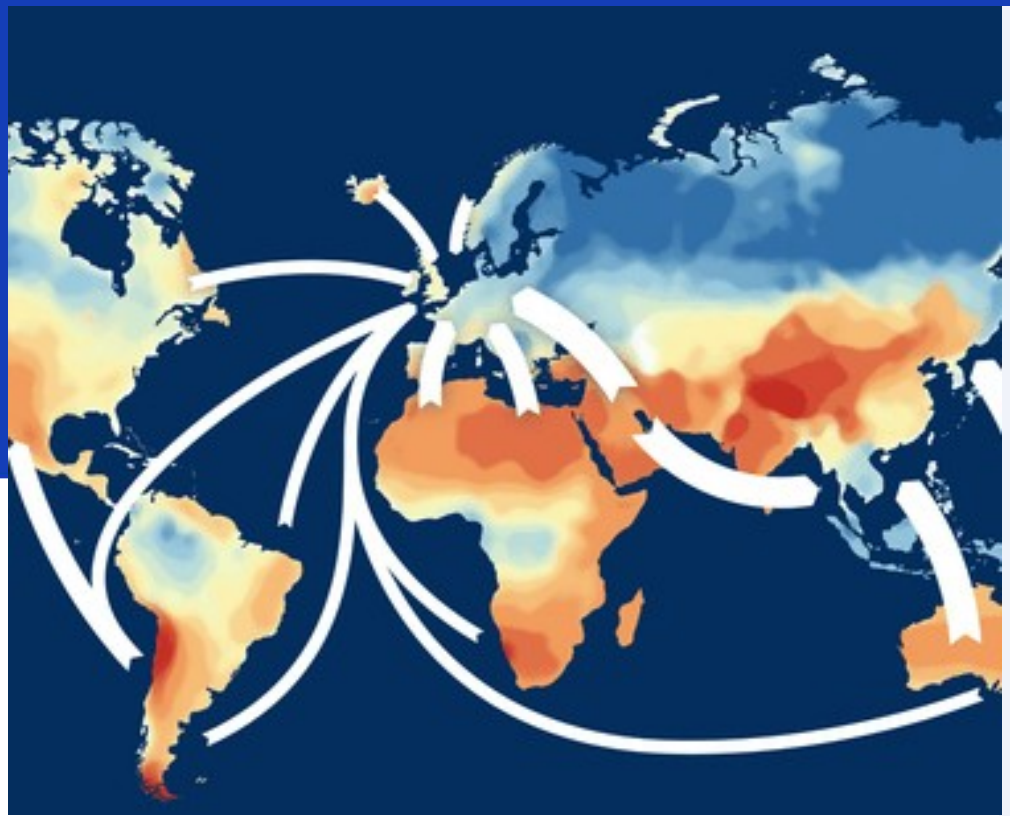
SHIP>NL sessie IX 2025

Drs. M.C.M. Rijkers

Start presentation

TNO innovation for life

Agenda SHIP>NL sessie 15 oktober 2025



1. Welkom
2. Deep Dive: Projects for Low-emission Ammonia Production and Utilization
   Kevin Rouwenhorst | Ammonia Energy Association
3. Afsluiting

Huisregels

- Camera aan, microfoon op ‘mute’
- Vragen?
  - Plaats verduidelijkingsvragen in de meeting chat; of
  - Steek je hand op!
- De moderator zorgt ervoor dat je vraag beantwoord wordt (eventueel achteraf).
- De slides worden na de sessie gedeeld. Slides van de andere sessies zijn te vinden op SHIPNL: Sustainable Hydrogen Import Program Netherlands | Nationaal Waterstof Programma

- We bespreken uiteraard geen marktgevoelige zaken.

- Chatham house rules: De besproken informatie mag gedeeld worden, maar zonder de spreker te onthullen.

Meerjarig kennisprogramma met 5 lijnen

- **In deze sessie:**

1 Technisch economisch	2 Beleid	3 Markt	4 Internationaal	5 Omgeving
▪ Inzicht in importketens productie-conversie-transport-opslag-reconversie-gebruik	▪ Impact van 'Fit for 55', REDII, Delegated acts, ETS/CBAM, etc.	▪ Marktmodellen: bilaterale contracten, vrije handel, waterstofbeurs	▪ Samenwerking met omringende EU/niet-EU importlanden om corridors te ontwikkelen	▪ Ruimtegebruik van ketenelementen
▪ Vraagontwikkeling, scenario's	▪ Impact van certificering en CO2 allocatie: emissiefactoren, LCA ketenanalyse, etc.	▪ Internationale handelsstromen: verwachte vraag- en aanbodvolumes en transportstromen	▪ Concurrentie met omringende EU/niet-EU importlanden	▪ Veiligheid: brandbaarheid, zorgwekkende stoffen, risicocontouren, etc
▪ Infrastructuur & systeemintegratie: corridors, benutten bestaande infra.	▪ Financiering en stimulering (EU & NL): IPCEI, PCI, TEN-E, JTF, EIB, Horizon Europe, MOOI, DEI, MIEK, SDE++, etc	▪ Importtarieven, trade agreements en handelsbeperkingen, WTO, etc.	▪ Geopolitieke aspecten: strategische voorraden, afhankelijkheid, politieke stabiliteit van exportlanden	▪ Milieu: stikstof, lekkage
▪ Technology assessments, R&D				▪ Maatschappelijke acceptatie
				▪ MVO / samenhang met SDG's in exportlanden

SHIP>NL Sessie IX 15 oktober 2025

Deep Dive: Projects for Low-emission Ammonia Production and Utilization

- Kevin Rouwenhorst | Ammonia Energy Association

TNO innovation for life

AMMONIA ENERGY ASSOCIATION

Projects for Low-emission Ammonia Production and Utilization

SHIPNL: Sustainable Hydrogen Import Program Netherlands

Kevin Rouwenhorst
krouwenhorst@ammoniaenergy.org

October 2025

SHIP>NL Sessie IX 15 oktober 2025

AEA Members: September 2025

* indicates representation on Board of Directors

PLATINUM: Adani New Industries, CF Industries*, Chevron New Energies, Copenhagen Infrastructure Partners, ExxonMobil*, InterContinental Energy, KBR*, LSB Industries*, Mitsui & Co., Monolith Materials*, Yara*. **GOLD:** ACME Group*, AFC Energy, AirGas*, Ambient Fuels*, Baker Hughes, Casale, Chemenergy Services PTE Ltd, China Energy Group, Clean Hydrogen Works, Enaex*, Eolian Energy, Equinor, Fertiglobe, Fortescue*, Hynfra, JERA, Keppel Infrastructure*, LBC Tank Terminals*, Maersk*, Mitsubishi Heavy Industries, Proton Ventures, S&P Global Commodity Insights, thyssenkrupp Uhde*, Topsoe*, Trigon. **SILVER:** AES, Air Products, Ammonigy, Argus Media, ATCO EnPower, bp, Bechtel, Black & Veatch, Bloom Energy, Burckhardt Compression, Bureau Veritas, Burns & McDonnell, Catator, Cavendish Renewable Technology, Ceres Power, Clariant, CMA CGM SA, ControlRooms.ai, Copernic Catalysts, CREADIS, CRU Group, CS Combustion Solutions, CTI Gas Detection Specialists, DNV Energy USA, Duiker Clean Technologies*, Dyno Nobel, EcoEngineers, EIFER (European Institute for Energy Research), Enbridge, Enertrag, Eneus Energy, ENGIE, Fidelis New Energy, First Ammonia, GenCell Energy, Green Energy Park, Green North Energy, Greens Combustion, GTI Energy, H2K B.V., H2Site, Heraeus, HyET NoCarbon USA, Iberdrola*, IHI Americas, Indorama Holdings, ITOCHU Corporation, JGC Corporation, Johnson Matthey, Kiewit Corporation, Linde, Liquium, Lynas Rare Earths, Mabanaft, MAE Energy, Masdar, Mintal Hydrogen, Mitsui OSK Lines, MODEC, Nel Hydrogen, Savage Services, Shell, Stamicarbon, Starbulk Carriers, Stolthaven Terminals, Switch B.V., Synergen Green Energy, Synergy Marine Pte Ltd, Technip Energies, Trammo, Tsubame BHB, UH2, Vesta Terminals B.V., Woodside Energy. **BRONZE:** 8 Rivers, AAR Inc., ABB Inc., ACEN Australia, Advanced Ionics, Advanced Thermal Devices, AHEAD Energy*, Alsys Group, AmHyTech, Ammobia, Amogy, Antea Group, Aragon, Ark Energy, AustriaEnergy, Authentix, Avalon International, Avina Clean Hydrogen, Aza Power Systems, Brittany Ferries, C-Job Naval Architects, C-MACC, Carbon-Neutral Consulting*, CDI Engineering Solutions, Chane, Chemical Market Analytics, Chiyoda Corp., Clearway Energy Group, Copenhagen Atomics*, Danaos Shipping, DENSO Corporation, DUBBL Pty Ltd., Ebara Elliott Energy, Energex Partners, Energy Invest, EnRUD Resources, Envision Group*, Eurenco, European Energy, Evrellence, Farm Synthesis, FarmN Pty Ltd, Firebird Future Solutions, Fourth Tack, Fuel Tech, Furstenberg Maritime Advisory, Future Pipe, GASMAR, GE Vernova, George Moundreas & Company S.A., GoSolar Energy, Green Ammonia Power, H2Carrier, Hayward Tyler, Honeywell, Hunt Guillot & Associates, Ignis Group, INPEX, Interoceanic Corporation, IT Power Australia, Jupiter Ionics, Kearney Korea, Klingspor Energy, MadoquaPower2X, Marubeni America Corporation, Marvel-Tech, MAYEKAWA, Mission Possible Partnership, Morrison Energy, Mysore Ammonia Cold Storage, Nebraska Public Power District, NET Srl, NGLStrategy, Nikki-Universal, Northern Plains Nitrogen, NovoHy, NYK Group Americas, Oceanic Vessels, P3 Energy Solutions, Pacifica Energy, Pacific H2, Pani Clean, PepsiCo, Polyatomic Ventures, Poten & Partners, Power-to-X Analytics, PX Limited, RTI International, RWE Supply & Trading GmbH, Samson Group, SBM Offshore*, Shrieve Chemical, SIAD Macchine Impianti, Company, Siemens Energy, SOFEC, Southern Devall, Stamford Shipping, Stamford Ship Management, Statkraft, Sumitomo Corporation of Americas, SVT Gmbh, Technical University of Denmark, Terrestrial Energy, TGE Gas Engineering, Thermon, TMEIC Corporation Americas, Tolero Renewables, TRIARC Tank, Uniper, Vahterus, Voltalia, Wärtsilä, Wood Mackenzie, Yokogawa Corp of America.

SHIP>NL Sessie IX 15 oktober 2025

Ammonia Energy Association

AMMONIA ENERGY ASSOCIATION

Clean ammonia energizes the future

Who we are

The **Ammonia Energy Association** (AEA) is a global industry association that promotes the responsible use of ammonia in a sustainable energy economy.

Members: 250+ global and cross-sectoral

Our mission

Accelerate the responsible adoption of clean ammonia by promoting cross-sectoral collaboration, knowledge sharing, global standards, and supportive policies.

