Pollution Probe

Alberta Hydrogen Export to Asian Markets:

COMMON UNDERSTANDING OF RISKS

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Executive summary

Low-carbon hydrogen is seen as the fuel of the energy transition in many parts of the world. Alberta has plans to become a large supplier of low-carbon hydrogen to the world, and there are potentially large export opportunities.

However, due to the nature of hydrogen, transportation and storage are major challenges. These challenges can be reduced and make the export of hydrogen more viable through using hydrogen “carriers,” such as methanol or ammonia, which are substances that chemically bind with hydrogen and can be more easily transported and stored. Ammonia is seen as the frontrunner hydrogen carrier for export in the next decade given that it is already a widely traded material, and markets in Asia, including South Korea and Japan, have declared needs for ammonia as they transition their energy systems. Thus it is likely that any hydrogen exports in the near-term will be through the use of ammonia as the chemical “carrier”.

Exporting hydrogen as ammonia to Asian markets would be accomplished by transporting it by rail from the Edmonton area, where many hydrogen projects are proposed, across northern British Columbia to the Port of Prince Rupert, where it would be transferred to marine carriers.

This paper outlines the safety, logistical, and regulatory challenges involved in exporting one million tonnes of ammonia per year from Alberta to Asia, which represents the volume of export that can reasonably be expected to be available from one project by 2030. The demand for low-carbon ammonia is anticipated to grow with infrastructure being developed to handle four million tonnes (Mt) of ammonia per year for export at the Port of Prince Rupert.

1 Introduction

1.1 Low-carbon hydrogen

Hydrogen has been recognized as important in the energy transition for its potential as a clean-burning fuel and its ability to generate electricity through fuel cell technology[1]. The International Energy Agency (IEA) underscores the role of hydrogen in its report, Net Zero by 2050: A Roadmap for the Global Energy Sector. According to the IEA, current hydrogen production is expected to double by 2030, reaching 150 million tonnes (Mt), increasing to 520 Mt by 2050.

To meet the growing global demand, Alberta is poised to become a key supplier of hydrogen for export to other parts of Canada, the U.S., and overseas markets. To export hydrogen from Alberta to markets overseas, the hydrogen will have to be transported by land to a port. This paper explores potential concerns for such an undertaking, considering the projected growth in export through 2040.

Hydrogen is a promising candidate for emissions-free fuel, but its use also presents challenges. Traditionally, hydrogen has been produced for a variety of industrial applications. It is a feedstock for producing chemicals such as ammonia and methanol, petroleum refining, the hydrogenation of oils and fats in the food industry, metallurgy, electronics manufacturing, and other purposes. Hydrogen can either be produced from hydrocarbon feedstock or through the electrolysis of water (**Table 1**).

Table 1: Hydrogen Production Methods

Method	Process	Inputs/Outputs	Outlook
Steam reformation (SMR)	Hydrocarbons react with steam under pressure with a catalyst.	CO_2 emissions during production.	Least expensive. Most common today.
Autothermal reformation (ATR)	Similar to steam reformation; some methane is combusted to provide heat.	More emissions are captured from the process.	More expensive, lower carbon intensity.
Methane pyrolysis	Emissions-free high-temperature process.	Produces solid (black) carbon.	More expensive. Limited market for byproducts.
Electrolysis	Hydrogen is generated through the electrolysis of water.	Requires water and electricity. Byproduct is oxygen.	Most expensive.

1 Kovač, A., Paranos, M., & Marciuš, D. (2021). Hydrogen in energy transition: A review. International Journal of Hydrogen Energy, 46(16), 10016–10035. https://doi.org/10.1016/j.ijhydene.2020.11.256

As a shorthand, the different types of hydrogen are often associated with colours on the rainbow (**Table 2**). Recent plans for low-carbon hydrogen production in Alberta are for "blue hydrogen", which is hydrogen produced through autothermal reformation (ATR) of natural gas, due to the large availability of natural gas in Alberta, with carbon capture and storage (CCS).

