



# Ammonia – fuel for net-zero

**MAN Energy Solutions**

Future in the making

Innovations in blue  
and green ammonia  
production

## List of standard abbreviations

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<b>approx.</b>	approximately
<b>e.g.</b>	for example
<b>et al.</b>	et alii (and others)
<b>fig.</b>	figure
<b>i.e.</b>	id est (that is)
<b>p.</b>	page
<b>tab.</b>	table

## List of technical abbreviations

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<b>ATR</b>	Autothermal reforming
<b>avg.</b>	Average
<b>BAT</b>	Best available techniques
<b>CCS</b>	Carbon capture and storage
<b>CCUS</b>	Carbon capture, utilization and storage
<b>CH<sub>3</sub>OH</b>	Methanol
<b>CH<sub>4</sub></b>	Methane
<b>CO<sub>2</sub></b>	Carbon dioxide
<b>CO<sub>2</sub>e</b>	Carbon dioxide equivalent
<b>HFO</b>	Heavy fuel oil
<b>EJ</b>	Exajoule = 10 <sup>18</sup> joules
<b>FS</b>	Flow switch
<b>FSS</b>	Fuel supply system
<b>FVT</b>	Fuel valve train
<b>GHG</b>	Greenhouse gas
<b>GJ</b>	Gigajoule = 10 <sup>9</sup> joules
<b>HC</b>	Hand controller
<b>HP</b>	High pressure
<b>LGI</b>	Liquid gas injection
<b>LH<sub>2</sub></b>	Liquid hydrogen
<b>LNG</b>	Liquefied natural gas
<b>LPG</b>	Liquefied petroleum gas
<b>LS</b>	Level switch
<b>LT</b>	Level transmitter
<b>MGO</b>	Marine gas oil
<b>Mtpa</b>	Million metric tons per annum
<b>NG</b>	Natural gas
<b>N<sub>2</sub>O</b>	Nitrous oxide
<b>NO<sub>x</sub></b>	Nitrogen oxides
<b>NH<sub>3</sub></b>	Ammonia
<b>PEM</b>	Proton exchange membrane
<b>POX</b>	Partial oxidation
<b>PV</b>	Photovoltaic
<b>RWGS</b>	Reverse water-gas shift
<b>SCR</b>	Selective catalytic reduction
<b>SMR</b>	Steam methane reforming

## Synopsis

**This white paper examines ammonia's role in future energy solutions, emphasizing its potential as a carbon-free fuel and energy carrier. Currently central to the agricultural and industrial sectors, ammonia can revolutionize maritime transportation, power generation, and hydrogen storage due to its high energy density and zero-carbon emissions. The transition to ammonia involves significant technical and economic challenges, particularly in production and infrastructure adaptation.**

To realize ammonia's full potential as a green fuel and achieve net-zero emissions by 2050, concerted efforts are required. Stakeholders across the spectrum must commit to continued innovation, collaboration, and sustainable practices. By investing in research, upscaling renewable energy, building infrastructure, enhancing safety, promoting collaboration, implementing supportive policies, educating stakeholders, and fostering innovation, we can pave the way for a sustainable future where all renewable energy sources work together in harmony. There is urgency to this matter. The time to act is now – let us embrace the concept of ammonia as the green fuel of the future and work together to create a cleaner, more sustainable world.

This paper aims to explore the current and future uses of ammonia to identify challenges, propose solutions, encourage sustainable practices and promote innovation. We will analyze the historical and projected demand for ammonia, examine ammonia production methods, and highlight case studies and projects. Finally we will recommend strategies for future development.

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# Various uses of ammonia

**Ammonia production has been a cornerstone of modern agriculture, supporting global food production by providing an essential component for nitrogen fertilizers, which account for nearly 70 % of the world's ammonia market.**

## From farming to fuels

Nitrogen fertilizers, including products like urea, ammonium nitrates, ammonium sulfate, ammonium phosphates, and nitrogen solutions, are essential for enhancing soil fertility and boosting crop yields. Various industrial applications, such as the production of explosives (ammonium nitrates), acrylic fibers and plastics (acrylonitrile), nylon (hexamethylenediamine and caprolactam), polyurethanes (isocyanates), and a range of amines and nitriles, account for the remaining, mostly industrial, uses of ammonia.

Ammonia's future uses are expected to expand beyond its traditional role in agriculture and industry, driven by its potential as an energy carrier. Liquid ammonia has a relatively high energy intensity of 18.6 MJ/kg and can be used as a carbon-free fuel and energy storage medium. For example, newbuild or retrofit ammonia ship engines provide a viable pathway to decarbonize the maritime industry, a hard-to-abate

sector responsible for about 3 % of global greenhouse gas (GHG) emissions. Furthermore, ammonia can be used as a hydrogen carrier, circumventing the need to liquefy hydrogen at cryogenic temperatures and maintain those temperatures for transportation and storage. Ammonia also has potential as a fuel for stationary power generation, where it can be co-fired with coal or used independently in dedicated ammonia-burning power plants.



**Historical demand and future expectations**

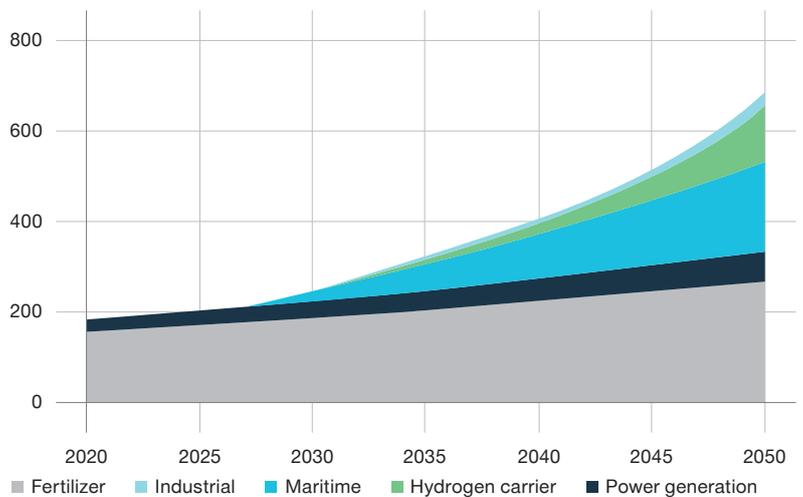
In 2020, global ammonia demand was approximately 183 million metric tons (see IRENA & AEA 2022). Until now, ammonia production has primarily been driven by the necessity to provide fertilizers to increase agricultural yields, and in the future a significant part of the demand will remain tied to food production for a growing world population.

