



VOTOB Safety Standards in the Ammonia Supply Chain

Antea Group

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1. Introduction

To meet climate targets, people in the Netherlands and Europe are looking for climate-neutral energy options. Exclusively generating green energy in the Netherlands, such as wind and solar power, for example, is nowhere near enough to meet the country's energy needs. This applies not only to the Netherlands, but also to its European hinterland. It also applies to its immediate neighbour, Germany, because of its limited availability of deep-sea ports.

Hydrogen is considered a suitable and emission-free energy source. We can import this hydrogen from several countries with many natural energy sources (such as wind and solar energy, in the Middle East and Africa, Canada, the United States, Latin America and Australia). This spread avoids dependency. However, transporting hydrogen over long distances is challenging. Currently, there are only two ocean-going tankers capable of transporting hydrogen in the world; however, given that hydrogen must be transported at very low temperatures, its transportation is very costly and risky.

Ammonia is a suitable and efficient hydrogen carrier in this respect. The storage and transport of ammonia has a high TRL (Technology Readiness Level): it has been transported and stored for decades. After arriving in Europe, the ammonia is cracked to produce hydrogen that can be used as fuel; it is also possible to use the ammonia directly as fuel.

It can be argued that nothing stands in the way of immediately using ammonia as a primary energy source and hydrogen carrier. However, a major concern is that ammonia is highly toxic. The impact area of an incident can extend up to several kilometres and a large-scale release could result in injuries and deaths in nearby inhabited areas. These characteristics mean that in addition to government concerns, there is a lot of resistance from the public, both in the immediate vicinity of a terminal but also along transport routes.

These characteristics also make the management of an ammonia terminal fundamentally different from that of a traditional fuel terminal: the bar on working safely is set even higher.

The new PGS 12 Dutch safety guideline for large-scale ammonia storage and handling was drafted in 2024 in cooperation with governments – environmental services and safety regions – and industry. It includes very strict requirements for the terminal's installations. As a result of these requirements, the probability of storage tank failure is not deemed realistic. This is recognised by all parties who collaborated on drafting the PGS 12. The relevant parties know how to handle ammonia (see High TRL - approx. 9).

Despite the PGS 12 and current experience, concerns remain. As indicated earlier, this is partly due to the toxic nature of ammonia, and partly due to past incidents. However, while zero probability is not realistic, the question is whether some of these incidents could not have been prevented by properly following the rules.

Another question is whether the rules are sufficiently clear and complete. Finally, we should mention that many new players are entering the ammonia market. It is important that from day one, all of these parties have full knowledge and the highest possible level of safety, and act accordingly.

Through means of the *"Ammonia Supply Chain Description"* document, the VOTOB and its members would like to provide clarity and openness on the state of affairs in the supply chain, the potential areas requiring attention and the role/responsibility of the terminal manager.

1.1 Document purpose

To provide an analysis of the ammonia supply chain with emphasis on the following components:

- General information about ammonia;
- Description of the distinct steps in the supply chain;
- The most recent regulations available specifically for ammonia's safety aspects;
- The main risks associated with each step in the supply chain;
- Evaluation/focal points;

- The applicable roles and responsibilities; and in particular
- The role/responsibility of the terminal manager.

1.2 Reading guide

This document is structured on the basis of the defined ammonia supply chain. First, some general aspects are discussed, such as the properties of ammonia and regulations regarding the supply chain. Next, the supply chain is reviewed in successive sections, focusing on the following aspects:

- Description of each step in the supply chain
- Risks associated with each step in the supply chain
- Legal requirements and safety measures/safety standards
- Evaluation/focal points
- Role of the terminal manager

2. General information about ammonia

2.1 Ammonia properties

Toxicity¹

Under atmospheric conditions, ammonia is a colourless, toxic gas with a strong pungent odour. Ammonia fumes are harmful to health. In high concentrations, it has a strong caustic effect on eyes and mucous membranes, it is a severe skin irritant, and is toxic when inhaled, which can lead to pulmonary oedema. When a human is exposed to an ammonia cloud with a concentration of 1,100 ppm (780 mg/m³) for one hour, the consequences are fatal. However, ammonia is already detectable by human senses at a concentration of 1-5 ppm (0.7 - 3.5 mg/m³), with no physical harm.



Ammonia is an aquatic toxic substance, which readily dissolves in water. It is designated H-400 and is labelled “very toxic to aquatic organisms”. Incidental discharges and leaks must therefore be avoided as much as possible. Moreover, surface water consequently cannot serve as a disaster buffer for liquid ammonia. In addition, when cold liquid ammonia at -33°C enters the water, about 50% will immediately evaporate and form a toxic vapour. The remaining 50% will dissolve in the water.

Flammability¹

Ammonia (NH₃) is not very flammable as it is difficult to ignite due to its high ignition temperature (around 630°C). The minimum ignition energy is 680 mJ (this is about 10,000 times higher than that of hydrogen). In addition, once ammonia burns, it does so with a relatively clean flame that produces few soot particles. Soot particles are normally responsible for heat radiation and flame visibility. Without these particles, the flame remains almost invisible and radiates little heat to its surroundings.



This means that insufficient heat is generated to evaporate the pool of ammonia and maintain the fire.

Furthermore, because the boiling point of ammonia at normal atmospheric conditions is around -33°C, it evaporates at temperatures below freezing. This is why ammonia is said to “boil cold”. However, because ammonia extracts a lot of heat from the environment as it evaporates, thereby cooling the surroundings, it reduces the energy available in the environment to ensure rapid evaporation.

When external heat is added by other means to keep the ammonia evaporation process going, such as from the (warm) ground or (hot) water, it is possible to create a sustained fire. The risk of fire and explosion exists almost exclusively in poorly ventilated spaces. The explosion limits in air are 15% (LEL) and 29% (UEL).

2.2 Probability and impact

Safety can be summed up in terms of risks. It is important to note that a risk is not an isolated term. Risks are composed of **probabilities** and **impacts**; both **together** determine the size of the **risk**: **probability x impact = risk**

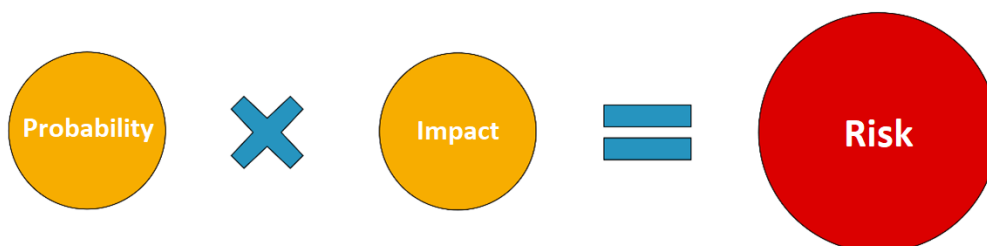


Figure 2.1: **Probability** times **impact** results in **risk**

¹ PGS 12 2024

A risk can be reduced by using safety systems and safety measures. This is because a safety system or safety measure reduces probability, impact or both. For example, consider a safety system that includes a dry-break coupling at a loading arm, which minimises the amount of dangerous substances released when the loading arm breaks – and therefore the impact. The use of a dry-break coupling releases less ammonia, which therefore reduces the impact. A safety measure, for example can increase the focus on procedures during a transfer operation; for example a comprehensive checklist and two-person checks laid down in a procedure can reduce the chance of human error. The use of such procedures reduces the chance of an incident.

When a company works with highly dangerous substances, this does not necessarily increase the likelihood of errors or impact in the event of an incident. Indeed, the company may be very well equipped from a safety perspective and have multiple safety systems and safety measures in place precisely because of the substance's dangerous characteristics, which minimises the chance of errors and the severity of impact.

2.3 The ammonia supply chain

The ammonia supply chain discussed in this document consists of 5 chain elements, see Figure 2.2:

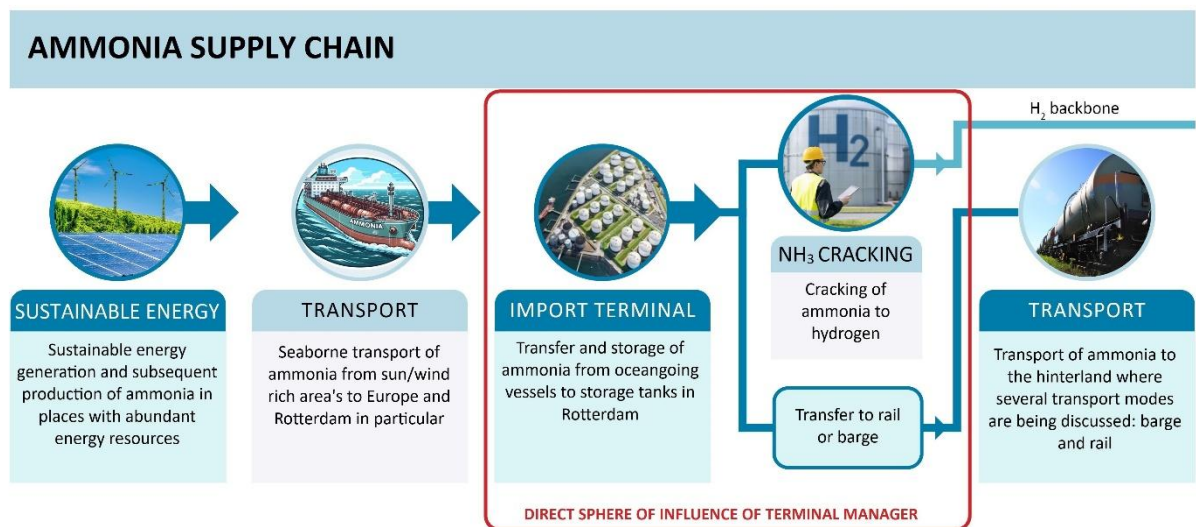


Figure 2.2: Ammonia supply chain overview.

*Transport by road is not included in transfer operations here as this is not a suitable transport mode due to the large flows involved and because terminals do not believe this to be a preferred mode of transport.

- Step 1: Generation of energy in countries with abundant natural energy resources;
- Step 2: Ammonia transport by sea from solar/wind-rich areas to Europe;
- Step 3: Storage and transshipment from ocean-going vessels to storage tanks in the Netherlands;
- Step 4: Ammonia cracking to produce hydrogen;
- Step 5: Transport of ammonia by pipeline, barge, rail and road.

In this case, the supply chain includes the sustainable production of hydrogen, which is then used to produce ammonia, through to transport from the terminal to the hinterland and its customers. Ammonia is present for each element in the supply chain and with it the risks associated with this substance.

The supply chain elements framed in red are the components that fall under the direct responsibility of the terminal manager.

2.4 The supply chain impact of the CSRD, CSDDD and RED III directives and green ammonia certification

The design of the supply chain depends on laws and regulations in addition to the techniques available in terms of the transport, processing, use and safety of ammonia. At the European level, the CSRD and CSDDD directives relating to sustainability, human rights and the environment apply. The overarching aim of these directives is to require companies to identify their sustainability, human rights and environmental impacts and take action to reduce negative impacts. Although the European Commission is relaxing these directives, it is still useful to have an understanding of the different steps in the supply chain from source to use, so that supply chain responsibility can be taken where desirable or mandatory, for example when supply chain partner(s) fail to meet their responsibility.

