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Green shift to create 1 billion tonne 'green ammonia' market?

Andrea Valentini, Principal – Projects at Argus Media provides an insightful and in-depth analysis of the exciting green ammonia market. Core areas of focus include the case for green ammonia, potential markets (such as fertilizer and industrial applications, marine fuel, power generation), logistical and capital/operating costs considerations - and a brief look at green ammonia projects.

Green hydrogen: Recent trends and the need for a green energy carrier

Increasingly stringent emissions regulations and ambitious zero-carbon energy goals are mostly relying on wind and solar energy taking prominent roles. There is also increasing awareness that ensuring energy security from these low-carbon intermittent sources requires long-term sustainable energy storage and the identification of suitable carriers.

The rapidly decreasing cost of renewable power generation is putting "green" hydrogen (i.e. produced through electrolysis powered by renewable energy) under the spotlight as a promising energy carrier for a number of applications. However, the storage, handling and transportation of hydrogen is notoriously challenging, and there are a range of mature and emerging hydrogen carrier and storage technologies being studied for potential commercial applications.

Hydrogen can be compressed or liquefied for storage and transport, a process that is far from ideal due to high CAPEX and OPEX requirements, as well as significant safety risks. Another method of transporting hydrogen via sea is to chemically convert the hydrogen molecule into an energy carrier such as ammonia, methanol or liquid organic hydrogen carriers . Ammonia is emerging as the most promising carrier owing to a number of factors, which will be examined in this white paper. Argus is currently helping potential investors, trading companies, existing nitrogen fertilizers producers and governments to evaluate the long-term prospects of green hydrogen-based applications, including green ammonia.

Why ammonia?

Similarly to fossil fuels, ammonia is both a chemical energy carrier and a potential fuel, where energy is released by the breaking of chemical bonds. Crucially, ammonia has the advantage of not releasing any carbon emissions if used as a fuel, and its green credentials can be enhanced even further if sustainable energy is used to power the production of ammonia.

Ammonia is the second-most-widely produced commodity chemical globally, with a production volume of over 180 million tonnes in 2019, and with approximately 20 million tons per year traded as merchant ammonia (mostly in the form of seaborne trade), and mostly utilized in agriculture as a fertilizer, a sector that is under increasing scrutiny due to its environmental impact.

Ammonia can be synthesized from nitrogen and hydrogen via various methods, with the Haber-Bosch process currently the only method used on a commercial scale. The resulting ammonia can be easily transported, stored and the hydrogen can be extracted again at the destination via a thermal decomposition and separation process.

There are a number of key features that make ammonia particularly suitable as a green hydrogen carrier. These include:

- Ease of storage and transportation: The energy storage properties of ammonia are fundamentally similar to those of methane. The volumetric energy density of ammonia is 150% of liquid hydrogen and these hydrogen densities can be achieved at near ambient storage conditions. This contrasts with the high pressures or low temperatures needed to achieve useful volumetric hydrogen density with pure hydrogen. Ammonia also has lower explosive limits in air than pure hydrogen. As a result, the storage of hydrogen is more difficult, energy intensive and expensive than storing ammonia.

- Established logistics and end-use markets: There is a high level of maturity in the ammonia supply chain thanks to its widespread use as a feedstock for inorganic nitrogen containing fertilizers and a variety of other industrial chemicals. Ammonia can count on an established global storage and trading infrastructure.

- High hydrogen density compared to other potential hydrogen carriers.

- Potential uses as a fuel: Crucially, ammonia can be used directly in ammonia-fired turbines and engines, which is also discussed in this white paper.

Unlike "brown" ammonia, which is made using a fossil fuel (typically natural gas) as the feedstock, the raw materials for green ammonia are hydrogen obtained through the electrolysis of water, a process powered by renewable energy sources, and nitrogen obtained from air using an air separation unit. Green ammonia production is currently limited to small-scale pilot plants, an overview of which is provided at the end of this white paper.