However, the use of ammonia as a carbon-neutral fuel for maritime transportation, power generation, and as a hydrogen carrier will exert extreme strains on the supply of ammonia, its price, and the allocation of its use. Fertilizer supply, and thus food production, should not be put at risk; therefore, careful policy measures and adequate construction of ammonia capacity are paramount to avoid fertilizer supply chain disruptions. Clearly, industry is supporting the emergence of ammonia as an energy carrier with over 290 mtpa of announced green and blue ammonia projects (see IRENA & AEA 2022; IEA 2023).

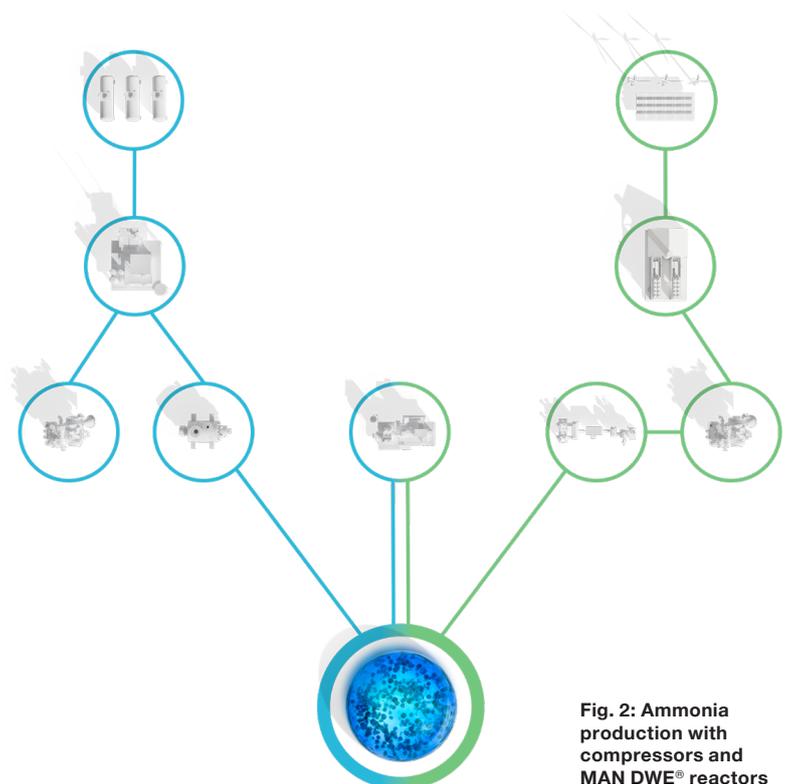
**Difference between gray, blue, and green ammonia**

Gray ammonia is produced using hydrogen derived from fossil fuels through traditional methods, where the excess carbon is released into the atmosphere. Blue ammonia refers to ammonia production where the excess carbon is captured and sequestered in secure geological formations. Finally, green ammonia describes ammonia produced with hydrogen generated by water electrolysis powered by renewable energy, making it carbon neutral.