Table 2: Hydrogen Rainbow

Type of Hydrogen	Production Method	Environmental Impact
White Hydrogen	Naturally occurring hydrogen is found in geological formations.	Depends on the extraction methods used.
Green Hydrogen	Electrolysis is powered by a renewable energy source.	Minimal carbon footprint. Expected to ramp up in the coming decades.
Grey Hydrogen	Produced from hydrocarbon fossil fuels, principally methane via steam methane reformation (SMR).	Produces CO_2 emissions.
Blue Hydrogen	SMR combined with carbon capture, utilization and sequestration (CCUS).	Reduced carbon intensity, offering a sustainable alternative to grey hydrogen.

The unique physical properties of hydrog en present a challenge for transportation and storage. Among fuel alternatives, hydrogen ranks highest for gravimetric energy density, but lowest on volumetric energy density. The volumetric density can be increased by compression or cryogenic liquification, both carrying substantial energy penalties.

Pure hydrogen can be compressed or cryogenically liquified by chilling the gas to -253°C, but this process is costly and will have low energy density, which makes it difficult to make it economical. In comparison, natural gas is cooled to -160°C for LNG transport. The most promising solution for the transportation and storage of hydrogen is to employ hydrogen carriers, molecules that can transport hydrogen more cost-effectively (**Table 3**), such as liquid organic hydrogen carriers (LOHC), methanol (CH_3OH), or ammonia (NH_3). These hydrogen carriers are more stable and require less energy to store and transport. Ammonia is the frontrunner hydrogen carrier for the export of hydrogen from the West coast to overseas markets, primarily in Asia.

Table 3: Hydrogen Storage

Storage Form	Chemical Formula	Molar Mass	Volumetric H_2 Density (kg/m3)	Gravimetric H_2 Density (wt %)	Gravimetric Energy Density (MJ/kg)
Compressed H_2 (700 bar)	H_2	2.016	42	100	120-142
Liquid Hydrogen	H_2	2.016	70.8	100	120-142
Toluene/ Methyl Cyclohexane	C_7H_8/C_7H_{14}	92.14/98.186	47.1-47.4	6.17	7.35
Methanol	CH_3OH	32.04	95.04-99	12.1	20.1-22.4
Ammonia	NH_3	17.031	107.7-120	17.65	21.18-22.5

Adapted from: Patonia, A., Poudineh, & Rahmatallah. (2023)

1.2 Global hydrogen market

Projections for growth of hydrogen demand vary, but many studies suggest that production could increase substantially by 2050. According to various IEA's scenarios of future energy demand in a net-zero world, global hydrogen production, which was around 90 Mt annually in 2020, is expected to grow nearly sixfold to 520 Mt by 2050.

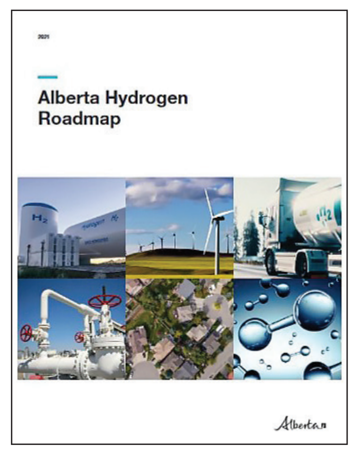
Globally, various markets are anticipating the need to import hydrogen to meet their commitments under the Paris Agreement for sectors they see as difficult to decarbonize with other options (**Figure 1**). These import markets are proactively securing their supply chains by signing letters of agreement (LOAs) and memorandums of understanding (MOUs) with hydrogen exporters around the globe, including those in Canada, and more specifically, in Alberta.

