ahead of the U.S.[66–69]

Figure 8: Canadian chemical industry imports and exports value



Source: Chemistry Industry Association of Canada, 2021 Economic Review of chemistry.

Future global growth

Globally, the chemical and fertilizer sectors are growing. **Since 2000, they have outstripped other heavy industries such as cement and steel, with demand for plastics alone almost doubling in the last 20 years.**[17] The IEA also forecasts strong growth in demand in all net-zero 2050 scenarios.[4]

Ammonia and methanol are expected to see significant growth in demand over the coming decades. For ammonia, expanded fertilizer use and other potential applications such as energy storage could see demand rise from 185 Mt globally in 2020 to 1 Gt by 2050. Methanol, with its widespread use in manufacturing a range of chemicals, is forecast to grow from 100 Mt of global production to approximately 440 Mt by 2050.[3] High-value chemicals (light olefins and aromatics) also see a projected 60% growth trajectory to 2050, driven by increased demand for plastics derived from ethylene and propylene.[17] The majority of this growth is expected to take place in the Asia Pacific region in the shorter-term and the Middle East and Africa in the longer-term.[17]

Canada has an opportunity to be a key global supplier of clean chemicals and fertilizers, with the ingredients to deliver both transitional, lower-carbon chemicals and a future of sustainable zero-carbon products (see decarbonization pathways). Private companies and international jurisdictions are already beginning to signal their preferences for such commodities. The European Union recently expanded its Carbon Border Adjustment Mechanism (a trade policy that would apply a carbon price to imported goods to match that of the internal market) to include both nitrogen fertilizers and hydrogen production, signaling that reducing carbon intensity will be a key factor in remaining trade-competitive in the future.[8]

Decarbonization opportunities and challenges

BloombergNEF estimates that decarbonizing the global chemicals sector by 2050 will require US$795 billion in investment, with electrification and CCUS set to be the key overarching pathways.

It is important to note that estimates for the cost of heavy industry decarbonization vary hugely depending on many variables: for example, McKinsey & Co. provide estimates between US$11 trillion and US$21 trillion depending on the price of clean electricity alone.[70,71] This transition will be capital-intensive, but delaying investment risks significant stranded-asset costs and missed opportunities when it comes to meeting the growing demand for clean chemicals and reducing the emissions intensity of food production.

The chemical and fertilizer sector is already a critical economic engine in Canada, creating hundreds of thousands of direct and indirect jobs. Decarbonization will be required simply to maintain the economic benefits of the sector in a net-zero future. But there is also a significant opportunity in growing the clean chemical and fertilizer sector in Canada.

SPOTLIGHT Canadian decarbonization projects

Enerkem Varennes

In 2020, Enerkem announced a new biofuels facility to be built in Varennes, Quebec. The facility will convert municipal solid waste into biofuels and recycled chemicals. The facility also incorporates green hydrogen produced via electrolysis. The $875 million facility (Shell is a principal investor) will come online in 2023. The plant follows Enerkem's first facility in Edmonton, Alberta, in operation since 2017, which uses 100,000 tonnes of dry municipal waste feedstock to produce 38 million liters of biomethanol and cellulosic ethanol each year.[96]

Key trading partners are already making the move into cleaner chemical production. The United States is making significant investments in heavy industry decarbonization through the Inflation Reduction Act (IRA) as well as introducing tax credits for key technologies such as CCUS and clean hydrogen production with investment and production tax credits.[72] The impacts of the IRA for the Canadian chemicals and fertilizers industry and its decarbonization efforts will need to be carefully evaluated, with Canada's response to be determined.