**Expected ammonia demand in mtpa**



**Fig. 1: Expected ammonia demand net-zero emission scenario**



**Fig. 2: Ammonia production with compressors and MAN DWE® reactors**

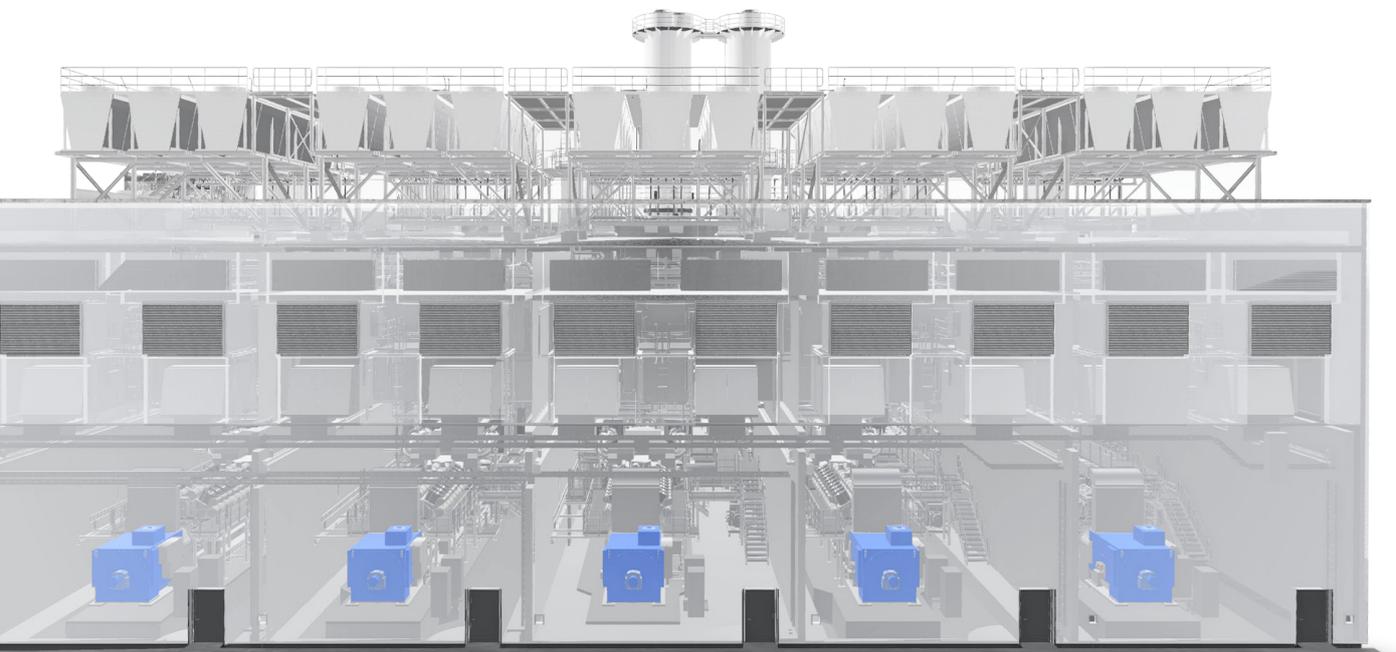
# Zero-carbon fuel with a bright future

**As a zero-carbon fuel, ammonia produces no CO<sub>2</sub> emissions in combustion and thus addresses the urgent need to reduce GHG emissions in difficult-to-decarbonize sectors such as the maritime industry, power generation, and others. Its production can leverage renewable energy sources, thus ensuring a sustainable, decarbonized fuel supply.**

## Use in power generation

Progress is being made in developing ammonia as a fuel for power generation as a supplemental fuel in coal power plants, for direct use in gas turbines and engines, or with decomposition prior to firing. The challenges of ammonia combustion in this area are similar to those for the maritime industry.

MAN Energy Solutions is at the forefront of using ammonia as a fuel for power generation as a result of leveraging its combined experience in the development of two-stroke and four-stroke dual fuel engines with outputs of up to 26 MW, targeting industrial power generation and, in a later step, utilities.



## Maritime transportation

Ammonia is recognized as a promising fuel for maritime transportation due to its overall favorable characteristics as a decarbonized fuel. Ammonia could account for up to 44 % of maritime fuel consumption by 2050, requiring the additional production of about 200 million tons of renewable ammonia per year by 2050 (see Raucci et al. 2023).

Ammonia's relatively high energy density compared to hydrogen makes it a more practical option for long-distance shipping, reducing the need for frequent refueling stops. Advanced combustion technologies and after-treatment systems can mitigate concerns over ammonia slip and nitrogen oxide (NO<sub>x</sub>) emissions, making it a cleaner

alternative to traditional fossil fuels. Furthermore, the existing global infrastructure for ammonia production and transport, primarily developed for agricultural use, can be adapted for maritime applications, facilitating a smoother transition (see DNV 2023; IRENA 2021).

Property	Ammonia (NH <sub>3</sub> at -33 °C)	Marine gas oil (MGO)	Liquefied natural gas (LNG)	Heavy fuel oil (HFO)	Methanol (CH <sub>3</sub> OH)	Liquefied petroleum gas (LPG)	Liquid hydrogen (LH <sub>2</sub> )
Lower heating value MJ/kg	18.6	42.7	50	40.5	19.9	46	120
Energy Density MJ/m <sup>3</sup>	12,700	35,700	21,200	36,500	14,900	26,700	8.5
Relative tank size, MGO = 100 %	280 %	100 %	170 %	97 %	240 %	130 %	420 %
Heat of vaporization kJ/kg	1,371	250	510	230	1,100	426	446
Autoignition temperature °C	651	250 – 300	537	250 – 400	470	450	500
Flame propagation speed cm/s	7.2	40	36 – 42	34	37 – 43	46	265 – 325
CO <sub>2</sub> emissions kg CO <sub>2</sub> /GJ	0	74	55	77	68	63	0
NO <sub>x</sub> emissions	Low (can be zero)	High	Low	High	Moderate	Low	Low
Typical uncombusted fuel	Very low (NH <sub>3</sub> slip)	1 – 2 %	0.1 – 0.5 %	2 – 3 %	0.5 – 1 %	0.5 – 1 %	Very low

Tab. 1: Properties of maritime fuels

## Pros and cons of ammonia as a fuel in maritime transport

The main strength of ammonia is that it is carbon-free: its combustion does not produce CO<sub>2</sub>. Furthermore, its nitrous oxide (N<sub>2</sub>O) content can be reduced in advanced catalytic reduction systems. Being a high-density fuel is critical for long-distance maritime transport. Another key advantage is that there is a mature ammonia industry: the handling of ammonia is known and proven, it is produced and transported

globally. Leveraging the existing supply chains to upscale storage (bunkering) and distribution should be relatively simple and fast.

On the other hand, ammonia is toxic at low concentrations and must be kept refrigerated or pressurized for storage. It is difficult to ignite, with slow flame propagation and high evaporation enthalpy. From an environmental

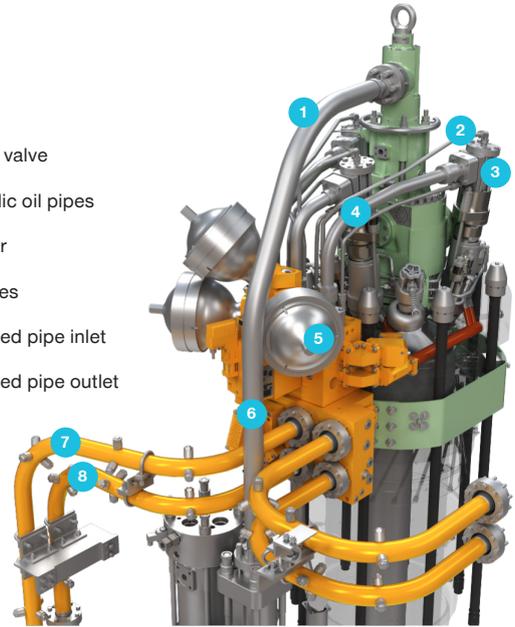
standpoint, its combustion produces N<sub>2</sub>O, a GHG, and the production of green/blue ammonia is not entirely carbon-free across its entire supply chain. Large investments in renewable ammonia production are necessary to meet demand and scale up the technology. It will take time to reach cost parity between renewable ammonia and current fuels to drive growth.