Figure 1: Global Hydrogen Trade Routes

1.3 Alberta hydrogen export opportunity

In a 2018 study, the Asia Pacific Energy Research Council (APERC) identified Canada as a potential exporter of hydrogen due to the abundance of natural gas and geology suitable for carbon capture and storage (CCS).[2] Japan and South Korea are both actively seeking supplies of low-carbon ammonia to foster their energy transition. Several projects are at various stages of development (Table 4), although many have paused active development, and so the timelines may be off from those presented here. These projects are centred around the Alberta Industrial Heartland, which boasts a robust supply of natural gas, clean water and electricity, access to railways and existing CCS facilities. All projects anticipate producing hydrogen and converting it to ammonia for transportation and export. These proposals generally project producing 1 Mt of ammonia from blue hydrogen per year. It is anticipated that the ammonia will then travel by rail to the Port of Prince Rupert for export, which is undergoing preparations to handle up to 4 Mt per year by 2030.

"Alberta exports 1 million tonnes of gaseous hydrogen, noting this would require a fully permitted and constructed pipeline to the west coast, liquefaction, and export infrastructure. In addition, Alberta also exports 1 million tonnes of hydrogen carriers (such as ammonia) to global markets by 2020."



2 APEC, Perspectives on Hydrogen in the APEC Region, 2018, https://aperc.or.jp/file/2018/9/12/Perspectives+on+Hydrogen+in+the+APEC+Region.pdf

In 2023, the Canada Energy Regulator (CER) modeled hydrogen production under three future scenarios: "Current Measures," "Canada Net Zero 2050," and "Global Net Zero 2050." These projections were generally more conservative compared to the ambitious growth trajectories presented in other reports such as from the IEA, Hydrogen Council, and the Alberta Government. The projections from CER correlates with the Alberta government's plan of having the capacity to export at least 1 Mt of ammonia in the short-term (**Figure 4**). This 1 Mt of ammonia for export by 2030 could be fulfilled by just one of the current proposed projects coming into production (**Table 4**). To produce 1 Mt of ammonia, 175,000 tonnes of hydrogen would be required, with some of the hydrogen consumed for process heat.

Table 4: Alberta Hydrogen Export Funnel

Opportunity	Details	Status	Projection
May 2023 Memorandum of Agreement signed between Pembina Pipeline and Marubeni	Joint Venture to produce low-carbon ammonia for export to Japan using steam methane reformation (SMR) + carbon capture and storage (CCS)	FEED to be completed late 2024. FID: 2025	2028: 1 Mt per year of low-carbon ammonia
May 2022 Feasibility Study conducted by Petronas Canada, Inter Pipeline, Itochu	Partnering on two new facilities for blue ammonia and blue methanol production from autothermal reforming (ATR) plus CCS	Final investment decision coming in 2024	2027: Thousands of tons per day of low carbon ammonia and methanol
Northern Petrochemical	Proposal to develop Grand Prairie Industrial Gateway (GIG) Carbon Neutral Ammonia and Methanol facility	Proposal stage $2.5B facility	200 Mt annual production of ammonia and methanol
October 2021 MOU signed between Alberta Government and JOGMEC	Promote hydrogen development in Alberta for hydrogen export to Japan	Ongoing cooperation	Primarily ammonia
TC Energy & Nikola Crossfield Hydrogen Hub	Clean Hydrogen Production	FID 2023	200,000 tonnes of hydrogen/year (1.1 Mt ammonia)
Hydrogen Canada Corp	$10M in seed capital for a new facility in Fort Saskatchewan. Offtake agreement with E1 (South Korea)	Pre-FEED 2024	1 Mt ammonia/year beginning 2028

FID: Final Investment Decision
FEED: Front End Engineering Design

2 Hydrogen carriers

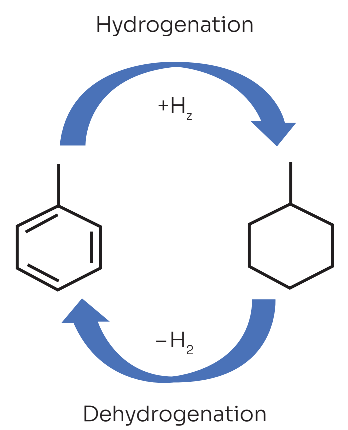
This section will focus on the best available technologies (BAT) for the transportation of low-carbon hydrogen. The key BATs are liquid organic hydrogen carriers (LOHC), methanol, and ammonia. Among these, ammonia stands out as the leading hydrogen carrier for overseas export, and most proposed projects plan to use ammonia as the hydrogen carrier.