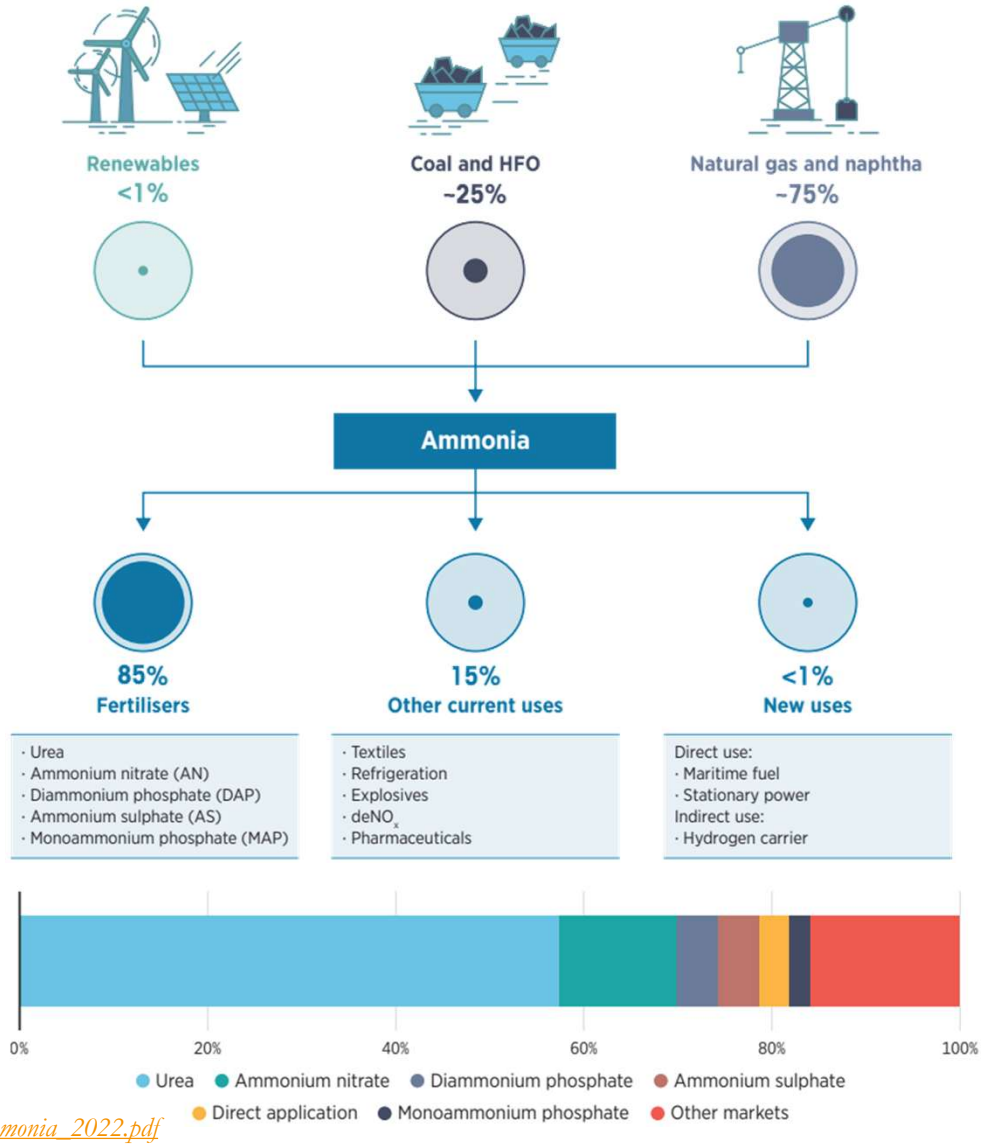
Strategic pillars

Knowledge stewardship,
Program development,
Collaboration,
Advocacy

Ammonia

- Ammonia (NH_3) is produced from hydrogen (H_2) and nitrogen (N_2) via the Haber-Bosch process at 350-550°C and 100-450 bar with an Fe catalyst
- About 200 MT annual production, mostly (90%) directly converted to fertilizers such as urea, ammonium nitrate, etc.
- Currently fossil-based production, responsible for 0.5 Gt-CO_2 per annum, or 1% of $CO_{2,eq}$ emissions
- About 17-20 MT (10%) of ammonia is shipped annually.

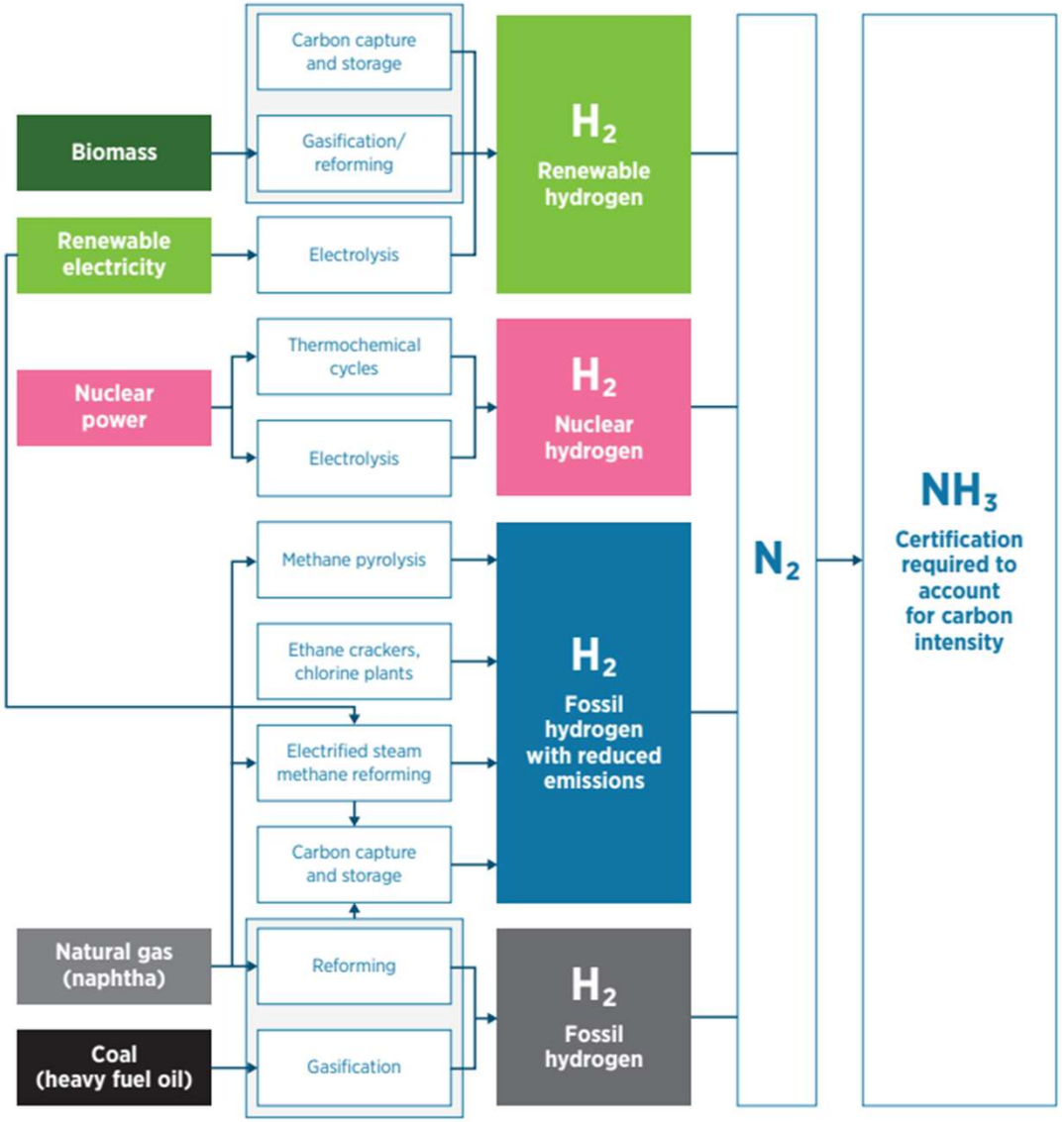
$$3H_2+1N_2 \rightarrow 2NH_3$$



https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf

Ammonia

- Ammonia decarbonization is all about decarbonizing the hydrogen feedstock
- About **90% of the energy input** is required for H_2 production, so determines CO_2 footprint!
- Colours of ammonia ≠ carbon footprint, as depends on Scope 1-3 emissions
- Certification is required to account for the carbon intensity



https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/May/IRENA_Innovation_Outlook_Ammonia_2022.pdf

Certification frameworks for low-emission ammonia trade

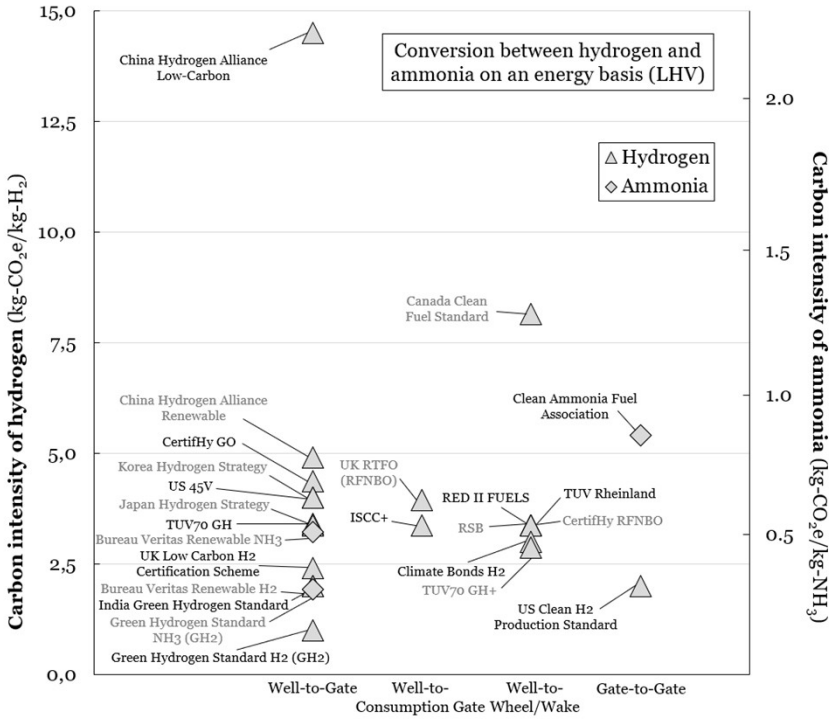
The different markets for low-emission ammonia will have different requirements for greenhouse gas (GHG) emission calculations, among other sustainability criteria & RFNBO-compliance in the EU.

As of August 2025, the AEA tracks and deconstructs 17 compliance frameworks, 18 voluntary frameworks, and 5 methodologies:

- These frameworks have varying carbon intensity thresholds, system boundaries, and cut-off criteria.
- Over the past years, the AEA has also developed its Ammonia Certification System, whose goal is to allow ammonia consumers to be reliably informed about the environmental attributes, namely carbon footprint and origin, of the ammonia supplied, as well as to make it easier for ammonia suppliers to demonstrate compliance with the requirements of various market and policy frameworks.

