Briefing Sheet

Stirling Infrastructure PARTNERS LTD

Hydrogen

Ammonia

www.stirlinginfrastructure.com

INTRODUCTION

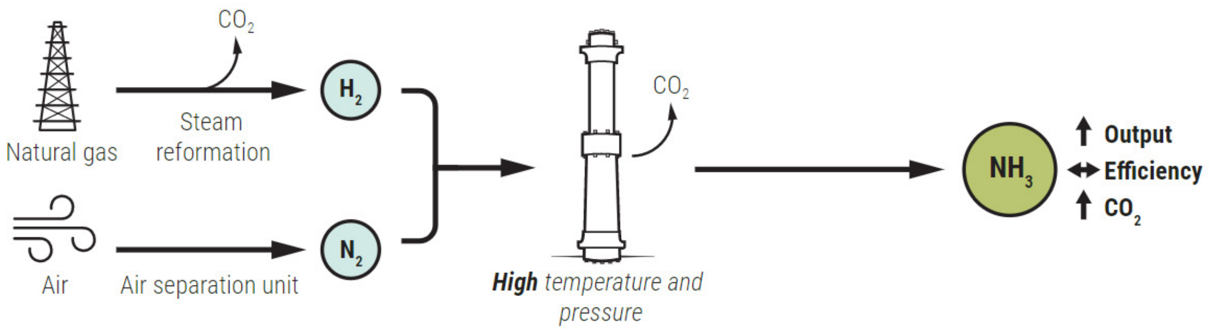
Ammonia has two major use cases: fertiliser and zero-carbon fuel. Since the invention of the Haber Process to produce ammonia at a large scale, it has been one of the most important and widely produced chemicals in the world thanks to its indispensable role as fertiliser in agriculture: currently around 180 million tonnes of ammonia is produced annually and 70%, 126 million tonnes, is used in the fertiliser industry.

Currently ammonia production constitutes the largest demand for hydrogen as its feedstock with 55% of global hydrogen production going into ammonia synthesis. Because of its strong presence in the fertiliser industry over the decades, there is already safety know-how and established infrastructures to store and transport ammonia globally.

PRODUCTION OF AMMONIA

Ammonia is produced through the Haber Process, a century-old chemical process, which uses nitrogen and hydrogen as feedstocks. They are pressurised and fed into a reactor with high temperature and pressure and iron as catalysts to speed up reactions. Hydrogen gas is produced on-site from either natural gas through Steam Methane Reformation (grey hydrogen) or from coal through coal gasification (brown hydrogen), while nitrogen gas is extracted directly from the air of which over 70% is nitrogen. Currently most ammonia plants globally use natural gas as feedstock except for China, where most plants still use coal which is more polluting than natural gas. The fact that current ammonia production still relies on fossil fuels to produce hydrogen leads to a substantial amount of carbon emissions, accounting for 1.8% of total global carbon emissions. To make the process more environmentally friendly, instead of using natural gas and goal, hydrogen can be produced on-site through water electrolysis from renewable electricity (green hydrogen) which leads to zero carbon emissions for hydrogen production. As no pollutant gases like carbon dioxide and sulphur dioxide are produced, production units to remove these gases are no longer needed so that the design of ammonia production plant can be simplified. There are already some green ammonia projects announced. For example, Air Products, Acwa Power and Neom plan to build the largest green ammonia plant in Saudi Arabia with an annual capacity of 1.2 million tonnes by integrating 4GW of renewable power from solar and wind.