Both ammonia and methanol are widely available at numerous ports worldwide and are already traded extensively as industrial or agricultural chemicals, while LOHCs are still an emerging technology.

2.1 Liquid organic hydrogen carriers (LOHC)

LOHCs are typically comprised of molecules with a benzene (or phenyl) ring component capable of reversibly being saturated into an alkane (hexane). The archetype for this type of LOHC is toluene, which becomes methyl hexane when saturated (**Figure 2**).

Figure 2: Liquid Organic Hydrogen Carrier



Toluene/methylcyclohexane LOHC system

Source: Southall, E., & Lukashuk, L. (2022).

While development of this chemistry continues, at present, LOHCs are not considered economically viable as an export pathway due to the difficulty and cost of converting the hydrogen to LOHC with available technology.[3] In addition, this class of chemicals are highly carcinogenic, which may make them unsuitable as a carrier due to their toxicity.

2.2 Methanol

Methanol is a naturally occurring metabolic compound. It is the lightest alcohol compound, with an odour like ethanol; however, it is far more toxic. As methanol can be produced through distillation of wood, it is sometimes referred to as wood alcohol. Methanol can also be produced from hydrogen through the catalytic hydrogenation of carbon dioxide or carbon monoxide. This process is carried out under specific conditions of temperature and pressure, with the help of a catalyst. When derived from atmospheric CO_2, it may be considered carbon neutral.

Liquid organic hydrogen carrier
Toluene/Methylcyclohexane has the archetypal chemistry of an LOHC. The latter, hydrogen -saturated molecule reverts to the flat unsaturated molecule and must be returned to the hydrogen source in this cycle. While having some potential utility, this type of hydrogen storage/transport is not economically viable.

3 Sage, et al., Recent progress and techno-economic analysis of liquid organic hydrogen carriers for Australian renewable energy export – A critical review; Meikle, Gray, & Van Den Assem, (2023). Hydrogen as an Alberta Export Opportunity: Gap Analysis, 2024

Methanol is widely traded globally for a variety of industrial uses in the production of thousands of everyday items, from plastics, paint, carpeting, antifreeze, denaturing ethanol, etc. It can be used directly as a fuel or as an add-mix for gasoline.

Methanol is a liquid at ambient temperatures with a boiling point of 62°C under atmospheric pressure. Methanol is highly flammable and explosive. Health risks are associated with skin contact, inhalation, eye contact and ingestion. Methanol can cause blindness from ingesting as little as 10 mL with a fatal dose at 30 mL. Methanol is toxic to aquatic life and can persist in the environment if not properly cleaned.

Methanol is a potential energy carrier and is considered economic. However, the flammability is considered a drawback, and as such, ammonia (see below) is generally the hydrogen carrier proposed in projects.

2.3 Ammonia

Ammonia is a naturally occurring molecule. It is a colourless gas with a very distinctive odour. Ammonia currently plays a crucial role in the production of fertilizer. Today, ammonia is the second most traded chemical globally. Ammonia also accounts for 1.8% of global energy use and 1.3% of greenhouse gas emissions due to most hydrogen production steam methane reforming from natural gas[4].

From 2013-2023, Canada produced on average 4.6 Mt of ammonia annually, with 90% of that production occurring in Alberta.[5] Nearly 1 Mt of this ammonia is exported to the U.S.,[6] and international infrastructure for ammonia transportation, including shipping terminals and vessels, is already well established.