**Engine and fuel supply developments**

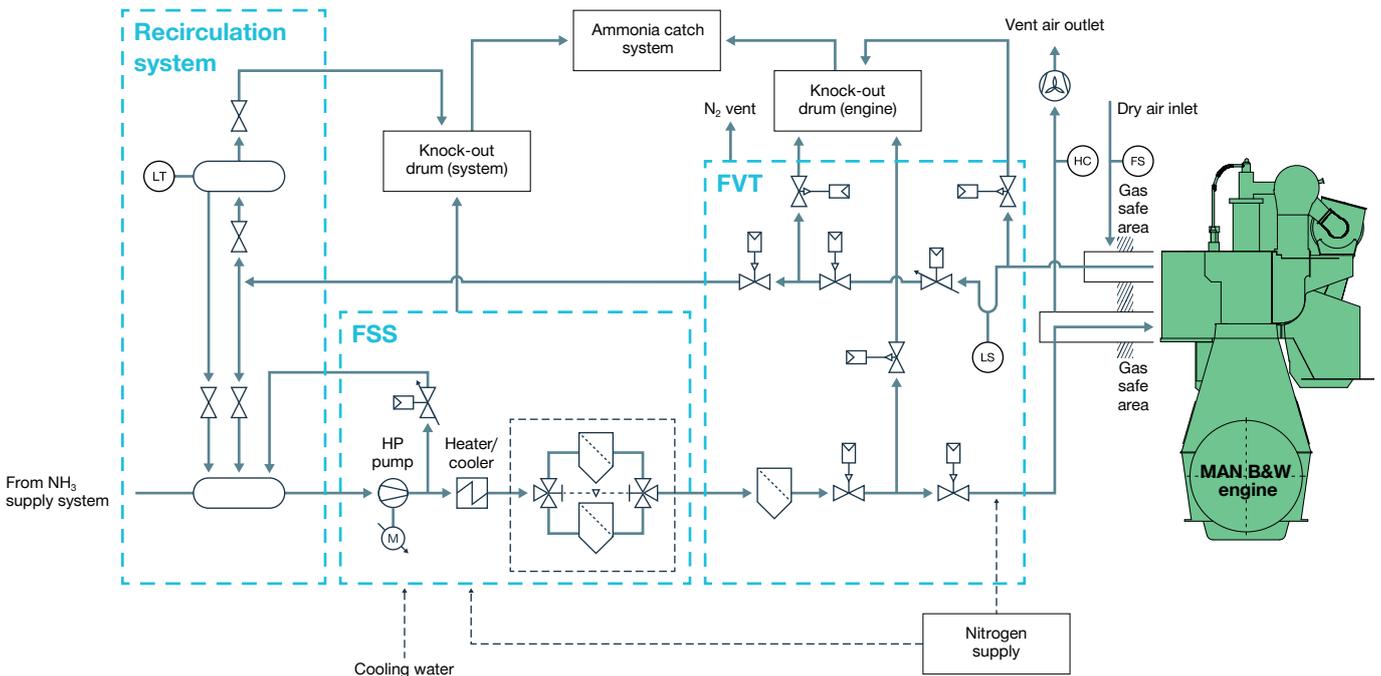
The use of ammonia poses several challenges. First, ammonia is toxic and therefore more difficult to handle than other hydrocarbon fuels. Second, ammonia’s combustion characteristics are poor due to the high ignition energy required, slow burn rate, and high enthalpy of evaporation. Third, its emission characteristics are distinct from conventional engines, necessitating specific solutions to remove unburnt ammonia and nitrous oxides from the exhaust. Fourth, the engine must have dual fuel capabilities because the bunkering infrastructure for ammonia is currently nonexistent (see Raucci et al. 2023).

MAN Energy Solutions has addressed each of these challenges in a comprehensive development program. Successful ammonia combustion tests were conducted on a MAN Energy Solutions two-stroke engine at MAN’s Research Centre in Copenhagen in July 2023.

- 1 Hydraulic oil
- 2 De-aeration point
- 3 Fuel booster injection valve
- 4 High pressure hydraulic oil pipes
- 5 Hydraulic accumulator
- 6 Hydraulic control valves
- 7 Ammonia double-walled pipe inlet
- 8 Ammonia double-walled pipe outlet



**Fig. 3: One-cylinder test setup with high pressure fuel oil and liquid ammonia injectors**



**Fig. 4: Ammonia supply system block diagram with main components**

### Based on proven technologies

The ammonia fuel supply system (FSS) is based on the LPG system but includes additional features to address ammonia's toxicity. Extensive safety measures were integrated into the engine test, including double-walled piping, ammonia sensors, system ventilation, and specialized water screens to contain any potential leaks.

The project also involved the development of advanced emission control technologies, using selective catalytic reduction (SCR) to manage NO<sub>x</sub> and N<sub>2</sub>O emissions and ensure compliance with environmental regulations.

These tests provided promising data on combustion stability and pilot oil usage:

- Pilot oil consumption is similar to that of other liquid gas injection (LGI) engines
- NO<sub>x</sub> emissions are similar to, or slightly lower than, those of engines operating on MGO
- Ammonia emissions are considerable and require removal by SCR
- N<sub>2</sub>O emissions are very low

Furthermore, Mitsui E&S and MAN Energy Solutions have partnered to develop, test, and commercialize a dual fuel ammonia engine targeted for delivery in 2024. The engine design is based on the MAN B&W ME-LGI engine design principle, ensuring safety through double-wall pipes with gas detection, a proven concept from existing dual fuel engines. A high pressure SCR system is employed to address NO<sub>x</sub> emissions, as traditional exhaust gas recirculation methods are ineffective for ammonia combustion.

### Hydrogen carrier for storage and transportation

The demand for hydrogen in industrial hubs is anticipated to increase and displace natural gas (NG) during the global energy transition. Green ammonia is a promising hydrogen carrier due to its high hydrogen content relative to its weight, simple liquefaction process, lack of need to return the carrier fluid, and the existing global infrastructure and international trade. To reduce the demand for hydrogen, many large and efficient industrial-scale ammonia cracking plants are in planning at the ports of destination, in particular in northern Europe and Japan.