CSRD²

The Corporate Sustainability Reporting Directive (CSRD) is a European directive that is part of the Green Deal requiring companies to report on their sustainability performance. The directive, in force since 2024, requires major companies to provide information on their environmental and social impacts, such as carbon emissions, biodiversity and human rights. Companies that meet at least two of the conditions below must comply with the CSRD:

1. More than 250 employees
2. Turnover higher than 50 million euros per year
3. A balance sheet of more than 25 million euros

The main points of the CSRD are:

- Reporting requirements: companies must produce detailed reports on their environmental, social and governance impacts. This includes information on carbon emissions, water consumption, social issues, human rights and more.
- Dual materiality: companies must report from two perspectives: the company's impact on the environment (impact materiality) and the environment's impact on the company (financial materiality).
- Value Chain responsibility: companies need to look beyond their own operations and also identify the impact of their suppliers and partners.

The CSRD aims to bring more transparency and standardisation to sustainability reporting, so that companies can be better compared on non-financial aspects. Due to the fact that it is mandatory for these companies to map their entire value chain, these regulations affect a company's entire value chain. Smaller companies in the value chain must therefore be able to provide this information to the larger reporting company. This way the CSRD helps promote sustainable business practices and reduce negative impacts on the world.

CSDDD

The Corporate Sustainability Due Diligence Directive (CSDDD) is a European directive that requires companies to take responsibility for the impact of their activities on human rights and the environment, throughout the entire value chain. Companies meeting the following criteria must comply with the CSDDD:

- Large EU companies: more than 1,000 employees and a global turnover of more than 450 million euros per year.
- Large non-EU companies: turnover of more than 450 million euros per year in the EU.

The main points of the CSDDD are:

- Responsibility in the value chain: companies must map the entire value chain and conduct risk analyses to identify human rights violations and environmental damage.
- Appropriate measures: when risks or abuses are found, companies must take appropriate measures to address and improve them.
- Sanctions: non-compliance with the CSDDD may result in penalties for the company.

² The European Commission wants to relax the CSRD directive for companies. On 26 February 2025, the European Commission presented an Omnibus proposal to this end. Although this is still only a proposal – and the European Parliament and European Council have yet to decide on it – it is expected that there will be some form of relaxation.

The CSDDD aims to ensure that companies not only report on their impacts (as required by the CSRD), but actually take action to reduce negative impacts. Again, because of the need to map the entire value chain, smaller companies in the value chain must be able to provide this information to the larger companies. This means that these smaller companies are also motivated to reduce their negative impact on people and the environment.

Certification

A key factor in the world of renewable fuels, and therefore ammonia as well, is certification. Certification ensures that people know what type of ammonia is involved in the value chain. The certificate indicates how the ammonia was produced and whether this involved high or low carbon emissions. For example, the certification requires that green ammonia must be manufactured using green hydrogen, generated using renewable energy sources.

Ammonia is generally divided into several colours, with green and blue ammonia being particularly relevant for the energy transition:

- **Grey ammonia**
 - Production from natural gas; high level of carbon emissions
- **Blue ammonia**
 - Production from natural gas; carbon emissions reduced through means of carbon capture and storage
- **Green ammonia**
 - Production from green hydrogen; little to no carbon emissions
- **Turquoise ammonia**
 - Production using methane pyrolysis, instead of carbon emissions, solid carbon is produced; little to no carbon emissions
- **Brown ammonia**
 - Production from brown hydrogen (coal); high level of carbon emissions

In the context of sustainability and environmental impact, environmental certifications are particularly important. Grey and brown ammonia do not qualify for environmental certification. Blue ammonia can be certified using systems that verify the reduction of carbon emissions, such as certain carbon offset programmes. Green ammonia can be certified as a fully renewable energy source. Turquoise ammonia can qualify for certifications that verify the absence of carbon emissions.

These certifications play an important role in the aforementioned CSRD and CSDDD directives. For example, green ammonia has a much smaller environmental impact than grey ammonia. Because of the CSDDD and CSRD, companies are being motivated to move towards the more sustainable fuel alternatives. A terminal could be motivated to store and tranship more green ammonia than grey ammonia, as a means of reducing its environmental impact.

RED III Directive

The Renewable Energy Directive III (RED III) is a European directive that aims to reduce greenhouse gas emissions, mainly by promoting renewable energy. RED III sets specific carbon emission reduction targets, especially for the transport sector. It imposes obligations on Member States to identify areas for accelerated renewable energy deployment and ensures accelerated permitting procedures for projects that contribute to the energy transition.

RED III is a revision of the earlier Renewable Energy Directive (RED II) and is part of the European Union's "Fit for 55" package, aimed at reducing greenhouse gas emissions by 55% compared to 1990. The main objective is to get 42.5% of total energy consumption from renewable energy by 2030, with a target of 45%.

Importance of RED III for carbon reduction:

- **Transport sector:**

RED III specifically targets the transport sector, and aims to reduce greenhouse gas emissions.

- **Renewable fuels:**

Member States must promote the use of renewable fuels, including advanced biofuels and renewable electricity, and encourage the production of renewable hydrogen and e-fuels.

- **Sustainability criteria:**

RED III imposes stricter sustainability criteria for the production and use of renewable energy, with the aim of minimising environmental impact.

- **Accelerating projects:**

Member states must designate renewable energy acceleration areas, where permitting procedures must be accelerated.

Value chain impact

The CSRD, CSDDD and RED III have a major impact on the ammonia supply chain. Because the first two directives apply to complete company operating chains, and in particular focus on sustainability and environmental impact, there is a greater incentive to use green ammonia.

As overall efforts are increasing towards renewable fuels, and ammonia so far is the best available hydrogen carrier, the directives may allow for increased production of green ammonia and ammonia shipments in the (near) future. For terminals, this means more storage and transshipment of ammonia compared to the current state of affairs.

3. Step 1: Generation of energy in countries with abundant natural energy resources

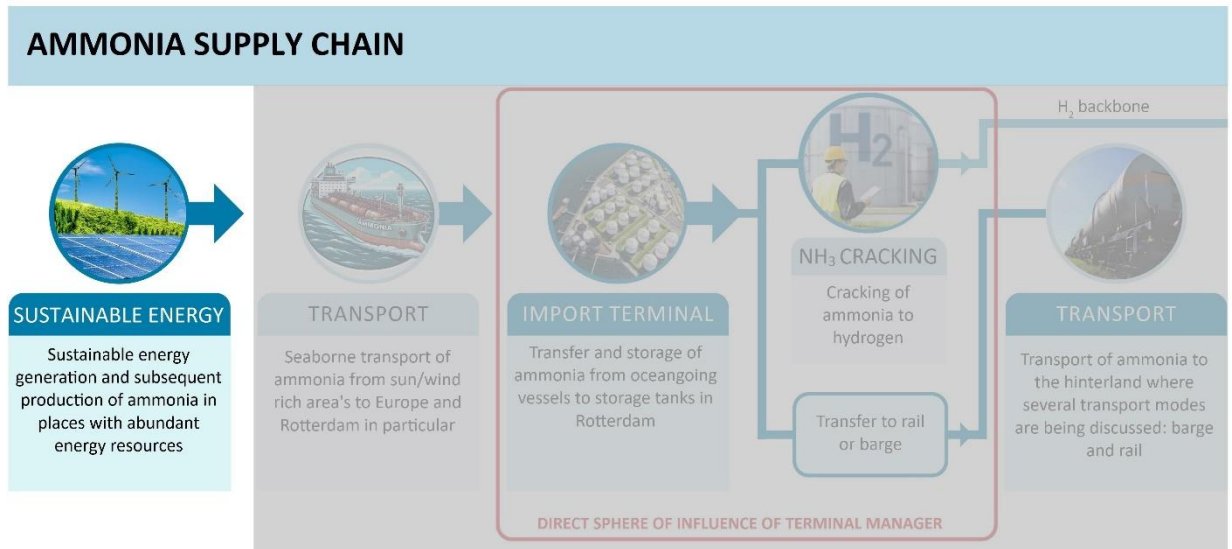


Figure 3.1

3.1 Description of step in the supply chain

Countries with many natural energy sources, such as solar, wind, hydro or geothermal energy, play a crucial role in the energy transition. Their unique position enables them to accelerate the transition to renewable energy worldwide. The diversity of countries also spreads dependencies in terms of the energy supply.

In Step 1, green energy is converted into green hydrogen using electrolysis – splitting water (H₂O) into hydrogen (H₂) and oxygen (O₂). This green hydrogen is then stored in the form of green ammonia using the Haber-Bosch process.

With the abundance of renewable energy sources, solar and wind-rich countries, with a historically high dependence on fossil fuels, can quickly switch over to renewable energy. This reduces domestic demand for oil, coal or gas and lowers carbon emissions. This is especially true for countries in the Middle East (such as Saudi Arabia and the United Arab Emirates), which are in the process of transitioning from oil to solar and wind power to future-proof their economies.

Countries with natural energy resources are key to the global energy transition. They can generate renewable energy on a large scale, export green energy, produce green hydrogen and drive technological innovations.

Through these benefits, they help reduce dependence on fossil fuels and support global efforts to combat climate change. Their role is crucial not only for their own economic development, but also for the global shift towards a low-carbon future.

3.2 Risks

The risks involved in generating energy in countries with many natural energy sources are highly dependent on the techniques, volumes, systems and any dangerous substances used, and on the locations where this takes place. In addition, risks also depend on circumstances, competences and related human actions. Moreover, the risks also depend on the safety measures used. These safety measures, in the broadest sense, can include anything from technical to procedural measures. The safety measures applied vary depending on the laws and regulations where production takes place, as well as on international and European guidelines.

As it is unknown under what conditions the generation process takes place outside Europe, we refer to Step 3 in the supply chain for a specific description of the risks: Import Terminal. Here we assume that similar risks exist for both ammonia export and import terminals. The VOTOB aspires to the same level of safety at export terminals as at Dutch import terminals and endorses the global use of the PGS 12 standard. Ultimately, this should lead to a global level playing field.

3.3 Legal requirements and safety standards

Laws and regulations, and hence the safety measures required to mitigate risks, vary from country to country. From a European perspective, there are directives and regulations. Directives must be transposed into national law before they are in force in a member state. As a result, implementation may differ from one member state to another: national laws and regulations are therefore not the same in many areas. Regulations are directly applicable, and therefore do not cause differences between member states.

Some of the European directives and regulations related to safety are:

- **REACH Regulation (EC) no. 1907/2006:** This regulation concerns the registration, evaluation, authorisation and restriction of chemical substances. The aim is to protect human health and the environment from the risks associated with chemical substances.
- **Seveso III Directive (2012/18/EU):** This directive focuses on controlling the hazards resulting from major accidents involving dangerous substances. The aim is to prevent serious accidents and reduce their impact on human health and the environment.
- **ATEX Directives (2014/34/EU and 1999/92/EC):** These directives cover the safety of equipment and workplaces in explosive atmospheres. They impose requirements on the equipment and protection systems used in such environments.
- **Chemical Agents Directive (98/24/EC):** This directive protects workers from the risks of chemical agents at the workplace. It includes risk assessment, prevention and protective measures.
- **Carcinogens and Mutagens Directive (2004/37/EC):** This directive provides protection against the risks of exposure to carcinogenic and mutagenic substances in the workplace.