2.3.1 Scope of ammonia export

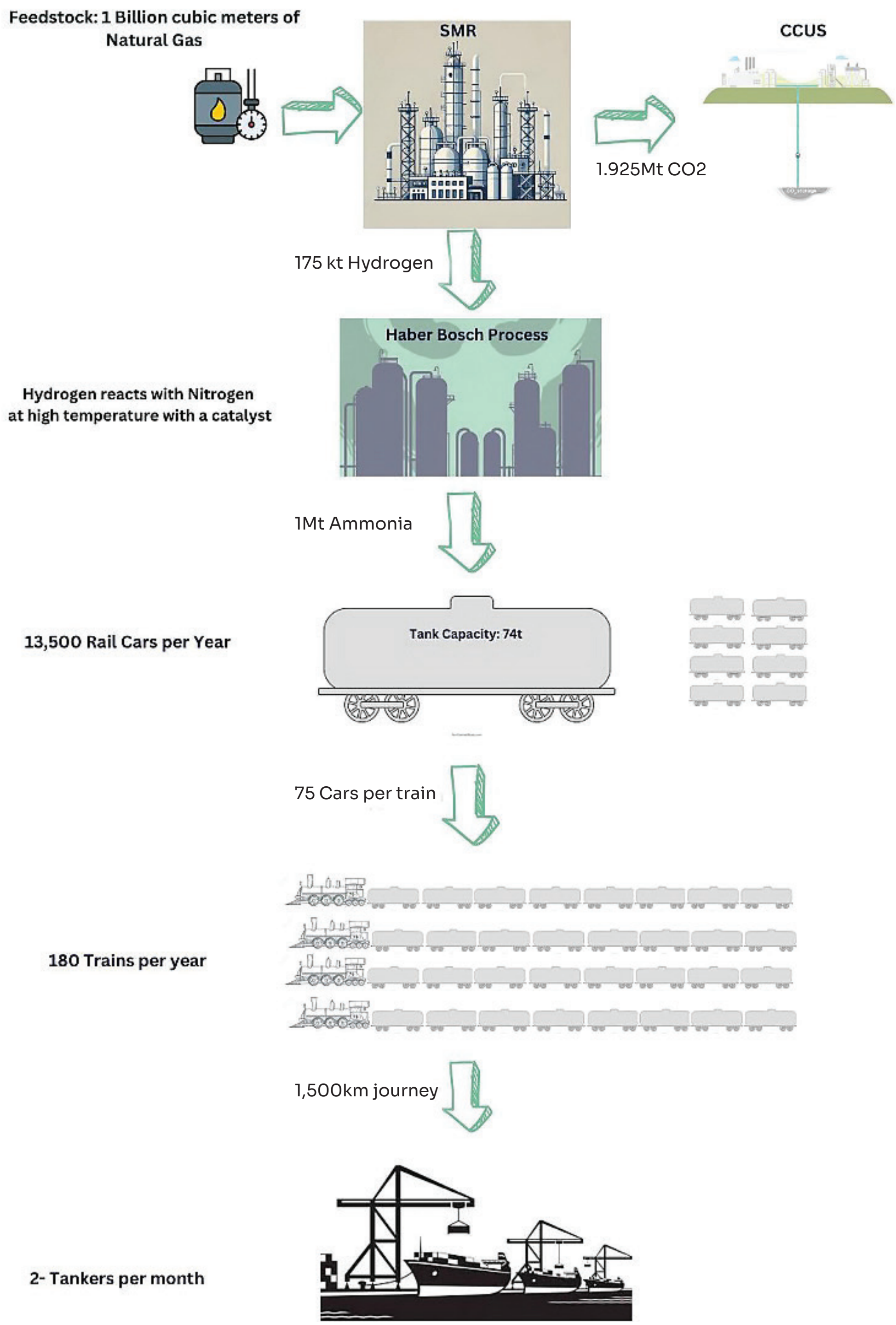
This paper assumes that Alberta will be exporting 1 Mt of ammonia by rail to Prince Rupert by 2030. This would assume the production of 175,000 tonnes of hydrogen and would require the implementation of just one of the projects outlined in **Table 4**.