Figure 1 - Ammonia production, Source: IRENA



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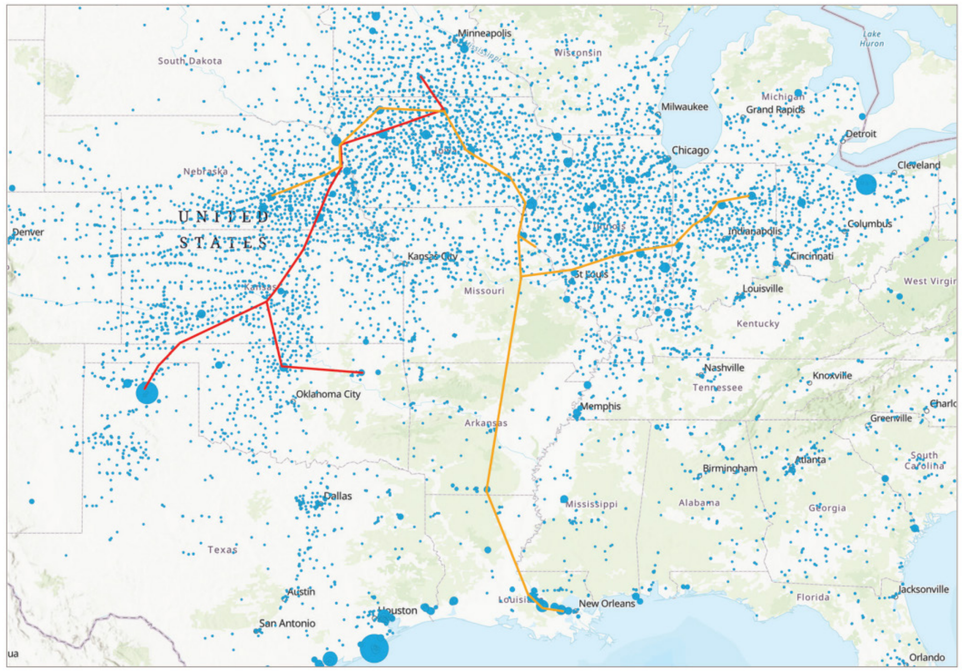
AMMONIA AS FERTILISER

Existing infrastructure

There are many existing ammonia production plants all over the world, and current ammonia production plants only need minor modifications to introduce green hydrogen for decarbonisation which involves replacing SMR facilities with electrolysers and sourcing renewable electricity from grid or island solar/ wind farms. There is also an established network of ports in the world that handle ammonia at large scale, which facilitates the international trade of ammonia. Considering ammonia's use case as fertilisers, most countries have ammonia pipeline and storage units. For example, in the United States, the fourth largest ammonia production country in 2019, had 3,281 km of ammonia pipelines in operation (with an annual transport capacity of 2 million tonnes) together with 10,000 ammonia storage units.

Figure 2 - Ammonia Infrastructure in USA

Liquefied ammonia storage and pipeline distribution networks in the US Mid-West[7]. The Kaneb (orange line) and Magellan Midstream (red line) ammonia pipelines are respectively 2,000 miles and 1,100 miles long.



Note: The Magellan Midstream pipeline will be decommissioned in 2020.
Circle areas are indicative of ammonia tonnage. The largest circles correspond to 100,000 tonne facilities. 2

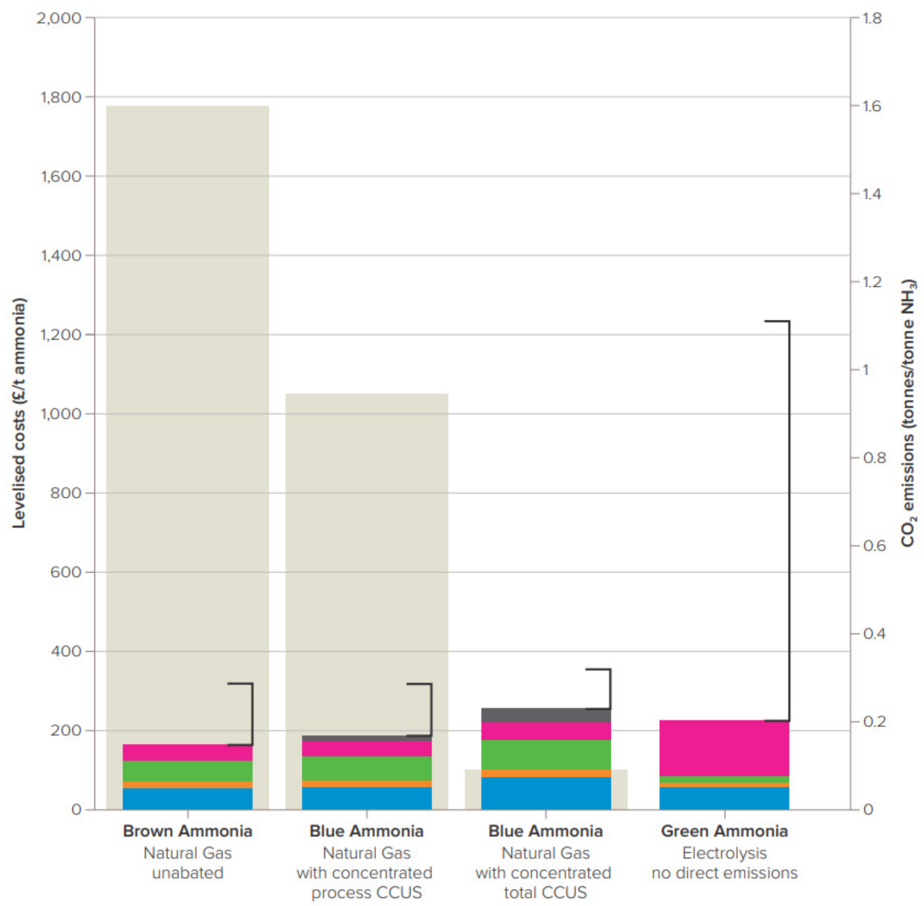
1 https://www.sciencemag.org/news/2018/07/ammonia-renewable-fuel-made-sun-air-and-water-could-power-globe-without-carbon
2 https://royalsociety.org/-/media/policy/projects/green-ammonia/green-ammonia-policy-briefing.pdf