Outside Europe, different safety standards and legal requirements obviously apply. How these compare with European equivalents depends very much on each country.

The Globally Harmonised System of Classification and Labelling of Chemicals (**GHS**) is a set of criteria for classifying the dangerous properties of substances and mixtures, and has international acceptance. The GHS originates from the United Nations. The criteria are not legally binding and thus leave countries free to choose among them. The introduction of the GHS will reduce the differences between legally required classification systems worldwide. It ensures more uniformity in classification criteria, hazard signs, pictograms and precautionary measures, which ultimately contributes positively to safety.

All in all, it is important for safety that global safety standards and knowledge are shared as much as possible. Similarly, international discussions are already taking place to declare the PGS 12 guidelines applicable worldwide.

3.4 Evaluation and focus points

As noted in a previous section, the risks associated with an export terminal are broadly similar to those of an import terminal in the Netherlands. However, laws and regulations vary from country to country, with the difference being even greater for an export terminal located outside the EU. Although the terminal manager in the Netherlands has no control or direct responsibility over the export terminal, a Dutch import terminal, in addition to the customer (the owner of the molecules), is increasingly expected to pay attention to the export terminal where the products stored here come from.

Not all places in the world have the same level of knowledge of certain technologies, or the safety standard and culture comparable to that in the Netherlands. For instance, sustainable technologies are generally quite new. On top of that, many of these new technologies have not yet been implemented on a very large scale. Nor can it be assumed without question that the same high safety standards apply at the export terminal.

It is therefore important to maintain and exchange knowledge within the industry at a global level about the risks of these technologies. It is also important that incidents are tracked and communicated so that the entire global industry can learn from them. Such an alignment already exists, namely *The Global Home of Chemical Engineers (AIChE)*³.

3.5 Role of the terminal manager

The terminal manager has no direct responsibility for this step in the supply chain. The terminal manager may impose requirements on the origin of the products stored and transhipped at the terminal in light of the CSRD and CSDDD. For example, certified green ammonia has a smaller environmental impact, which is reflected in the CSRD reporting.

When the terminal is a company or part of a company covered by the CSDDD, there not only is a reporting obligation, but also the active action required to reduce negative environmental and social impacts. Importing certified green ammonia can thus directly contribute to a target set by the CSDDD.

A terminal manager could impose requirements on the products offered by customers for storage: is the customer able to demonstrate that the ammonia was produced and stored responsibly and safely in the country of origin (for example, was the PGS 12 a guideline in the construction of the export terminal?), is the terminal of origin affiliated with a global alignment platform such as AIChE, for example?

³ AIChE | The Global Home of Chemical Engineers

4. Step 2: Ammonia transport by sea from solar/wind-rich areas to Europe

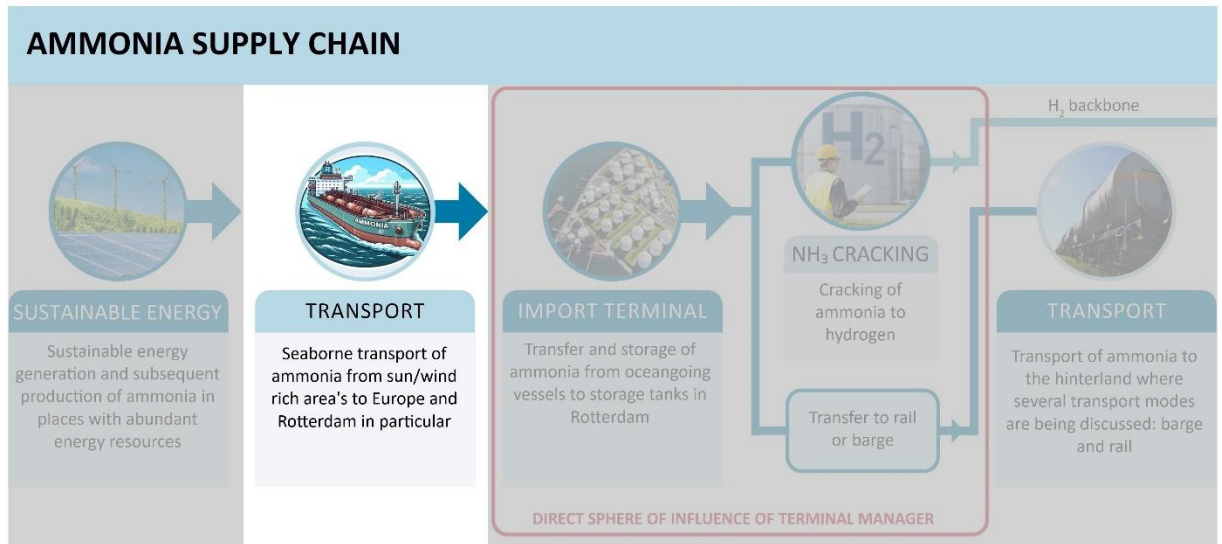


Figure 4.1

4.1 Description of step in the supply chain

Transporting green ammonia by sea from solar and wind-rich countries to Europe, and ports in the Netherlands, plays a vital role in the global energy transition. This provides a solution to the challenges associated with energy storage and distribution over long distances.

Ports in the Netherlands are connected to an extensive network of pipelines, roads, railroads and rivers that link these ports to the rest of Europe. This makes ports in the Netherlands an ideal hub for the import and onward distribution of hydrogen to industrial clusters in Germany, Belgium, and other European countries.

Hydrogen produced in countries with abundant solar and wind energy, such as North Africa, the Middle East, USA, Canada and Australia, can be transported by ship to the Netherlands and then be used for industrial processes, mobility, and electricity generation across all of Europe. It should be noted that transport by ocean-going vessels currently still generates significant carbon emissions. The International Maritime Organisation (IMO) is working on phasing out greenhouse gases in global maritime shipping by 2050. Ocean-going vessels running on cleaner fuels, including ammonia, are currently scarce.

4.2 Risks

Ammonia leaks on a ship

The likelihood of an ammonia leak on a ship is highest during transfer operations. Ammonia is a colourless, toxic gas with a strong pungent odour. The gas is lighter than air (its vapour density relative to air is 0.6). Compressing and cooling allows the gas to be compacted into a liquid. The release of liquid compressed gas or large quantities of ammonia gas leads to the formation of a cold mist. This behaves like a heavy gas and can expand across the ground. In case of cold ammonia, if a pipe ruptures during a transfer operation, the vast majority will be released as a liquid and condense (rainout); in the case of warm ammonia (under pressure), however, a larger proportion will be released as a gas creating a toxic cloud. During flashing, some of the liquid ammonia is carried away as small droplets into the outside air. The plume then consists of ammonia vapour, ammonia droplets and air. Pools of liquid ammonia may be created by ammonia droplets falling down on the ship's deck. Liquid ammonia can also end up in the water. This can happen directly, through rainout of the flashed ammonia cloud or by the pool of ammonia as it enters the water. Some of the ammonia will immediately dissolve in the

water, while the remaining part will spread across the water by the current and wind and evaporate or still dissolve.

Maritime incidents⁴

Globally, in the past 10 years, most incidents (reported to insurers) involving ocean-going vessels were caused by machinery damage or defects (11,506), followed by collisions with other ships (3,014), groundings (2,808) and contact with port infrastructure (1,916).

The annual loss of ocean-going vessels has fallen by 70% over the past decade (89 in 2014, 26 in 2023). Sinking, beaching and fire/explosion were the main causes of completely lost ships. 12 tankers were completely lost, out of a total of 729 ships lost.

The British Isles/North Sea/English Channel/Bay of Biscay have reported the most shipping incidents in the past 10 years (5,279, 19% of the total 27,821 incidents reported), followed by the eastern Mediterranean and Black Sea and China, Indochina, Indonesia and the Philippines.

Developments in maritime safety

The shipping industry is increasingly subject to uncertainties due to war and geopolitical developments, climate change such as drought in the Panama Canal, the resurgence of piracy and the rise of the “shadow fleet”. Use of new technology brings new risks, such as cyber attacks, GPS interference and drone attacks.

One of the biggest concerns in this regard is the safety and welfare of seafarers. The maritime sector has been struggling for decades with a shortage of seafarers with the right knowledge and skills. There is great concern that the crises of recent years will affect the recruitment of seafarers at a time when the sector needs to meet the growing demand for reduced carbon emissions and increased reliance on technology.

The above provides a general impression of the risks and developments in the maritime shipping sector.

However, in the chemical industry, standards for, and supervision of, chemical tanker safety tend to be higher than for container and bulk shipping.

4.3 Legal requirements and safety standards

International maritime shipping is highly regulated by the International Maritime Organisation (IMO). The IMO is a specialised United Nations organisation responsible for regulating maritime safety and security, and preventing maritime pollution from ships.

The carriage of ammonia as cargo in tankers is specifically regulated in IMO's **IGC Code (International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk)**, which is mandated through the SOLAS Convention. This code has existed since 1986. The purpose of the Code is to set an international standard for the safe carriage by sea in bulk of liquefied gas and the substances named in the Code, by prescribing the design and construction standards of ships, as well as the equipment they are required to carry onboard, to minimise the risk to the ship, crew and environment, taking into account the nature of the products involved. In addition to the ship's technical requirements, the Code includes requirements for crew training, holding a pre-cargo operations meeting, completing a recognised industry checklist, and testing alarms and safety devices prior to a transfer operation.

IMO is currently working on “**Interim guidelines for the safety of ships using hydrogen and ammonia as fuel**”. These guidelines will apply to ships carrying ammonia in their fuel tanks for their own use. First, several years of experience will be gained with the guidelines before IMO will make them mandatory.

Apart from this, of course, IMO's general international conventions aimed at all types of ocean-going vessels are important for safety. These include:

- **SOLAS** convention (Safety of Life at Sea), focused on ship safety.
- **MARPOL** convention (Marine Pollution), aimed at preventing pollution from ships.
- **STCW** convention and Code (Standards for Training, Certification and Watchkeeping of Seafarers).

Besides IMO, classification societies such as DNV, Lloyd's Register and Bureau Veritas, for example, also play a major role in the safety of ocean-going vessels. They each have their own rules that can be used to classify ships. The selected classification society and the vessel's class certificates provide insight into the safety of the

⁴ Lloyd's List Intelligence Casualty Statistics Data Analysis & Allianz Commercial, Safety and Shipping Review 2024

vessel's construction. The classification is necessary to be able to insure the ship, gain access to ports and demonstrate reliable and safe transport. The large prominent classification societies recognised in the Netherlands are leading the way in developing rules for new types of ships (due to the energy transition as well as other developments) and are closely involved in new shipbuilding.

In addition, standards, guidelines and programmes (e.g. for audits, self-assessments and vettings) issued by international sector organisations are also relevant. These provide a more detailed interpretation of laws and regulations. Through membership in sector organisations and adherence to their standards, safety-conscious tanker owners can distinguish themselves. The sector associations have observer status within IMO and provide input on IMO laws and regulations through that channel.

