Low-carbon Ammonia:
Facilitating the transition to a sustainable future

A strategic study on the market potential of low-carbon ammonia

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Ryan Monis, Director, Chemical Consulting, ryan.monis@spglobal.com

Nara Vasa, Senior Consultant, Chemical Consulting, nara.vasa@spglobal.com

Seán Mulholland, Director, Agri Consulting, sean.mulholland@spglobal.com

Simon Wood, Director, Gas, LNG and Low-carbon Gases Consulting, simon.wood@spglobal.com

S&P Global
Commodity Insights

Executive Summary

LC ammonia will transform the ammonia landscape: driven by evolving decarbonization regulations across the world, the change is already underway

Decarbonization policies around the world are transforming the economic fundamentals of LC ammonia and already taking it from concept to reality.

- Targeted financial incentives through the IRA in the US have boosted the competitiveness of LC ammonia projects and helped trigger proposals for over 30 million tons of LC ammonia capacity.
- The escalation of carbon emissions penalties in the European Union and the introduction of the Carbon Border Adjustment Mechanism (CBAM) in 2026 will enhance the competitiveness of LC ammonia supply in Europe and beyond.
- Japan and South Korea have set ambitious targets for the use of low-carbon hydrogen and ammonia in their national energy strategies.

Low-carbon 'blue' ammonia will already be structurally more cost competitive than 'grey' ammonia in some markets before 2030.

- Our cost modelling demonstrates that the growing impact of emissions penalties and the introduction of CBAM in Europe will improve the economics of 'blue' ammonia versus 'grey' ammonia.
- Planned emissions trading systems in other markets are expected to have a comparable impact when implemented.
- Understanding this, early movers are already making final investment decisions on LC ammonia projects.
- 'Green' ammonia will require further policy support beyond the incentives already announced in order to make it cost competitive in most markets.

A total reconfiguration of the global energy system is required in less than 30 years if society is to reach net-zero by 2050.

- Decarbonization initiatives are all driven by the imperative to cut carbon and other greenhouse gas emissions (GHG) to net-zero by 2050 as detailed in the 2015 Paris Agreement.
- Globally, current CO_2 emissions of around 50 billion metric tons of CO_2 equivalent will need to be targeted to achieve net zero.
- The growth in renewable energy production and electrification of the transport sector, for example, will play a major role in decarbonizing the economy. However, an alternative to electrification will be needed in hard-to-abate sectors.

LC ammonia as a hydrogen carrier, fuel and industry feedstock can play a major role in decarbonizing key sectors including power generation, shipping and heavy industry (e.g. steel, cement) as well as the conventional ammonia sector itself.

- The production of LC ammonia is now proven to be both technologically and economically feasible. As a hydrogen carrier, ammonia (NH_3) exhibits a number of advantages over alternative proposals
  - It is cheaper to liquefy and transport than hydrogen.
  - One cubic meter of ammonia contains 70% more hydrogen than liquid H_2.
  - Ammonia has a pre-existing network of storage tanks, liquefied petroleum gas (LPG) carriers and a functioning market that ships 17-19 million metric tons (MMt) annually.
- As a bunker fuel LC ammonia also has a lower carbon intensity than other low-carbon alternatives.

LC ammonia will transform the ammonia landscape: driven by evolving decarbonization regulations across the world, the change is already underway (continued)

In our base case we forecast that LC ammonia *will* play a major role in decarbonizing key hard-to-abate sectors; as a market we believe it will grow from its nascent state today to 420 MMt in 2050

- Adoption of LC ammonia in the power generation and marine fuel sectors will be a key growth driver.
  - Demand for LC ammonia as a hydrogen carrier will drive 155 MMt of demand growth for power generation and industrial uses. The co-firing of ammonia in coal power generation, especially in Eastern Asia, represents a major opportunity.
  - Demand for ammonia as a low-carbon fuel in shipping is projected to reach 166 MMt in 2050.
- Outside the energy sector, an estimated additional 100 MMt of LC ammonia will also enable decarbonization of downstream fertilizer and industrial products, excluding urea.

The rapid growth in the ammonia market will change it beyond recognition

- The diversification of supply routes and demand applications will introduce carbon capture, renewables, power utility and shipping market participants to an industry currently dominated by fertilizer producers.
- JVs between renewable energy producers, hydrogen producers and ammonia producers will emerge.
- Traded volumes will grow tenfold to around 160 MMt by 2050, significantly increasing market liquidity and necessitating a major expansion in ammonia storage and transportation infrastructure.
- The market fundamentals of marginal supply costs and demand drivers will radically alter pricing dynamics.

