BLACK & VEATCH

Ammonia for Energy:

A Green Hydrogen Catalyst for APAC?

Contents

Introduction

Hydrogen (H_2) has emerged — with its potential as a low or zero emissions fuel source — as a critical consideration for energy producers and providers, large intensive users of energy as well as governments planning to achieve a sustainable future. In turn, and often less discussed, Ammonia (NH_3) is one of the front runners to transport hydrogen by ship throughout maritime Asia Pacific (APAC). This ebook serves as an introduction to Ammonia's role in the energy equation, for new investors in ammonia infrastructure and highlights a number of areas for further investigation and discussion such as often overlooked importance of water management, co-firing of ammonia at power generation facilities, and the potential of reducing the carbon foot print of food (fertilizers), itself a source of energy.

The energy transition is complex and challenging. The reality is that the green hydrogen economy does not exist today; most predict and discuss hydrogen maturation in the context of decades i.e. where will we be by 2030, or even 2050? Over the last few years, as interest in hydrogen as an energy transition fuel has accelerated, we have seen governments set forth hydrogen strategies and incentivize pilot production and research. Commercial developers throughout the region have proposed dozens of large green hydrogen developments and commissioned multiple early-stage project feasibility studies and research.

Arriving at commercial feasibility is not easily achieved, however, given current market dynamics. Scale and time are required to bring down electrolyzer costs and improve efficiencies, and given maturity levels, government subsidies and incentives play a critical role in advancing projects. In addition, and often less appreciated, to truly arrive at commercial success, subsidies for offtakers are vital. While some buyers will accept a small premium for green hydrogen (to an extent), governments and the nascent hydrogen industry must create the right conditions for hydrogen to be competitive and encourage market takeoff.

With effective business plans, some of these projects have advanced and secured the right level of financing, such as the Advanced Clean Energy Storage (ACES Delta Hydrogen Hub) Project in Utah, United States, where Black & Veatch is engaged in project delivery. It really boils down to finding the right business model and implementation strategies. While the costs and technologies for green hydrogen continue to trend in the right direction, the industry may find that business models that essentially lower the carbon footprint of existing facilities may form the best entry point as the corporate world and governments seek commercially viable approaches to curb climate change.

What's more, not all hydrogen projects will emerge as mega-scale facilities with large scale industrial off-takers located on their doorstep. Where it makes sense to produce hydrogen — supply centers — won't always match with where users will live and use the energy — demand centers.

Blue hydrogen production will occur near natural gas supply infrastructure and incorporate carbon capture into the processing. Likewise, green hydrogen production requires availability of natural renewable energy resources — solar, wind, hydropower.

How will we move hydrogen efficiently to buyers located further afield? Hydrogen will require transportation from point of production to end-use and, in APAC, this will sometimes demand transportation across seas distancing hundreds or even thousands of kilometers. Just as methane is liquefied to LNG, the very low density of hydrogen gas requires an additional step before shipping. When compared to the liquefaction approach used with LNG, converting hydrogen to ammonia has emerged as the most efficient and market ready method for the scale needed to transport hydrogen to countries where production resources are not adequate.

A robust global infrastructure already exists for the production and transport of ammonia. Expanding from this base for ammonia can serve as a near-term catalyst for stimulating further hydrogen investment and speed the maturity of the market.