Key sector organisations that focus on ammonia transport include:

- **INTERTANKO** ([About INTERTANKO](#)) – International Association of Independent Tanker Owners, interest group for tanker owners; publishes guidelines (guidance documents). Examples include “Practical Guidance on Loading Limits for Gas Carriers” and “Framework for the Development of a Fuel-Handling Manual: Alternative Fuels”.
- **CDI** ([CDI-Marine](#)) – Chemical Distribution Institute: This organisation maintains an international “vetting programme” (inspections and audits) for tankers and terminals (similar to OCIMF's SIRE programme for oil tankers).
- **SIGTTO** Society of International Gas Tankers & Terminal Operators Ltd. ([Home | SIGTTO – The Society of International Gas Tanker and Terminal Operators](#)): This organisation issues standards in the field of liquefied gas transport, such as the “Liquefied Gas Handling Principles on Ships and in Terminals” and “Liquefied Gas Terminals – Site Selection, Design and Operation of Marine Facilities”.

Finally, because ammonia and hydrogen shipments are expected to increase in the near future, coastal and port states will have to start work on identifying appropriate mitigation strategies for dealing with incidents involving the release of ammonia from a ship at sea or in a port. In the Netherlands, this is an area of focus for the Ministry of Infrastructure and Water Management, Directorate-General for Aviation and Maritime Affairs, Rijkswaterstaat, and the Dutch Coast Guard. The existing policy documents and contingency plans, such as the Maritime and Aeronautical Emergency Response Memorandum and the North Sea Incident Response Plan, are currently being updated, with this being one of the (many) areas of focus.

4.4 Evaluation and focus points

The energy transition is creating new international shipments with substances not previously transported in such volumes. From an ammonia perspective, international transport via ocean-going vessels is not new. Currently, around 20 million tonnes⁵ of ammonia are transported annually by ocean-going vessels. This is mainly done with large gas tankers: Large Gas Carriers (LGC), and medium-large gas tankers: Medium Gas Carriers (MGC). In the (near) future, this will include Very Large Gas Carriers (VLGC).

The issue in maritime shipping is not about a lack of regulation or standards, but about ships being able to evade legislation and standards by using flag states and classification societies that are less than diligent in monitoring and inspecting their ships, by carrying out minimal maintenance on ships, and by hiring poorly skilled, low-cost crews that are employed under international (ILO) seafarer welfare standards. This aspect deserves extra attention given the increase in the transport of ammonia. While the transport of ammonia by sea is currently carried out by a select group of reputable shipowners, that may change in the future due to a fast-growing market. As “customers”, the owners of the ammonia can exert pressure on shipowners to ensure transport safety.

In addition, more attention is needed to quantify the collision risks of ammonia ships in port areas, moored and sailing. Information on numbers, speeds and sailing behaviour of ships at any location in Dutch ports is currently available (AIS). (Collision) risk calculations based on that information are therefore possible.

It is recommended that, for the approach routes where one or more potential ammonia terminals will be located, a study of the collision risks for ammonia ships along the route to/from the terminal site and the collision risks for a berthed ammonia ship at the terminal should be carried out. However, the existing Dutch

⁵ Source: <https://www.maritimeoptima.com/insights/will-the-ammonia-shipping-market-boom>

QRA calculation rules are not up-to-date and not very specific in this area. Also, maritime shipping is not well anchored in Basisnet, and a validated counting and calculation methodology for maritime shipping is lacking. However, the Maritime Research Institute Netherlands (MARIN) has developed a methodology for calculating the collision risks for ships and could potentially use additional simulation studies to demonstrate the nautical risks at various locations. Such risk studies have already been carried out for several terminals. However, the calculation methodology could be further refined for ammonia ships in port areas and could then be widely shared and applied.

4.5 Role of the terminal manager

Terminal managers are not responsible for the safety of ocean-going transport, but there are ways they can exert influence on this (for example, by including it in the Product Acceptance Procedure or jetty conditions), such as:

- Communicating the terminal's HSE policy to ship crews: for example, that unsafe work must be stopped, PPE and the terminal's rules of conduct, and to report incidents and near misses (set an example);
- Recording clear signals of unsafe work practices by ship crews or defects on ships making use of the terminal, and calling the captain to account, possibly also informing the cargo owner about this;
- Investigating incidents that occur on the ship while at the terminal, or having them investigated, and learning from these incidents;
- Participating in national and international sector organisations that issue standards and influence legislation.

In addition, the terminal manager can facilitate the safety of ships by ensuring that the design of the terminal takes into account the collision risks of ships berthed at the terminal.

5. Step 3: Storage and transshipment from ocean-going vessels to storage tanks in the Netherlands

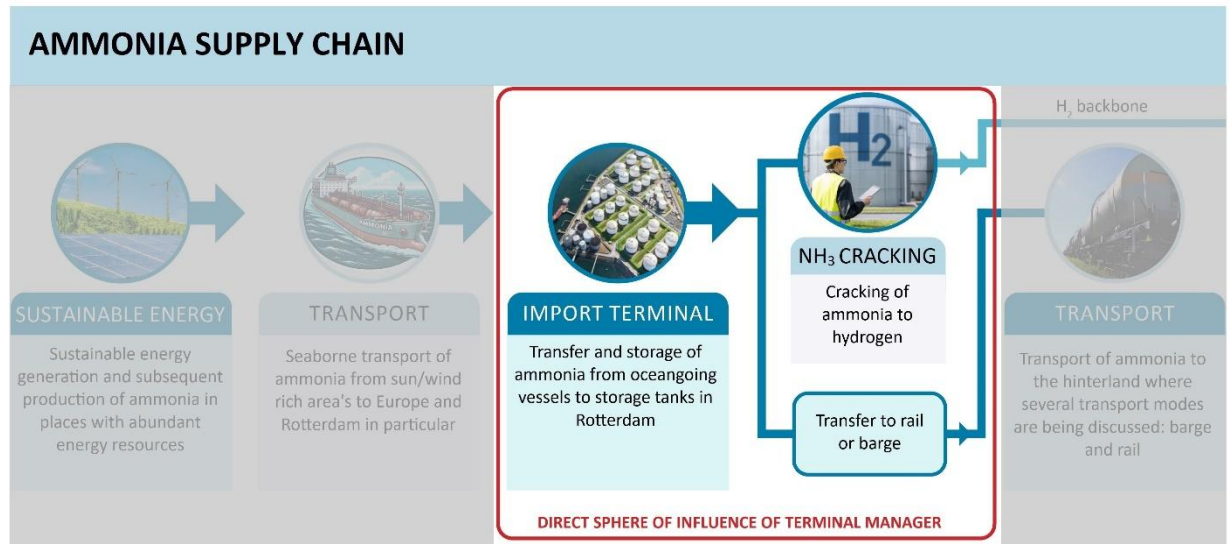


Figure 5.1

5.1 Description of step in the supply chain

Once green ammonia arrives at a Dutch port, storage is an important aspect. A new guideline that ammonia storage tanks must comply with has recently been developed in the Netherlands: the **PGS 12**

The PGS 12 guidelines were tightened in 2024 because the industry is already preparing for the expected strong growth in ammonia storage needs for hydrogen production. The industry is already anticipating this, with plans to expand existing ammonia storage terminals and applications for both cryogenic tank conversions, as well as the construction of new storage tanks.

The PGS 12 guidelines put the Netherlands at the forefront of ammonia terminal safety. The PGS 12 is internationally considered important. Consequently, a version in English will soon be available, so that the PGS 12 can also be used internationally.

Hydrogen, on the other hand, requires special cryogenic tanks or high-pressure tanks for storage. After arriving at a port, ammonia can be stored and gradually converted into hydrogen when needed for industrial processes.

The transfer of ammonia to a storage tank is a safety-critical process: a quantitative risk analysis has shown transfer to be one of the most critical processes in determining the risk profile. Loading and unloading facilities should therefore be equipped with the necessary safety measures, and staff should be well trained and aware of the risks during this process.

5.2 Risks

Transshipment from ocean-going vessels to storage terminals is one of the most risky activities in this step. This is because it involves a relatively large number of operations. Coupling and uncoupling the ship comes to mind here, for example.

These risks are also different from a fixed system that is simply located on land. A ship is docked and tied to the quay, but it is still floating in water. As a result there always is a risk of collision with another vessel.

During transfer (from ship to tank and from tank to barge/train/truck), the transfer link, a loading arm, may leak or break down. The effects are much smaller than an (unlikely) tank failure, but the probability is higher. To reduce this risk, under the new PGS 12 only special loading arms equipped with automatic couplings and automatic emergency dry break systems may be used.

The biggest risk during ship-to-tank transfer operations is the temperature of the ammonia during the transfer. The storage tank is designed to store the ammonia around its boiling point at atmospheric pressure, corresponding to a temperature of around -33°C. If the temperature of the ammonia in the ship is significantly higher, this could result in overpressure in the storage tank. The new PGS 12 includes safeguards to prevent this and requires a “terminal specification” that specifies the maximum cargo temperature.

In contrast, storage in a tank, which is always fixed in the same place, is considerably less risky than a transfer operation. Nevertheless, preventing a tank failure definitely deserves attention: if an ammonia storage tank were to actually fail, along with a failure of all of the safety systems, and a large uncontrolled amount of ammonia were to be released from the storage tank, this would be a disaster. The new PGS 12 directive specifies a safe design for a storage tank.

The toxic cloud produced when an entire tank of ammonia spills out has an impact area of several kilometres. Within this area, there is a significant risk of people dying from exposure to the ammonia vapour. For this reason, the safety requirements for an ammonia storage tank are high.

For example, the storage tank requires no physical human handling. Moreover, according to current standards, the storage tank must be designed such that the probability of the tank failing or leaking is so low that it can virtually be ruled out. For example, full-containment storage tanks are required, which are basically two tanks in one. The primary containment is the inner tank. The secondary containment can accommodate the entire contents of the inner tank, in case the primary containment fails. This provides the tank with dual safety and in fact two tanks must fail for ammonia to be released.

Finally, the whole tank is protected by a third concrete wall, minimising the risk of damage to the inner tanks by a projectile, overpressure, or heat radiation from outside.

The requirements for a tank, in accordance with the PGS 12, are therefore very high. To maintain high quality, maintenance needs to be effectively safeguarded.

Table 5.1 displays the ammonia storage and transshipment risks⁶. The PGS 12 contains a full list of possible incident scenarios for the Storage Tank, Product Pipelines, Loading and Unloading and for the Heat Exchangers used to heat liquid ammonia.

Table 5.1 Summary of storage and transshipment risks⁷

Action	Risk	Risk interpretation
Transshipment	Relatively large	<ol style="list-style-type: none"> 1. Transfers involve many operations. While the likelihood of an incident is relatively high, the impact is relatively minor: this is at most the amount discharged by the loading arm during failure, whereby the loading arm is automatically shutdown within a very short time, as soon as ammonia vapour is detected. This applies to any type of transfer, including from/to ocean-going vessel, barge, train and truck; 2. The ships are docked in the (busy) harbour, which still leaves a chance of collision with another ship.
Storage	Very small	<ol style="list-style-type: none"> 1. The tank’s design requirements are so strict that the probability of an incident is very low. However, the impact is large as there is a large amount of ammonia release; 2. As the storage is static and on land, there is no risk of collision with a ship or other vehicle, as is the case with docked ships.
Pipe burst /leak	Relatively large	<ol style="list-style-type: none"> 1. Leaks in a pipeline can involve significant outflows. This can be reduced by dividing the pipelines into segments using flanges, so that the damaged section can be isolated, thus limiting the overall outflow. Care should be taken to avoid providing the pipeline with too many flanges: in principle, it is best to leave the pipeline as uninterrupted as possible.