Despite major improvements to the economic fundamentals of LC ammonia, key uncertainties remain that will ultimately shape the future of the market:

- Certification and classification systems for LC ammonia are not agreed on internationally in a way that would segregate and harmonize its trade.
- Some major markets including Europe are yet to clarify and define the acceptable emissions threshold for hydrogen and ammonia in their decarbonization plans.
- The International Maritime Organization will play a defining role in regulating ammonia as a bunker fuel.
- Technology will need to advance to improve the efficiency of ammonia's use in power generation and other new applications.

This report is structured around the following seven strategic topics

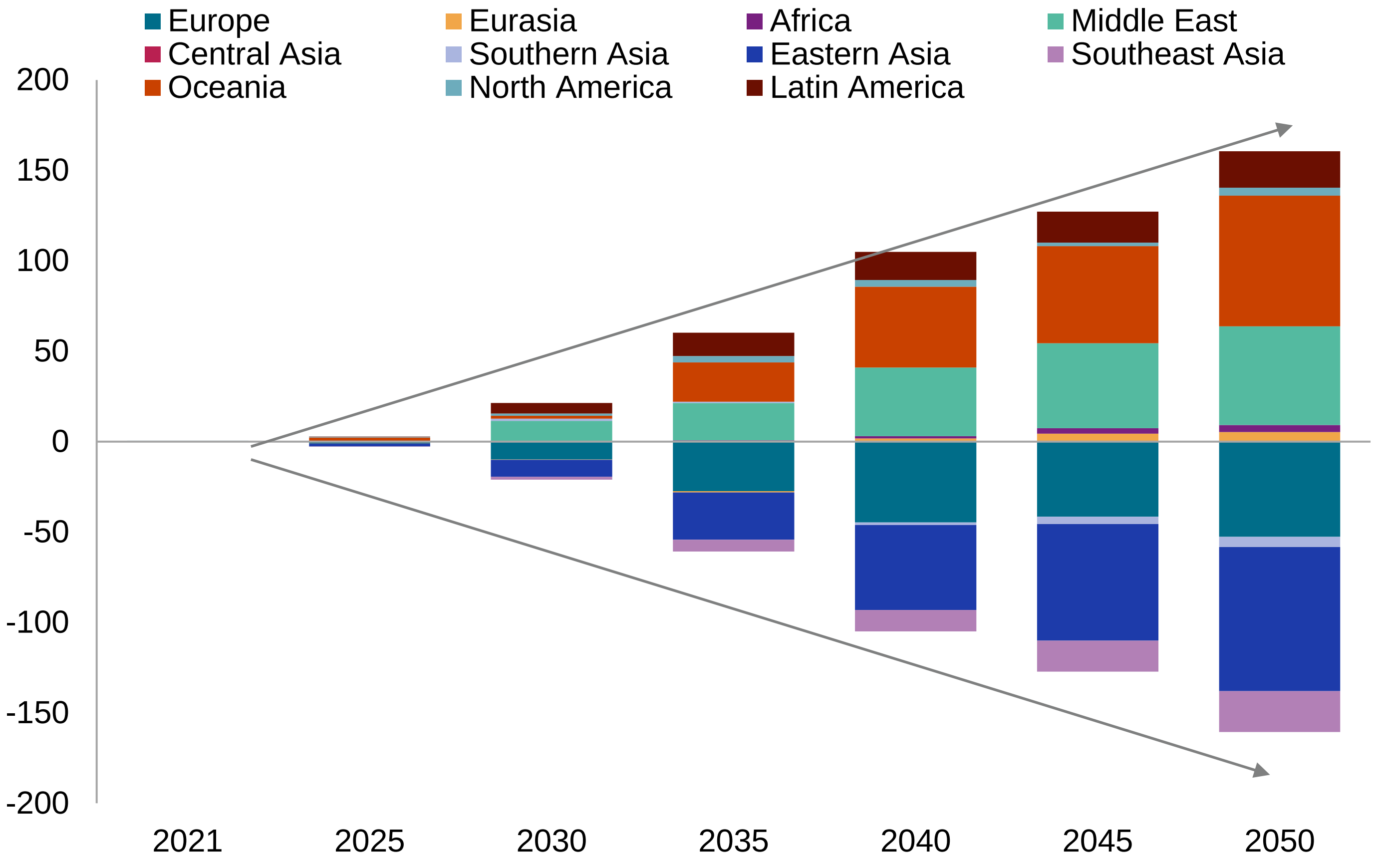
1. Hydrogen and Ammonia in the new energy mix
2. Emerging demand for LC ammonia
3. Diversification of supply landscape
4. LC ammonia production cost drivers
5. A transformed trade picture for ammonia
6. Uncertainties, upsides and risks to the LC ammonia outlook
7. Signposts for the future