Figure 3 illustrates the export requirements for ammonia. Each rail car designed for the transport of ammonia has the capacity to carry 130,700 litres or 74 tonnes. Therefore, transporting 1 Mt to Prince Rupert annually would require 13,500 rail cars, each approximately 20 metres in length. One full train every second day would be sufficient to carry 1 Mt per year of ammonia to port.

Once at port, two ammonia tanker vessels per month would be required to ship it to overseas markets. It should be noted that these numbers are scalable. For example, if 2 Mt are exported in 2035, it would require a doubling of the infrastructure requirements noted.

4 IEA, Ammonia Technology Roadmap, 2021
5 Statistics Canada. Table 16-10-0041-01 Chemicals and synthetic resins production, annual, https://doi.org/10.25318/1610004101-eng
6 WITS, Anhydrous ammonia exports by country in 2021m https://wits.worldbank.org/trade/comtrade/en/country/ALL/year/2021/tradeflow/Exports/partner/WLD/product/281410

Figure 3: Requirements for Exporting 1 Mt of Ammonia



2.3.2 Ammonia safety

Ammonia is highly volatile with a boiling point of -33°C under atmospheric pressure. It will rapidly boil off into a vapour cloud if released at temperatures greater than -33°C. Storage and transportation of ammonia are very similar to liquid petroleum gas (LPG). Both LPG and ammonia must be stored in a pressurized tank to remain liquid at ambient temperatures, and both rapidly evaporate with the potential consequence of frostbite with exposure. The risk profiles differ in that propane is highly explosive, while ammonia is toxic and has a low risk of explosion. When released into the environment, ammonia rapidly evaporates to form a white cloud that will float upwards due to its low density and buoyancy.

Due to its thermodynamic properties, ammonia is extensively used as a refrigerant for food processing facilities and ice rinks, where large volumes of refrigerant are required. In these settings, the ammonia is hermetically sealed, remaining in service for years to decades. While there have been some high-profile accidents internationally, it has largely been handled safely by this industry. In Canada, there have only been a few major incidents with ammonia.

2.3.3 Ammonia and human health

Exposure to low levels of ammonia has little risk, at higher levels, the main risks of ammonia include:

- **Main Routes of Exposure:** Inhalation, skin contact, eye contact.
- **Inhalation:** Ammonia is considered toxic and can be fatal at high concentrations. It can cause severe irritation of the nose and throat, potentially leading to life-threatening pulmonary edema (fluid accumulation in the lungs). Symptoms may include coughing, shortness of breath, difficulty breathing, and chest tightness, which can develop hours after exposure and worsen with physical activity. Severe short-term exposure can result in long-term impacts.
- **Skin Contact:** Ammonia is corrosive and can irritate or burn the skin, leading to permanent scarring. Direct contact with liquefied ammonia can cause frostbite, with symptoms including a burning sensation and stiffness. In severe cases, the skin may become waxy white or yellow, and blistering, tissue death, and infection can develop.
- **Eye Contact:** Ammonia is corrosive to the eyes, potentially causing permanent damage, including blindness from direct contact.
- **Effects of Long-Term (Chronic) Exposure:** Ammonia may harm the respiratory system and can irritate and inflame the airways.[7]

Characteristics of ammonia
Ammonia has a sharp, distinct, penetrating odour, detectable at very low concentrations. At moderate concentrations, ammonia can irritate the eyes and respiratory tract; at high concentrations, it can cause ulceration to the eyes and severe irritation to the respiratory tract.

Health effects of ammonia
Source: Government of Alberta, Ammonia Emissions and Safety, June 2006

7 Canadian Centre for Occupational Health and Safety, Ammonia Profile, https://www.ccohs.ca/oshanswers/chemicals/chem_profiles/ammonia.html

2.3.4 Ammonia and the environment

When released into the environment, ammonia can have harmful effects on ecosystems and aquatic life. Ammonia reacts with water to form ammonium hydroxide, which is highly corrosive, raising pH levels and impacting water quality, leading to ecosystem imbalances that affect aquatic flora and fauna. At lower concentrations, ammonia can promote the growth of algae, leading to eutrophication. Chemical changes of ammonia in the atmosphere can contribute to particulate air pollution and soil acidification. Ammonia can be persistent in the environment, leading to long-term environmental problems if not properly removed.