⁶ Also see PGS 12 and NIPV: <https://scenarioboeken.nipv.nl/scenariokaarten-externe-veiligheid/>

⁷ See PGS 12 for a detailed overview of the risks

5.3 Regulations presently current and available for the ammonia safety chain

Depending on the facilities and processes used at a terminal, several laws and guidelines may apply. We limit ourselves here to the principal ones for a hydrogen import terminal whereby ammonia is the hydrogen carrier.

PGS 12

In the Netherlands, the PGS 12 is the guideline for the safe storage and transfer of ammonia. Due to the energy transition and the associated large-scale storage of ammonia, PGS 12 was tightened for newly built tanks in 2024, and among other things covers the following aspects:⁸

- Specifications for the construction and maintenance of storage tanks, including pressure resistance and corrosion protection requirements;
- Full containment: double-walled steel and, in addition, an outer protective concrete wall;
- No more lead-throughs through the tank wall; all connections are at the top, the pumps are inside the liquid in the tank. In case of pump failure or pipe breakage, this will keep the ammonia in the tank;
- Protection against leaks: measures to prevent and control leaks, such as secondary containment systems, gas detection systems and regular inspections;
- Fire safety: fire prevention and suppression requirements, including the presence of fire extinguishers and fire-resistant materials;
- Monitoring and control: continuous monitoring of storage conditions, such as temperature and pressure, to detect and remedy abnormalities early.

The PGS 12 will be revised and supplemented in stages. The first phase was completed and focused exclusively on the new construction of storage facilities for and the transfer of cold, liquefied ammonia at atmospheric pressure. Phase 1 was published in 2024. Phase 2 deals with existing tanks and conversion to ammonia tanks. Phase 3 will review the (smaller) storage facilities for warm ammonia.

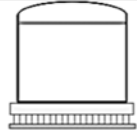
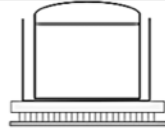
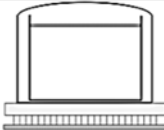
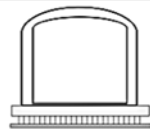
Tank Containment Types				
Containment Type	Tank Single Containment	Tank-in-Wall Double Containment	Cup-in-Tank "Full" Containment	Tank-in-Tank Full Double Containment
				
Inner Tank	Liquid Tight Vapor Tight	Liquid Tight Vapor Tight	Liquid Tight	Liquid Tight Vapor Tight
Outer Tank	- -	Liquid Tight	Liquid Tight Vapor Tight	Liquid Tight Vapor Tight
Outside of inner and inside of outer exposed to products during normal operation	N/A	NO	YES Vapor Condensate	NO

Figure 5.2 Tank containment types⁹

Figure 5.2 provides an overview of the possible tank containment structures. In the PGS 12, it was agreed that full containment double-walled steel tanks with a concrete shell for protection from external impact would be built for newly to be constructed storage tanks for the large-scale storage of ammonia.

⁸For a full overview, see PGS 12: <https://publicatiereeksgevaarlijkstoffen.nl/publicaties/pgs12/>

⁹ Source: <https://www.arbeidsveiligheid.net/veiligheidsartikelen/gevaarlijke-stoffen/streng-eisen-aan-grote-hoeveelheden-ammoniak>

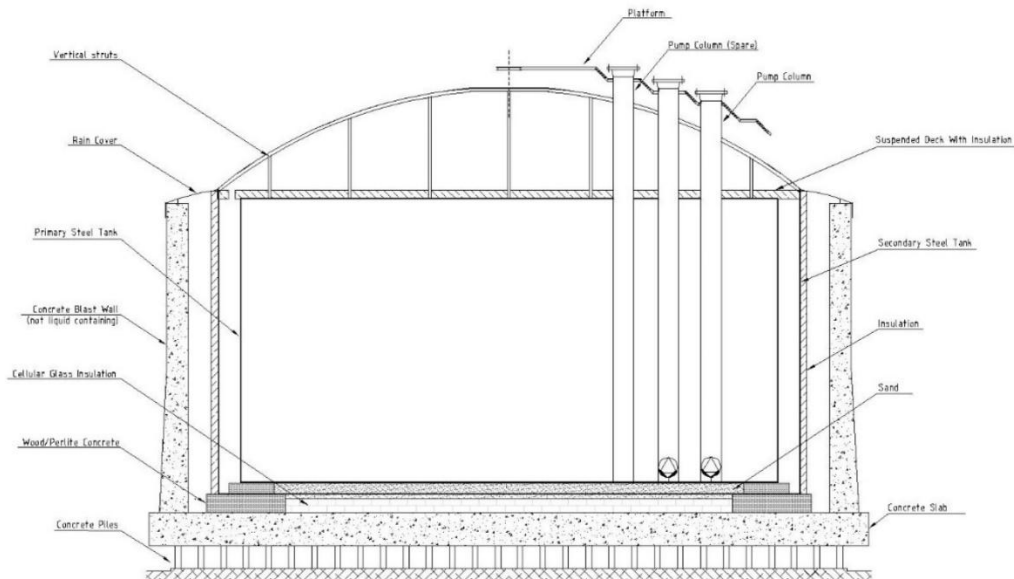


Figure 5.3 Storage tank as prescribed in PGS 12 (source: PGS 12)

For transshipment, the following guidelines apply, among others:

- Safety procedures: detailed procedures for the safe loading and unloading of ammonia, including emergency procedures in case of incidents;
- Personal Protective Equipment (PPE): regulations on the use of PPE such as respiratory protection, gloves and protective clothing to prevent exposure to ammonia;
- Training and Education: regular training for staff to raise awareness of hazards and proper procedures for handling ammonia;
- Technical Facilities: requirements for technical equipment and infrastructure, such as leak detection systems and ventilation, to ensure safety during transshipment.

SEVESO regulations

Besides PGS 12, companies that produce, store or process large quantities of dangerous substances generally must comply with the SEVESO III directive. Storage and transshipment terminals house large quantities of dangerous substances and as a rule, the SEVESO III directive therefore always applies.

The Seveso III directive¹⁰ is a European directive (2012/18/EU) that prescribes safety measures for companies that produce, store or process large quantities of dangerous substances. It aims to prevent serious industrial accidents and minimise the impact of potential incidents on people and the environment. The directive is named after a serious chemical accident in Seveso, Italy in 1976, which released large quantities of dioxin. The Seveso III Directive came into force on 1 June 2015, replacing the earlier Seveso II Directive. The amendments to Seveso III take into account changes in regulations on chemicals (such as REACH and CLP) and strengthen transparency and communication to local residents and other stakeholders.

SEVESO III makes a distinction between two types of companies: Low threshold and High threshold companies. These two types of companies differ in the amount of dangerous substances handled. Low threshold companies operate with a lower quantity of dangerous substances compared to High threshold companies. Moreover, the

¹⁰ SEVESO III directive: <https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:197:0001:0037:NL:PDFm>

requirements Low threshold companies are expected to meet are less severe than those of High threshold companies.

The main elements of the SEVESO III directive are:

Application and scope

- The directive applies to companies working with large quantities of dangerous substances, such as flammable, toxic or environmentally dangerous substances.
- It makes a distinction between two categories of companies:
 - Low threshold companies: with smaller quantities of dangerous substances.
 - High threshold companies: with larger quantities of dangerous substances and stricter obligations.

Major accident prevention

- Companies must have a major accident prevention policy (BPZO) in place, describing their risk management strategies.
- High threshold companies are required to implement a comprehensive safety management system.

Safety report

- High threshold companies must also submit a safety report to the competent authorities. This document includes a description of the:
 - Identified risks;
 - Preventive measures;
 - Potential impact of incidents;
 - Internal and external emergency procedures.

Inspections

- Competent authorities carry out regular inspections to verify company compliance with the directive;
- High threshold companies are inspected at least once a year, while low threshold companies are inspected less frequently.

Emergency plans

- Companies must prepare internal emergency plans in coordination with local authorities who are responsible for external emergency plans;
- These plans describe how to act in case of incidents, especially focusing on the evacuation and protection of local residents;
- Emergency plans should be practised jointly with local authorities.

Communication to local residents

- Seveso III puts more emphasis on transparency. Local residents must be informed about:
 - The nature of the hazards present;
 - How they can protect themselves in case of an incident.
- Information must be freely available, for example, online.

Environmental protection

- The directive stresses the importance of minimising the environmental impact of industrial accidents.

The Seveso III directive is a cornerstone of industrial safety in Europe. It helps manage major accident risks, protects people and the environment and promotes transparency. Companies handling large quantities of dangerous substances must strictly adhere to this directive to avoid legal sanctions and the serious consequences of incidents. Storage and transshipment terminals based in Europe that deal with ammonia therefore fall under the Seveso III directive and must adhere to these minimum safety requirements and standards.

5.4 Evaluation and focus points

Ammonia storage and transfer is not new. However, what is new is the large volumes that will be involved in the (near) future. With the PGS 12, the Netherlands has shown that it has already given careful consideration to the risks involved in the transfer and storage of ammonia and to risk mitigation measures, thereby providing due consideration to the fact that future volumes will increase significantly. Together with the other safety-related laws and regulations mentioned earlier, this provides a solid basis regarding the safe transfer and storage of ammonia.

Instructions to employees¹¹ concerning ammonia storage and transfer operations and the associated risks, and general information on ammonia and the associated risks, also contribute to safety. With this information, employees become aware of risks, are able to better assess dangers and act accordingly in safer ways. Automation also plays a very big role here. Eliminating the “human handling” factor by using automated safety devices with a high level of reliability ensures a higher Safety Integrity Level. In addition, developing and practicing (for example, “serious gaming”) emergency plans in consultation with local authorities is a key focus.

There are concerns about the entry of many new players into the ammonia market and the question of whether these new players have sufficient knowledge and skills to do so in safe ways and, above all, whether there is sufficient awareness that the storage and handling of ammonia requires a more critical approach to safety. This aspect certainly needs attention. It is therefore worth noting that several initiatives are now in place: for example, the VOTOB (Association of Dutch Tank Storage Companies), together with its members, plans to develop standards and agreements on how to set a minimum safety standard for working with ammonia as a sector. The document Curriculum for Ammonia Terminal Managers (2025) expands on this. There are also various training and education programmes for employees about working in an ammonia storage and transshipment company.

Sharing international knowledge and experience also makes a positive contribution to the safety of ammonia storage and transfer processes. Furthermore, keeping an incident database¹² helps provide insight into problems and issue an effective response. Such a database will allow for continued review resulting in safer ways and systems to store and transfer ammonia, thus minimising risks. There are also international bodies where substantive knowledge and techniques are shared, such as the Ammonia Energy Association (AEA), or the NH₃ Event Europe (NH₃ Event Foundation) which organises annual conferences, and the AIChE (The Global/American Home of Chemical Engineers). Industry associations can also play an active role in this respect. Within an industry association, discussions and meetings enable people to learn from one another's incidents.