Ammonia decomposition is not only an endothermic reaction but also requires energy to vaporize and heat the ammonia before it enters the reactor. Energy losses to the environment are substantial. Typically, ammonia provides this energy to the fired furnace, leading to a considerable loss of product. Therefore, the development of large-scale ammonia crackers employing renewable energy instead of ammonia is ongoing (see Trangwachirachai et al. 2024).

	RWGS reactors	Ammonia crackers
Operating temperature	500 – 550 °C	500 – 550 °C
Operating pressure	1 to 30 bar	< 10 bar
Reaction type	Endothermic	Endothermic
Reactants	CO <sub>2</sub> , H <sub>2</sub>	NH <sub>3</sub>
Products	CO, H <sub>2</sub> O	H <sub>2</sub> , N <sub>2</sub>
Phase	Gas Phase	Gas Phase
Applications	CO <sub>2</sub> utilization, syngas production	Hydrogen production, fuel cells, chemical synthesis
Products, if green hydrogen is used	Green methanol, Fischer Tropsch Fuels, Dimethyl ether (DME), Oxo alcohols	Green hydrogen

Tab. 2: Technical comparison between RWGS reactors and ammonia crackers

Reverse water-gas shift (RWGS) reactors and ammonia cracking reactors share several similarities in terms of their operational principles, conditions, and catalytic requirements. Both technologies will find application in the quest for renewable energy, petrochemicals, and plastics.

MAN Energy Solutions is investigating the benefits of using renewable electric energy instead of burning ammonia. The goal is to develop an ammonia cracker by leveraging the knowledge gained from RWGS reactors. An important feature will be the provision of the heat of reaction by molten salts heated with renewable electric power and introduced into the reactor with a heat exchanger.

# Ramping up ammonia production

The worldwide effort to decarbonize is driving demand for alternative fuels. As a CO<sub>2</sub>-free fuel, ammonia is an attractive option for the chemical, maritime, and energy sectors.

## Present and future conditions

The current ammonia production of approximately 190 million metric tons per year accounts for about 8.6 EJ or 2 % of the world's total energy demand. Today, every ton of ammonia requires an average of 45 GJ and emits 2.4 tons of CO<sub>2</sub>e. With the use of best available techniques (BAT), the energy intensity could be lowered to about 30 GJ per ton of ammonia and the carbon intensity reduced to 1.7 tons of CO<sub>2</sub>e; with CCUS, the carbon intensity could be reduced to about 0.6 tons of CO<sub>2</sub>e per ton of ammonia. Further improvements are

expected by producing hydrogen through electrolysis and sourcing electric power from solar PV (0.6 tons) or wind power (0.2 tons of CO<sub>2</sub>e per ton of ammonia).

The Haber-Bosch process is at the core of all industrial ammonia synthesis processes. The synthesis of ammonia is the same regardless of the hydrogen source. High temperatures (400–650 °C) are needed to activate the reaction in the presence of a catalyst, and high

pressure (100–400 bar) is necessary for the reaction to occur at an economically viable speed for industrial production. The overall reaction is exothermic, thereby producing enough energy to power the process, although some electricity is required for motors and other equipment. Only a proportion of hydrogen is converted after cycling through the reactor, necessitating a large recycle flow of the unconverted hydrogen and nitrogen after the ammonia condenser.

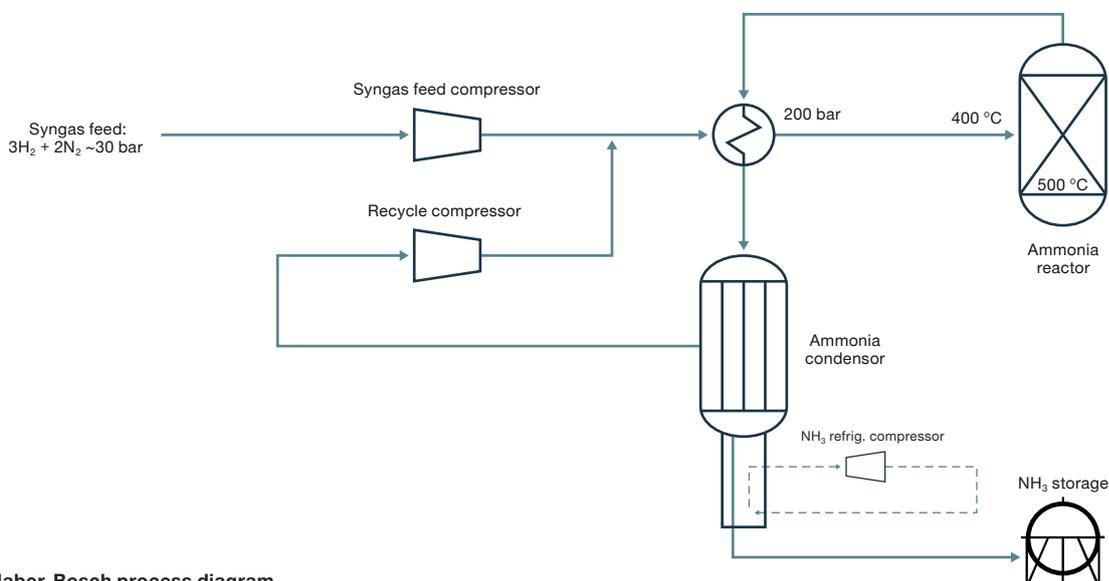


Fig. 5: Haber-Bosch process diagram

## Steam methane reforming (SMR)

SMR is the primary method for producing hydrogen used in ammonia production. This process is well-established and widely adopted due to its efficiency and existing infrastructure. It involves the reaction of methane ( $\text{CH}_4$ ), typically derived from NG, with steam ( $\text{H}_2\text{O}$ ) to produce syngas, a mixture primarily of hydrogen ( $\text{H}_2$ ) and carbon monoxide ( $\text{CO}$ ). The overall process can be broken down into the following steps.

### - Reforming

In the presence of a catalyst, methane reacts with steam at high temperatures ( $700\text{--}1,000\text{ }^\circ\text{C}$ ) to produce syngas:  
 $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$ .