Opportunities

- **First mover advantage**: With many of the decarbonization technologies for the sector still in prototype and demonstration phase,[41] we are entering a period of significant potential knowledge acquisition and skill development in designing low-carbon facilities and producing clean chemicals.[41] Making Canada the destination for these investments could bring significant prosperity and an opportunity for Canada to export our innovations and expertise. There are indications that we are currently losing out to other jurisdictions in this respect. Nutrien, Canada's largest fertilizer producer, recently announced plans to build the "world's largest clean ammonia facility" in Geismar, Louisiana.[73]

- **Net-zero opportunities:** Chemicals and their derivatives are modelled to have a significant role in a net-zero 2050 through their existing uses. But as we seek novel ways to decarbonize our economies, chemicals have additional and changing roles in the net-zero future. Ammonia could be a critical solution to decarbonizing shipping and as a hydrogen-carrier for long-distance transportation (the planned approach for shipping hydrogen produced from the latest Canada-Germany Hydrogen Alliance).[74] Finnish shipping company Meriaura is building ammonia-ready cargo ships to enter service in 2024 and will switch its fuel to green ammonia in 2026.[75] Methanol is also being explored as a marine and vehicle fuel to reduce emissions. There are over 100 methanol dual-fuel vessels operating or on order, representing three million tonnes per year of methanol demand potential in the coming years.[76] Chilled ammonia is also being tested as the key ingredient in a new carbon capture technology by energy technology company Baker Hughes.[77]

- **Growing markets:** International partnerships are coalescing to create a private sector market for cleaner chemicals. The First Movers Coalition is an international initiative aiming to leverage the purchasing power of large companies to decarbonize heavy industry sectors including steel, concrete and chemicals.[78] Further to this, the World Economic Forum and partners have created the Mission Possible Partnership and Low Carbon Emitting Technologies (LCET) platform, "an ambitious effort to trigger a net-zero transformation of seven industrial sectors [including chemicals], leveraging the convening power, talent and expertise of world-leading organizations on climate action."[79] Canada has recently joined the First Movers Coalition as a partner country,[80] alongside key trading partners including the U.S.[80] Many of the chemical companies that operate in Canada, including Dow and BASF, are part of the platform.[81,82] Some jurisdictions are also taking a more direct approach to driving the market for low-carbon chemicals: India's draft hydrogen strategy requires 5% minimum green ammonia production for the domestic fertilizer sector by 2023-24 and 20% by 2027-28.

- **International momentum:** Several jurisdictions are beginning to develop strategies to decarbonize their chemicals and fertilizer sectors. The U.S. Department of Energy published its strategy in 2022.[6] Similar strategies have also been produced by Japan and the EU.[83,84] The U.K. was an early entrant into this space, publishing its *Industrial Decarbonisation & Energy Efficiency Roadmap* in 2015. These strategies examine key technology and business-case barriers, research and development, human capital needs, and external factors including scaling up the clean electricity grid.[5] Some of the world's largest chemical companies, including Dow Chemicals and BASF, have publicly committed to net-zero 2050 for scope 1 and 2 emissions.[85,86]

Challenges and policy levers

A review of existing modelling for net-zero chemical production and jurisdictional strategies presents a number of common challenges for decarbonizing the sector, including insufficient price signals for decarbonization, significant upfront capital costs, and technology availability and scalability.

Insufficient price signal: Decarbonizing chemicals and fertilizers is an expensive endeavour, which will impact the price of clean chemicals in the short- to medium-term. Support will be needed to create a market for these chemicals as a result. Currently, no jurisdiction has committed to the carbon price level required to create a significant market shift in the chemical industry. The World Economic Forum suggests that the carbon price may need to be as high as US$360/tonne to create a viable market for zero-emission ammonia. For comparison, Canada's carbon price is currently $50 ($65 from April 1, 2023) and is scheduled to rise $15 a year to hit $170 in 2030.[35] Policies that may be able to address this challenge include:

- Carbon Contracts for Difference that provide transitional assurance on the carbon price and ensure that low-carbon products can be market-competitive as soon as possible.
- Supporting buyers clubs and other mechanisms that create a critical mass of companies/jurisdictions that are seeking to access lower-carbon chemicals and are willing to pay temporarily higher prices.
- Carbon Border Adjustment Mechanisms, which seek to limit the trade of higher-carbon products undermining the carbon price and related costs of producing clean chemicals in a given jurisdiction.
- Prioritizing low-carbon chemicals and chemical products (e.g., batteries, plastics) in public procurement and ongoing spending. Essentially, a 'Buy Clean' approach for chemicals and fertilizers.