A Little Bit about Ammonia

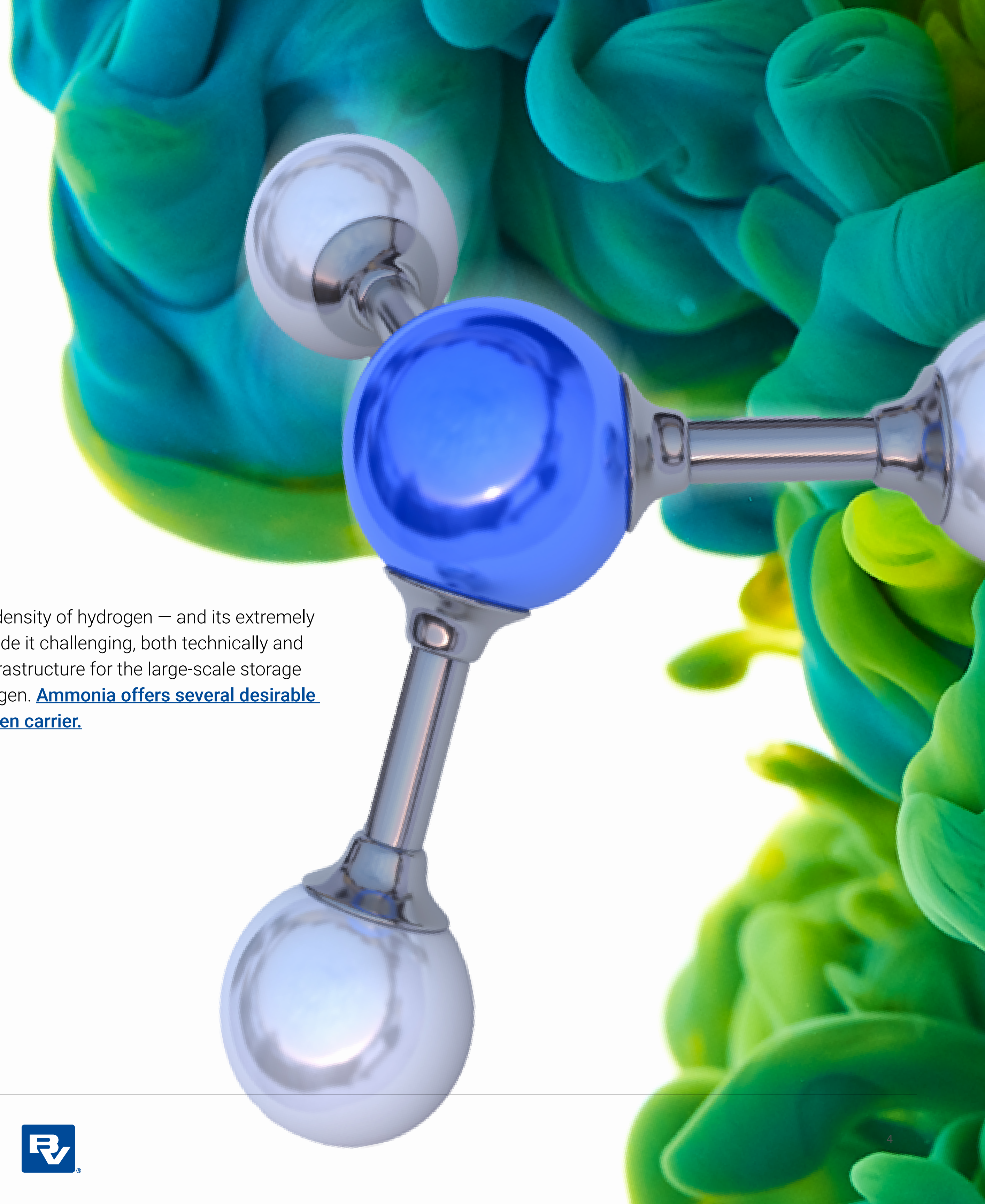
After Fritz Haber and Carl Bosch (the Haber-Bosch method) successfully synthesized ammonia in 1909, ammonia played an important role in feeding our growing planet post World War I, with commercial production advancing throughout the world. More than 60 percent of ammonia is used for fertilizers globally today with other uses across refrigeration systems, explosives, and textile and pharmaceutical production.

Ammonia has been a rewarding, stable business, with one percent annual growth and an investment profile that closely mimics food security investments. It is gaining attention in other applications as the world plans its pathway to a carbon-free energy future.