5.5 Role of the terminal manager

All processes and the maintenance of facilities and assets within a terminal are the responsibility of the terminal manager. This also applies to the processes or installations operated or managed by a third party at the terminal. The following two examples are relevant to an ammonia import terminal:

- If an installation (for example a cracker) within the facility is managed and operated by a third party, the terminal manager remains responsible under the Environmental Permit (also see next section).
- Once an ocean-going vessel or barge is docked, the terminal manager becomes responsible for the vessel or barge as it is then part of the facility. This also applies to the loading and unloading of ships.

The terminal manager is also responsible for working with local authorities on coordinating the terminal's contingency plans with the local authorities' contingency plans.

¹¹<https://votob.nl/home/kennisbank/ammoniak/module-energietransitie/>

¹²<https://ammoniaknowhow.com/discussion-board/forum/incident-database/>

6. Step 4: Ammonia cracking

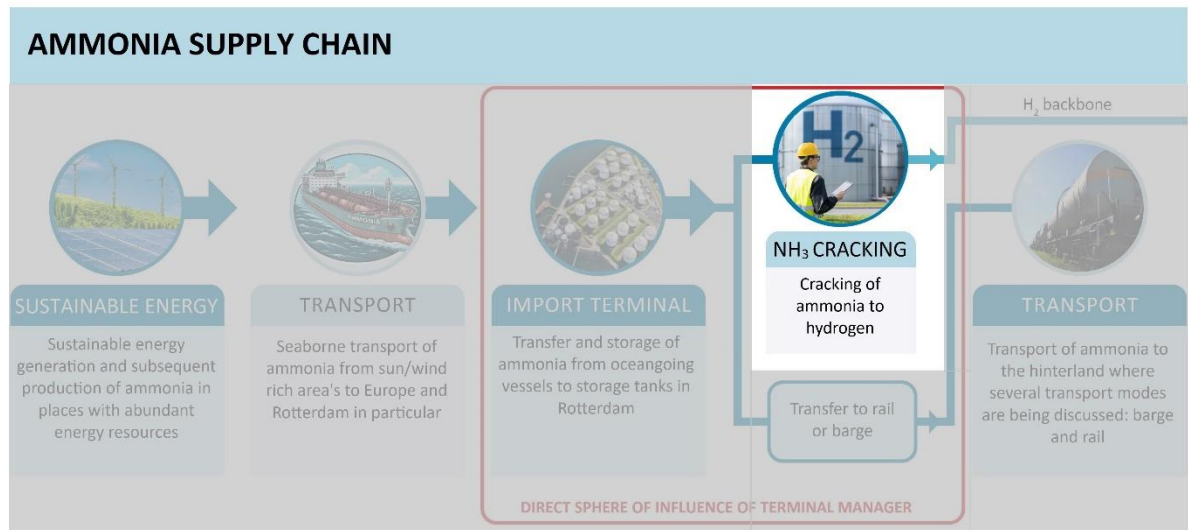


Figure 6.1

6.1 Description of step in the supply chain

Ammonia cracking to produce hydrogen plays an important role in the energy transition. This process is crucial for exploiting hydrogen as a carbon-free fuel, especially in sectors such as heavy industry, transport and power generation.

In ammonia cracking, also known as ammonia decomposition, the ammonia can be cracked at the point of use to produce hydrogen. This process breaks down ammonia molecules into hydrogen and nitrogen in accordance with the following chemical reaction: $2\text{NH}_3 \rightarrow 3\text{H}_2 + \text{N}_2$

The nitrogen (N₂) is safely released into the atmosphere. This can be done without any problems and is not environmentally damaging, since the nitrogen was extracted from the atmosphere during the ammonia synthesis process and is now released back into the atmosphere. The hydrogen can then be used as fuel for various applications:

- **Fuel cells:** hydrogen is used in fuel cells to generate electricity, for example in vehicles or in power generation facilities;
- **Industrial processes:** hydrogen is used in chemical processes, such as in refineries and the steel industry, where it replaces fossil fuels to reduce carbon emissions;
- **Energy storage:** excess renewable energy is stored in the form of ammonia, and the hydrogen produced from its decomposition can be used to generate electricity when demand is high.

Ammonia cracking to produce hydrogen is a key technology in the global energy transition. It solves the challenges of hydrogen storage and transport, enables large-scale energy storage and export, and supports the decarbonisation of key sectors. Although technical and economic challenges exist, the combination of ammonia as a hydrogen carrier and hydrogen as a fuel offers a promising route to a low-carbon future.

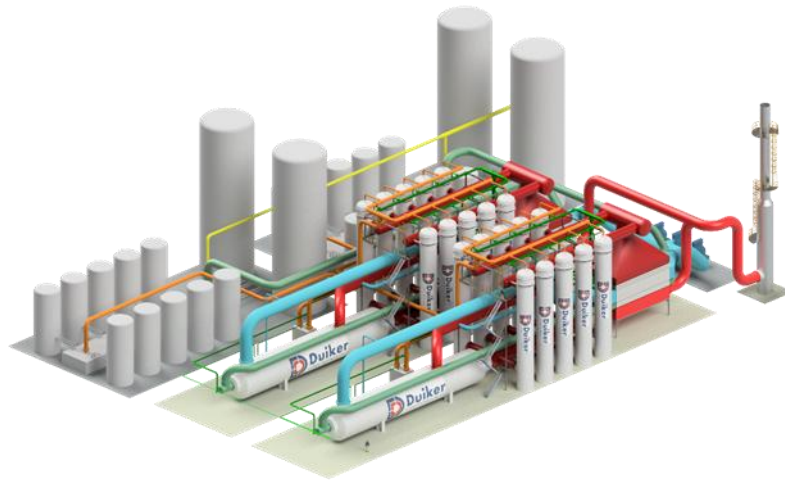


Figure 6.2 Example of an NH₃ cracker AHC plant – Source: Duiker Clean Technologies

6.2 Risks

Ammonia cracking is a specific process and therefore has different risks than conventional systems that only use ammonia. The input to the cracker consists of ammonia. The cracker decomposes the ammonia to produce hydrogen.

There are several techniques for this, which are still in full development. Typically, ammonia is cracked under elevated pressure and temperatures; namely pressures of +30 bar and temperatures of around 800-1200°C. Ammonia is therefore present in a cracker in gaseous form. Thus, when a leak or rupture occurs in this part of the system, gaseous ammonia can escape. This immediately creates a toxic cloud. However, the amounts of ammonia that potentially could be released in a cracker incident are limited compared to transport through pipelines and transfer operations.

In addition to ammonia, the system also contains hydrogen. Hydrogen is not toxic, but it is highly explosive. When hydrogen is released, there is an increased risk of explosion. Hydrogen is not a primary part of the scope of this document, but that does not alter the fact that the sector is concerned about the hydrogen-related risks. For completeness, the annexes therefore include information about the hydrogen-related risks.

The consequences in the event of an ammonia gas leak in the cracker remain limited compared to storage, transfer and other transport activities due to the limited quantities in the cracker that can therefore be released (provided, of course, that the ammonia supply line to the cracker is segmented). This does come with the risk of explosion due to the release of hydrogen gas. When an explosion occurs, it creates a pressure wave, which can also damage other nearby systems and, as a result, further incidents, or a domino effect, can occur.

Domino effect accident (incident)

A domino effect accident is one in which a primary adverse event sequentially or simultaneously causes one or more secondary adverse events in nearby equipment or facilities, leading to secondary accidents that are more severe than the primary event. A domino effect accident actually is a sequence of multiple events, which is analogous to a falling row of dominoes. The term domino accident is also used.

6.3 Safety standards in the supply chain

In addition to the previously mentioned applicable laws and regulations for companies handling dangerous substances, in addition to ammonia, the hydrogen risks must also be considered in case of a cracker. Hydrogen is an explosive gas and therefore general safety guidelines regarding explosive gases apply.

The **NPR 7910-1** is a Dutch code of practice that provides guidance on classifying hazard zones with regard to gas explosion hazards. This guideline is based on the international standard NEN-EN-IEC 60079-10-1 and provides a practical interpretation for identifying and classifying areas where explosive atmospheres may occur.

Key aspects of NPR 7910-1:

- **Hazard zone classification:** the guideline helps define zones where explosive atmospheres may be present. This includes identifying the probability and duration of the presence of an explosive atmosphere;
- **Explosion safety document (ESD):** employers are required to prepare an ESD, which describes the hazard zone classification and the measures taken to control explosion hazards;
- **Risk inventory and evaluation (RI&E):** the guideline stresses the importance of conducting a comprehensive RI&E to identify and assess explosion hazard risks;
- **Preventive measures:** to minimise the risk of explosive atmosphere formation, for example, through proper ventilation and avoiding ignition sources;
- **Protective measures:** mitigating the consequences of a potential explosion by, for example, using explosion-proof equipment and structures;
- The **NPR 7910-1** provides a structured approach to identifying, evaluating and controlling explosion hazards, which contributes to a safe working environment.

ATEX plays a crucial role within NPR 7910-1. ATEX stands for “ATmosphères EXplosibles” and comprises two European directives that focus on explosion protection in environments where explosive atmospheres may occur.

- ATEX directives
 - **ATEX 153:** focuses on protecting workers from explosion hazards. Employers must take technical and organisational measures to prevent explosive atmospheres, avoid ignition and limit the effects of an explosion;
 - **ATEX 114:** focuses on equipment and protective systems used in explosive atmospheres.
- Hazard zone classification: NPR 7910-1 uses the principles of the ATEX directives to classify danger zones. This helps identify areas where explosive atmospheres may occur and determine appropriate safety measures.

In addition, there is the Generic Guideline for Hydrogen Safety, which focuses specifically on hydrogen and provides guidelines for the safe handling of hydrogen in the energy transition. This supplement can be found in Annex 1.

6.4 Evaluation and focus points

When a cracker is added to a storage and transshipment terminal, the terminal effectively transforms from a storage and transshipment terminal to a process technology plant. A cracker is a large plant within which various physical and chemical processes take place. There are several techniques for this that are still in development. In fact, by adding a cracker, the terminal becomes a chemical production plant that also processes various substances. Managing a process plant is a different business compared to solely dealing with storage and transshipment operations at a terminal. The terminal manager must therefore take ancillary and other responsibilities into account. It is also possible to opt for a Joint Venture in which the terminal cooperates with a party specialised in the process industry to manage a cracker on the site. Preparing mutual agreements is crucial in this respect.

Due to the fact that large-scale ammonia cracking is new, means that the technology used is subject to innovative change. Added to this is the fact that both the dangers of ammonia (toxic) and hydrogen (explosive) have to be considered for a cracker. When hydrogen is released, an explosion hazard arises. An explosion in a cracker may lead to the release of the ammonia present in the cracker.

6.4.1 Role of the terminal manager

To properly manage this new part of the terminal, requires a broadening of the current scope. A cracker obviously has different risks and challenges than a tank storage facility, which the terminal manager now also needs to fully understand. The terminal manager must therefore be well aware in advance of the processes that take place in and around the cracker, as well as the risks involved.