In March 2024, an ammonia spill in southwest Iowa killed over 750,000 fish within a 100 km stretch of the East Nishnabotna River, making it the largest fish kill in the state in a decade. The spill was caused by a valve malfunction at NEW Cooperative in Red Oak, which resulted in 265,000 gallons of liquid nitrogen fertilizer leaking into the river.

SOURCE: GBRX

2.3.5 Rail transport of ammonia

If Alberta is to export ammonia to Asian markets, rail transport will be the primary method for reaching ports in the short- to medium-term, driven by economic considerations and the time required to develop new pipelines. The increased production for export introduces a broader spectrum of risks that must be managed effectively. As stated in a recent Transport Canada briefing, "Canada has a robust regulatory regime governing the safe movement of dangerous goods (like ammonia) by rail, which is regulated under the *Transportation of Dangerous Goods Act, 1992* and associated regulations, as well as the *Railway Safety Act* and associated rules and regulations, including the Railway Safety Management Systems Regulations, 2015 and Rules Respecting Key Trains and Key Routes."[8]

Transport Canada, in collaboration with Natural Resources Canada, is streamlining hydrogen and derivative transport, particularly for export. This includes working with Indigenous Peoples, provinces, and industry, with a focus on safety. To meet global hydrogen demand, especially in East Asia, Transport Canada has created the Transportation of Hydrogen Directorate. This body coordinates efforts for hydrogen and ammonia transport, including increasing ammonia rail shipments, while ensuring compliance with Canada's regulations for the safe transport of dangerous goods.

2.3.6 Marine transportation

Ammonia is seen as the frontrunner hydrogen carrier in part because it is widely traded and, as such, necessary infrastructure and supply chains already exist. In 2020, global production of ammonia was approximately 200 Mt, with about 10% of that volume transported internationally by maritime carrier between 192 ports currently equipped for ammonia. At present, there are approximately 40 tankers dedicated to ammonia transport, and a total of 200 tankers capable of carrying ammonia.

For the export of ammonia from Alberta, the proposed port to transfer from rail to ship is located in Prince Rupert, British Columbia. Traditionally, this port has been used for exporting coal to Asia. The federal government recently promised to phase out all exports of coal by 2030.

The Port of Prince Rupert is operated by Trigon and it is undergoing a major transition and expansion to increase its capacity for exporting LPG and to begin exporting ammonia. To facilitate the LPG export, Trigon is building a 98,000 m^3 propane storage tank.[9]

AMMONIA SPILL IN MINOT, ND

In January 2002, a Canadian Pacific train derailed near Minot, North Dakota, releasing 146,700 gallons of anhydrous ammonia after five tank cars ruptured. The vapor cloud spread over a five-mile area, affecting 11,600 residents. The accident resulted in one fatality, 11 serious injuries, and significant environmental damage. The National Transportation Safety Board (NTSB) investigation attributed the accident to inadequate rail inspections and the use of non-normalized steel in the tank cars. Following the incident, the NTSB recommended improvements in track maintenance, tank car safety, and emergency communication systems.

