GREEN AMMONIA: A NEW SUSTAINABLE FUEL SETS SAIL

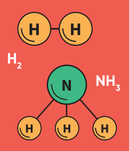
STATUS QUO

WHAT'S ALL THIS AMMONIA MANIA?

The search for green energy has never been more urgent. And while we are all getting used to hydrogen popping up in policy targets and news headlines, ammonia is the apparent new kid on the block. In reality, ammonia has been around for over a century, just not as fuel – almost 90% of ammonia today is used as fertiliser, the rest for cleaning and chemical processes. But **could green ammonia be the sustainable fuel of the future?**

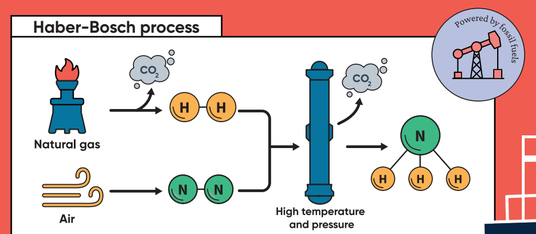
88%
OF AMMONIA TODAY IS USED AS FERTILISER

MEET THE MOLECULE



Ammonia, chemical formula NH_3, is a simple molecule built from one nitrogen atom and three hydrogen atoms. Liquid ammonia is therefore an excellent source of hydrogen, containing **50% more hydrogen by volume than pure liquid hydrogen** (a molecule of hydrogen has just two hydrogen atoms). Ammonia is normally produced through the Haber-Bosch process, which is energy intensive and currently powered by fossil fuels, thus contributing significantly to global greenhouse gas emissions.

Haber-Bosch process



A RISING TIDE FOR GREEN AMMONIA

About **183 million tonnes** of ammonia are produced in the world every year, and annual **demand is set to rise to 688 million tonnes by 2050**. This increase in demand is mainly due to a whole new market opening up: the energy sector! Clean energy is in high demand, and especially hard-to-decarbonise sectors such as heavy transport and shipping are in dire need of sustainable fuel alternatives, like green ammonia. Green ammonia is produced with renewables, meaning the Haber-Bosch process is powered by wind or solar energy, instead of fossil fuels. And that is the plan: **By 2050, 80% of ammonia is projected to be produced with renewable energy – up from just 0.01% today!**

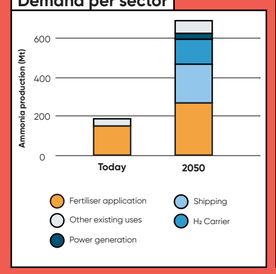
183 million tonnes of liquid ammonia could fill more than

100,000
OLYMPIC SWIMMING POOLS

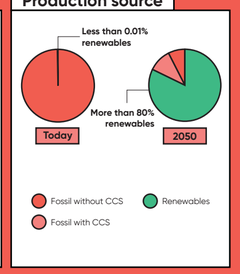
688 million tonnes of ammonia is almost four times as much!

PROJECTED DEMAND AND PRODUCTION OF AMMONIA BY 2050

Demand per sector



Production source



FUEL COMPARISON

FOSSIL FUELS? TIME TO ABANDON SHIP

The shipping industry accounts for three per cent of global greenhouse gas emissions. It is largely powered by heavy fuel oils (HFO), the world's dirtiest, most polluting fuel. A green alternative is urgently needed: a fuel with high energy density and low emissions. The main options currently on the table are hydrogen and ammonia – both can be produced with renewable energy and offer up to ten times the energy density of a lithium-ion battery. Each of these fuels has its pros and cons, as shown in this table.

	HEAVY FUEL OIL	HYDROGEN	AMMONIA
👍	• Very high energy density • Easy to handle and transport (liquid at room temperature and atmospheric pressure) • Excellent combustion properties	• Can be produced with renewables • Releases no GHG emissions when used • Very little toxicity in case of leaks • Excellent combustion properties	• Can be produced with renewables • Reasonable energy density (50% higher than liquid hydrogen) • Liquifies below -33 °C
👎	• High GHG emissions • High air pollution • Serious toxicity to humans and ecosystems in case of leakage • Major contributor to current climate crisis	• Very low energy density (20% of heavy fuel oil) • Costly and energy-intensive to store and transport: H2 liquifies below -253 °C and it makes steel tanks brittle • Risk of explosion due to high flammability	• Low energy density (30% of heavy fuel oil) • Low flammability • Risks linked to leaks: toxic to humans and marine ecosystems • Harmful greenhouse gas emissions (nitrous oxide)

94% GHG emission reduction compared to HFO

29x cheaper to store ammonia than hydrogen

Cargo vessels are behemoths: They can be up to 60 metres wide and over 400 meters long. That's longer than the Eiffel Tower! For scale: try to find the human on this vessel. Below, we explain the importance of ammonia in the green fuel mix that may one day power these giants.

FUEL UTILISATION

DUAL FUEL: THE BEST OF BOTH WORLDS

We've seen that both ammonia and hydrogen have their own drawbacks that can make them challenging to use. A dual-fuel engine could be the answer, using a fuel mix that combines the high energy density of ammonia with the easy combustion of hydrogen. Ammonia is mixed with a small amount of hydrogen, which is produced on site by converting (or 'cracking') part of the ammonia into pure hydrogen. This dual fuel is burnt in the combustion engine and voilà! Propulsion!

Pros
- Hydrogen enables easy combustion
- The hydrogen can be cracked from ammonia on site
- Faster and more complete combustion already at 5% hydrogen by weight added
- Even less emissions than from pure ammonia combustion
- Existing maritime internal combustion engines can be retrofitted to be dual fuel compatible

Cons
- Additional conversion step needed to produce pure hydrogen for addition to the fuel
- Mitigating measures needed to eliminate remaining emissions

WHAT ABOUT FUEL CELLS?