Three Sample Pages

Traded volumes will reach 60 MMt by 2035 and exceed 160 MMt by 2050, requiring a substantial expansion of terminals and fleet

LC ammonia Trade Outlook to 2050

MMt



- As of 2023, 99% of ammonia traded globally is derived from fossil fuels, and the trade of low-carbon Ammonia has not yet begun.
- LC ammonia trade is not the norm for current ammonia trade but in terms of scale, is likely to be much larger than conventional ammonia.
- Today, is less than 20 MMt of ammonia is traded globally per year in total.
- It is likely that LC ammonia trade will reach this level by 2030. By 2050, the forecast calls for nearly 160 MMt to be traded per annum.
- This means that the ammonia trade of the future will require additional infrastructure to support such an increased volume and to support a changing end user.
- Certification and classification systems for LC ammonia are not agreed on internationally in a way that would segregate and harmonize its trade.

On an energy equivalence basis, different types of LC ammonia become viable depending on individual production costs and specific logistics

Cost and freight (CFR) Far East of conventional ammonia derived from fossil fuels in the Far East (e.g., Japan) are shown by the line. This price includes a carbon cost, which is derived from the carbon cost of the marginal producing region (Europe).

Delivered green from Australia to the Far East: This comprises LCOA Solar PV Alkaline Australia — the levelized cost of production of green ammonia using the Solar PV Alkaline technology in Australia. This production cost includes capital expenditure (capex) and operations and maintenance (O&M), feedstock, electricity and water for hydrogen production, hydrogen storage and ammonia production and storage costs. Also included are the logistics costs to deliver from Australia to the Far East. (No efficiency measures are considered here).

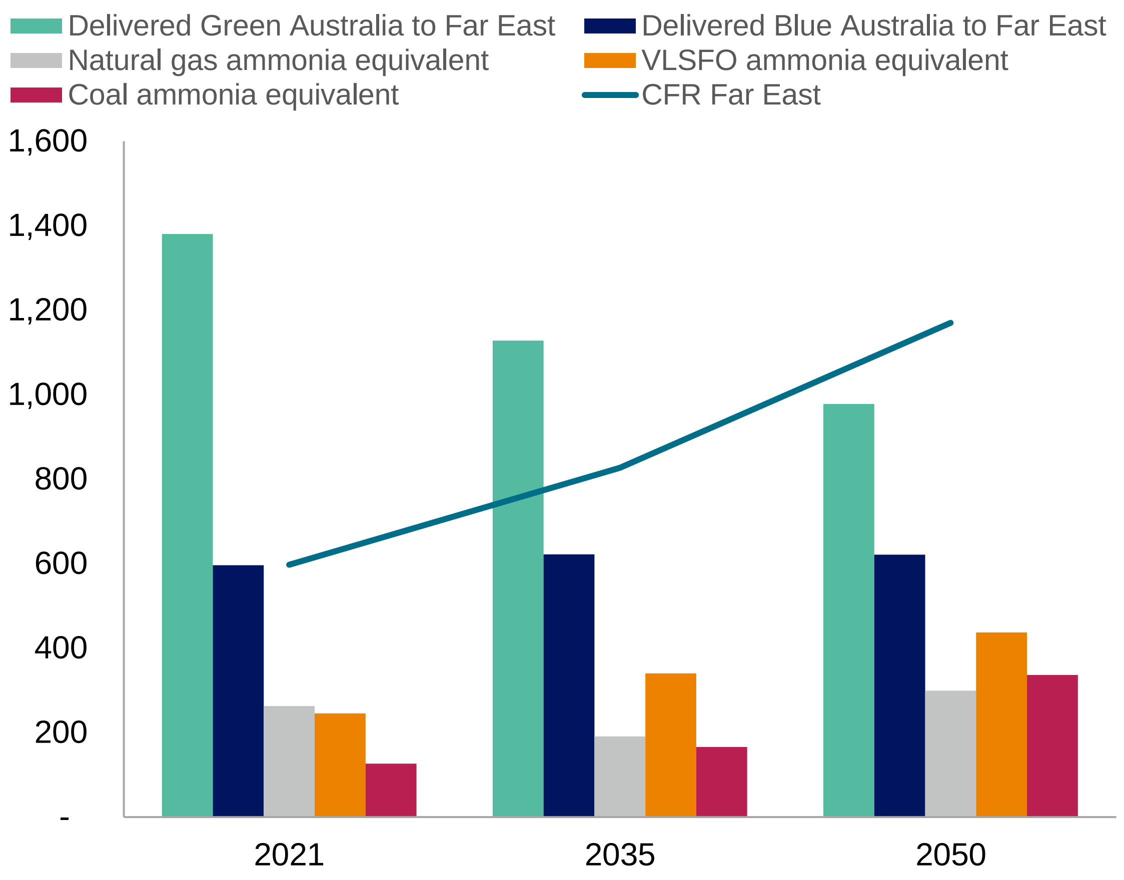
Delivered blue from Australia to the Far East: This comprises LCOA 92% Capture Blue Australia — the levelized cost of production of blue ammonia using the Solar Autothermal Reforming (ATR) 92% CO_2 capture technology in Australia. This production cost includes capex and O&M, feedstock, electricity, carbon emissions cost, carbon transport and storage for hydrogen production, and ammonia production and storage costs. Also included are the logistics costs to deliver from Australia to the Far East (No efficiency measures are considered here).