Potential markets

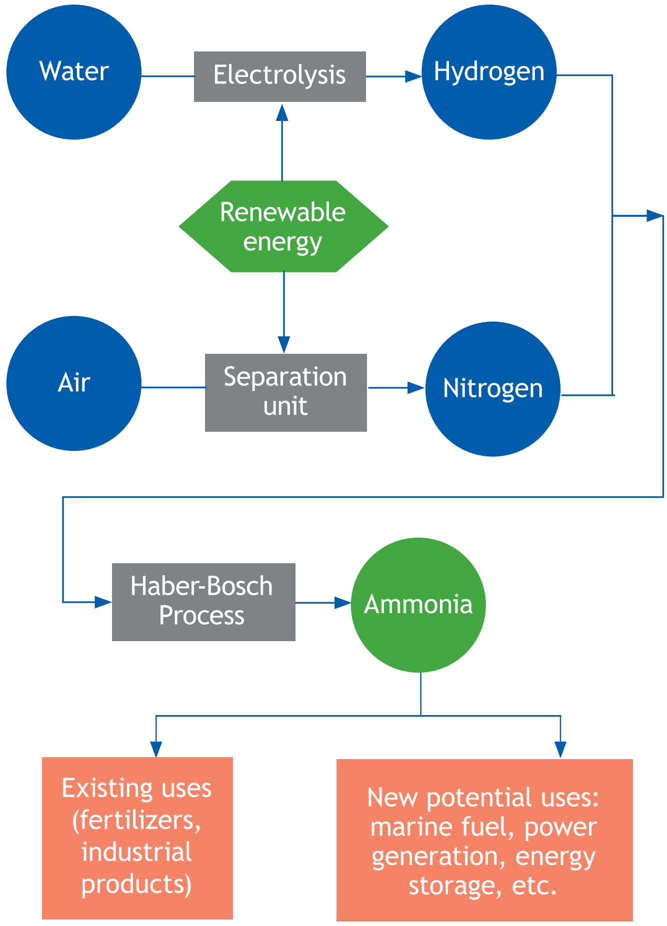
In addition to its current main use in the fertilizer industry, green ammonia has the potential to play a role in other applications, especially if considered as part of a decarbonisation strategy.

Traditional end uses (fertilizers and industrial applications): The main issue for the adoption of green ammonia for its traditional fertilizer and industrial applications is price. Given the expected high cost of production (which will be discussed later in this paper) green ammonia will likely need a legal and market framework to either mandate its use (similar to biofuels) or through a two-tier pricing system (similar to power markets). Although there is no regulatory framework in place yet, Argus has been in discussions with some end users who would be willing to pay a premium for green ammonia in the context of creating a fully carbon-free agricultural or industrial supply chain (depending on the downstream use of ammonia), and therefore allow consumers to choose premium products priced accordingly, similarly in some ways to how organic food is marketed.

In addition to end users that might be willing to pay a premium for green ammonia, projects in this space might be supported by "green finance" through bonds, loans and other facilities that are already available to support such investments.

Although it is likely that the adoption of green ammonia in fertilizer and industrial markets will be led initially only by a small number of buyers who will be able to successfully pass through the price premium to their end users, it is also possible that this could lead to more widespread market acceptance in the longer term.

Figure 1: Green ammonia production and end uses



— Argus Media

Ammonia as a marine fuel: There is a growing interest in ammonia in the transportation sector as a shipping and marine fuel, primarily due to its zero-carbon emissions, and also due to its zero-sulphur content, which results in lower emissions of particulates and improved air quality, and ensures compliance with IMO 2020 and IMO 2050.

Combustion of ammonia does lead to emissions of NOx, which would be an issue in low-NOx emissions zones mandated by MARPOL Annex VI (i.e. currently North America, with North Sea/Baltic likely to follow soon). However, most ships operating in these areas already use selective catalytic reduction systems to abate NOx emissions (mostly using a 40% urea solution), which could be operated with the same ammonia used on board as fuel.

Several projects are currently testing the use of ammonia as a marine fuel. Yara is planning to supply a retrofitted North Sea supply vessel with ammonia as a marine fuel by 2024. In addition, a cross-industry consortium of Japanese companies (including Mitsui and Itochu) is considering launching ammonia-fuelled commercial vessels, as well as developing ammonia supply infrastructure in Japan, to provide the shipping industry with an alternative marine fuel to reduce greenhouse gas emissions.

The interest in ammonia as a marine fuel is not limited to green ammonia, but it is also involving brown ammonia, purely on the basis of its zero-carbon/sulphur properties, even though on a net basis there would not be any CO_2 emissions advantages from switching from conventional marine fuels to brown ammonia. Nevertheless, the use of brown ammonia as a marine fuel could facilitate the transition towards increased usage of blue and green ammonia in the longer term.

Ammonia in power generation: Ammonia can also be burned directly in gas turbines in a mixture with natural gas or hydrogen. If ammonia is imported as a hydrogen carrier, burning it directly could eliminate the requirement for ammonia cracking (needed to reconvert it into hydrogen), thus removing an energy-intensive stage of the process. Additionally, as mentioned above, ammonia requires a much smaller storage volume than hydrogen. Ammonia is also less reactive than hydrogen, and burns at a lower temperature with reduced flame speed and a narrow flammability range.