Carbon intensity thresholds of hydrogen & ammonia certification schemes, regulations & standards

2025 Q3



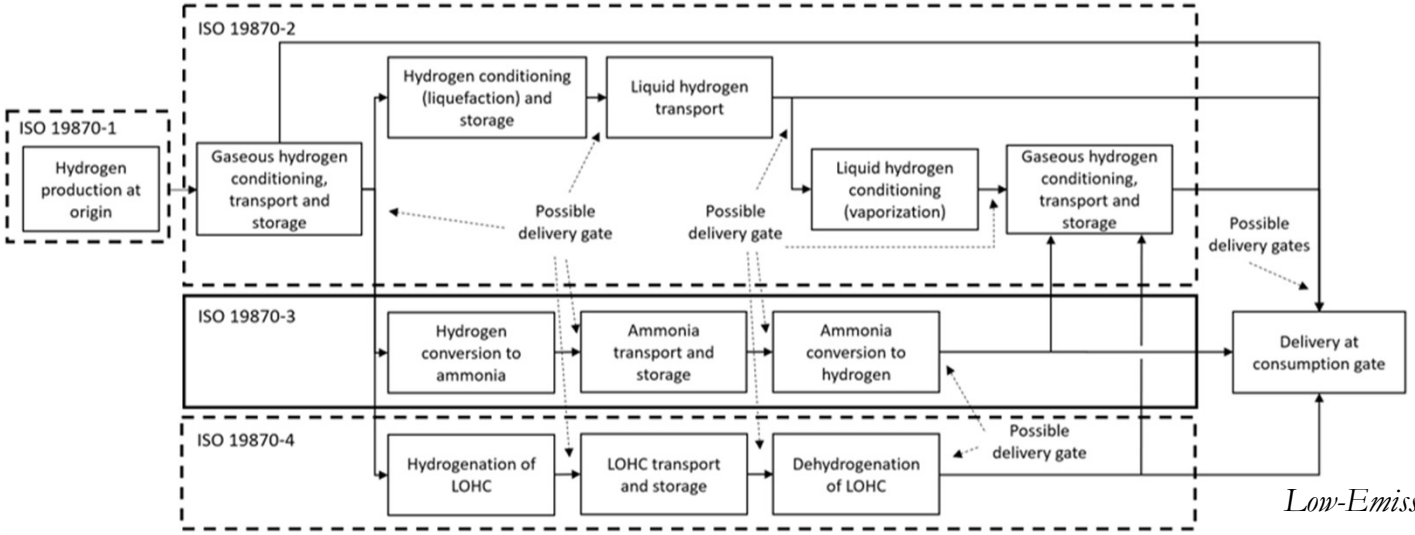
Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Certification frameworks for low-emission ammonia trade

AMMONIA ENERGY ASSOCIATION

ISO is developing a suite of standards related the carbon footprint of hydrogen production (ISO 19870-1), hydrogen liquefaction and hydrogen transport (ISO 19870-2), ammonia production, storage, and cracking (ISO 19870-3), and LOHC-based hydrogen carriers (ISO 19870-4)

- In early 2025, the AEA initiated the drafting of the ISO 19870-3 code for determining the carbon footprint of ammonia production, ammonia storage, ammonia transport, and ammonia cracking. The ISO 19870-3 code is set to become a Draft International Standard (DIS) prior to COP30, with publication in early 2026.



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Project intelligence database

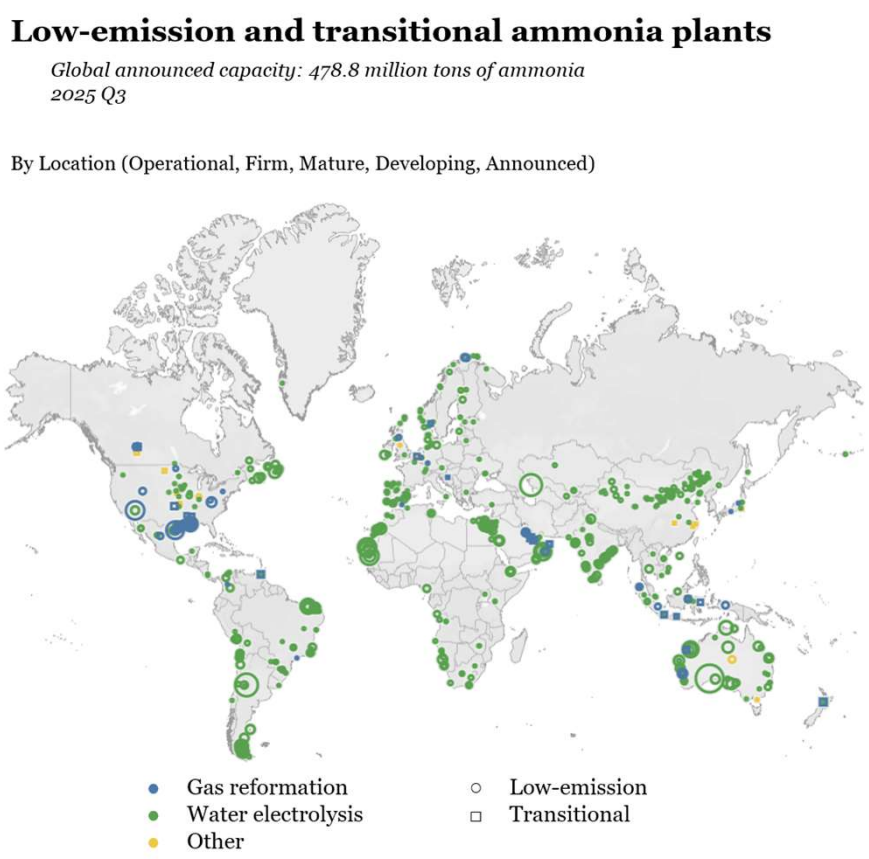
The AEA's project intelligence database has been available to members of the AEA since April 2022, and contains details on all the Low-emission (and Transitional) ammonia production plants that have been announced.

The database has grown quickly:

- December 2022: 103 projects
- August 2025: 562 projects (688 phases of expansion), for a total of 478.8 million tons

Projects are categorized according to technology pathway:

- **Gas reforming** (CCS, CCU, EOR, biogas)
- **Water electrolysis** (renewable, grid, nuclear), and
- **Other** (pyrolysis, gasification, electrochemical, byproduct hydrogen, etc).



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Low-emission ammonia projects

AMMONIA ENERGY ASSOCIATION

As of August 2025, 478.8 million tons (MT) of Low-emission and Transitional ammonia have been announced.

By 2030, 46.8 MT could become operational

- 6.5 MT is already Operational (up to Q3 2025)
- 10.8 MT is Firm (eg, under construction / FID)
- 29.6 MT is Mature (eg, offtake / EPC selected / FEED)

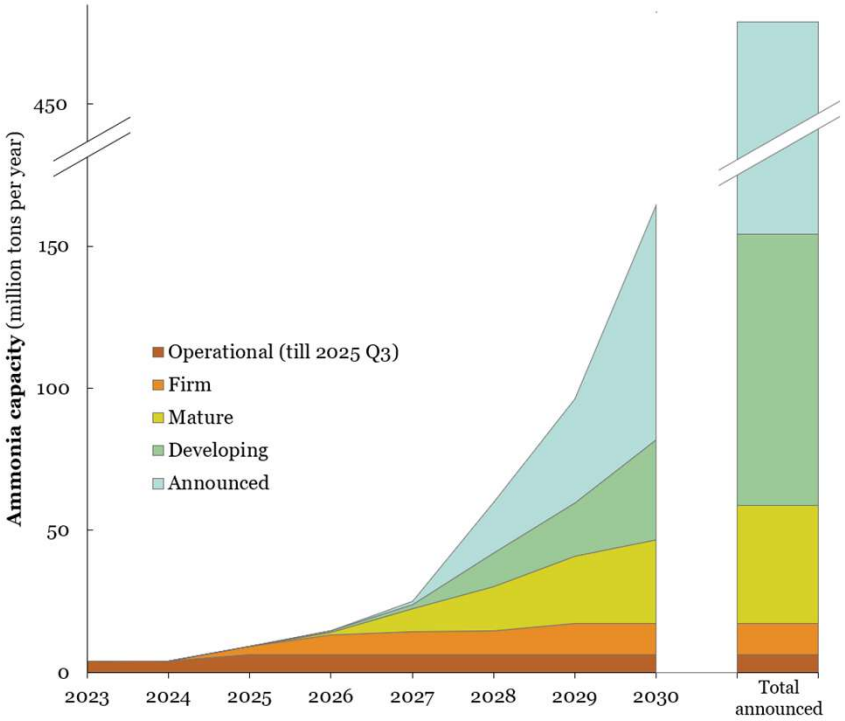
In total, 324.5 MT is classified as Announced with few public details. Another 95.6 MT is Developing (eg, making clear progress to FID), of which 34.9 MT targets to start this decade.

Key conclusions:

- Within the large funnel of projects, a significant number of projects are maturing to meet increasingly clear demand signals.
- Concrete demand, regulatory certainty and successful permitting will be required to move more of these projects towards FID.

Low-emission and transitional ammonia plants

Global announced capacity: 478.8 million tons of ammonia
2025 Q3



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Project updates this quarter

AMMONIA ENERGY ASSOCIATION

Significant Low-emission ammonia capacity moving toward realization. 0.5 million tons (MT) of renewable ammonia capacity came online in China and Uzbekistan in the last quarter.

- Envision Energy started its 0.3 MT renewable ammonia plant in Chifeng, Inner Mongolia, based on off-grid renewables (primarily wind) to feed around **530 MW** electrolysis capacity. Marubeni secured offtake from Envision's Chifeng project. The project secured ISCC PLUS certification, as audited by Bureau Veritas.
- Jilin Electric Power commissioned its Da'an Project in Jilin, China in late July 2025, with a capacity of 0.18 MT renewable ammonia basedon around **320 MW** electrolysis capacity.
- The **20 MW** Chirchiq project in Uzbekistan started producing renewable hydrogen from wind, for 0.02 MT renewable ammonia production. The project was developed by ACWA Power, the EPC managed by PowerChina with LONGi electrolyzers, and the hydrogen used in an existing ammonia plant operated by Uzkimyosanoat for fertilizers.

Top: Envision Energy, Chifeng, Inner Mongolia.
Bottom ACWA Power, Chirchiq, Uzbekistan.

Availability this decade

Looking only at Operational, Firm, and Mature projects, 46.8 million tons (MT) of Low-emission and Transitional ammonia capacity could be Operational in 2030.

- 5.8 MT of Transitional capacity is already operational. This could increase to 12.6 MT of Transitional capacity in 2030.
- 0.7 MT of Low-emission capacity is already operational. This could increase to 34.3 MT of Low-emission capacity in 2030.
- About half of Low-emission and Transitional capacity this decade comes from Gas reformation projects, totalling 24.9 MT in 2030.
- Water electrolysis projects begin operating at scale in 2025-2026, and reach 19.0 MT capacity in 2030.

Key conclusions:

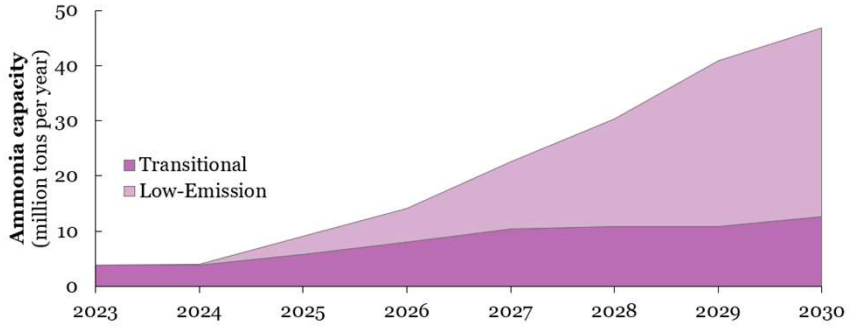
- Transitional ammonia plants serve existing markets (fertilizers, chemicals, explosives), but are not expanding long-term.
- Gas reformation projects are developing at large-scale, especially at existing sites, while some Water electrolysis projects are scaling toward the size of Gas reformation projects in the late 2020s.

