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Advancing Green Ammonia Economics: Towards Decarbonization of China's Chemicals Industry



Report / February 2025



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Authors and Acknowledgments

Authors

RMI	CPCIF.HEC
Ting Li	**Weishan Sun**
Shuyi Li	**Yongliang Li**
Peishan Wang	**Miao Li**
Yujun Xue	**Xiaoli Zhu**
Haoran Li	**Yichen Jia**

Contact

Shuyi Li, sli@rmi.org

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RMI, CPCIF.HEC, *Advancing Green Ammonia Economics: Towards Decarbonization of China's Chemicals Industry*, 2025, **https://rmi.org/insight/advancing-green-ammonia-economics-towards-decarbonization-of-chinas-chemicals-industry/**

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Acknowledgments

The authors warmly thank Shuo Gao, Yihan Hao, Jun Li, Qiyu Liu, Yujing Liu, and Zhe Wang from RMI for their valuable comments to this report.

The authors would like to express sincere thanks to the following experts for their insight and comments:

Quanwei Li, East China Engineering Science and Technology Co., Ltd.
Siming Liu, National Petroleum & Chemical Planning Institute
Jianying Su, China Nitrogen Fertilizer Industry Association

The contents of this report do not represent the views of the above experts and institutions.

Table of Contents

Introduction 5

1. Overview: From Present to Future 7

1.1 Policy and progress 7

1.2 Conventional production process and carbon emissions 11

1.3 Towards green ammonia production 12

2. Economic Challenges of Green Ammonia Production 15

2.1 Production cost under ideal conditions 15

2.2 Impacts of stable production on cost 16

2.3 Impacts of utilizing surplus electricity on cost 18

3. Boosting Multiple Use Cases: Driving Cost Reduction and Closing Gaps 20

3.1 Scenario 1: Ammonia for agricultural use 20

3.2 Scenario 2: Ammonia as maritime fuel 26

3.3 Scenario 3: Blending ammonia for power generation 28

3.4 Outlook of green ammonia in multiple use cases 30

4. Global Practices and Implications 34

4.1 Yara — Joint efforts of subsidy, certification, and value chain collaboration 34

4.2 Talus — A distributed development model 35

4.3 NEOM— Large-scale production 36

5. Recommendations 39

Endnotes 41

Introduction

Ammonia (NH_3) is an important basic chemical product with a wide range of applications in agriculture, industry, and other fields. At present, ammonia is mainly used in the agricultural sector. Globally, more than 70% of ammonia is used for producing nitrogenous fertilizers to secure the food supply. Meanwhile, as an emerging energy source, ammonia also has great potential to support the shipping and power sectors' decarbonization.

Currently, ammonia production relies on traditional paths that utilize coal and natural gas as raw materials, showing high levels of carbon intensity and energy consumption. Ammonia production accounts for about 2% of final global energy consumption and 1.3% of global carbon emissions.[1] Coal and natural gas represent about 19% and 78% of raw materials in global ammonia production, respectively. In China, coal is the dominant raw material in ammonia production, with more than 75% of ammonia production based on coal. Therefore, the carbon emissions per unit product's energy consumption are higher than the global average. The carbon intensity of coal-based ammonia is about 4.4–4.8 tons of carbon dioxide (t CO_2)/t NH_3, over two times that of natural gas–based ammonia.

In absolute terms, China is the world's largest producer and consumer of ammonia. In 2022, China produced about 53.21 million tons of ammonia,[2] accounting for 30% of the world's total. In 2020, the ammonia industry generated 219 million tons CO_2 of direct emissions.[3] This represents about 2.2% of China's total carbon emissions and nearly one-fifth of carbon emissions of the chemicals industry, making it the top emitter among chemicals. At the same time, ammonia is the basic raw material of many chemical products. By reducing carbon emissions during the production of ammonia, the total carbon footprint of chemical products can be significantly reduced, propelling the low-carbon transition and sustainable development of the industry. Therefore, the low-carbon transition of the ammonia industry is not only crucial to the green development of China's chemicals industry, but also key to the low-carbon transition of the global chemicals industry.

During production, more than 85% of the carbon emissions could be reduced by switching to clean and low-carbon feedstocks and fuels. Green hydrogen, as an alternative feedstock and fuel produced through electrolysis of water with renewable-based power, plays an important role in substantial carbon reduction. Green ammonia synthesized with green hydrogen and the nitrogen separated from air is thus gaining increasing attention and expected to become an important clean feedstock and energy source in the future, providing solutions for decarbonization across several industries. At present, China is actively advancing the low-carbon transition of the ammonia industry. *The Implementation Guidelines for Energy-Saving and Carbon-Reducing Transformation and Upgrading of Ammonia Industry, Implementation Plan for Carbon Peaking in Industrial Sector*,[4] and several other policies issued by the National Development and Reform Commission (NDRC), the Ministry of Industry and Information Technology (MIIT), the Ministry of Ecology and Environment (MEE), and other ministries have set forth specific targets for carbon emissions before and after 2025 for the ammonia industry. At the same time, the development of wind, solar photovoltaics (PV), and other renewable energy sources also provides a technological basis and resources for the growth of green ammonia in China. The country has highlighted the objective of building a sustainable chemical industry in the 14th Five-Year Plan (2021–2025), encouraging the ammonia industry to gradually shift to low-carbon production routes including green hydrogen.