Ammonia firing also provides a flame stability challenge, although less so than for hydrogen, with NOx abatement remaining the key challenge. However, as mentioned above, NOx abatement with well-proven selective catalytic reduction systems is already successfully used in most stationary NOx sources like power stations in several countries, and would be adequate to tackle this issue.

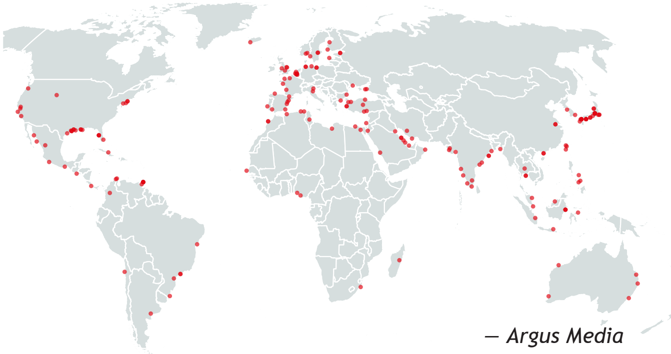
Several companies are developing engines and turbines which can use ammonia as a feedstock. For instance, Mitsubishi is developing a gas turbine which can directly take ammonia as feedstock. The ammonia is thermally cracked to produce hydrogen, nitrogen and trace amounts of ammonia, and it is used in the gas turbine as fuel.

Similarly to the potential use of ammonia as a marine fuel, the only way to reduce the carbon footprint of the generation fuel mix is by using green ammonia rather than brown ammonia.

Logistical considerations

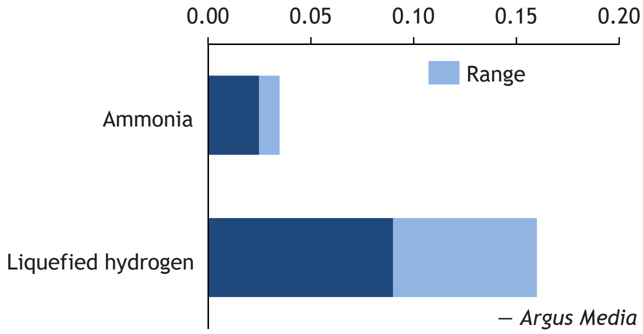
Ammonia logistics are perhaps the key feature that make ammonia particularly suited to contribute to a hydrogen-based economy, in addition to its current role as a fertilizer product and feedstock. The supply chain and logistical infrastructure for ammonia trade is mature and very well developed. As shown in the map below, there is a wide network of ports and storage facilities worldwide that handle ammonia in large volumes, and shipping routes are well-established. This existing logistical infrastructure is a key advantage over hydrogen, and could enable the early adoption of large-scale transportation of ammonia as an energy carrier and fuel.

Figure 2: Global ammonia terminals, 2020



Crucially, the ease of storing and shipping ammonia make it particularly cost effective relative to other hydrogen carriers, shown in the chart below.

Figure 3: Hydrogen carriers seaborne transport cost comparison ($/t H2 km, 2020)



Ammonia, however, is also a toxic gas, and requires great care to prevent and control environmental release. While ammonia has a gas density comparable to that for natural gas, its energy density (in lower heating value terms) is less than half that of natural gas, and so it is also likely that fuel delivery systems to certain non-traditional end users will need replacing for ammonia (e.g. for power generation).

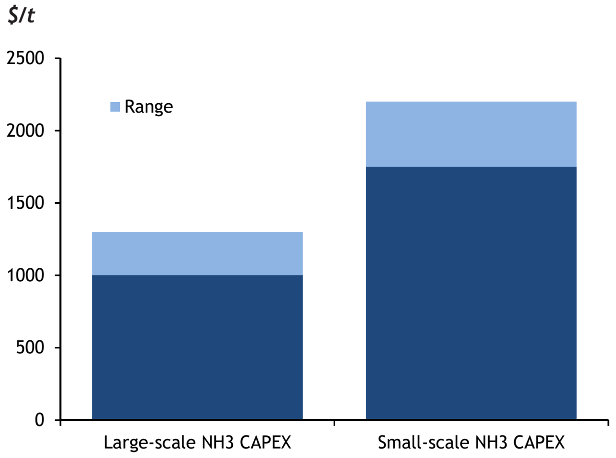
Capital costs considerations – is there a future for small-scale ammonia plants?

Since existing ammonia capacity is largely already utilised, future demand for ammonia from marine and other applications will require significant additional supply investment. From a capital cost perspective, economies of scale still favour conventional ammonia plants. Most of the green ammonia projects are small-scale. However, with shrinking electrolysis unit costs this gap is expected to narrow in the medium to long term.