A gas at room temperature, ammonia is incredibly stable and can be easily liquified for storage and shipment around the globe in the same fashion as liquefied natural gas (LNG), taking advantage of much existing logistical infrastructure. It can be used across energy-intensive industries in several ways, helping to lower our carbon footprint.

Made up of one nitrogen and three hydrogen atoms (NH_3), ammonia can also be decomposed or "cracked" to produce hydrogen along with nitrogen, a non-toxic, nongreenhouse gas. Ammonia produced from renewable energy ("green ammonia") can serve as an energy storage medium, able to store electricity during high periods of production and transport that energy to parts of the globe with limited access to renewable energy sources. Ammonia can also be burned directly as a carbon emissions-free energy source, thanks to the development of new technologies that produce ammonia from renewable energy or reforming of methane with CO_2 capture.

The low volumetric energy density of hydrogen — and its extremely low boiling point — have made it challenging, both technically and economically to develop infrastructure for the large-scale storage and transportation of hydrogen. **Ammonia offers several desirable characteristics as a hydrogen carrier.**



Current Ammonia Supply Challenges: a Sellers' Market Ahead

The global ammonia supply market is under strain to meet demand for existing uses and customers.

150 million tons were produced in 2021. Facilities across Russia and Ukraine combined accounted for more than 10 percent of global production with capacity of more than 18 million. Considering these two nations remain at conflict (at time of writing), the impact of the COVID-19 pandemic, the shut down of many ammonia facilities across Europe reliant on off-now, on-now gas from Russia, Gulf Coast spot prices for ammonia have surged from approximately US$250 per tonne in 2019 to US$500 in October 2021 to highs of US$800 by early 2022.

In addition, for example, these volatile trading markets and supply constraints meant that Australia found itself with less than one month's supply of DEF (Diesel Exhaust Fuel, a derivative of urea and essential for emission control in diesel engines in the transportation sector) in early 2022.

Other Asia Pacific nations were more insulated from these impacts, given across Asia ammonia production largely resides with the government sector. This means pricing is artificial and mostly subsidized to keep food prices under control.

Heavily populated China, India and Indonesia are the first, fourth and fifth largest producers of ammonia, respectively, and treat the industry as strategic for their national interests. China pursued the coal gasification route to ammonia/urea production and flooded the markets with cheap urea. However, due to environmental issues and poor operational efficiencies, China has had to shut down about 3 million tons of urea capacity between 2019 and 2021. During the same period, India added about 6.5 million tons of additional urea capacity, continuing to lower its dependence on global supplies.

The bigger picture for ammonia production and related infrastructure investments is that even with 150 million tons of production in 2021, supply-side wires had been tripped (before the Ukraine-Russia conflict), signaling that the market is ready for green field capacity. What incumbent producers and the investment community must bear in mind is how ammonia for energy gains momentum, and how these additional demands will maintain a sellers' market and create opportunities for much further growth.

5 reasons why ammonia could emerge as a predominant hydrogen carrier

1. Like hydrogen, Ammonia (NH_3) does not emit CO_2 when burned
2. Ammonia can be stored and transported as a liquid under modest pressure and temperature conditions (it has a better volumetric density than hydrogen, about 45-percent higher than that of liquid hydrogen; more hydrogen can be stored in liquid ammonia compared to liquid hydrogen with the same volume)
3. The ammonia industry is mature dating back to the early 20th century, with proven production, storage and liquid transportation methods at scale
4. A large ammonia market already exists and can be leveraged as we transition to greener and larger production facilities, of which uses could include:
   - Ammonia could be co-fired directly with coal to significantly reduce emissions at many newly built coal facilities across Asia Pacific
   - Ammonia can be used directly to power shipping vessels with estimates that 25 to 30 percent of shipping fuel could be ammonia by 2050
   - Ammonia also has potential as a blend with jet fuel
5. Much existing LNG infrastructure may be readily and effectively repurposed to export and import ammonia