At a global scale, many countries and regions are also accelerating the adoption of green ammonia in different ways. For example, Saudi Arabia is building a large-scale green ammonia project that integrates more than 4 gigawatts (GW) of wind power and solar PV to provide clean and cost-competitive electricity for green ammonia production. The planned green ammonia production capacity of the project is 1.2 million tons/year. Japan intends to enhance the support for the utilization of green ammonia as fuel through government grants, tax exemptions, and investment in infrastructure to facilitate decarbonization of power generation, shipping, chemicals production, and other industries. The Renewable Fuels of Non-Biological Origin (RFNBO) bill issued by the EU further specifies the requirements for green hydrogen and green hydrogen–derived fuels in terms of additionality, timeliness, and geographical relevance, providing a key reference for monetization and verification of green product value. Practice has shown that multiple conditions should be met to promote green ammonia at scale, including the stability of the renewable electricity supply, cost-effectiveness, policy incentives, and the support of market rules, which provide important reference for green ammonia's development.

Driven by policy and the market, China is swiftly rolling out green ammonia projects, announcing a total planned green ammonia capacity of more than 13 million tons. Although this means that China's green ammonia industry is experiencing rapid development, it still faces challenges in terms of technology and cost. Technologically, the core of green ammonia production is the utilization of renewable electricity, which must adjust the fluctuating, intermittent power supply to a continuous and stable power supply for industrial production through process optimization and support. A novel process of ammonia synthesis should be developed to provide more friendly and adaptable working conditions for renewable electricity, while the process that converts green electricity to green hydrogen and finally to green ammonia should further evolve. In terms of cost, applications of green ammonia in existing agricultural scenarios, as well as in emerging scenarios such as shipping and power generation, face the problem of much higher cost than the conventional methods. So, it is necessary to evaluate the synergy of multiple factors such as technology iteration, policy support, market instruments, and demand-side drivers based on different scenarios for options and approaches that achieve cost parity for green ammonia's early application.

Starting from the status quo and the potential of green ammonia in China, this report explores the relevant production technologies as well as key issues and future trends under the iteration of renewable hydrogen production and ammonia synthesis processes. It also provides a cost-effectiveness analysis of green ammonia production under several scenarios, discusses the factors affecting the economics, and predicts future changes in the economics. Based on these factors, the report summarizes the potential market and promotion prospects of green ammonia application scenarios, such as agriculture, shipping, and power generation, and explores the conditions and possible solutions to achieve green ammonia's cost parity based on these scenarios. In the discussion of possible solutions, the potential contribution of market mechanisms such as policy, downstream premiums, and the carbon market is highlighted. Also, by comparing and analyzing typical green ammonia projects at global scale, this report provides reference for further scaling up green ammonia in China. Furthermore, it suggests actions from the perspectives of policy, industry, and enterprises to accelerate the development of China's green ammonia industry and help enable the chemicals industry to achieve the green low-carbon transition.

1. Overview: From Present to Future

1.1 Policy and progress

China is the largest producer and consumer of ammonia in the world. In 2022, it produced about 53.21 million tons of ammonia,[5] representing 30% of the world's total. Because China is rich in coal, and poor in oil and gas, coal is the main feedstock for ammonia production, supplemented by natural gas. About 76% and 21% of ammonia is based on coal and natural gas, respectively, with the remaining small share based on coke oven gas.

Policy guidance and industrial transformation are imminently needed to address the high energy intensity and carbon intensity feedstock structure of ammonia production. Since China set forth the carbon peaking and carbon neutrality goals, government agencies represented by NDRC, MIIT, MEE, and the National Energy Administration (NEA) have led the development of the *Implementation Guidelines for Energy-Saving and Carbon-Reducing Transformation and Upgrading of Ammonia Industry, Implementation Plan for Carbon Peaking in Industrial Sector, Special Action Plan for Energy Conservation and Carbon Reduction in Ammonia Industry, Implementation Plan for Accelerating the Application of Clean and Low-Carbon Hydrogen in the Industrial Sector*,[6] and other documents (see Exhibit 1). These specify targets of carbon emission controls for the industry before and after 2025. China highlighted the objective of building a sustainable chemicals industry in the 14th Five-Year Plan (2021–2025), encouraging the ammonia industry to gradually shift to low-carbon production paths based on green hydrogen and other paths. The rapid development of wind power, solar PV, and other renewable energy sources has provided the technological basis and resources for the further development of green ammonia.