AMMONIA ENERGY ASSOCIATION

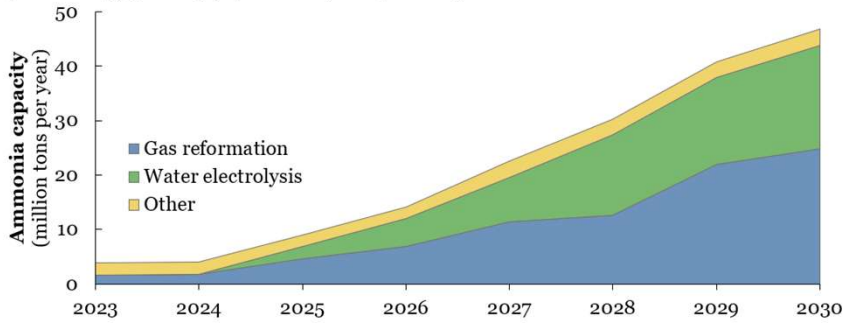
Low-emission and transitional ammonia plants

46.8 million tons of ammonia by 2030 (Operational, Firm, Mature)
2025 Q3

By Category (Operational, Firm, Mature)



By Technology pathway (Operational, Firm, Mature)



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Plants by Project Type

Nearly 80% of the Operational, Firm, and Mature projects is Newbuild capacity by 2030 (37.0 MT), with only 20% representing revamps (9.9 MT). This aligns with the continued growth of ammonia production, combined with a shift of ammonia production to locations with abundant natural gas and to locations with the best renewable potential.

Newbuild projects:

- Gas reformation via autothermal reforming with full CCS, focused on long-term low-emission ammonia markets.
- Water electrolysis projects ranging from small-scale to world-scale.

Revamp projects:

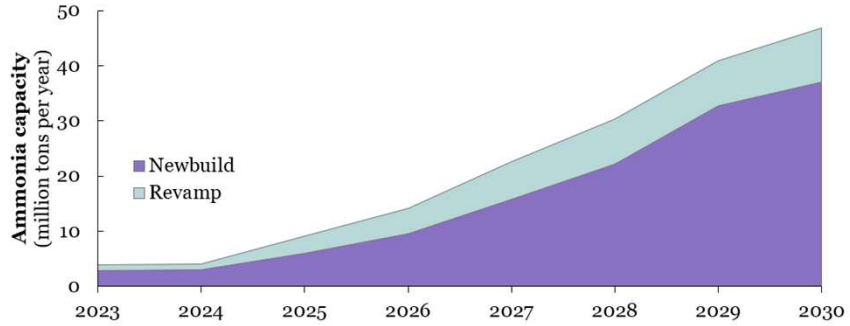
- Gas reformation revamp projects typically have partial CCS (1) to comply with near-term markets in East Asia and Europe, and (2) to benefit from tax credits at production locations.
- Water electrolysis projects have 20-240 MW capacity to decarbonize 5-20% of the hydrogen supply. The exception is India, with various full revamp projects with grid connection.

AMMONIA ENERGY ASSOCIATION

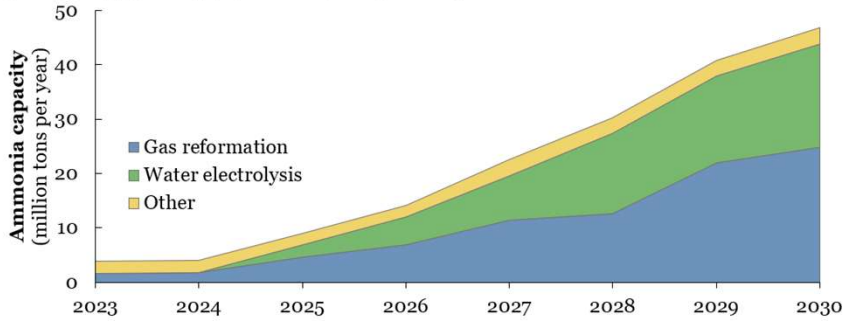
Low-emission and transitional ammonia plants

46.8 million tons of ammonia by 2030 (Operational, Firm, Mature)
2025 Q3

By Project Type (Newbuild, Revamp)



By Technology pathway (Operational, Firm, Mature)



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Plants by Region: North America

AMMONIA ENERGY ASSOCIATION

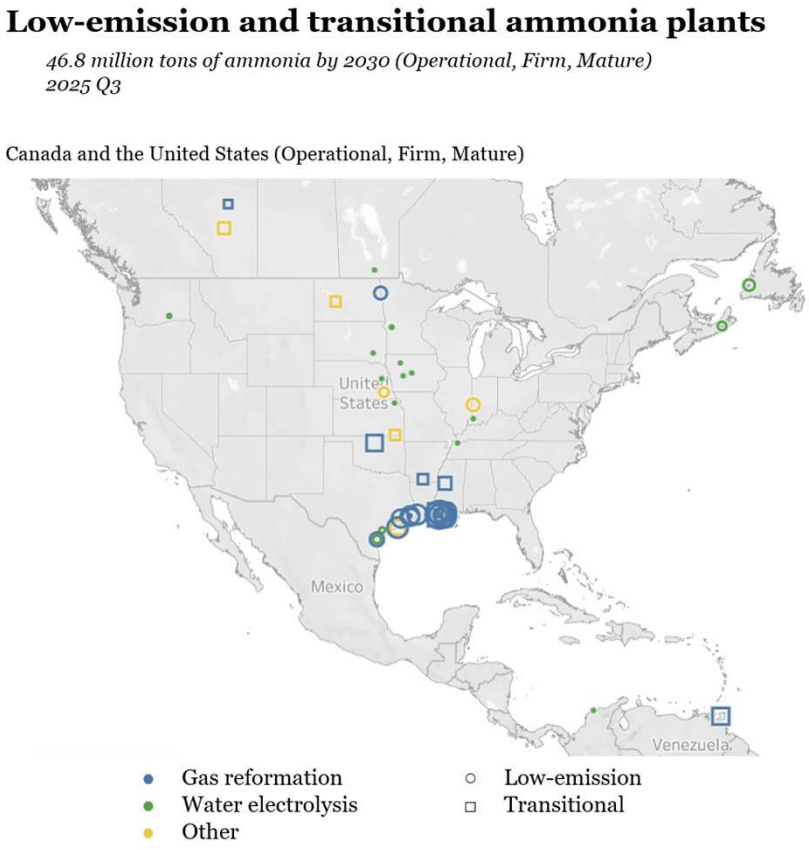
Newbuild Gas reformation projects are typically located in regions with abundant natural gas, such as the US Gulf Coast, the Middle East, and Indonesia.

Projects in the US Gulf Coast mostly focus on Gas reformation with CCS:

- Sometimes at existing ammonia plants serving existing markets, with some first-mover offtakes into energy markets.
- East Asia and Europe are set to become a key offtake market for newbuild Low-emission ammonia capacity.
- 45Q in the United States provides a tax credit for 12 years of around 85 USD per tonne CO_2 stored, which is relevant for newbuild and revamp projects. 45V may also be relevant, but project updates in the last quarter do not yet reflect the impact of 45V.

Projects in Eastern Canada focus on Water electrolysis, coupled to wind electricity:

- Initial offtake is focused on Europe, with RFNBO-compliant ammonia production.
- The ammonia plants may also provide grid services in Eastern Canada.



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Plants by Region: Asia

AMMONIA ENERGY ASSOCIATION

Newbuild Water electrolysis projects have various narratives:

- Optimal regions for solar and wind such as Australia, Chile, China, Eastern Canada, Egypt, India, Morocco, Namibia, Saudi Arabia, etc.
- A highly renewable grid with substantial hydropower in Brazil and Norway, and in parts of India.
- Replacing coal-based production in China.

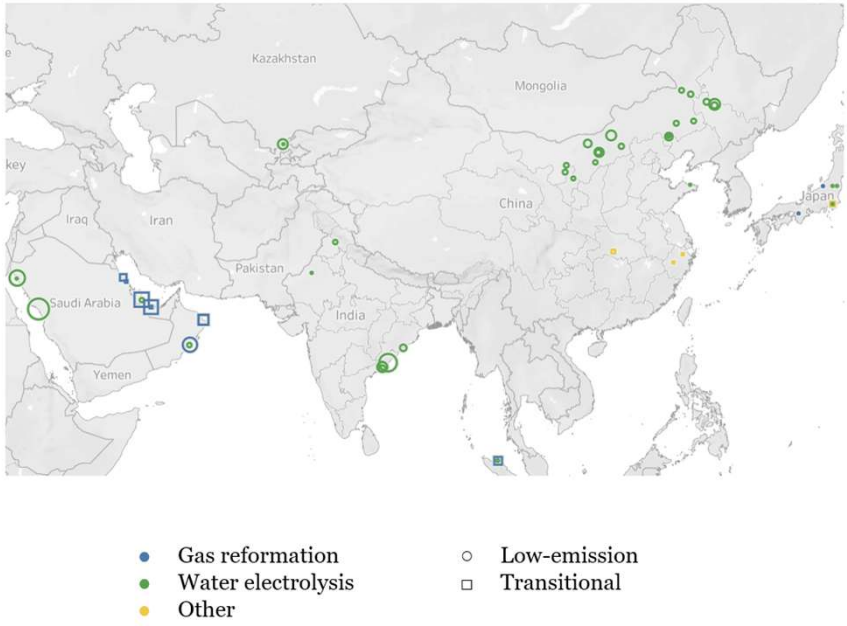
Various Water electrolysis projects are maturing globally, with an emphasis on China, India, and the Middle East:

- In China, 0.2-0.3 MT plants are already operational, with other similar-sized plants expected to become operational in the coming months.
- In China, India and the Middle East, initial offtake of RFNBO-compliant ammonia may be focused on Europe.
- Trading companies are increasingly engaging in offtake with focus on supplying East Asia and maritime markets.
- The cost gap between Coal gasification and Water electrolysis is closing in China, implying local offtake may also become significant.
- Noting that India is a net ammonia importer, ammonia produced via Water electrolysis can displace imports to serve local markets.