8 Transport Canada, TRAN March 21, 2024, Briefing on Infrastructure in Canada, https://tc.canada.ca/en/binder/tran-march-21-2024-briefing-infrastructure-canada
9 Trigon, Trigon LPG Project, 2024, https://www.trigonbc.com/wp-content/uploads/Trigon-LPG-Project-Description-2024-01-10.pdf

Trigon's Berth Two Beyond Carbon project involved dredging and expanding the port's infrastructure, with federal support. In July 2024, Trigon announced a milestone of 50% of marine construction completed, which puts the project on target for service in 2027. [10]

2.3.7 Ammonia risks summarized

The fertilizer industry is a large user of ammonia and has a long history of safely handling ammonia, and has developed best practices. Fertilizer Canada's Anhydrous Ammonia Code of Practice is an industry-led program that provides uniform safety and security practices for the safe handling and storage of anhydrous ammonia at agri-retail facilities across Canada. The Ammonia Code originally came into force in 2009 and is updated periodically. It is the first industry-led program of this magnitude for the safe and secure handling of anhydrous ammonia. Compliance with the Code is required for all ammonia shipments and storage facilities in Canada. Public consultation is mandated for communities near these sites. Emergency Response Plans, public awareness campaigns and employee training are all discussed in the code.[11]

Under the auspices of the U.S. Department of Homeland Security, the Jack Rabbit III Initiative investigated accidental releases of Toxic Inhalation Hazards (TIH) substances, including ammonia and chlorine, and field-tested releases of ammonia to finetune dispersion models to assess the threats posed by accidental or intentional releases of the chemical. The study involved consultation with the private sector to identify risks of handling and transporting ammonia, with transportation and emergency response highlighted as the greatest safety concerns.[12]

Risks associated with ammonia are compared to other fuels in Table 5. The dangers relate to toxicity, rather than explosion or flammability.

10 See Trigon, Trigon Pacific Terminals surpasses half-way mark on Berth Two Beyond Carbon project build, 2024, https://www.trigonbc.com/trigon-pacific-terminals-surpasses-half-way-mark-on-berth-two-beyond-carbon-project-build/ and Trigon, Berth 2 Beyond Carbon, https://www.trigonbc.com/trigon-terminals-set-to-nearly-double-terminal-capacity-and-advance-green-diversification-with-new-federal-funding/

11 See Fertilizer Canada, Anhydrous Ammonia Code of Practice, 2022, https://fertilizercanada.ca/wp-content/uploads/2024/05/FertilizerCanada_2022-Ammonia-Code_Version-1.2May-2024_FINAL-1.pdf

12 Department of Homeland Security, Jack Rabbit III Initiatives: Chemical Threat Characterization through Experimentation for Strengthening Safety and Security of Critical Infrastructure, 2020, https://www.cisa.gov/sites/default/files/publications/2020-seminars-jack-rabbit-III-508.pdf

2.4 Summary of risks

Table 5 summarizes the risk of transporting ammonia or methanol. The transportation of LPG and LNG are included to provide context and a comparison for understanding the different risks.

Table 5: Fuel Risk Comparison Chart

Low risk | Medium Risk | High Risk

Fuel	Health Risks	Environmental Risks	Explosion Risk	Flammability
Ammonia	Toxic if inhaled (can cause respiratory irritation, pulmonary edema), irritant to skin and eyes. (High Risk)	Highly toxic to terrestrial and aquatic life. Can persist in these environments. (High Risk)	Explosive when mixed with air (15-28% concentration), but requires an ignition source. (Low risk)	Flammable but requires a high ignition temperature (~651°C). (Low risk)
Methanol	Highly toxic if inhaled, ingested, or absorbed through the skin. (Medium Risk)	Toxic to aquatic life. Can persist in the environment. (Medium Risk)	Moderate risk of explosion in confined spaces; vapour is heavier than air, can travel to ignition sources. (Medium Risk)	Highly flammable (High Risk)
LPG	Not toxic, but can cause asphyxiation at high concentrations. (Low risk)	Can contaminate soil and groundwater. (Medium Risk)	High risk of explosion in confined spaces when mixed with air. Vapour is heavier than air and accumulates in low areas. (High Risk)	Highly flammable (High Risk)
LNG	Not toxic, but can cause asphyxiation at high concentrations. (Low risk)	Readily evaporated, contributes to GHG emissions. (Medium Risk)	High risk of explosion in confined spaces when mixed with air. Leaks can lead to dangerous gas clouds (High Risk)	Highly flammable (High Risk)

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