7. Step 5: Transport of ammonia to the hinterland

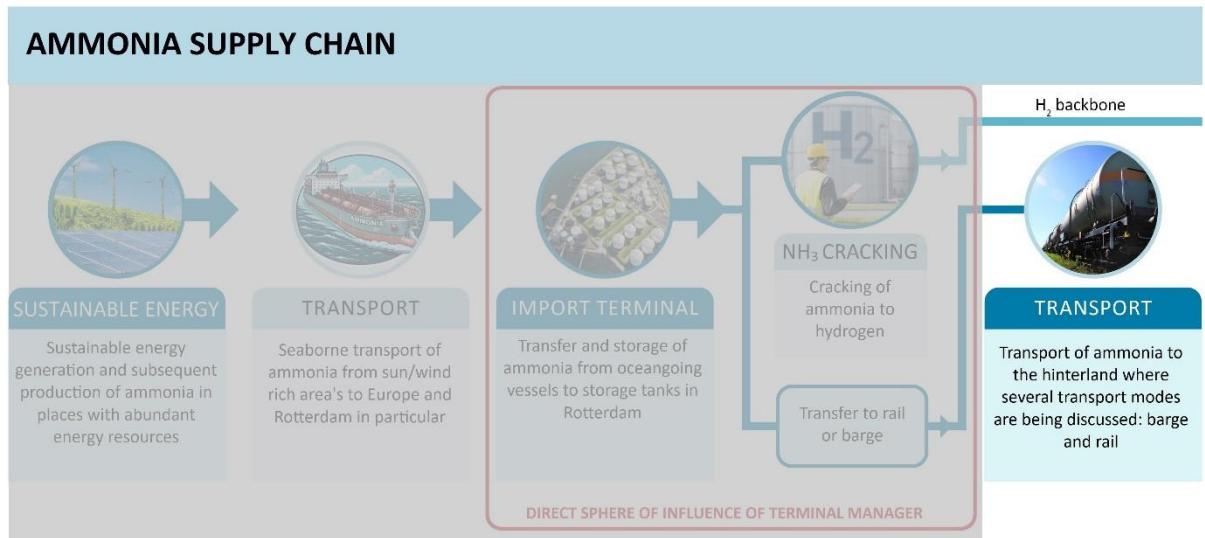


Figure 7.1

7.1 Description of step in the supply chain

Transport of ammonia and hydrogen to the hinterland plays a crucial role in the energy transition. Each mode of transport – pipeline, barge, rail (train) – offers unique advantages and challenges. The choice of transport mode depends on several factors, such as the size of the transport flow, the route and the ammonia receiver's capabilities. A choice can also be made concerning the point in the transport route where the ammonia is to be cracked. Direct cracking at the import terminal will be preferred in many cases, after which the hydrogen will be transported to users via the existing natural gas grid or the construction of a hydrogen backbone such as at the Port of Rotterdam. Transporting hydrogen poses different risks from transporting ammonia: for example, hydrogen is flammable and explosive, while ammonia is toxic.

In this document, only the rail and barge modes are discussed in more detail, since these are the transport modes expected by the market in the first phase of the hydrogen economy's development¹³. All transport modes are suitable for transporting ammonia from both a technical and legal point of view. The Cabinet's vision of hydrogen carriers (November 2024), incidentally, identifies transport via pipeline and inland waterway as preferable, with – as long as alternatives are lacking – room for rail and road as well. From the perspective of the storage and transshipment terminals, transport by road is not considered a suitable mode of transport due to the large volume flows. Furthermore, no pipelines are currently available for transporting ammonia. Since a large-scale pipeline network cannot be constructed overnight, this leaves only the rail and inland waterway transport modes for large volumes.

The transport modes below zoom in on transport in the form of ammonia. A comparison with hydrogen is added in Annex 2.

Barge/inland navigation

Advantages: transporting ammonia by barge/inland waterway is an efficient and relatively cost-effective way to transport large quantities of ammonia through rivers and canals. Barges often have a large carrying capacity, which means they are capable of transporting significant quantities of ammonia at once. This is especially important for large ammonia terminals and industrial clusters.

Challenges: transport by barge depends on water levels, which can affect the capacity and speed of transport. In addition, transshipment between ships and ports is more operationally challenging than transshipment to train.

¹³ Given the expected volumes, large-scale transport by road is not an option.

To date, transport of warm ammonia in particular takes place by barge. However, transport of cold ammonia by barge is currently under development. This yields the advantage that the risks (or rather the impact in the event of an unexpected incident) are significantly lower. In the event of a spill, a part of the ammonia will dissolve in the water immediately, while the remaining part will spread across the water by the current and wind and will then evaporate or still dissolve.

Rail

Advantages: Rail transport is a flexible option for transporting ammonia over land to the hinterland; rail tankers are especially suitable for medium distances. In general, rail transport is seen as a safe option; safety standards (especially in the Netherlands) are high. Ammonia transport by rail uses specialised rail tankers that can withstand the chemical properties of ammonia, with a greater wall thickness that makes them more resistant to external impacts.

Challenges: Rail transport is more sensitive to disruptions, such as delays or capacity constraints, depending on the rail network and available routes. In addition, governments in the Netherlands see rail transport passing through inner cities as a major obstacle.

Overview of transport modes

The table below shows all transport modes with advantages and challenges:

Table 7.1 Means of transport with advantages and challenges

Transport mode	Capacity	Cost	Speed	Flexibility	Safety risks
Barge	High	Average	Moderate	Flexible along waterways	Probability of incident very low, but potentially large impact in case of a leak (large calamity with toxic cloud, local pollution of river water resulting in the death of flora/fauna)
Rail	Average	Average	Moderate	Flexible for land transport	Probability of incident very low, outflow smaller than for barge, transport usually through inner cities

Transporting ammonia and hydrogen to the hinterland is likely to require a mix of different transport modes, depending on distance, available infrastructure, and safety needs. Barges are best suited for large-scale long-distance transport, while rail transport is more flexible for regional distribution.

The choice of means of transport will be determined by economic, technical and safety considerations, as well as the availability of infrastructure in specific regions. Such choices are now made by individual companies and local governments. However, from both a safety and efficiency perspective, direction from the Dutch government through the development of a national transport policy for the transport of ammonia from ports to the German border would be preferable.

7.2 Risks

Many aspects play a role in selecting a transport mode: accessibility, distance, cost, size of quantities to be transported, etc. While safety is an important aspect, it is not the only factor to consider in making a well-informed choice. It is also worth noting that each transport mode has high safety standards, together with a corresponding set of laws and regulations, to mitigate and reduce risks as much as possible.

This study only considered the safety aspect in making a choice.

Each transport mode has its own risks. These risks are set out below by transport mode. The sequence in which the transport modes are presented indicates the preferred mode of the Dutch government.

Pipeline

The likelihood of an incident is very low. In case of smaller accidents, the effects are mainly limited to soil and nature. For larger scenarios, such as a pipe burst, the large volumes involved (as the pipe's diameter increases,

the volume discharged also increases), can result in a very large impact of longer duration. PGS 12 prescribes that the distance between valves should be chosen so that a maximum of 50 tonnes can flow out¹⁴. From a government perspective, transport via pipeline is the preferred mode due to the low accident probability. Pipelines are primarily located underground and are static objects. This makes it easier to incorporate safety systems to reduce outflow in the event of an incident. Densely populated areas can be optimally avoided when the pipeline's route is established. However, it takes many years to build a pipeline.

In anticipation of any pipeline construction, recent studies (such as the Antea Group (see footnote 14) and ISPT studies¹⁵) have been carried out concerning the requirements to be met by a pipeline for ammonia. In this study, they outline a preferred construction pipeline route, among other things (see Figure 7.2).

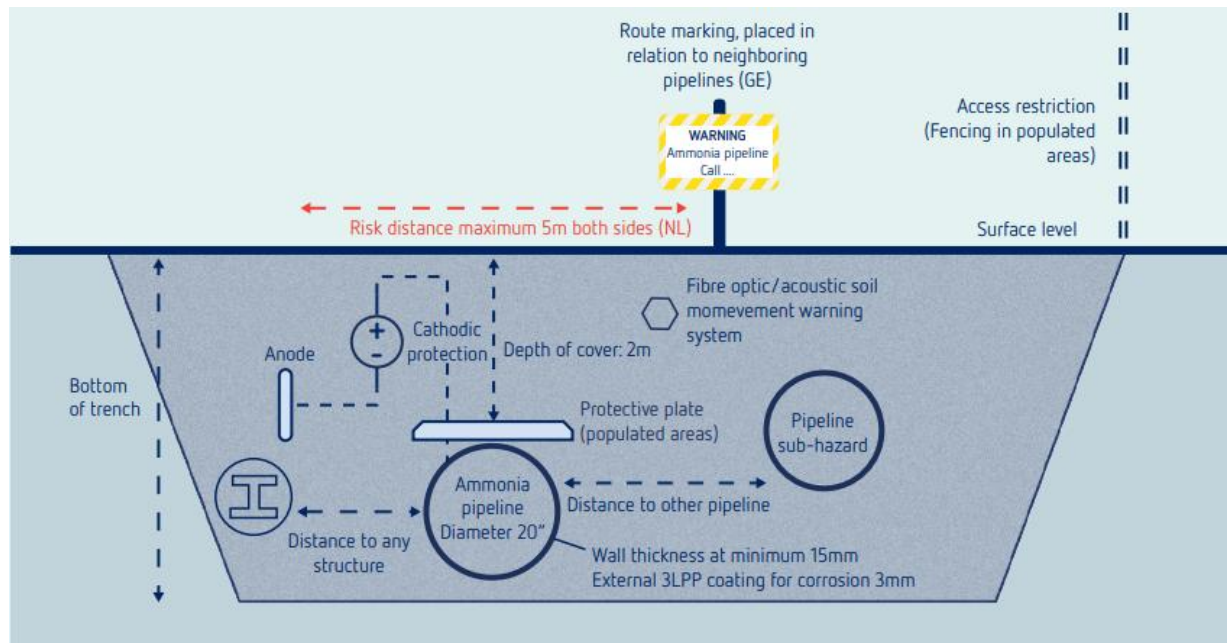


Figure 7.2 Example of a safe route for an ammonia transport pipeline (see footnote 15)

Note that in Germany, the preference is for transport by barge or train: the short-duration passage of barge or train is seen as less risky than an underground pipeline, with a potentially large impact in case of a Loss of Containment after an incident (for example, damage caused by excavation work).

Inland navigation

This is currently considered the safest option for transporting ammonia. Transport is via waterways, which relatively often still passes through inhabited areas which is undesirable. An additional advantage of transport by inland waterway is that the ammonia can also be transported cold. Transporting cold ammonia poses a lower risk compared to warm ammonia.

Rail

Less risky than road transport because it involves a traffic control system. The railway does pass through inner cities, so an incident could have a potentially major effect. The preferred route is the Havenspoorlijn-Betuweroute, which is a dedicated freight route that does not pass through inner cities. However, a level playing field involving ports other than Rotterdam must also be taken into account. To date, no major incident involving the release of dangerous substances during rail transport has occurred in the Netherlands, although a major incident involving the release of a flammable substance did occur once during shunting (hump shunting) operations (Kijfhoek ethanol fire, 2011). Incidents are known to have occurred abroad, however, such as in neighbouring Belgium (Wetteren, 2013) or Serbia (2022). Although, these situations generally are not comparable to the Dutch situation, such accidents do show that safety remains a major concern.