Low-emission and transitional ammonia plants

46.8 million tons of ammonia by 2030 (Operational, Firm, Mature)
2025 Q3

China, India and the Middle East (Operational, Firm, Mature)



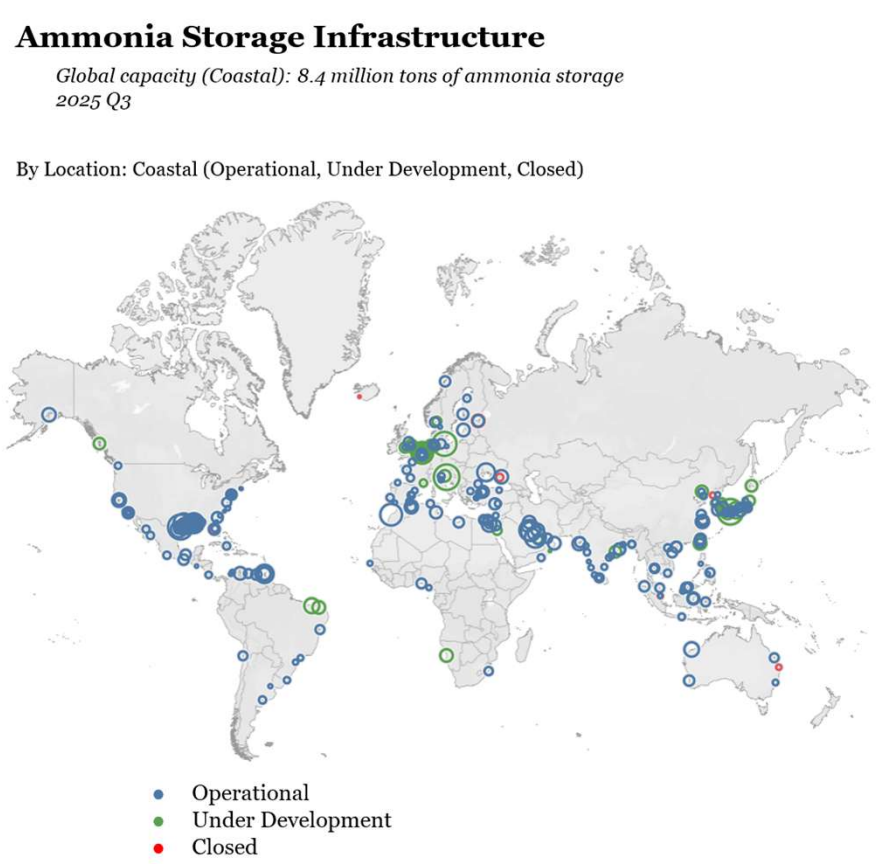
Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Global Ammonia Terminal Capacity will expand

The AEA tracks 925 ammonia terminals, of which 331 are in industrial ports. Assuming 25 turnovers per year, and a similar distribution of importing and exporting terminals in industrial ports, around 105 MT can be transported annually. This exceeds the 17-20 MT of ocean-going transport each year, allowing for ammonia trade to expand.

The United States has many inland ammonia terminals and the largest existing capacity (6.5 MT of existing capacity, including 2.9 MT in coastal ports, and 3.7 MT inland), due to the direct use of ammonia as fertilizer in the US Midwest. This also implies significant inland ammonia transport and storage.

Around the rest of the world, ammonia storage terminals are mostly located in industrial ports, for ammonia import and for ammonia export. New export locations with multiple low-emission ammonia projects also announce centralized storage facilities, such as in Brazil and Namibia.



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

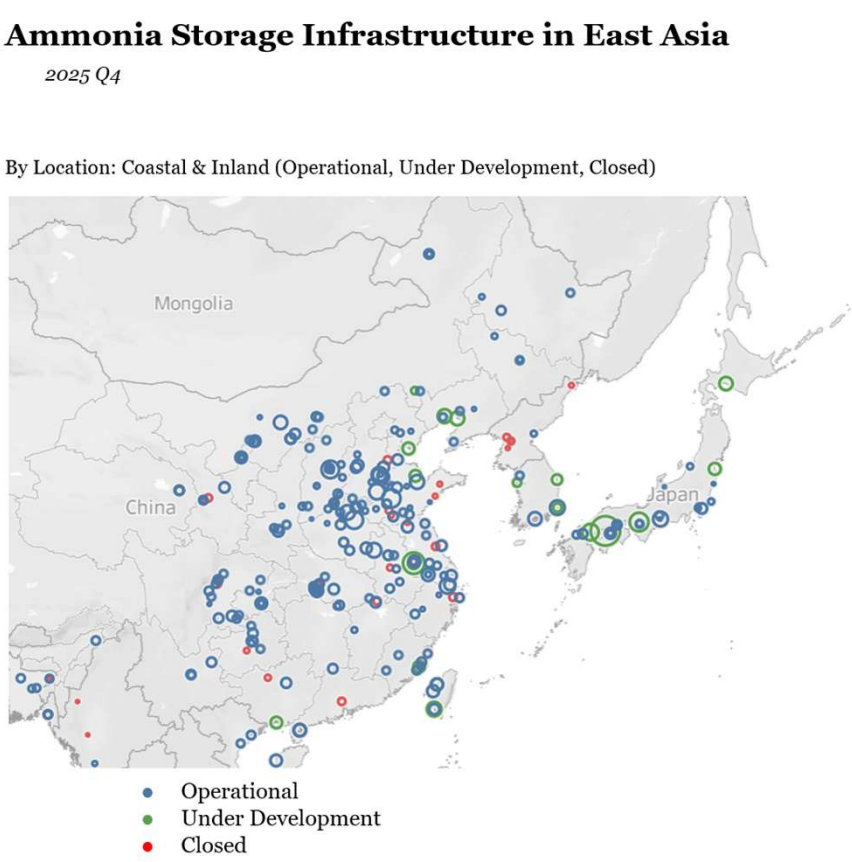
Global Ammonia Terminal Capacity will expand in East Asia

AMMONIA ENERGY ASSOCIATION

In East Asia, Japan and South Korea aim to import significant volumes of ammonia for energy applications, next to existing uses of ammonia in the chemical industry. Thus, ammonia storage facilities are Operational or Under Development in all industrial clusters.

Japan aims to increase ammonia imports from around 0.2-0.3 million tons (MT) in the early 2020s, to 3 MT in 2030, and to 30 MT in 2050.

Assuming 25 turnovers per year, Japan's Operational ammonia storage capacity can process 7.1 MT. If the capacity Under Development is also included, about 20.1 MT of ammonia can be processed annually, indicating Japan is on track for its required ammonia import infrastructure.



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

SHIP>NL Sessie IX 15 oktober 2025

Global Ammonia Terminal Capacity will expand in West Europe

AMMONIA ENERGY ASSOCIATION

In West Europe, Belgium, Germany, the Netherlands, and the United Kingdom aim to import ammonia for energy applications. Also, the phase out of free allowances for CO_2 emissions in the European industry by 2034 will also result in the import of low-emission ammonia to Europe for existing markets.

Rotterdam (The Netherlands) is the largest port in Europe with 13% of all energy utilized in Europe passing through the Port of Rotterdam. Rotterdam is also a major bunkering hub for vessels.

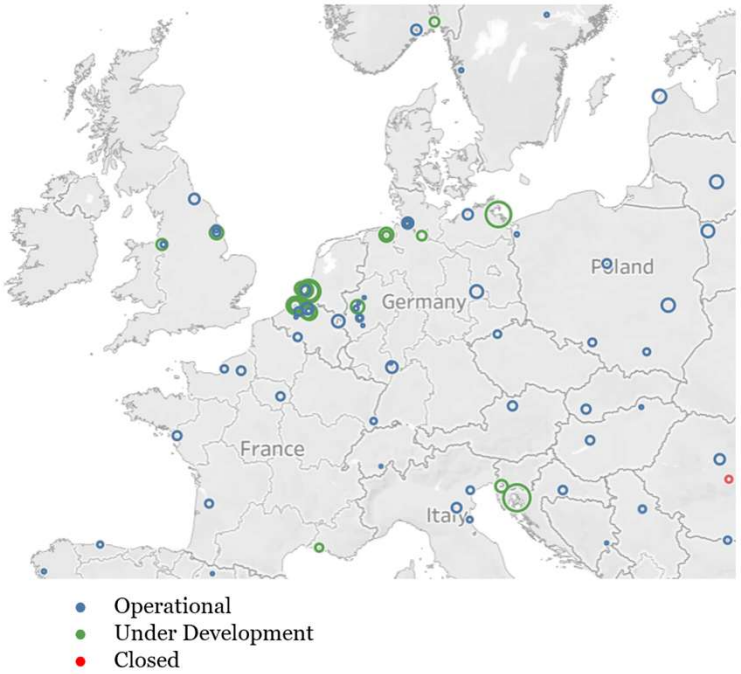
New import capacity for hydrogen and derivatives has been announced. Assuming 25 turnovers per year, 18.1 million tons (MT) of ammonia throughput capacity is Under Development in the Port of Rotterdam. To account for increased ammonia volumes, the PGS-12 design code for ammonia storage and handling has been updated recently.

***Webinar**: Updated PGS-12 code: Preparing for increased ammonia imports to the Netherlands*
https://ammoniaenergy.org/webinars/updated-pgs-12-code-preparing-for-increased-ammonia-imports-to-the-netherlands/

Ammonia Storage Infrastructure in West Europe

2025 Q4

By Location: Coastal & Inland (Operational, Under Development, Closed)

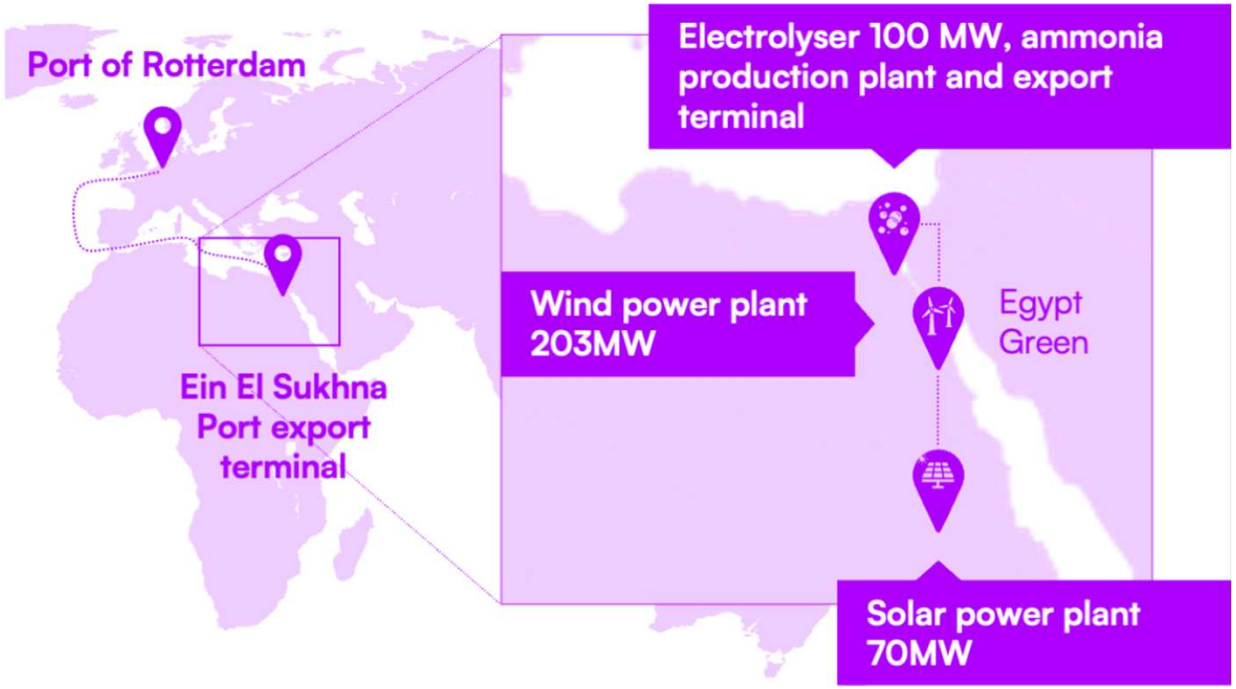


Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Rotterdam: Increasing Ammonia Imports

Rotterdam (The Netherlands) is the largest port in Europe with 13% of all energy utilized in Europe passing through the Port of Rotterdam. Rotterdam is also a major bunkering hub for vessels.

Rotterdam has an existing ammonia terminal (around 30 kT capacity). The terminal is set to receive 397 kT of RFNBO-compliant ammonia from Ain Sokhna (Egypt) between 2027 and 2033, as part of the H2Global pilot auction.