Risks

Currently the cost of producing green ammonia is high, about two to three times higher compared to that of conventional ammonia. This is largely due to the price of renewable electricity, which makes up 85% of the total cost, for producing green hydrogen because renewable electricity is much more expansive than natural gas in most counties.

While the ammonia industry is still carbon intensive using natural gas as feedstock, there are low incentives for governments to decarbonise the fertiliser industry for political reasons. Governments are under pressure to exempt the fertiliser industry from carbon tax due to concerns of rising food prices, which could potentially lead to lowered living standard for the poor and a lost competitiveness in the international food export market. Direct subsidies to green ammonia plants might not be a long-term solution as well, as the cost of green ammonia is not a matter of economic scale but of the cost of renewable electricity.

Figure 3 - Ammonia production cost breakdown by method



Note: Range refers to the range of total levelised costs across regions, the lower end of the range is disaggregated into cost categories. Electrolysis is assumed to be powered by 100% renewable electricity; the 'feedstock cost' is the electricity for the electrolyser, and 'fuel cost' is additional electricity for the air separation unit, synthesis loop etc. CCUS costs include capture, transport and storage of carbon dioxide; process CCUS is only process emissions; total is process and energy related 3

According to The International Energy Agency, by assuming a gas price at 3 to 10 US cents/MMBtu, electrolysis is cost competitive with Steam Methane with electricity prices between 1 to 4 US cents/kWh. However, from research on renewable power generation costs in IRENA, global electricity costs from solar PV, onshore wind and offshore wind are 6.8, 5.3 and 11.5 US cents/kWh respectively.[4]

Although current renewable electricity prices remain high globally, as more renewable power generation plants are installed, and more countries roll out their national decarbonisation plan, we expect green ammonia to be cost competitive with conventional ammonia soon. On a country scale, in countries with abundant renewable potential like Chile and Saudi Arabia, auction prices of electricity from solar PV are 3.2 and 2.3 US cents/kWh respectively, and green ammonia projects in these countries are already announced.

3 https://royalsociety.org/-/media/policy/projects/green-ammonia/green-ammonia-policy-briefing.pdf
4 IRENA (2019), Renewable Power Generation

AMMONIA AS A ZERO-CARBON FUEL IN THE MARINE INDUSTRY

Ammonia as a zero-carbon fuel

Ammonia has the potential to be a marine fuel thanks to its relatively high energy density and zero carbon emissions nature. Compared with pure liquid hydrogen, ammonia as a hydrogen carrier is less energy intensive to transport and store and has a higher energy density by weight. Thanks to a long history of handling ammonia as fertiliser, there are already established methods regarding the transportation and storage of ammonia. Compared with diesel and petrol, ammonia is less energy dense but there is zero carbon emission when using ammonia as a fuel by either direct combustion in engines or electrolysis in fuel cells.