Capital and operational costs: Investing in decarbonization solutions such as clean hydrogen production, CCUS, electrification, circularity/recycling, and, particularly, alternative feedstock technologies will involve significant upfront capital investment with long-term operational premiums. Analysis of the EU's chemical industry estimates that decarbonizing the sector will cost in excess of €1 trillion. Of that, €650 to €950 billion is from capital expenditure on technologies and upgrades and a further €200 to €300 billion is on "standstill costs" (revenue lost due to inoperation of facilities while being upgraded).[87] Once facilities are operational, production of low-carbon chemicals may also have ongoing cost increases, both to cover the initial capital investment and the operational costs of systems such as carbon capture and storage or increased fuel prices. Policies that may be able to address this challenge include:

- Targeted investments, loans, and subsidies to reduce capital cost expenditure and improve the business case for investing in new facilities.
- Competitive financial mechanisms for key cross-sector technologies such as CCUS and hydrogen (e.g., investment and/or production tax credits).
- Policies that create an attractive investment environment by addressing relevant external factors (e.g., clean electricity regulation).
- Financial support mechanisms such as Production Contracts for Difference that can provide an agreed ongoing subsidy to cover some or all of the increased operational costs on a short- to medium-term basis in order to ensure market competitiveness.

SPOTLIGHT Canadian decarbonization infrastructure

Alberta Trunk Line

The 240-kilometre trunk line, operated by Wolf Midstream, is the world's largest-capacity pipeline for CO_2 from human activity. The line currently transports 1.6 million tonnes of CO_2 a year from the NWR Sturgeon Refinery and Nutrien Redwater Fertilizer facility to an oil reservoir for enhanced oil recovery. The project was designed with further expansion in mind, with other emitting facilities encouraged to join the pipeline network. The pipeline has a capacity of 14.6 Mt CO_2 a year. [98,99]

Technology availability and scalability: IEA modelling places a requirement for innovative production routes to scale from 1% in 2020 to 94% of chemical production by 2050. However, the majority of pathways remain in either early stage technology readiness or face challenges in scaling (e.g., materials for electrolyzer production). For example, only chemical-absorption carbon capture technology for ammonia is currently a mature technology when it comes to CCUS.[31] More attention and investment needs to be made now to enable the sector to contribute to a net-zero 2050. Policies that may be able to address this challenge include:

- Targeted investments in research and development to accelerate the next generation of low-carbon technologies.
- Support for first-of-a-kind and demonstration facilities to scale decarbonization technologies and attract further investment.
- Onshoring key technology manufacturing where clear advantages exist (e.g., growing Canada's electrolyzer production capacity utilizing our existing base of knowledge and manufacturing capacity combined with Canada's critical mineral supply chain).[88]

Key external factors

Like with other heavy industries, the decarbonization pathways for chemicals and fertilizers are heavily reliant on factors external to the decarbonization of a specific site or facility. Four key factors include:

The decarbonization and expansion of electricity generation and transmission to provide low-cost, reliable access to electricity. A critical external factor given the importance of electrification for clean hydrogen feedstock production and, in the future, process energy. The sector cannot reach net-zero without this being delivered, and as such is the primary policy priority for international industry representatives such as LCET.[89] Estimates for the EU suggest that electricity requirements for a net-zero chemicals sector could be as much as 3.2 PWh of clean electricity, five times the current volume of renewable energy generated in the region today.[87]

Low cost and reliable access to alternative feedstocks, particularly clean hydrogen, which underpins the production of ammonia and methanol, as well as providing clean fuel to replace fossil-fuel-based energy for heat in chemical production (e.g., renewable natural gas).[90]

Availability of recycled feedstock will be largely dependent on the collection rate of recyclable materials in the wider economy. The supply of material will also depend on trends in the global trade of recycled materials. Countries, particularly in Europe and North America, are moving toward the onshoring of recycling to serve domestic markets, ensuring supply and avoiding global supply chain issues.[91]

The appropriate geology and regulatory environment for effective and affordable carbon sequestration to facilitate successful CCUS implementation—something that is currently limited to certain geographies in Canada.[92,93] This combines with a lack of national transport infrastructure for CO_2. It is also worth noting that for some production processes (e.g., making urea for nitrogen fertilizer), some CO_2 is still required and, if no longer produced on-site, will need to be provided from a secondary source.