5 challenges facing ammonia for energy development

1. Building and upgrading new facilities and import/export infrastructure is capital intensive
2. Ammonia processing facilities are complex; without the right experience, new entrants may face challenges developing and operating these facilities successfully
3. Without direct use, converting ammonia back to hydrogen or into other products will lose energy through the process and be an additional cost to bear
4. Ammonia production is a water intensive process with every ton of ammonia requiring 3-5 tons of water
5. Ammonia is a toxic substance that must be handled with care and while ammonia itself does not emit CO2 during combustion, it can produce nitrogen oxides (NOx) when burned in internal combustion engines

Ammonia for Energy: Asset Acquisition Planning for New Entrants

With expectations that existing demand will outstrip supply for a number of years ahead, the world's new drive for ammonia for energy could see a twenty to thirty year decarbonized or green capacity building cycle. Investments into new build ammonia facilities could scale between US$200 billion to US$300 billion over this period. And this forecast does not include additional and significant requirements to invest in end-of-life replacement of existing older plants.

Ammonia is a commercially and technically complex global business with many risks that need to be managed, mitigated and navigated around during asset acquisition planning:

Political considerations *(taking a short-, medium- and long-term view)*

- Geo-political impact on global trade
- Given strategic food security links, the ammonia markets are subjected to continuous tinkering by governments (e.g. at 147 million tons of production capacity in 2020 there was a perceived supply glut)
- Urgency of meeting farm demand at prices that will keep food quantity and prices affordable
- Countries tend to drive towards captive production

Planning complications

- Ammonia facilities are highly complex facilities with multiple upstream and downstream considerations
- Taxation, subsidies and environmental regulations can change with local or national level jurisdictions, and further change over time, setting up a perpetually in flux playing field

Uncertainty of the Ammonia-for-Energy market:

- With more than 180 proposed decarbonized ammonia projects globally, the use of ammonia as decarbonized energy may swing from one extreme to the other, as the frenetic search for sustainable energy continues

Emergence of new technologies:

- Ammonia as a fertilizer may get obviated or demand significantly reduced through genetic research
- Technologies emerge that potentially produce and deliver ammonia on the spot at the farm
- Multiple new technology options, from biogas to electrolyzers, that have not been proven commercially

Facing this multi-dimensional complexity, developers of future ammonia infrastructure must test the validity of a project's business case through project front-end loading (FEL) phases. The FEL phases are small bets in terms of capital, until the opportunity's credentials are well established for a financial investment decision (FID). The project definition rating index (PDRI) process developed by the Construction Industry Institute (CII) provides quantitative and objective assessment of sufficiency of FEL phase work performed.

FEL-0 — The Business Innovation Phase: This is not a standard front-end phase, and helps an organization prepare for specific project for the FEL process. Typically part of an organization's innovation and strategic planning process, investment opportunities are identified and understood by the organization on a broad or programmatic scale.

FEL-1 — The Business Definition Phase: This is an important phase in which the organization lays down its business case including:

- Categorical and unequivocal go and no-go criteria for the investment
- Definitive market studies
- Evaluation of buy, merger and build options

The FEL-1 phase business case establishes the investment premise that must remain valid for the project to be implemented, and an AACE Class 5 order of magnitude estimate confirms the investment premise.

FEL-2 — Facility Definition Phase: Defines the scope of the facility to be built and generates an AACE Class 4 estimate, based on a technology selected for the asset. The phase needs to confirm that the investment premise established in FEL-1 still holds.

FEL-3 — Project Definition Phase: This phase is where the scope of work developed during the FEL-2 is married to a project execution plan. Project definition is developed further by developing engineering to 15 to 35 percent and thus getting a better glimpse of the shape and size of the undertaking. This phase will generate an AACE Class 3 investment grade estimate. If the project makes the cut, a financial investment decision (FID) is made, and the project goes for implementation.