¹⁴ Ammonia Pipelines, Antea Group on behalf of the Ministry of Infrastructure & Water Management, 31 March 2025

¹⁵ Institute for Sustainable Process Technology (ISPT): 2025-ISPT-Ammonia-Pipeline-report_version-2.0.pdf

7.3 Regulations presently current and available for the ammonia safety chain

In the Netherlands, rail and inland waterways are subject to the following legal requirements for the transport of dangerous substances, including ammonia:

General

- **Dutch Dangerous Goods Transport Act (Wvgs):** This law aims to ensure the safety of people and animals when transporting dangerous materials by road, rail and inland waterways. Accidents involving the transport of dangerous goods must be reported to the Dutch Human Environment and Transport Inspectorate (ILT).
- **Regulation on the Transport of Dangerous Goods (Bvgs):** This regulation stipulates that the transport of dangerous goods must comply with international regulations for various transport modes. Land transport is governed by ADR, inland waterways by ADN, and rail transport by RID.
- **Basic Network and Basic Network Regulation (Rb):** This regulation determines risk ceilings along transport routes and sets rules for spatial development along these routes. The Basic Network Act is evolving, however. A recent Parliamentary letter proposed major changes to the Basic Network (Robust Basic Network¹⁶).

Rail

- **Regulation for the transport of dangerous goods by rail (Vsg):** This regulation contains specific provisions for the transport of dangerous goods by rail in the Netherlands.
- **RID (Regulations concerning the International Carriage of Dangerous Goods by Rail (RID)):** The RID is the European legislation for the transport of dangerous goods by rail and sets out requirements, criteria and procedures for the hazard classification of dangerous goods, conditions of carriage, packaging, tanks, labelling and documentation.

Inland navigation

- **European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN):** The ADN contains all the requirements that the transport of dangerous goods must comply with, such as safety regulations, packaging standards and labelling.

7.4 Evaluation and focus points

The preferred modes of transport described above, highlight the fundamental importance of conducting a risk assessment adapted to each transport mode and volume to ensure safety. In this respect it is worth noting that selecting a transport mode also depends on many other factors, whereby the availability of a transport mode and cost also are important factors.

From the figure below, it can be deduced that currently most dangerous substances generally are transported by pipeline and inland waterway, followed by transport by road, with a very limited proportion going by rail.

¹⁶ Parliamentary letter on a Robust Basic Network and safety of railway yards | Parliamentary document | Rijksoverheid.nl

Transport of dangerous substances by transport mode (2023)

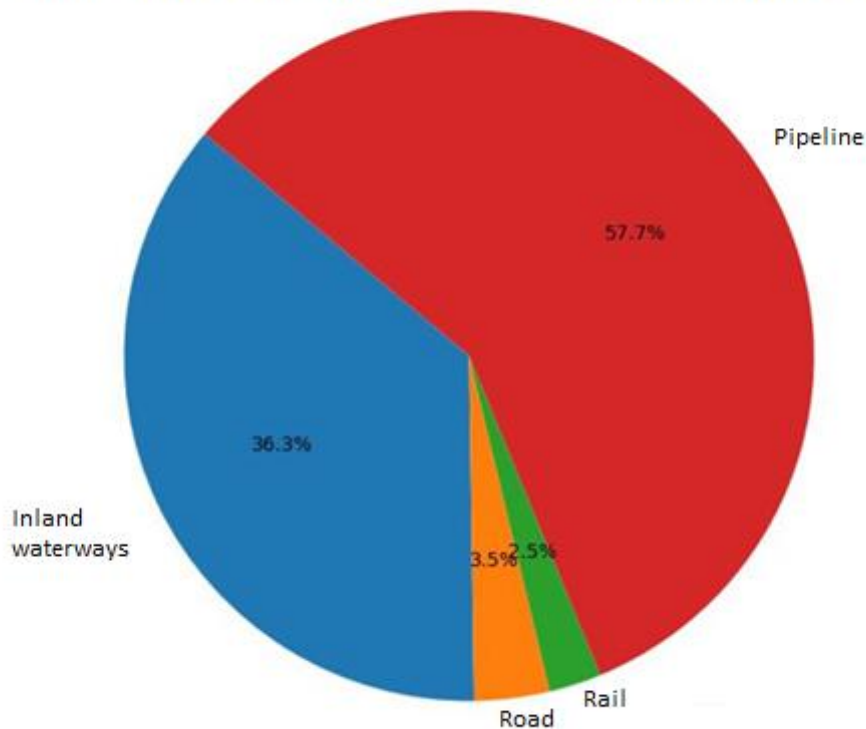


Figure 7.3 Transport of dangerous substances by transport mode, Source CBS (Statistics Netherlands)

Pipeline transport is currently considered a preferred mode of transport by governments in particular. Important considerations here are that the pipelines must not pass through inner cities and that there is minimal risk of impact. However, the volumes are large and an incident can therefore have a major impact. Currently, there are no pipelines for transporting ammonia: building a pipeline is very costly and involves a lengthy process. As a result, no pipelines are expected to be available for transporting ammonia for the next 10-20 years.

Transport concerns in relation to the energy transition:

- Transporting ammonia is not new: it has been done for decades and there has never been an incident involving the release of ammonia in the Netherlands. However, because the volumes that will be transported for the purpose of the energy transition are expected to increase substantially, and ammonia is toxic and has a potentially large impact area if released, a proper risk assessment must be conducted for each transport mode and route. There are as yet no ammonia transport pipelines and the preferred transport mode from the government's point of view is transport by barge, and if this is really not possible, transport by rail. However, customers often want security of supply: for this reason barge and rail, or barge and cracker, or a combination of cracker, barge and rail will be the preferred choice in some cases. This will need to be well justified to the local community.
- Use of ammonia as a fuel, which means that the transport of non-dangerous goods may also entail the possibility of an incident involving the release of dangerous substances.
- Cooperation in case of an incident: in industrial port areas, there is much readily available knowledge. This means that first and foremost, companies themselves possess comprehensive knowledge. In addition, trained emergency services are available: for example, the Rotterdam port area has a Joint Fire Brigade, which has several stations in the Port of Rotterdam and is a well-practised and trained organisation. This is not always the case in other parts of the country: here, voluntary fire brigades often have virtually no experience with incidents involving the large-scale release of dangerous substances. The Joint Fire Service has specific knowledge related to fighting ammonia incidents. This knowledge should be shared with all fire brigades/responders.

Action perspective for local residents: a transport incident can occur in many places. It is important to think carefully in advance about how the population will be alerted in time and the instructions that may be issued.

- The last area of concern is coherence within the supply chain – or rather the lack of it – at the time of an incident. The supply chain consists of separate links: after a cargo leaves the terminal, the cargo is completely out of the terminal's purview. One of the suggestions is to conduct the emergency response as a Serious Gaming exercise focused on an ammonia incident to identify and discuss any bottlenecks.

7.5 Role of the terminal manager

The terminal manager must check the loading process and transport units (or have them checked) before the barge/rail tanker leaves the terminal:

- An important factor in the transfer of ammonia by rail and inland navigation is that it currently involves warm ammonia, where the presence of oxygen in the gas phase acts as a corrosion initiator, which creates a risk of stress corrosion cracking (SCC).
- Preventing drip leaks: while these are not a primary external safety problem, leaks are considered carelessness on the part of the terminal.

Formally, the terminal manager no longer has responsibility for the transport once it has left the site. The Dangerous Substances Adviser of the relevant Safety Region has the expertise required to provide advice in case of an ammonia incident during transport in the Netherlands. Ammonia documents (Material Safety Data Sheets) also provide information on this.

Annex 1 Hydrogen (H₂)

This supply chain document focuses on ammonia. Ammonia cracking produces hydrogen; this substance comes with its own safety risks. This annex briefly covers these risks:

Generic Guideline for Hydrogen Safety

This guideline aims to control and minimise the safety risks of hydrogen, especially in new applications for which specific laws and regulations do not yet exist. The guideline provides guidance on:

- Risk assessment and management
 - The guideline describes methods for identifying and assessing the safety risks associated with the use of hydrogen;
 - Additional risk reduction requirements are specified to minimise the likelihood of incidents.
- Conformity and compliance
 - The guideline outlines how companies can demonstrate compliance with set safety standards and regulations;
 - Consideration is given to dealing with uncertainties in the use of hydrogen.
- Monitoring and evaluation
 - The guideline stresses the importance of continuously monitoring and evaluating hydrogen projects to ensure safety;
 - Guidelines are provided for investigating incidents and learning from them to reduce future risks.
- Communication and supervision
 - The guideline contains recommendations for effectively communicating safety risks to all stakeholders;
 - Supervision and enforcement frameworks are provided to ensure compliance with safety measures.

The guidelines are designed to support the safe and responsible integration of hydrogen into the energy transition.

Annex 2 Transporting hydrogen to the hinterland

The transport of hydrogen to the hinterland plays a crucial role in the energy transition. Each mode of transport – pipeline, barge, rail (train) and road (truck) – offers unique advantages and challenges. The choice of transport mode depends on several factors, such as the size of the transport flow, the route and the ammonia recipient's capabilities (for example, inland shipping is very safe but its network is not as extensive as, for example, rail). The transport modes below zoom in on the transport of hydrogen.

Pipeline

Advantages: Hydrogen pipelines are attractive for large-scale transport, especially for industrial clusters and energy storage. The use of pipelines for hydrogen can be relatively efficient because they can provide a constant flow without requiring much transport energy.

Challenges: Transporting hydrogen through pipelines requires special materials and technologies. The hydrogen molecule is very small and can leak through materials that are suitable for transporting natural gas, for example. Moreover, hydrogen can also cause a pipeline's metal structures to become brittle (hydrogen embrittlement). There are a few hydrogen pipelines, such as the European "Hydrogen Backbone" project, but large-scale infrastructure still needs further development.

Barge/inland navigation

Advantages: Although directly transporting hydrogen by barge is less common, it can be transported in special containers in liquid (LH₂) or compressed form. Barges can also carry hydrogen-derived products, such as ammonia or liquid organic hydrogen carriers (LOHCs).

Challenges: Transporting pure hydrogen by barge is complicated because of its low energy density and the need for cryogenic conditions (very low temperatures for liquid hydrogen). In addition, few/no barges and inland waterway infrastructure specifically designed for transporting hydrogen are currently available.

Rail

Advantages: As with ammonia, hydrogen can be transported in liquid or compressed form by train, often in special cryogenic rail tankers for liquid hydrogen. Rail offers economies of scale, especially for long hinterland distances.

Challenges: Transporting pure hydrogen by rail requires specialised cars and additional safety protocols due to the low energy density of hydrogen and the potential risks of leakage. As with other means of transport, rail transport is relatively slow compared to pipelines. In addition, it should be noted that rail transport moves through inner cities.

Road

Advantages: Hydrogen can be transported in special tankers under high pressure (compressed hydrogen) or in cryogenic form (liquid hydrogen). This makes trucks a flexible option for shorter distances and for delivery to specific customers, such as hydrogen filling stations or industrial facilities.

Challenges: As with ammonia, freight transport of hydrogen is limited in scale and capacity. Compressed hydrogen takes up more space, meaning trucks can carry relatively small amounts of hydrogen. In addition, liquid hydrogen requires very low temperatures, which requires special trucks and insulation techniques.

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