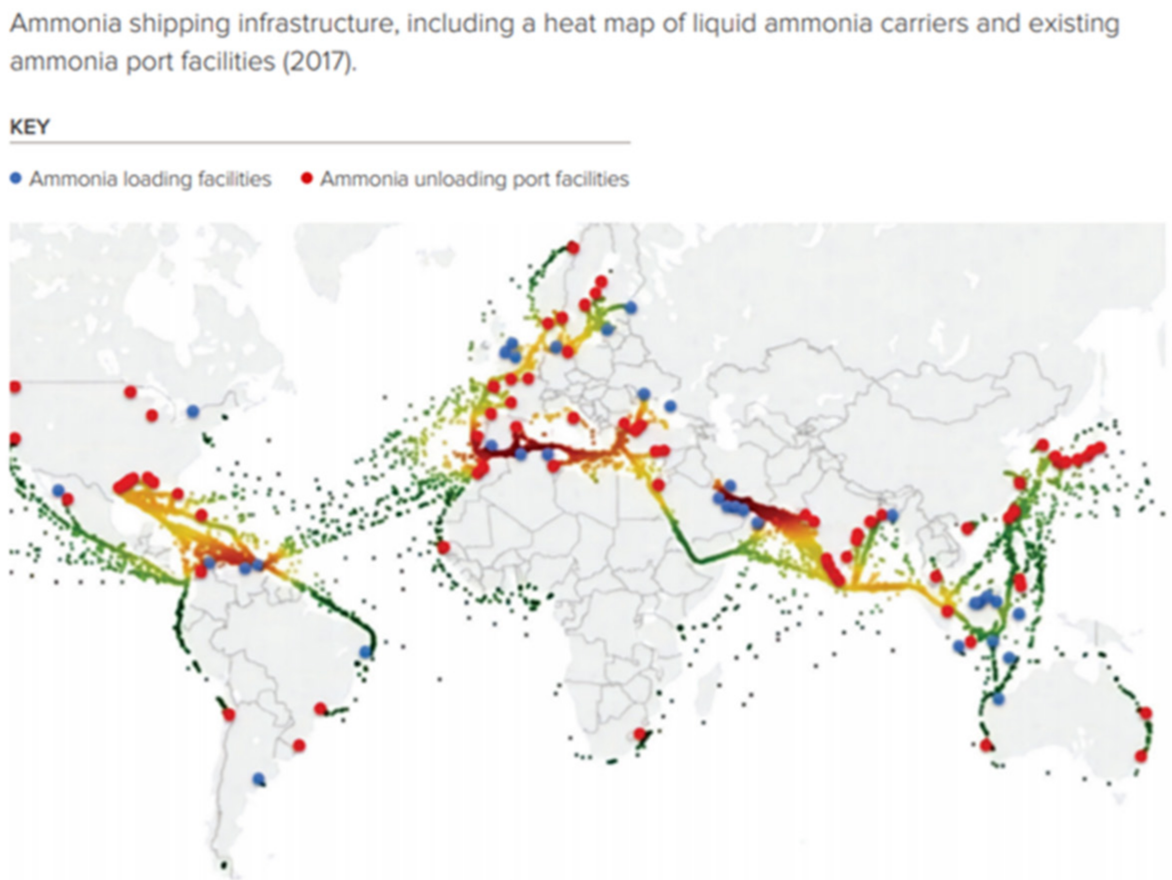
Ammonia in road and marine transport

Ammonia has potential to be a fuel in heavy industries because its significantly higher energy density than batteries is able to meet the demand for energy for heavy duty vehicles on road and in seagoing marine vehicles. While it is costly to build a network of refuelling stations for ammonia on road and dangerous for ammonia-powered vehicles to carry pressurised ammonia storage tanks, marine industries can make use of existing ammonia storage sites in ports to be refuelling stations and safety issues are not a big concern. Seagoing vehicles like cargo vessels travel on sea where there is low population density, and decades of industry experience to transport ammonia on sea at a large scale has proved the feasibility to store and transport ammonia on ships safely.