Project Implementation Phase: Given the long gestation period of these asset acquisition programs, it's highly recommended to confirm the validity of the business case with an AACE Class 2 estimate at 60 percent engineering development stage.

A Strategic Approach to Asset Acquisition

Ammonia Production is Water Intensive

How ammonia production facilities manage water will be a future and growing concern for buyers as they seek more sustainable products, using less water and energy. Did you know that for every ton of ammonia produced at traditional facilities today, three to five tons of water is required? And as the industry transitions to green ammonia production, water management issues will remain a key operational concern for owners.

In the conventional process, methane and water each contribute about half of the hydrogen in the syn gas, whereas water provides 100 percent of the hydrogen for electrolysis. Coupled with the very large cooling demand of electrolysis, the result is green ammonia has higher water demand than the conventional method. What's more, if the forecasted doubling of global ammonia demand is achieved by 2050, the demand for water will be compounded further.

This means water management plans and strategies should be essential components of any ammonia project FEL process. Many existing ammonia facilities today feature poor water management system designs or are already constrained by water usage limitations.

Ammonia developers must factor the growing importance of both water availability and the associated disposal costs of wastewater into facility investment plans. Such foresight will lead to early engagement with permitting processes to understand water limitations of the site. For example, even if there is plentiful river water or groundwater nearby, project planning needs to understand the withdrawal limits. Water treatment costs will vary with the level of contaminants in the water as well. For instance, treatment of water to increase cycles of concentration in the cooling water system may be necessary to meet withdrawal limits or discharge limits.

The main water users in traditional ammonia and fertilizers facilities are:

- Feed for chemical reaction to generate syn gas generation;
- Evaporation, mist carryover, and blowdown from the cooling tower;
- Steam vents, condensate drains, boiler blowdowns which are not recovered;
- Wastewater generation from the production of demineralized water;
- Fractional water content in ammonia, UAN, and urea products.

Focusing on system design in these areas during FEL development phases is recommended, inculcating a view of life cycle costs and ever tightening regulatory regimes.

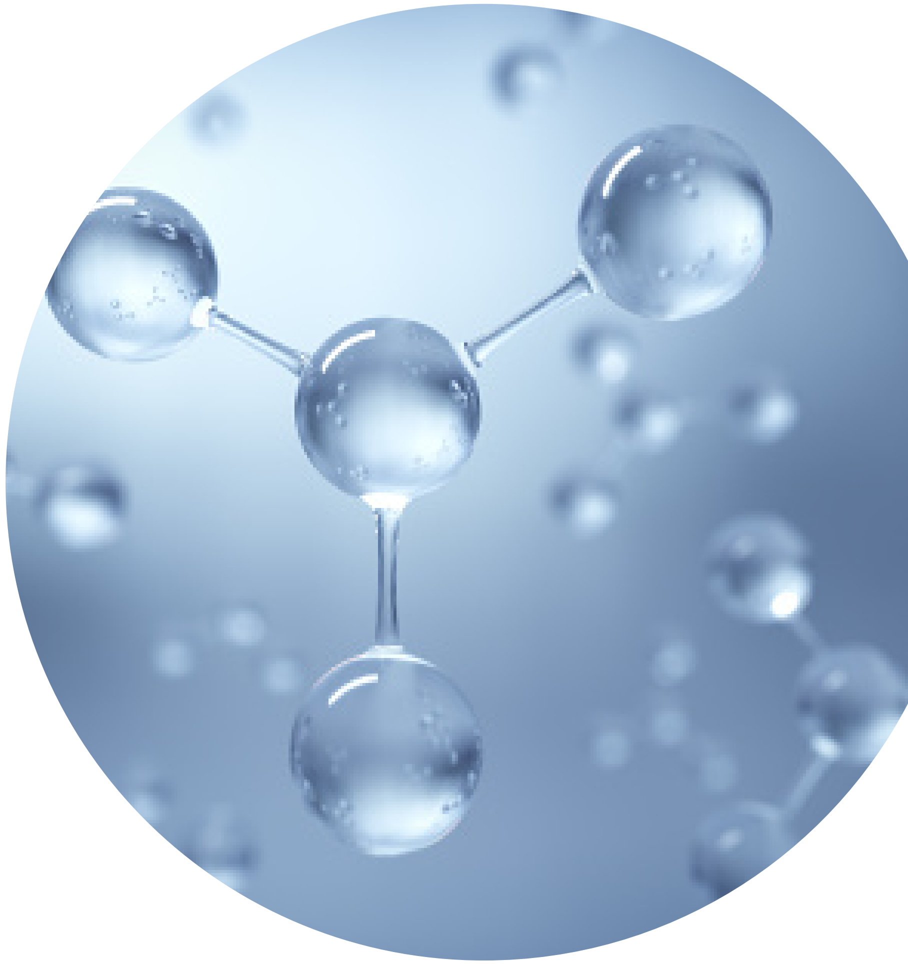
Gaining a clear understanding early in project development of the regulations and permits — for example, heavy metal contaminants in the water that may result from pumping local groundwater into a cooling tower system — could impact water discharge considerations.