Natural gas ammonia equivalent: If the energy output of burning natural gas and ammonia are equated through energy density, this shows the value of ammonia in the Far East in dollars per metric ton. This price then also includes carbon cost in addition to this, which is derived from the carbon cost of the Far East.

Very-low-sulfur fuel oil (VLSFO) ammonia equivalent: If the energy output of burning VLSFO and ammonia are equated through energy density, this shows the value of ammonia in the Far East in dollars per metric ton. This price then also includes a carbon cost in addition to this, which is derived from the carbon cost of Far East.

Coal ammonia equivalent: If the energy output of burning coal and ammonia are equated through energy density, this shows the value of ammonia in the Far East in dollars per metric ton. This price then also includes a carbon cost in addition to this, which is derived from the carbon cost of the Far East.

Levelized cost of ammonia versus ammonia energy equivalence ($/t)



As of June 2023.
Source: S&P Global Commodity Insights.

Most policies do not specifically target ammonia (except end-use policies). They address it indirectly in five regulatory areas, which impact significantly across different regions

EXCERPT

Country	Carbon pricing	Financial incentives	Hydrogen economy	CCUS deployment	End-use policy and regulations	Overall score and commentary
United States	1	3	3	3	1	**Overall: Medium/high policy support.** Businesses are incentivized to invest in clean energy projects in the US, taking advantage of tax credits and direct funding opportunities. With the introduction of the IRA last year, the US became the lowest-cost destination for green hydrogen production.
European Union	3	2	3	3	2	**Overall: High support.** The EU has strong regulations that drive producers to switch to low-carbon solutions in the industrial sector by imposing penalties and fees on polluters. The region is leading the way in the development of clean energy transition; however, more financial incentives are needed (e.g., the US's IRA) for companies to invest in low-carbon projects.
India	1	2	2	1	2	**Overall: Low/medium support. F**inancial support is available on the national and state levels, aimed at green hydrogen production, from which LC ammonia can benefit. India aims to replace all imported ammonia-based fertilizers with domestically produced green-ammonia fertilizers by 2035; however, no clear policy is in place on how to reach the targets.
Mainland China	1	1	1	1	1	**Overall: Low support.** Currently, mainland China has a weak regulatory policy framework to support the production/demand of LC ammonia. The attention is now on the development of ETS that may facilitate producers to switch to low-carbon solutions in the future on state/regional incentives to support clean hydrogen uptake.
Japan	2	3	3	2	3	**Overall: High support.** Japan has strong financial support for hydrogen-related projects, along with the funding of its "Fuel Ammonia Supply Chain Program", which provides pathways and targets for clean ammonia in power generation. Japan relies on international cooperation for clean ammonia imports.
South Korea	2	3	3	2	3	**Overall: High support.** Like Japan, South Korea is set to use clean ammonia in power generation with ambitious targets announced. The sector has governmental support via subsidies and funding. Meeting its targets will depend on international cooperation and companies' investments outside South Korea to secure imports of clean ammonia.
Australia	1	3	3	3	1	**Overall: Medium/high support**. Like Canada, Australia has strong financial incentives and funding from which LC ammonia can benefit. However, it lacks regulatory/policy developments to facilitate domestic demand.

Score explanation.
1. The policy and regulatory framework in the segment has low support for low-carbon ammonia development.
2. The policy and regulatory framework are available or expected to be developed in the near future/cannot be ruled out based on the governments' announcements and targets.
3. The policy and regulatory framework in the segment has strong support for low-carbon ammonia development.

Further explanation on how scoring is allocated can be found in the Appendix.

As of June 2023.
Source: S&P Global Commodity Insights.

Contact us

John Mulholland (Americas)

john.mulholland@spglobal.com

Luca Raffellini (Europe)

Luca.Raffellini@spglobal.com

Mohit Sood (Middle East)

Mohit.sood@spglobal.com

Hormuzd Karanjia (Asia)

Hormuzd.Karanjia@spglobal.com

Aman Arora(India)

Aman.Arora@spglobal.com

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