H2Global pilot auction results in RFNBO-compliant ammonia transport from Ain Sokhna (Egypt) to Rotterdam (The Netherlands).
https://ammoniaenergy.org/articles/fertiglobe-success-in-h2global-pilot-auction-marks-milestone-in-renewable-ammonia-supply-for-eu/

Rotterdam: Increasing Ammonia Imports

Rotterdam (The Netherlands) is the largest port in Europe with 13% of all energy utilized in Europe passing through the Port of Rotterdam. Rotterdam is also a major bunkering hub for vessels.

New import capacity for hydrogen and derivatives has been announced. Out of the 13 hydrogen import projects in the Port of Rotterdam, 6 projects aim to develop additional ammonia terminals, of which some multi-phase projects with multiple ammonia storage tanks.

To account for increased ammonia volumes, the PGS-12 design code for ammonia storage and handling has been updated recently (via the *Polder model*; industry, permitting authorities, government).

Announced import capacity for hydrogen and derivatives in the Port of Rotterdam (The Netherlands), 6 out of 13 projects are ammonia terminals.
https://ammoniaenergy.org/articles/updated-pgs-12-code-preparing-for-increased-ammonia-imports-to-the-netherlands/

SHIP>NL Sessie IX 15 oktober 2025

Ammonia Transportation is set to Scale-up

AMMONIA ENERGY ASSOCIATION

Ammonia transportation is set to scale-up, because (1) existing ammonia supply is decarbonized and (2) ammonia is adopted as zero-carbon fuel and hydrogen carrier. Both imply the scale-up of ammonia exports and imports. This builds on a significant existing international infrastructure.

In 2024, around 45 million tons (MT) of ammonia (22% of production) was transported via various modalities, domestically and internationally. Most of the ammonia (17-20 MT) is transported internationally via gas carriers. Inland transport occurs via barges on rivers, via pipelines, via rail tank cars (RTCs) on rail, and via trucks on highways:

- Large volume, inland ammonia transportation can be performed by liquid pipelines. Long-distance ammonia pipelines exist in the US-Midwest (1.5 MT of ammonia), Mexico, and Italy.
- A typical train with 20 rail tank cars transports 1,000 tons of ammonia. In Europe, around 1.5 MT of ammonia is transported by rail.
- Ammonia transport via trucks is used for short distances (below 150 kilometers), carrying around 15 to 18 tons of ammonia. Last mile delivery occurs via nurse tanks with a capacity of 2-4 tons of ammonia, with 800 filling stations in Iowa.

Ammonia Transportation

By modality
2025 Q4

Modality	Distance	Ammonia capacity	Transport cost
Vessel *Ocean*	○●●	○●●	$
Barge *River*	●●○	○●○	$$
Pipeline *Land*	●●●	○●●	$$
Rail tank cars *Rail (Land)*	●●○	●●○	$$$
Truck *Road (Land)*	●○○	●○○	$$$$

Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

SHIP>NL Sessie IX 15 oktober 2025

Maritime Ammonia Trade is ready to Scale-up

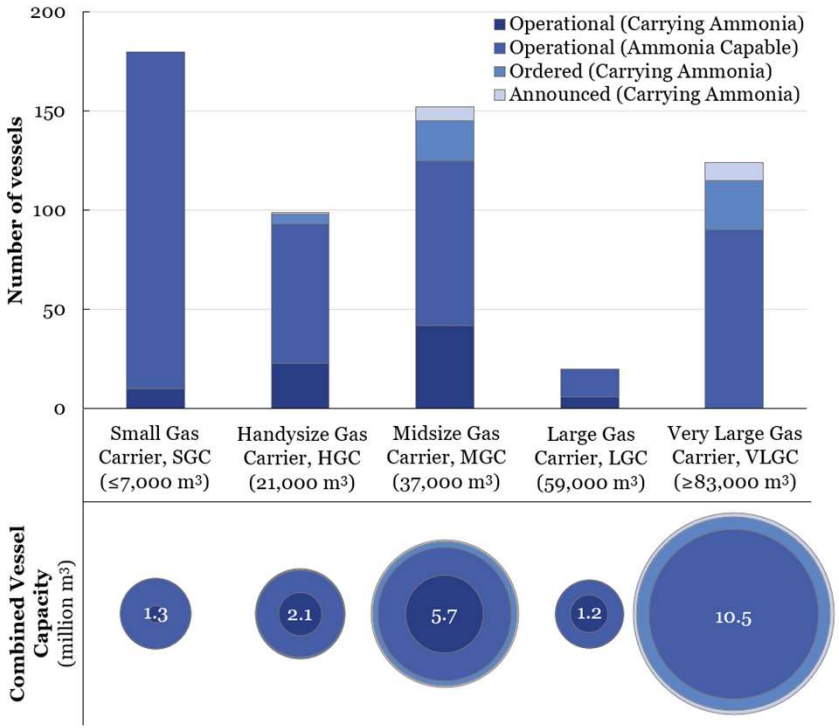
AMMONIA ENERGY ASSOCIATION

The existing fleet of ammonia carriers is capable of expanding in the near term. Around 17-20 million tons of ammonia is transported by vessels every year. The existing ammonia fleet consists of around 81 vessels, with most vessels in the MGC class (Midsize Gas Carrier, around 37,000 m^3 or 25.2 kT). However, around 508 ocean going vessels are capable of carrying ammonia, although most of these vessels carry LPG. Therefore, ammonia trade can expand significantly with existing vessels in the near term.

The ordered and announced ammonia carriers are Midsize Carriers and Very Large Gas Carriers. Around 63 new vessels have been announced (41 have been ordered). This is in anticipation of the increased ammonia trade for energy applications, and for current uses in energy import locations. Most of the orderbook for ammonia carriers consists of VLGCs (Very Large Gas Carriers, ≥83,000 m^3 or ≥56.6 kT), allowing ammonia trade to scale up for energy applications. Existing VLGCs for LPG trade can also be used for ammonia trade.

Existing and future fleet of ammonia carriers & ammonia capable vessels

Operational Vessel Data (April 2025): Affinity Research & Argus Media 2025 Q4



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Ammonia Cracking is Developing with Pilots Under Construction

AMMONIA ENERGY ASSOCIATION

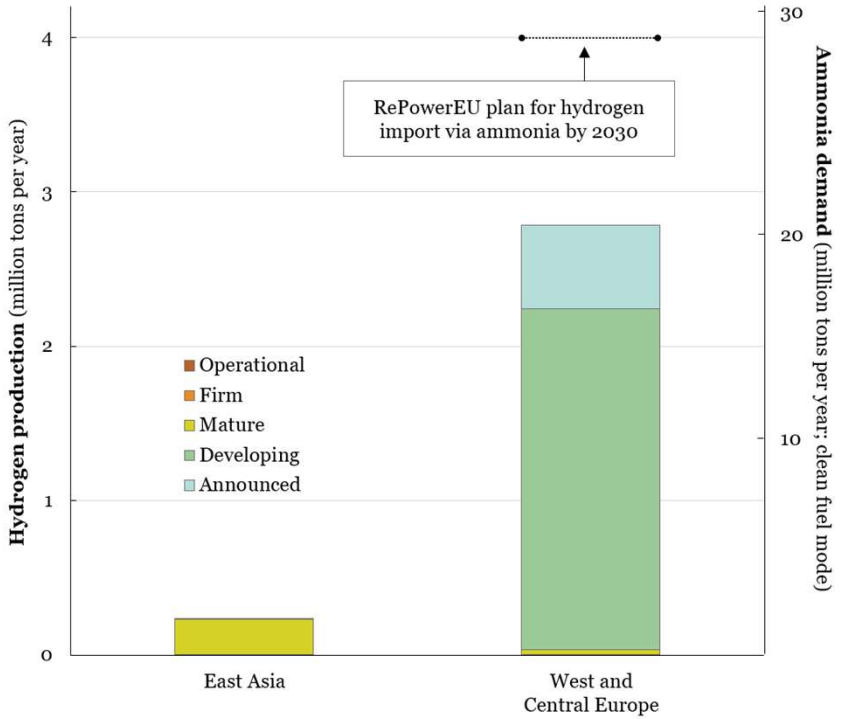
As of October 2025, at least 28 industrial-scale ammonia cracking projects are under development with 3.0 million tons (MT) of hydrogen capacity.

- Depending on the technology choice, this is equivalent to between 17.7 MT and 21.9 MT of ammonia feedstock.
- While most projects are in early stages of development, several pilot-scale crackers are under construction in locations that import energy. The three Firm and Mature projects in East Asia (0.23 MT of hydrogen / 1.1-1.3 MT of ammonia) are focused on power generation and industrial hydrogen supply. The six Operational, Firm and Mature projects in West and Central Europe (0.03 MT of hydrogen / 0.2 MT of ammonia) are focused on industrial hydrogen supply.

In 2022, the RePowerEU plan indicated 4.0 MT of hydrogen would be imported via ammonia by 2030. The ammonia cracking projects announced so far could supply nearly three quarters of this target. In addition, however, imports of ammonia for direct use (not cracking) may also be counted within the EU's target.

Ammonia cracking for hydrogen production

Global announced demand: 17.7-21.9 million tons of ammonia
2025 Q4



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Ammonia to Power is Demonstrated as Projects and Policies develop

AMMONIA ENERGY ASSOCIATION

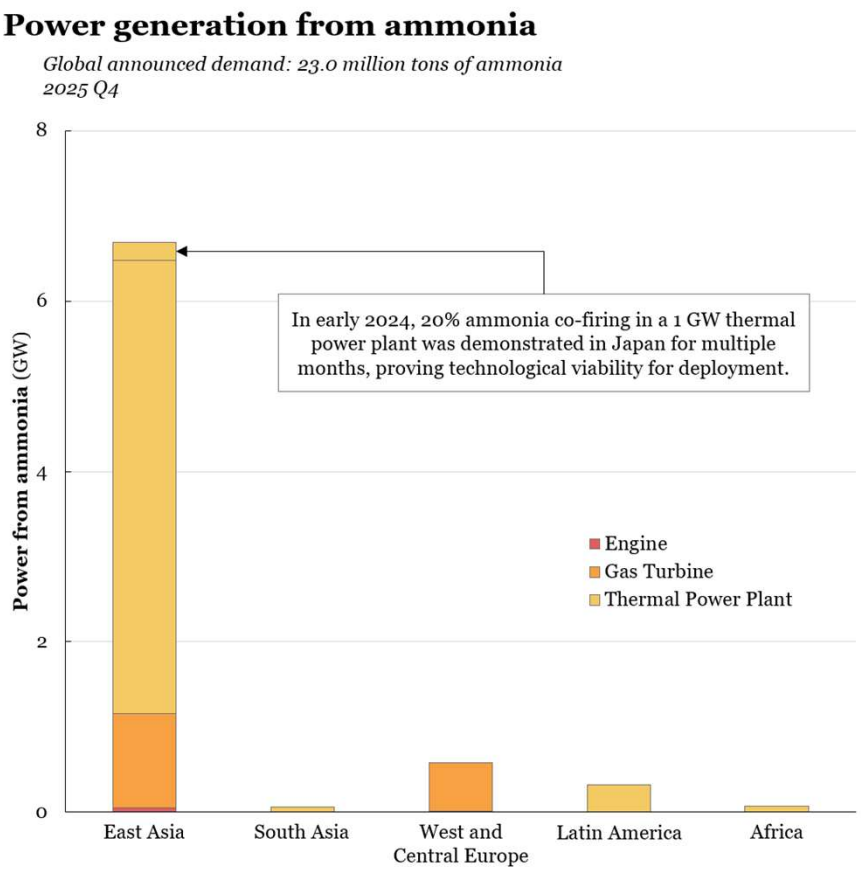
As of October 2025, at least 55 Ammonia to Power projects are under development, mostly based on ammonia co-firing in thermal power plants (35 projects) and ammonia-fueled gas turbines (14 projects). These projects have a combined power output of 7.7 GW from ammonia, and could represent up to 23.0 million tons (MT) of ammonia demand.