Water recycling may be an option to minimize wastewater and overcome supply limitations. Compiling a comprehensive plant water balance, with particular attention to water quality and analysis through individual processes, can help to identify opportunities for re-use or recycling. Many facilities overlook being able to re-use process condensate, for example.

During either new plant or upgrade projects, efficiencies can be designed into water treatment systems, leading to lifecycle saving managing the cost of water use and chemical disposal. For example, selecting an electro deionization system for your final demineralized water polishing step in lieu of a chemically regenerated mixed bed eliminates the need for the chemical regeneration, and does not produce the chemical water that is sometimes difficult to dispose.

Operationally, the biggest water user in the plant is typically the cooling water system. Minimizing cooling water usage can reduce treatment chemical costs, lower pumping costs, lessen resultant blowdown leading to lower wastewater treatment or disposal costs and more.

By setting clear water management strategies early in development, owners can offset many future challenges and also incorporate designs that will improve overall plant reliability and operational cost. It is a consideration often overlooked but is of critical business value.



Australia's Ammonia Ambitions

It is estimated that Australia will invest $1.4 billion in building a hydrogen industry and predicted that Australia will supply 13 percent of global carbon-free ammonia by 2035. From importing more than exporting today, if realized, this would make Australia the world's largest ammonia exporter. Huge integrated investment will be required to build and convert infrastructure for the hydrogen and ammonia production processes as well as many necessary upstream renewables and related export facilities.

Multiple projects — at various stages of development — have already been announced across the country. Proximity to existing infrastructure — whether LNG infrastructure that could be adapted or existing transmission lines and substations — alongside some initial federal or state funding will prove critical factors improving these projects' economically feasibility.

For example, the Pilbara project in Western Australia, which broke ground in April 2023, will process natural gas from the nearby Scarborough field to produce urea fertilizer by 2027 (ammonia is an intermediate stage product that is then converted to urea). Two major Northern Australia Infrastructure Facility (NAIF) loans were secured and underline the importance of planning and funding the related infrastructure ecosystem. The Pilbara Ports Authority will receive AU$159 million for a new multi-user wharf and facilities at the Port of Dampier and the Water Corporation $96 million for the expansion of the Burrup seawater supply and brine disposal scheme that will connect to the Urea Plant. As of today, the investment envisions the plant to meet local and international agriculture and other industrial demands, although there is potential to develop other adjacent downstream processing and hydrogen facilities.

Expanding and Improving Existing Ammonia Facilities

A large number of ammonia plants currently in operation are more than 50 years old. Given the technological advances over the last couple of decades, plant operators now have the opportunity to implement new technologies to increase capacity and/or increase energy efficiency.

Considering plant expansion and improvement are timely as demands grow for ammonia for energy and greener sources of ammonia transition. Such nearer term thinking will facilitate market maturation.