Fuel cells use pure ammonia or hydrogen at higher energy efficiencies than internal combustion engines (ICE). This technology is still in early development stage for shipping applications.

KEELING OVER EMISSIONS

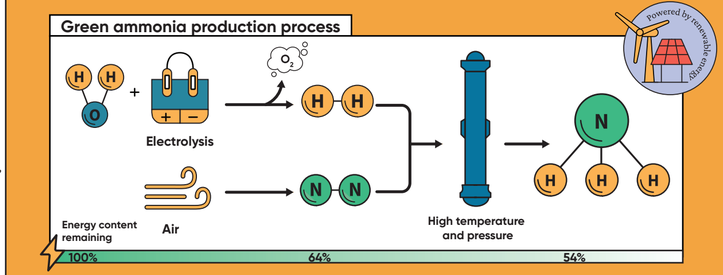
Green ammonia is CO_2 free, but still causes some emissions, and leakages could happen. These can be mitigated with the right precautions. The possible emissions are:
- Nitrous oxide (N_2O) is a potent greenhouse gas, with 300 times the atmospheric warming capacity of carbon dioxide! Mixing ammonia with hydrogen and optimising the combustion process cuts down these harmful emissions.
- Nitrogen oxides (NO_x) affect the ozone layer and cause smog. They can be filtered out at the exhaust and neutralised.
- Ammonia itself is dangerous if it leaks into the environment. This can be prevented with careful storage construction, like double tank walls.

FUTURE CHALLENGES

ALL ABOARD FOR GREEN AMMONIA!

Ammonia boasts many benefits! It produces no carbon dioxide emissions, can be produced with renewable electricity, can be used in fuel cells and combustion engines, has a higher energy density than batteries or hydrogen, and existing infrastructure can process and transport it.
So, how do we get more of the stuff?

Green ammonia production process



MORE RENEWABLES, PLEASE!

Producing more green ammonia will require more green power – a lot more, given that a great deal of energy content gets lost in the conversion process, as we've seen above. How much more renewable power production will be needed for our green ammonia ambitions of 688 million tonnes per year?

To power the production of the 2050 goal of 566 million tonnes of green ammonia, we'd need A SOLAR FARM ALMOST TWICE THE SURFACE OF BELGIUM!

CURRENT AND PLANNED GREEN AMMONIA PLANTS

Right now, there is only one green ammonia production plant in the world, located in Cusco, Peru. There are more green ammonia plants in the pipeline, but the combined production capacity only adds up to 71 millhion tonnes per year. More investment and concrete plans are needed to bring this green fuel to the forefront!

ANCHOR AWEIGH!

To sum up, the benefits of green ammonia are big, and the (climate) stakes are high. So, what needs to happen for green ammonia to scale up and the market to take off?

POLICY
We need a political commitment to green ammonia, accompanied with clear targets and supporting regulatory mechanisms such as green certification and incentives to create a stable investment climate.

TECHNOLOGY & INFRASTRUCTURE
From ports to bunkering stations, infrastructure for the production, transport and storage of ammonia must be increased and adapted for its deployment as a fuel.

RENEWABLE ENERGY
Renewables will need to expand greatly to produce enough green ammonia. This means boosting domestic renewable capacity, and building international partnerships!

INTERNATIONAL COLLABORATION
We need a common international standard to enable a global green ammonia market. The International Maritime Organisation, already set to approve ammonia as a shipping fuel in 2023, is well placed to lead this process.

EMPLOYMENT
The socio-economic benefits of green fuels are enormous: 30 million jobs will be created in the broader hydrogen market by 2050! R&D, innovation and training are key to tap into these benefits.

COSTS AND CARBON PRICING
To accelerate investments in green ammonia, there must be a level playing field: let's start with phasing out fossil fuel subsidies and introducing an effective carbon price!

CATCH THE WAVE!

Ammonia – in the form of fertiliser – already helps feed the world today. Soon, it will have another essential task: to counter climate change as a sustainable fuel. Renewable ammonia is not the only green alternative to fossil fuels, but it is one of the most promising approaches to powering the climate-neutral economy of tomorrow. We must act now: at current levels of emissions, we have until 2030 before the Paris Agreement goals become impossible to achieve. Green ammonia may not be a silver bullet – but it's certainly a shot worth taking.

IKEM

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Sources: Status Quo: Hatfield, 2020. Seo et al., 2021. Aziz et al., 2020. Robert, 2018. Rouwenhorst et al., 2022. NCBI, 2022. Fuel comparison and utilisation: Faber et al., 2020. McKee et al., 2014. Valera-Medina et al., 2018. Comer, 2019. Cames et al., 2021. DeCola et al., 2018. Dincer, 2012. Ciniviz et al., 2012. Aziz et al., 2020. Lindstad et al., 2021. Kim et al., 2015. Barthes, 2012. Hockstad et al., 2022. Ravishankara et al., 2009. Gallucci, 2021. Future challenges: Hank et al., 2020. Rouwenhorst et al., 2022. Rouwenhorst et al., 2022. Zincir, 2022. Salmon et al., 2021. Nayak-Luke et al., 2020. Hydrogen Taskforce, 2020. Bartels, 2008.

Assumptions: Olympic swimming pool size: L 50m, W 25m, D 2m, liquid NH3: 0.68 kg/L. Renewable ammonia production: 10 MWh per tonne. 980 MWh/ha per year: average yield for solar field in Germany. Storage comparison over a six-month period.