Most **projects** (49) are located in East Asia, with a significant focus on ammonia co-firing in thermal power plants (31 projects).

- In early 2024, 20% ammonia co-firing in a 1 GW thermal power plant was demonstrated in Japan, with full-scale implementation toward the late 2020s.
- The first commercial demonstration of an ammonia-fueled gas turbine will be a 60 MW pilot project in Jurong Port (Singapore).

Significant **policies** are also visible in East Asia.

- Japan aims to complete its Contract for Difference scheme in 2025.
- South Korea concluded its first ammonia for power auction in December 2024, with the second round in 2025.



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Ammonia to Heat is Demonstrated as Policies and Projects develop

AMMONIA ENERGY ASSOCIATION

Ammonia is a zero-carbon fuel and a scalable solution for high temperature heat. Electrification is another option to decarbonize heating, but will be limited by electricity transmission infrastructure and the availability of low-cost renewable electrons.

- For example, renewable electrons are not available below 0.10-0.15 USD/kWh in Japan, making a zero-carbon fuel like ammonia competitive for heating.

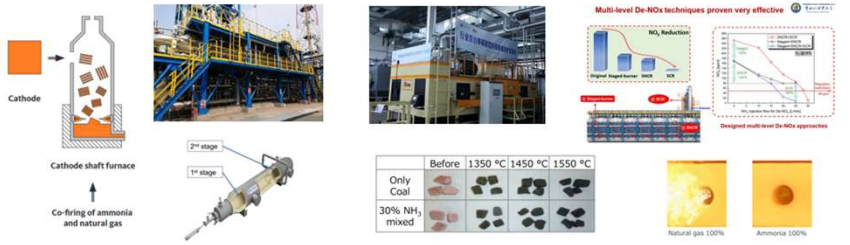
Ongoing commercial-scale Ammonia to Heat applications:

- In China, pilot-scale **ceramics fabrication** with ammonia was achieved in 2021, with ongoing commercial-scale ceramics fabrication since September 2024. **Aluminum rod heating** was also achieved in September 2025.
- In Japan, commercial-scale testing has commenced for ammonia co-firing in **cement manufacturing** in 2024, targeting 30% ammonia co-firing during operation.

Ammonia to Heat Applications

By status
2025 Q4

Application	Status
Hydrotreating	○○● Commercial operations, usually mixed with hydrogen sulfide
Glass manufacturing	○●○ Demonstrated mono-firing ammonia burners, in larger gas-fired furnace
Ceramics manufacturing	○○● Commercial operations with mono-firing ammonia burners
Copper refining	○●○ Demonstrated 20% ammonia co-firing in gas-fired furnace
Cement production	○●○ Demonstrated 30% ammonia co-firing in coal-fired furnace, commercial operations expected later in 2025
Aluminum heating	○●● Demonstrated mono-firing ammonia burners, in commercial-scale furnace



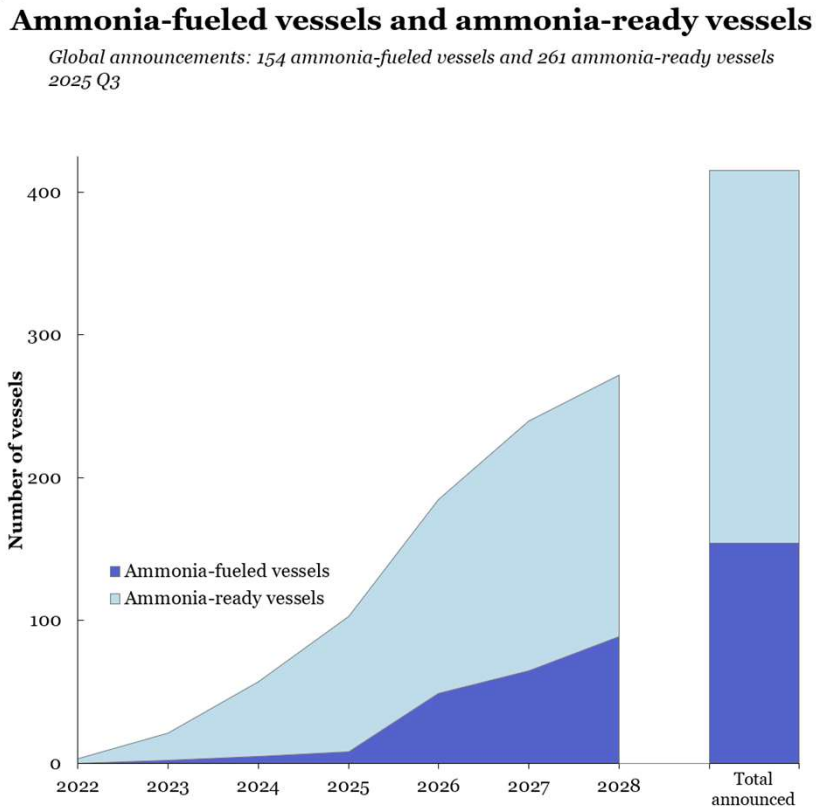
Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Significant Orderbook for Ammonia-fueled & Ammonia-ready Vessels

AMMONIA ENERGY ASSOCIATION

As of September 2025, the AEA tracks 415 vessels. Of these, 154 are Ammonia-fueled vessels and 261 are Ammonia-ready vessels.

- Out of these, 5 vessels are currently operational using ammonia, which are Supply vessels & Tug boats, entering the waters in 2023 and 2024.
- The first Ammonia-ready vessel entered the waters in early 2022. 77 Ammonia-ready Vessels are operational, including Ammonia carriers, Bulk carriers, Auto carriers, Container vessels, Oil carriers, and Supply vessels.



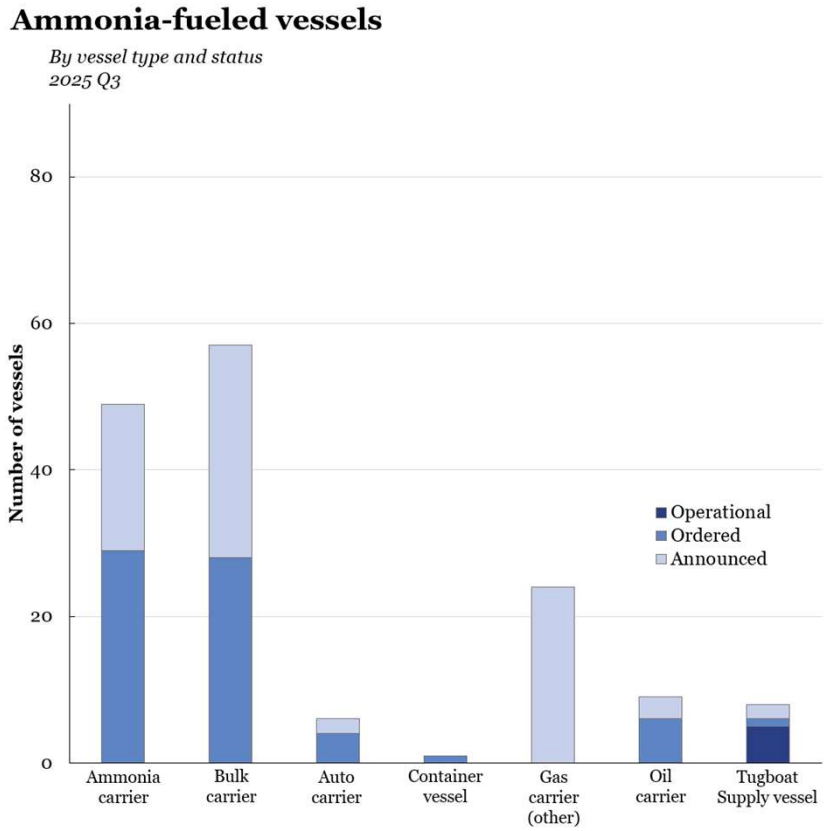
Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Ammonia-fueled Vessels: Ammonia carriers & Bulk carriers

AMMONIA ENERGY ASSOCIATION

As of September 2025, the AEA tracks 154 Ammonia-fueled Vessels.

- Out of these, 5 vessels are currently operational using ammonia, which are Supply vessels & Tug boats, entering the waters in 2023 and 2024.
- Out of the 69 ordered Ammonia-fueled vessels, almost all vessels are Ammonia carriers (29) and Bulk carriers (28). These vessels are expected to hit the waters in 2026 and 2027, and these vessels will start using ammonia as a fuel.
- Although Auto Carriers, Container vessels, and Oil carriers represent a small portion of the Ammonia-fueled vessels to date, these Vessel classes are well represented in the Ammonia-ready vessels.



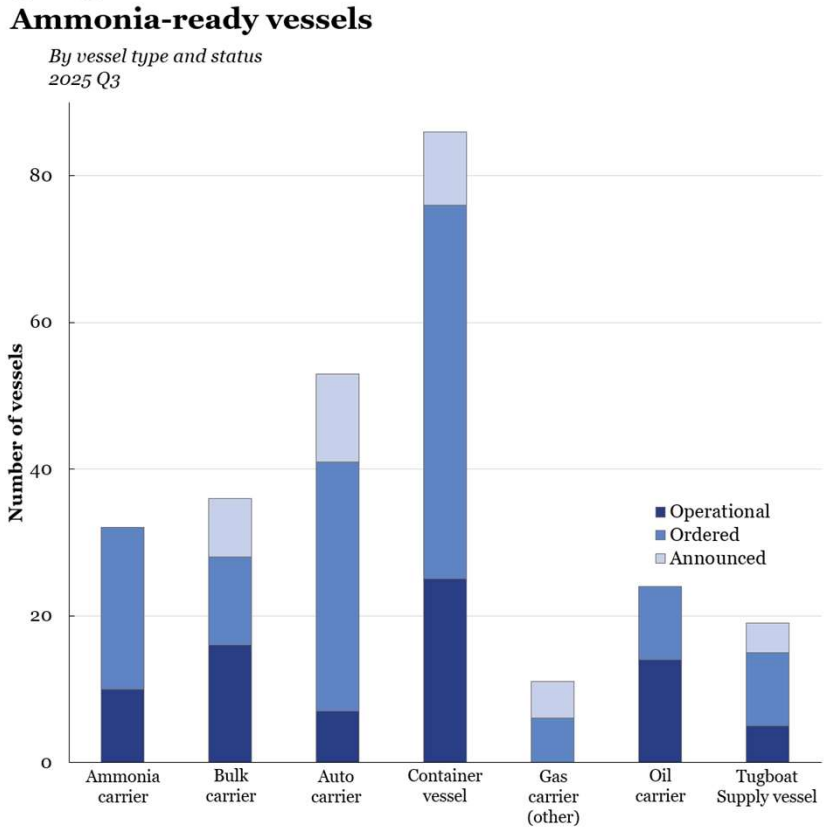
Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

Ammonia-ready Vessels: Ammonia carriers, Auto Carriers & Containers

AMMONIA ENERGY ASSOCIATION

As of September 2025, the AEA tracks 261 Ammonia-ready Vessels.