SPOTLIGHT Canadian decarbonization projects

BHP Potash Mine

The Government of Canada (through the Strategic Innovation Fund) announced an agreement in 2022 to provide $100 million to BHP, the world's largest mining company, to decarbonize the recently announced potash mine in Jansen, Saskatchewan. This will be primarily achieved through the electrification of mining vehicles and other technologies.[100]

BHP

Recommendations

Chemical products have a key role in many low-carbon technologies utilized throughout the economy, and decarbonizing Canada's chemicals and fertilizer sector will be crucial to meeting our national emissions targets.

As with other hard-to-decarbonize sectors, chemicals and fertilizers will require policymakers to explore every tool in the toolbox to achieve the required emissions reductions.

With industry making early moves to decarbonize, and initiatives such as the First Movers Coalition creating new markets for clean chemicals, Canada is in a strategic moment where the right policies and investments could drive growth and prosperity for the sector in a net-zero future, positioning Canada as a hub for clean technologies that will be critical in the coming decades.

Jurisdictions globally are increasingly recognizing the range of actions both internal and external to the sector that are critical to successful decarbonization—and why a strategic approach is necessary.

Work to advance the decarbonization of this sector, and further explore its economic potential, should be done by industry, government and other stakeholders. Our preliminary recommendations to achieve this include:

1. **Canada should develop an overarching net-zero industrial strategy that includes chemicals and fertilizers** that takes a holistic approach to decarbonization as we have seen in the U.K. and other jurisdictions, integrating:
   - Financing levers. Government should consider the accessibility of current funding programs to the chemical industry, as well as complementary fiscal levers such as the recently announced program of Carbon Contracts for Difference within the Canada Growth Fund.
   - An evaluation of the effectiveness and interoperability of policies that impact the success of the sector in reducing emissions (e.g., the Hydrogen Strategy, Clean Electricity Regulations, investment tax credits, research and development, and innovation funds like the Net Zero Accelerator).
   - Creating markets for clean chemicals and fertilizers by exploring a 'Buy Clean' policy or designing a clean chemical quotas approach within government, and supporting private and public buyers clubs.

2. **Focus on industrial and agricultural chemicals as the initial basis for a decarbonization strategy** as the largest source of emissions:

   - Targeting this sub-sector, particularly ammonia, would align with international priorities enhancing opportunities for collaboration and innovation sharing.
   - Further work on reducing emissions from nitrogen fertilizer in Canada may be of particular importance given its role in agriculture and domestic production for export.
   - Industrial chemical production occurs in a small number of large facilities. Focused decarbonization efforts on a small number of plants (e.g., the top five emitting chemical plants) can potentially have a significant impact on the overall emissions profile of the sector.

3. **Governments and industry should work to evaluate and advance the best market opportunities for Canada in the clean chemicals sector.** This work should include:

   - Analysis of international policies, such as the U.S. Inflation Reduction Act, and how they impact Canada's competitive advantage.
   - Canada should build on its membership of the First Movers Coalition and explore opportunities to work with like-minded countries seeking to decarbonize the chemicals and fertilizer sector, which could help address price signal issues.

4. **Further research and strategizing is also required to understand the scale of deployment and planning for critical decarbonization pathways that the sector will require.** For example, the expected demand for clean hydrogen and electricity to support the clean transition.

   - Work needs to be done to understand the gap in the price signal between existing investments/carbon pricing and what will be required to decarbonize.
   - Strategic understanding of where the most significant growth opportunities exist, including exporting.

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