An important factor to consider for green ammonia project is the plant size. The average size of today's wind and solar power plants could not support a standard Haber-Bosch ammonia plant. As a result, green ammonia project activity has been focusing on small-scale ammonia production, which currently implies higher capital intensity compared with conventional plants.

Recent greenfield investments in standalone ammonia plants had a capital intensity of $1,000-1,300/t per year of capacity, depending on the location and year of construction. Conventional wisdom suggests that smaller plants, with capacities under 200,000 tonnes per year, are less competitive. Indeed, recent small-scale investments in ammonia capacity were in the $1,750-2,200/t per year range. Recently, Proton Venture's green ammonia project in the Netherlands estimated a capital expenditure equivalent to $1,700/t per year, although we recognise that it is still in its early stages, and that capital costs might eventually be higher.

Figure 4: Ammonia capital intensity, 2015-2020 averages (based on conventional gas-based plants)



— *Argus Media*

Operating costs – the biggest hurdle

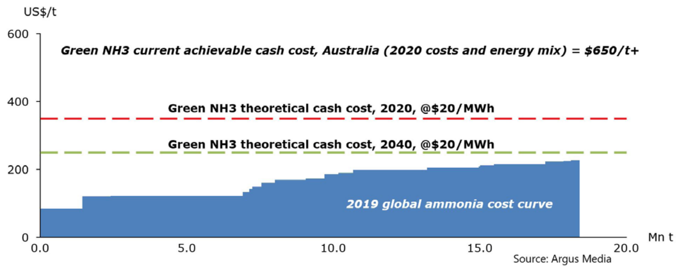
Availability and cost for green electric power is another key driver, and certainly the main issue that needs to be considered when we look at the long-term economic feasibility of green ammonia.

According to Argus estimates, at current electricity prices the levelized cost of hydrogen in Australia (a country chosen as an example due to the significant green ammonia project activity) would be around $4-5/kg, which would result in an ammonia cash cost of over $650/t (assuming 2020 costs, technology, energy mix and an average electricity cost of $50/MWh). This cash cost only refers to operating cost, excluding capital costs for both hydrogen and ammonia itself.

Things would get more interesting if electricity prices dropped below $20/MWh, a price at which the levelized cost of hydrogen would drop to $2.30/kg, and result in a cash cost of ammonia of around $335-340/t. Taking into account reasonable assumptions for long-term efficiency gains, we are assuming that a levelized cost of hydrogen could drop below $1.50/kg by 2040, which in turn would allow ammonia cash costs in the $245-250/t region (roughly the cash cost of production of a plant supplied with $6/mmBtu gas).

Despite these encouraging figures, we must stress that even considering long-term efficiency gains and lower levelized cost of energy for renewable energy, green ammonia will struggle to be competitive with brown ammonia. Most of the recent ammonia plants were built on the back of extremely competitive gas prices, which in most cases were lower than $3/mmBtu, which implies an ammonia cash cost of $140/t, with many world-scale recent projects achieving <$100/t (as shown below).

Figure 5: Global ammonia cost curve and green ammonia cost estimates



Therefore, a key component of the commercial adoption of green ammonia in the future will be the level of incentives provided or regulation enforcing its use. The most likely incentive could come in the form of CO_2 taxation and credits. Taking as an example the current CO_2 pricing in Europe of $25/t, and estimated average emissions of 1.2-1.6t of CO_2 per t of brown ammonia (based on current technology), it is clear that the potential application of such CO_2 taxation or credit system could be a big driver towards the adoption of green ammonia as a carbon-free energy carrier. We assume that based on the lowest green ammonia cash costs achievable today (i.e. above $300/t), CO_2 prices would have to climb at least above $50/t to level the playing field for green vs. brown ammonia.

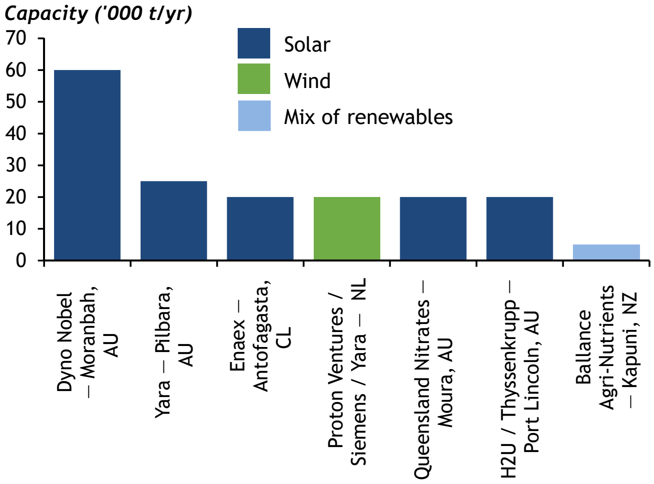
Regulations could play a pivotal role for the adoption of green ammonia, similarly to how they incentivised investments in renewables. For instance, legislation from the IMO could enforce absorbing the higher cost of ammonia in marine application. In addition, the implementation of a two-tier pricing system for ammonia (for any application), similar to power markets, would also provide additional support to green ammonia.