In most cases, when revamping a plant to increase production rate, the energy efficiency of the plant is also improved due to more efficient processes. Even if a full revamp isn't in the immediate plans, performing a revamp study can prove valuable, particularly when it comes to identifying plant bottlenecks. The study can also help inform a roadmap towards planning future replacement of equipment that may be nearing end of life.

Modifications and improvements can be considered across multiple operations and processes. As plants age, for example, the convection section is often impacted as the primary reformer is fired more than initial design, resulting in more flue gas, at higher temperature, going to the convection section. Alternatively, adding a pre-reformer can result in significant energy savings or deploying a medium pressure condensate stripper can also lower energy consumptions and reduce emissions.

CO_2 removal improvements could also be addressed, focusing on lowering energy consumption by converting from single stage to two stage regeneration for better heat integration, changing from single stage flash drum with multi-stage flash drum with steam ejectors, adding a low pressure stripper, adding a hydraulic turbine on the high pressure solution going to the stripper, and changing packing in the absorber and stripper to improve performance and reduce pressure drop.

Syngas compressor capacities, ammonia converters and stream systems also present opportunities to improve plant operations and efficiencies at existing ammonia facilities.

Repurposing LNG Infrastructure for Ammonia Import and Export

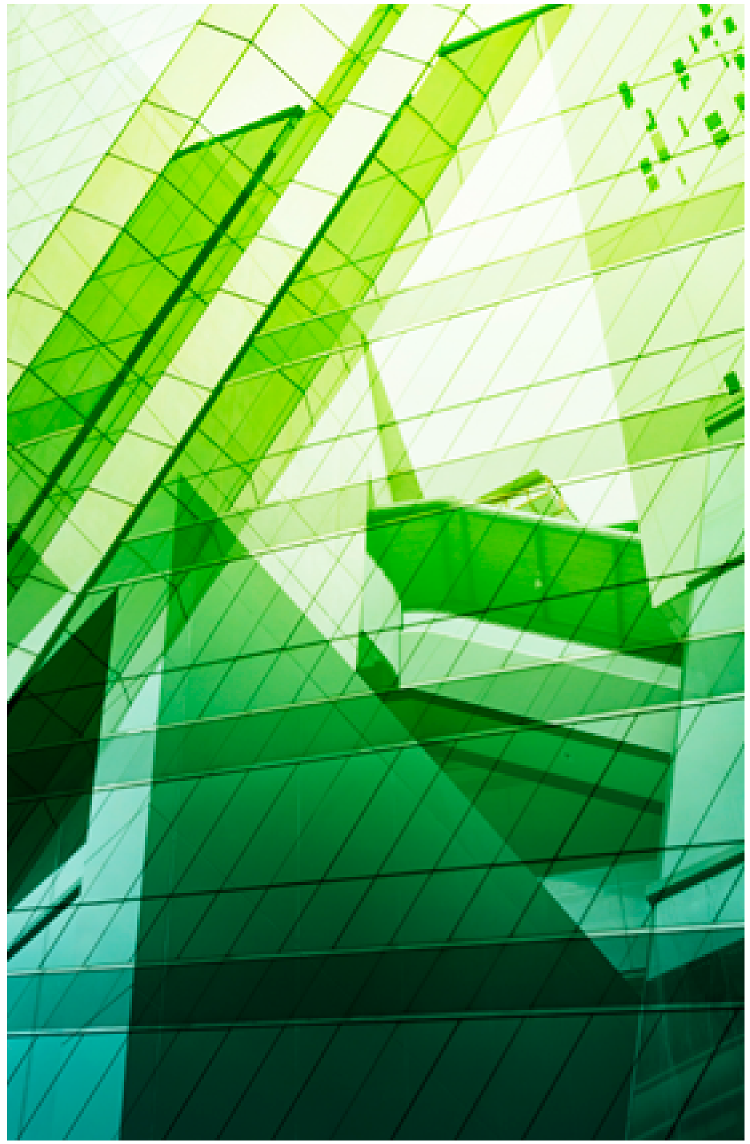
Ammonia-ready storage and transportation infrastructure will be a catalyst for making ammonia a key player in the zero-carbon energy landscape across maritime Asia Pacific.