### - Water-gas shift reaction

The carbon monoxide in the syngas reacts in two stages (high temperature and low temperature) to maximize the conversion of  $\text{CO}$  into  $\text{CO}_2$  and  $\text{H}_2$ :  $\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$ .

### - Secondary reforming

The secondary reformers typically operate at 35 bar. The reforming air at this pressure level is most efficiently provided by an integrally geared compressor, for which MAN Energy Solutions has extensive experience in various processes. Air is introduced into the reformer where the oxygen in the air reacts with the methane, producing additional hydrogen while the nitrogen remains in the gas mixture, thus providing the required nitrogen for the Haber-Bosch process. Impurities from the air, such as argon and residual oxygen, must be removed in a subsequent step.

### - $\text{CO}_2$ removal

The  $\text{CO}_2$  produced in the shift reactions is removed using amine absorption and/or pressure swing absorption methods.



Fig. 6: Integrally geared air compressor

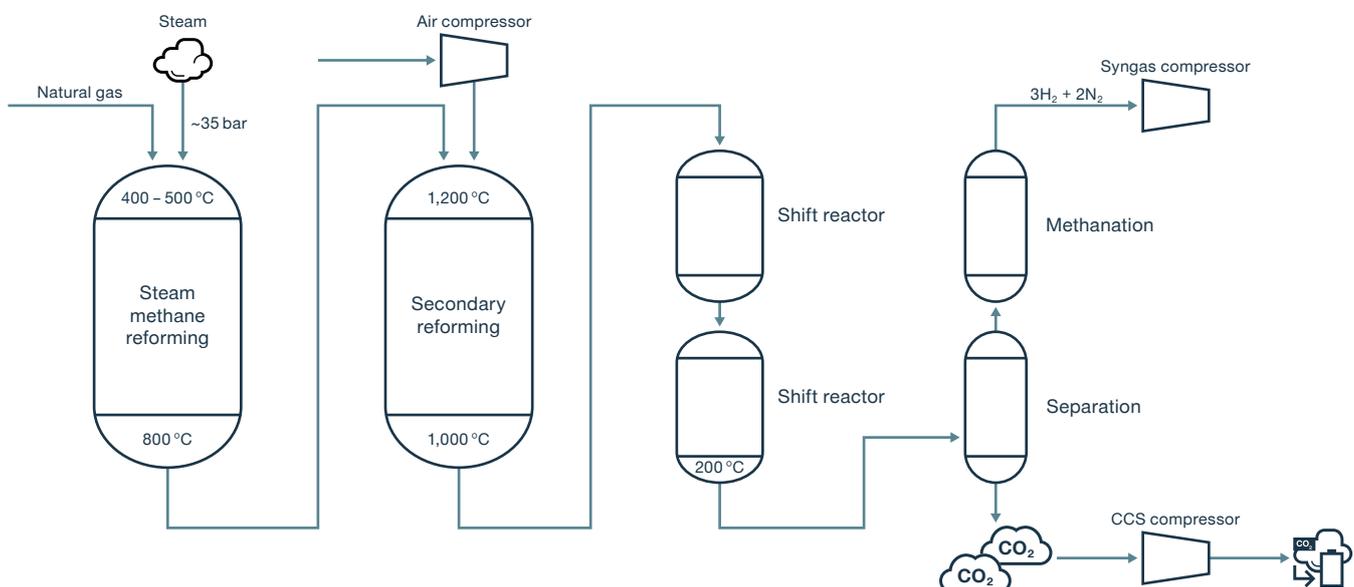


Fig. 7: SMR process diagram

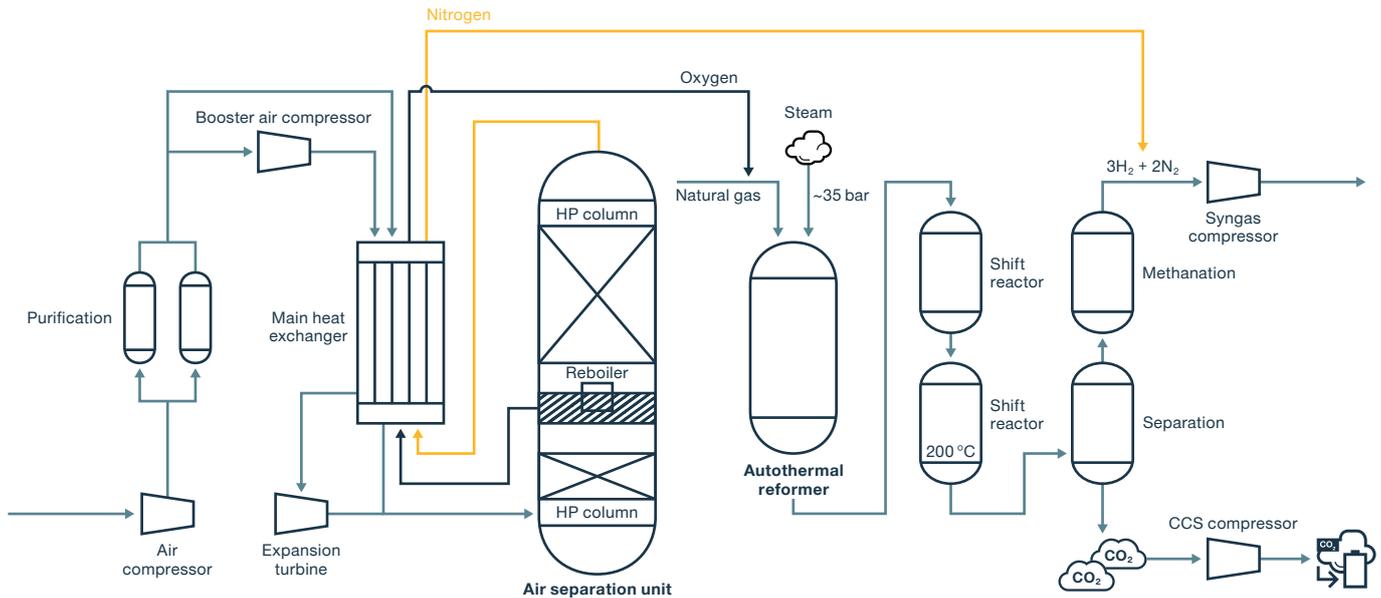


Fig. 8: Block diagram of ATR including air separation plant

### Autothermal reforming (ATR)

ATR is used in some ammonia plants (to a lesser extent than SMR). It is typically chosen for its thermal efficiency and flexibility with heavy hydrocarbon feedstocks, including coal or biomass. The overall process can be broken down into the following steps.