- The first Ammonia-ready vessel entered the waters in early 2022. As of September 2025, 77 Ammonia-ready vessels are operational, including Ammonia carriers (10), Bulk carriers (16), Auto carriers (7), Container vessels (25), Oil carriers (14), & Supply vessels / Tug boats (5).
- Out of the 145 Ordered Ammonia-ready vessels, most are Ammonia carriers (22), Auto carriers (34), and Container vessels (52).
- Ammonia-ready vessels typically have provisions for ammonia fuel supply systems, ammonia release mitigation systems, and Tank C tanks for ammonia fuel storage. Also, retrofit packages exist for Engines to use ammonia as fuel.



Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

SHIP>NL Sessie IX 15 oktober 2025

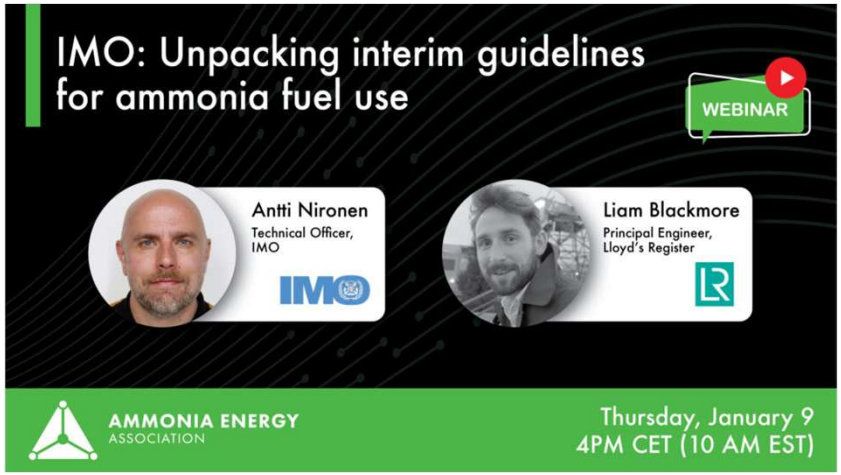
IMO Guidelines for Ammonia-fueled Vessels are in Place

In September 2024, the IMO (International Maritime Organization) Sub-Committee on Carriage of Cargoes and Containers (CCC) finalized interim guidelines for the use of ammonia as a fuel for vessels, ensuring safe handling of ammonia.

Following the 109th meeting of the IMO's Maritime Safety Committee (MSC) in early December 2024, these interim guidelines for the use of ammonia fuel onboard vessels have been approved. Cargo ships weighing 500 gross tons or more and passenger ships using non-cargo ammonia as fuel can now use the guidelines as a basis for vessel design and systems layout, with work to continue on more detailed amendments to the IGF code.

In terms of the use of ammonia cargo as fuel (currently prohibited by IMO regulations), changes to the IGC code will enter into force on 1 July 2026 that allow for this fuel pathway. This aligns with the first large-scale ammonia-fueled vessels hitting the waters in 2026.

https://ammoniaenergy.org/articles/imo-approves-interim-fuel-guidelines/



Low-Emission Ammonia Data, Ammonia Energy Association

https://ammoniaenergy.org/lead/

SHIP>NL Sessie IX 15 oktober 2025

Ammonia-fueled Engines are ready for Deployment

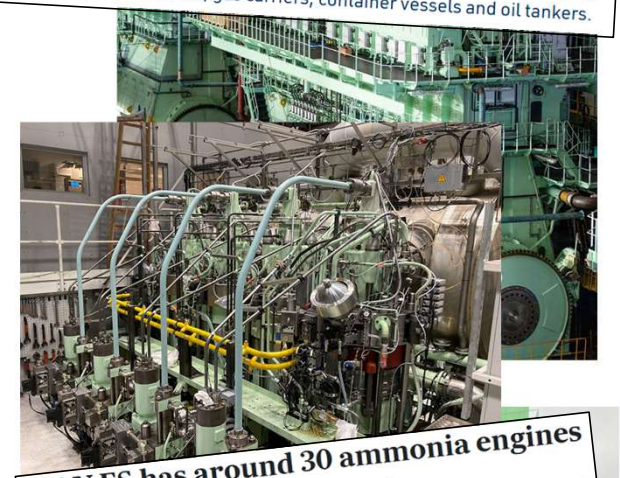
AMMONIA ENERGY ASSOCIATION

Engine manufacturers have performed extensive testing of ammonia-fueled two-stroke and four-stroke engines. In fact, the first ammonia-fueled four-stroke engine was delivered and deployed 2024, with the first ammonia-fueled two-stroke engines delivered in 2025. Engine manufacturers are ready for scale-up, with 60+ engines ordered. Also, retrofit packages exist for engines to use ammonia as fuel.

A two-stroke engine (the majority of ammonia-fueled engine orders) can operate with up to 95% ammonia as fuel, requiring around 5% pilot fuel such as fuel oil or diesel. In ammonia mode, NO_X emissions are up to 40-50% lower than in fuel oil mode. In ammonia mode, N_2O emissions are typically below 3-5 ppmv, and ammonia slip emissions are below 10 ppm. For context, this is well below the thresholds set for ammonia leakage in the IMO Interim Guidelines for ammonia-fueled vessels: 25 ppm in enclosed spaces, and 110 ppm in secondary enclosures.

Thus, ammonia-fueled engines are compliant with IMO Tier II NO_X emission limits without DeNOx, and are compliant with IMO Tier III NO_X emission limits with DeNOx.

WinGD has secured close to 30 orders to date for ammonia-fuelled X-DF-A engines, with sizes ranging from 52- to 72-bore, for vessels including bulk carriers, gas carriers, container vessels and oil tankers.



MAN ES has around 30 ammonia engines on order amid trial success

Top: WinGD. Middle: MAN ES. Bottom: NYK.

https://ammoniaenergy.org/articles/emission-performance-of-ammonia-fueled-two-stroke-marine-engines/

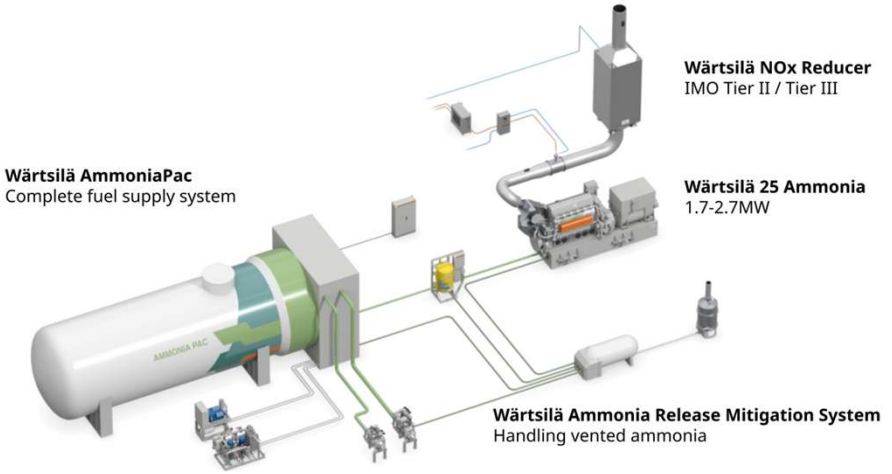
Technology toolkit ready for Deployment

In addition to engines being commercially available, the rest of the technology toolkit is ready for ammonia-fueled vessels, in line with the timeframe for the IMO guidelines:

- **Onboard ammonia fuel storage**: Ammonia fuel will be stored in Type C Tanks on the deck of a vessel. These tanks are also used for LNG, LPG, LEG, Hydrogen, etc.
- **Ammonia bunkering**: Various ship-to-ship bunkering operations have been safely demonstrated in 2024 and 2025.
- **Ammonia Fuel Supply System (AFSS)**: Safe ammonia supply systems (liquid or gas) supply ammonia to the engine
- **Ammonia Release Mitigation System (ARMS)**: Safe handling and dilution of vented ammonia at acceptable concentrations.
- **Gas detection**: Potential leaks can be measured with gas detection, allowing for immediate action, and ammonia containment.
- **Emission mitigation**: DeNOx systems are commercially available, reducing NO_X emissions down to IMO Tier III levels.

https://ammoniaenergy.org/articles/ammonia-energy-conference-2024-ammonia-for-maritime-propulsion-is-full-speed-ahead/

AMMONIA ENERGY ASSOCIATION



Top: Fuel Supply System, Ammonia Release Mitigation System, DeNOx (Wärtsilä). Bottom Left: Ship-to-Ship bunkering (GCMD). Bottom Right: DeNOx system (BUTTING).

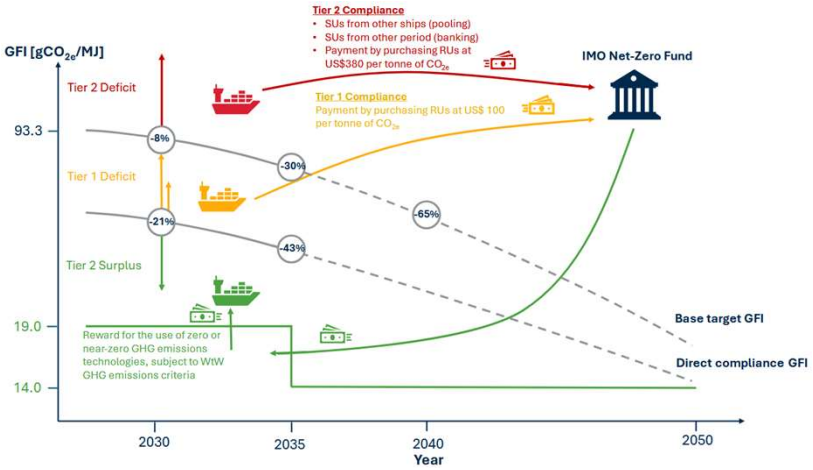
SHIP>NL Sessie IX 15 oktober 2025

Emission Pricing Mechanism for Global Shipping

AMMONIA ENERGY ASSOCIATION

In April 2025, global shipping got its first-ever emissions pricing mechanism at MEPC 83. This marks an important step towards establishing a legally binding framework to reduce GHG emissions, with a two-tier compliance system.

- The regulation will be mandatory for ocean-going ships over 5,000 gross tons (a vessel cohort responsible for 85% of the total CO_2 emissions from international shipping).
- Low-emission ammonia is a zero or near-zero (ZNZ) fuel, compliant with the most stringent greenhouse gas fuel intensity (GFI) requirements, eligible for overcompliance rewards. Detailed treatment of ammonia as a ZNZ will be clearer following the October 2025 meetings.
- Formal approval is expected at MEPC 84 in early 2026, followed by entry into force in March 2027.



Visual representation of compliance thresholds for vessels under the new IMO regulations (Source: ABS).

Low-Emission Ammonia Data, Ammonia Energy Association
https://ammoniaenergy.org/lead/

https://ammoniaenergy.org/articles/mepc-83-global-shipping-gets-its-first-ever-emissions-pricing-mechanism/

Thank you!

Q&A

Volgende kennissessies

Volgende F2F sessie
woensdag 12 november a.s.

Programma o.a. :

- Importstudies CE Delft & PWC
- Reflecties Import vs eigen productie Yara, Shell, Air Products

Data 2025	
Woe 12 november	F2F
Woe 17 December	Online

SHIP>NL Sessie IX 15 oktober 2025

Hartelijk dank voor uw aandacht

Vragen? Neem gerust contact met mij op:

Monique Rijkers
Monique.Rijkers@tno.nl
+31 6 23 34 65 16

De slides van alle sessies zijn te vinden op:
SHIPNL: Sustainable Hydrogen Import Program Netherlands | Nationaal Waterstof Programma