- Considerations and early movements on expanding a supply chain for ammonia across Asia Pacific is currently underway, and now is the time to consider using the world's extensive Liquefied Natural Gas (LNG) infrastructure — its existing LNG receiving terminals and storage facilities — to facilitate the safe, efficient transport of ammonia.

LNG has been used as an energy source for more than 50 years, due to its reputation as the cleanest fossil fuel as well as its ability to balance out the power generation mix. This has led to widespread investment in LNG storage and transportation infrastructure.

According to the 2022 International Gas Union (IGU) World LNG Report, the global supply chain for LNG is mature and continues to grow with LNG receiving terminals (global nominal regasification capacity of ~902 metric tons per annum [MTPA] across 40 markets), LNG liquefaction terminals (global liquefaction capacity of ~472 MTPA), and LNG tankers (global fleet of 641 active vessels). With this extensive global infrastructure in place, LNG receiving terminals and storage facilities can be modified to facilitate the safe, efficient transport of ammonia globally. As such, LNG and gas power plant owners and developers would be well-served to begin preparing now for their LNG receiving terminals to become ammonia-ready, and to receive liquefied ammonia when needed as renewable energy production continues to increase.

The opportunities for hybrid LNG and ammonia infrastructure development is covered in detail in this previous Black & Veatch eBook. The publication addresses how to convert LNG import terminals and storage tanks to handle ammonia, as well as how to design these facilities to be ammonia-ready.



Ammonia Co-Firing

The pace and process of transitioning away from coal is both slow and complex, especially for many nations across Asia Pacific with relatively recent investments in coal-fired power fleets that were designed to provide affordable power (and sometimes opening access to power) for their people as their economies grew and expanded. Coal still accounts for about two thirds of the world's power sector generation capacity and multiple solutions have to be considered such as fair and just investment programs that will epurpose the assets in a variety of ways such as including carbon capture solutions or, potentially, considering co-firing ammonia to lower overall emissions.

When considering the longevity of newer coal-fired power assets, ease of implementation and maintaining existing commercial arrangements where possible, co-firing ammonia can be a feasible option.

Such a solution requires investigation on a case by case basis. As a fuel, ammonia is in limited supply locally and globally as outlined earlier. Power producers may be competing with food security interests and required to pay a relatively high price, driving up levelized cost of electricity (LCoE) calculations. That said, compared to other capital intensive investments such as repurposing or fully compensated retirement of coal assets, preliminary estimates on a 500 MW facility under certain conditions — considering remaining life of asset and associated net present value (NPV) calculations — indicate there is potential to explore ammonia co-firing for select decarbonization scenarios.

Black & Veatch is seeing rising market interest in exploring such cases, modelling economic scenarios, investigating boiler modification requirements and performance predictions as well as studying and advising around dependent ammonia logistics and unloading infrastructure requirements.

Continue the conversation with Black & Veatch experts

We work across the entire value chain of ammonia, providing integrated solutions that drive execution certainty, safe production and outcomes that improve efficiencies and yield greater returns over a project lifecycle.

Our 80+ years of experience covers all commercial ammonia process equipment and technologies and offers full-service consulting, permitting, design, engineering, procurement, construction, commissioning, program management and operations and management. Additionally, Black & Veatch expertise includes design of ammonia and urea production with all major technology licensors and have recent track record partnering with client on brownfield capacity expansion and debottlenecking as well as in optimizing the production of chemicals such as nitric acid, UAN and ammonium nitrate

Planning to convert, expand or build new ammonia facilities.

Talk to our team today.

Contact us