#### – Reforming and partial oxidation (POX)

Combines the elements of SMR and POX in the same reactor, simplifies heat management, and leads to a more compact and integrated process design.

#### – Water-gas shift reaction

Similar to SMR.

#### – Secondary reforming

Not necessary. High purity nitrogen from the associated air separation plant is used.

#### – CO<sub>2</sub> removal

Similar to SMR.

Air separation plants are typically built with an isothermal main air compressor delivering air at about 5.5 bar to the cryogenic separation column. Part of this air is further compressed with a booster air compressor to a pressure sufficiently above the thermal pinch point in a heat exchanger. Here, the air is liquefied while the liquid oxygen is vaporized at the pressure needed by the primary reformer, typically around 35 bar.

In conclusion, ATRs need less fuel and the conversion rate to hydrogen is higher than in an SMR, thereby reducing total CO<sub>2</sub> emissions. An additional investment in an air separation plant with motor-driven compressors is necessary to deliver the oxygen. The pure nitrogen produced provides a clean feedstock for ammonia synthesis and avoids the need for removal of impurities such as argon and other rare gases.



Fig. 9: RIKT main air compressor and RG booster air compressor for a 1500 ton oxygen per day air separation plant

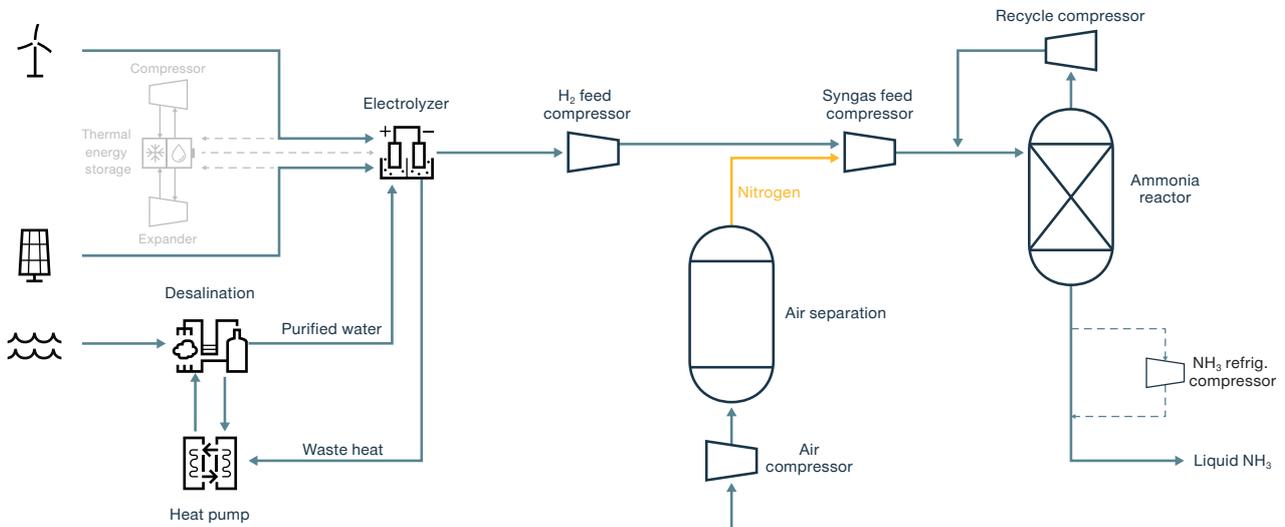


Fig. 10: Compression services in green ammonia plants

### Hydrogen electrolysis

The carbon intensity of hydrogen production using SMR or ATR can be significantly reduced by capturing and sequestering carbon dioxide emissions. This is frequently denominated as blue hydrogen as opposed to green hydrogen. With the push towards producing renewable electricity via solar and wind, the emissions intensity of hydrogen can be lower than what is possible using carbon capture and storage. Electricity from most power grids still has high emission factors, therefore, abundant renewable power from wind, solar PV, hydropower, and nuclear power is necessary to produce ammonia with the lowest possible GHG emissions.

Alkaline electrolyzers produce hydrogen at near atmospheric pressure, far below the feedstock delivery pressure from SMRs or ATRs (30 to 35 bar). For this reason, the hydrogen feed compressors, nitrogen delivery pressure from the air separation plant, and syngas feed compressors must be optimally reconfigured to boost the hydrogen and nitrogen up to the syngas reactor pressure in the most efficient and cost-competitive manner.

Here, MAN Energy Solutions has substantial experience in all compression services to determine the best configuration.

Electrolysis needs large amounts of purified water that can be provided by thermal desalination plants employing heat pumps that source the low temperature heat from the electrolyzers. In addition, large amounts of low-temperature heat from the electrolyzers provide an opportunity to stabilize intermittent renewable energy with thermal batteries, where MAN Energy Solutions is providing compressors for grid-scale energy storage.

PEM electrolyzers deliver high-purity hydrogen at a pressure similar to SMRs, thereby reducing the need for configuration changes to the compression systems. In addition, PEM electrolyzers have quick response times and better integration with grids predominantly powered by renewable energy sources. MAN Energy Solutions' subsidiary, Quest One, focuses on producing hydrogen at higher delivery pressures, which reduces compression requirements for feeding hydrogen into pipeline networks and many industrial processes.



Fig. 11: Modularized 10 MW PEM electrolyzer with materials and energy balance

# Big challenges and innovative solutions

The ramp-up of low-emission ammonia production faces several challenges. These challenges can be categorized into technical, economic, regulatory, and infrastructure issues. MAN Energy Solutions can provide all the technologies necessary for large-scale production.