Existing infrastructure

There is a well-established network of ports worldwide that handle ammonia at large scale making refuelling of ammonia easy and possible. As ammonia has been traded internationally on sea for decades, there are existing loading and unloading facilities and large scale ammonia storage tanks in ports. This combination of these two kinds of facilities lays foundations of building potential ammonia refuelling stations for ammonia-powered ships. As an example of scale, there is an ammonia storage tank in the port of LA with a capacity of 150,000 tonnes.

Figure 4 - Existing Ammonia Infrastructure in port



Risks

Little progress has been made in the decarbonisation of the marine industry because of unengaged government attitudes and slow technological developments in ammonia-based engines.

Compared with the decarbonisation of road transport, governments pay little attention to marine transport. No countries have set up plans to ban fossil-fuel ships, but in contrast the EU plans to ban fossil-fuel road vehicles by 2035. Nevertheless, most countries do not take emissions from the marine industry into account when outlining their carbon neutral strategies for 2050. The International Maritime Organisation (IMO), a specialised agency of the United Nations responsible for international shipping, has yet to include ammonia as a legitimate marine fuel. Although the IMO has a decarbonisation plan to cut emissions by 50% compared to 2008 by 2050, its top priority is to stick with conventional fuels and reduce emissions by boosting engine efficiencies and limiting speed.

Due to a lack of government support, private sectors are hindered by these uncertainties to develop ammonia-based engines: no prototype of ships based on ammonia has been completed yet. However, efforts have been made to develop engines powered by ammonia. Current research focus, which is at a very early stage, is to develop internal combustion engines that burn ammonia directly instead of through ammonia fuel cells. To give an example of current progress in ammonia engines, Man Energy Solution, a German ship engine manufacturer, is cooperating with a group of tech companies in Denmark to develop dual fuel internal combustion engines that can burn ammonia as well as diesel. This dual fuel engine aims to offset the uncertainties and cost of building entirely new engines if ammonia fails to be the mainstream fuel in the future.

STIRLING INFRASTRUCTURE'S VIEW

Ammonia production is likely to be one of the first industries to adopt green hydrogen for decarbonisation. From a scientific perspective, decarbonisation of ammonia production is straightforward by replacing SMR facilities with electrolysers without significant modification to their overall design. From an economic perspective, cheap renewable electricity prices in some countries already gives the ammonia industry an advantage to produce green ammonia at a comparative cost compared with conventional ammonia. As renewable electricity prices decrease further in the future, we expect to see a strong demand for green hydrogen in the ammonia industry for fertiliser production. Ammonia's potential in marine fuels is huge but it is not expected to become significant in the next two decades unless governments are more engaged in decarbonising the marine industry.

APPENDIX

CASE STUDY: YARA

Yara, headquartered in Norway, is one of the largest ammonia manufacturers and distributors in the world, and is pioneering a transition into green ammonia production. It has ammonia production plants all over the world, including countries with abundant renewable capacities, showing great potential to produce green ammonia at a competitive cost. Yara's decarbonisation plan has two initiatives, firstly decarbonise existing ammonia plants to be green by plugging in electrolysers while secondly building new green ammonia plants.

An example of the first initiative is Yara Pilbara Hydrogen Hub. Yara is cooperating with Engie to turn the largest ammonia production site in the world, located in Pilbara, Australia, into a green plant. With current production capacity of grey ammonia with 850,000 tonnes per year, Yara plans to build a 10MW electrolyser and on-site facility of 18MW PV panels to generate hydrogen as an additional 0.6% of current inputs, with an objective of 3700 tonnes of green ammonia per year.

The second example is Yara's green ammonia project in Porsgrunn Norway. This new green ammonia plant is expected to have a production capacity of 500,000 tonnes per year by using electricity from Norway's energy grid, which is 98% renewable thanks to abundant hydroelectric resources. Yara's intention is for the green ammonia produced from this project to be particularly used as marine fuel.

With the completion of these pioneering projects, Yara is able to represent to the world the feasibility of decarbonising the ammonia industry through green hydrogen. It is also demonstrating its confidence in future green ammonia demand in fertiliser and marine fuel use, which coincides with our conclusion that ammonia production is likely to be the first industry to adopt green hydrogen.

FOR FURTHER INFORMATION

This paper provides insights into allocating capital into the hydrogen value chain.

The firm provides a comprehensive range of services which includes M&A transaction services and raising both debt and equity to finance hydrogen projects globally.

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