Green ammonia projects

Recognising the future potential of ammonia as a fuel or feedstock, there are several green ammonia projects currently under development. As mentioned previously, most of these projects are pilot scale with an expected capacity of 20,000-60,000 tpy. Interestingly, most are located in Australia, a country that has been investing significant resources in developing a green hydrogen economy.

Despite the small scale of these projects, we recognise that in some cases there is a possibility that the higher costs of green ammonia can be absorbed by the presumed benefit of being able to sell carbon-free products manufactured with ammonia (e.g. nitrates and other industrial products).

Figure 6: List of green ammonia projects



— Ammonia Energy Association, Argus Media

Conclusion

Although at present the economics of green ammonia are not particularly favourable, it is possible that with significantly lower capital costs, efficiency gains, aggressive decarbonisation policies and lower renewable energy costs, a significant market for green ammonia will develop in the long term. There is real potential for adoption of green ammonia in traditional fertilizer and industrial markets, especially from end users who are willing to pay a premium for carbon-free ammonia. In addition, with the right incentives, we can foresee scenarios in which the market adoption of ammonia in energy applications could outstrip demand for traditional ammonia applications such as fertilizers.

We also note that a gradual transition can be made possible by the fact that existing ammonia producers can use green hydrogen as a feedstock mixed with hydrogen produced from steam reforming, therefore allowing for a gradual increase in their carbon-free feedstock component.

In addition, the shipping industry could use brown ammonia as a stepping stone to transition to green ammonia in the medium term, thereby impacting the existing ammonia market, and providing further support for alternative uses for ammonia.

Argus Consulting Services and our work in green ammonia

Argus has an established track record of delivering bespoke client studies through its Consulting Services division and has undertaken a wide range of market studies across a full range of products, including energy, fuels and fertilizer products – with increasing analysis of green ammonia.

Recent project examples

Client: A major nitrogen fertilizers producer.

Task: Industry overview and analysis of the competitive position of a proposed major nitrogen greenfield project.

Result: Argus provided an overview of the nitrogen market, including demand, supply and price forecasts for regional, domestic and international fertilizer markets. The study included an analysis of the competitive strengths and weaknesses of the project relative to existing and potential competitors, as well as an analysis of all the possible product options for further upgrading of ammonia and urea, including the potential for green ammonia.

Client: A major bunker fuel trader.

Task: Ammonia industry overview and ammonia logistics analysis, with the aim of supporting internal study of ammonia as a marine fuel.

Result: Argus provided an overview of the global ammonia market, including demand, supply and price forecasts, as well as an overview of the current cost structure of the industry. In addition, Argus provided a comprehensive dataset with key data on over 200 ammonia terminals globally, with information on terminal owners/operators, capacity and port data.

Client: Singapore Prime Minister's Office (PMO): Roadmap to decarbonising the economy.

Task: The Singapore government's planning division (PMO) commissioned a study to assess the viability of developing a green hydrogen-based supply chain, with focus on applications in power generation and transportation.

Result: The potential demand for hydrogen for the economy was examined at the sectoral level. The magnitudes and the entry price levels for each of the sectors was established. Thereafter, the most viable sectors were examined in greater detail, including a detailed cost analysis of the most likely hydrogen carriers, including ammonia.

Questions? We'd be happy to address questions and explore how we can support you in capitalising on this emerging sector. Please contact us directly at **fertilizer-m@argusmedia.com**

More about Argus and our consulting services

Consultancy portfolio	Types of work
Market studies (Market demand, supply or price focused)	Market entry or evaluation Competitor analysis Marketing and sales strategy Sourcing strategy Supply chain analysis
Marketability (Price focused)	Pricing support Support for off-take agreement negotiation
Project evaluation or financing (Project focused)	Project evaluation for financing/permitting, e.g. (pre-) feasibility/scoping studies
Transaction support (Company focused)	Process, procurement or sales improvement Benchmarking
Performance improvement (Operation/company focused)	Process, procurement or sales improvement Benchmarking
Regulatory and policymaking advice	Advice on policy
Other types	Litigation Survey/interview Event attendance Expert opinion

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