Production route	Natural gas SMR	Natural gas ATR	Coal gasification	SMR with CCS @95%	ATR with CCS @95%	Coal with CCS	Electrolysis
<b>Energy intensity (GJ per ton NH<sub>3</sub>)</b>							
Feedstock	21	25.8	18.6	21	25.8	18.6	0
Fuel	11.1	2.1	15.1	11.1	2.1	15.1	0
Electricity	0.3	1	3.7	1	1.5	4.9	36
Steam	-4.8	0	-1.3	-3.1	0	2.6	-1.6
Gross	32.4	28.9	37.4	33.1	29.4	38.6	36
Net	27.6	28.9	36.1	30	29.4	41.2	34.4
<b>Direct CO<sub>2</sub></b>							
tons CO <sub>2</sub> e per ton NH <sub>3</sub>	1.8	1.5	3.2	0.2	0.2	0.2	0
<b>Indirect CO<sub>2</sub> emissions (tons CO<sub>2</sub>e per ton NH<sub>3</sub>)</b>							
Plant & maintenance	0.025	0.025	0.028	0.029	0.029	0.033	0.015
Feedstock and fuel	0.2	0.17	0.32	0.2	0.17	0.32	0
Total incl. electricity at world avg.	1.79	1.85	3.93	0.37	0.54	1.23	4.3
Total incl. electricity with wind	1.98	1.74	3.57	0.4	0.36	0.55	0.21

Tab. 3: Emission intensity of various ammonia production routes

### Important steps in the energy transition

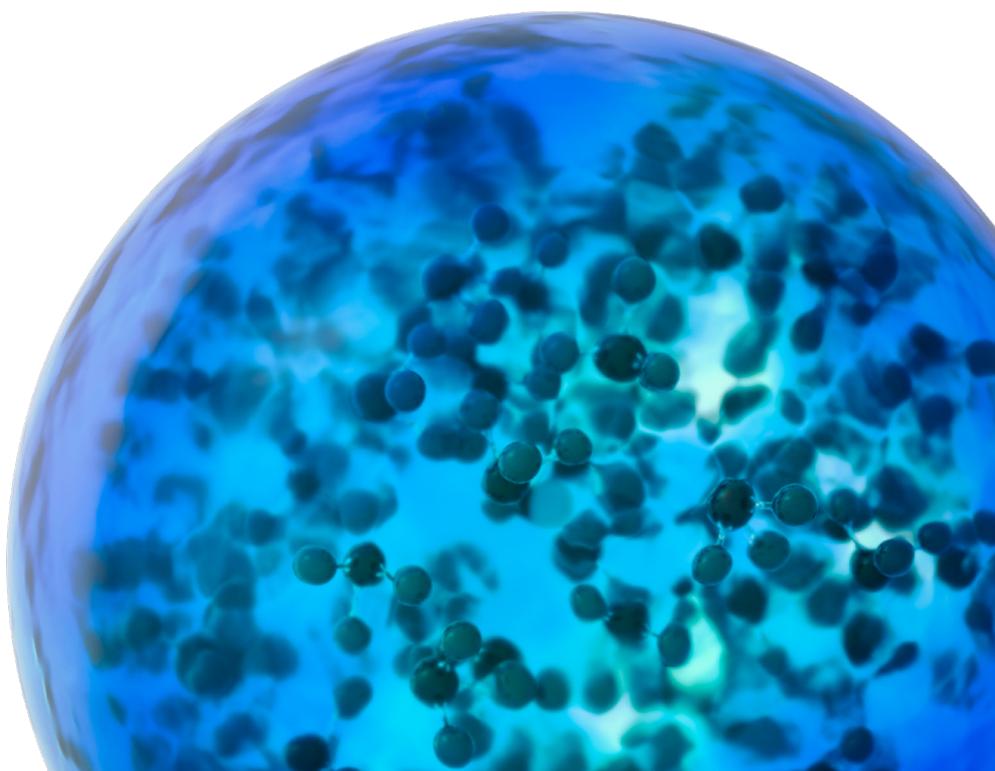
Transitioning to renewable energy sources to power the Haber-Bosch process is challenging due to the intermittency and current costs of renewables. The intermittency of solar and wind power necessitates the development of reliable storage solutions for electric power to ensure a stable supply for the electrolyzers, as well as hydrogen storage to provide a constant feedstock flow to the ammonia synthesis plant.

The initial capital expenditure for setting up green ammonia production plants, including renewable energy infrastructure, is considerable and poses a hurdle when compared to conventional or blue ammonia production. While renewable power generation has shown significant economies of scale, electrolyzers must follow suit to close the capital cost gap.

Blue ammonia should not be produced for fuel use, since NG can be used more efficiently and at a lower cost by industrial users. Blue ammonia should target fertilizers and current industrial uses in an effort to curb the high emissions of conventional plants.

Competing with conventional ammonia production, which is cheaper due to established infrastructure and lower costs of NG, presents a significant economic barrier. Effective regulatory and policy measures must be enacted and followed globally to address this issue.

Finally, green ammonia is not the production route with the lowest GHG emissions if it is powered by grid electricity with an emissions factor above 200 g/KWh. Dedicated renewable power generation is necessary for green ammonia to fulfill its promise.





## Conclusion

**Achieving net-zero emissions requires collaboration across sectors. This is true for ammonia as well. Governments, industries, research institutions, and international organizations must work together to share knowledge, resources, and technologies.**

Upscaling renewable energy is essential. Renewables must provide a cost-competitive energy supply that will serve as the foundation for rapidly increasing the production of sustainable fuels and feedstocks. In the case of ammonia, the existing infrastructure must be extended with a focus on safety. Sharing knowledge and collaborating across sectors through partnerships and joint ventures multiplies the reach and speed of our progress towards a sustainable future.

The worldwide effort to decarbonize is driving demand in the chemical, maritime, and energy sectors. As a CO<sub>2</sub>-free fuel, ammonia is an attractive option as fuel and hydrogen carrier. MAN Energy Solutions can provide all the key technologies necessary for safe and cost-effective blue and green ammonia production.



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