Exhibit 1. **Key policies for the low-carbon development of the ammonia industry**

Date issued	Policy and key content	Issuers
February 2022	***Implementation Guidelines for Energy-Saving and Carbon-Reducing Transformation and Upgrading of Ammonia Industry*** By 2025, the production capacity above the energy efficiency benchmark level in the ammonia industry shall reach 15% and the production capacity below the benchmark level shall be basically eliminated.	NDRC, MIIT, MEE, NEA
March 2022	***Guiding Opinions on Promoting High-Quality Development of Petrochemical and Chemical Industry in the Fourteenth Five-Year Plan*** Encourage petrochemicals and chemicals enterprises to develop and utilize green hydrogen in a reasonable and orderly way according to local conditions. Promote the demonstration of the coupling of refinery and coal chemicals industries with green electricity and green hydrogen industries.	MIIT, NDRC, MOST, MEE, MEM, NEA
March 2022	***Medium- and Long-Term Plan for the Development of Hydrogen Industry (2021-2035)*** Explore the demonstration of hydrogen production from renewable energy sources as a substitute for fossil energy sources in industries such as ammonia, methanol, refinery and chemicals, and coal-to-oil and coal-to-gas.	NDRC, NEA

Continued on next page

Continued from previous page

August 2022	***Implementation Plan for Carbon Peaking in Industrial Sector*** Promote the replacement with low-carbon raw materials. Encourage eligible areas to utilize renewable energy for hydrogen production. Optimize the feedstock structure of coal chemicals, ammonia, methanol, and other industries. Promote the electrification of industrial energy.	MIIT, NDRC, MEE
June 2024	***Special Action Plan for Energy Conservation and Carbon Reduction in Ammonia Industry*** By the end of 2025, the production capacity above the energy efficiency benchmark level in the ammonia industry shall be increased to 30%, and production capacity below the benchmark level shall complete technological transformation or be phased out. Key tasks include optimizing and adjusting the deployment of production capacity, accelerating energy-saving and carbon-reducing renovation and equipment renewal and modernization, advancing the efficient use of residual heat and pressure, replacing with low-carbon raw materials and fuels, and boosting digital empowerment.	NDRC, MIIT, MEE, SAMR, NEA
July 2024	***Action Plan for Low-Carbon Transformation and Construction of Coal-Based Power Generation (2024-2027)*** Propose three low-carbon technology routes for coal-based power generation, including biomass-blended burning, green ammonia–blended burning (coal power units should have more than 10% green ammonia capacity after renovation), and carbon capture, utilization, and storage.	NDRC, NEA
December 2024	***Implementation Plan for Accelerating the Application of Clean and Low-Carbon Hydrogen in the Industrial Sector*** Accelerate large-scale applications of clean and low-carbon hydrogen in metallurgy, ammonia, methanol, and petrochemicals while implementing demonstration applications in industrial green microgrids, shipping, aviation, and rail transportation.	MIIT, NDRC, NEA

Note: MEE = Ministry of Ecology and Environment; MEM = Ministry of Emergency Management; MIIT = Ministry of Industry and Information Technology; MOST = Ministry of Science and Technology; NDRC = National Development and Reform Commission; NEA = National Energy Administration; SAMR = State Administration for Market Regulation.
RMI Graphic. Source: RMI analysis

These policies provide the following guidelines for the low-carbon development of the ammonia industry:

- **Energy-saving and carbon-reducing renovation:** For example, the requirement for the proportion of production capacity above the energy efficiency benchmark level has been increased from 15% to 30% by 2025, and the production capacity below the benchmark level has been required to complete technological renovation or be phased out. Key tasks are highlighted, such as accelerating energy-saving and carbon-reducing renovation and equipment renewal and modernization, and advancing efficient use of residual heat and pressure.

- **Feedstock substitution:** Eligible areas are encouraged to utilize renewable energy for hydrogen production to optimize the feedstock structure, including coal-based chemicals, ammonia, and methanol.

- **Optimized deployment production capacity:** New ammonia production capacity is to be reasonably controlled and guided to enterprises and regions with more comparative advantages. Petrochemicals and chemicals enterprises are encouraged to develop and utilize green hydrogen in a reasonable and orderly way according to local conditions. Also, promotion is needed to demonstrate the coupling of refinery and coal chemicals industries with green electricity and green hydrogen industries.

In addition to the national-level policy, local government is also propelling the coupling of green hydrogen with traditional industrial sectors. With reference to the 14th Five-Year Plan, 14th Five-Year Energy Development Plan, Special Planning for Hydrogen, Implementation Plan for Carbon Peaking and Carbon Neutrality, and other policies of provinces, cities, and regions, Qinghai, Ningxia, and Inner Mongolia have already mentioned the exploration of the application of green hydrogen in the chemicals and metallurgy industries, and have set phased targets of renewable energy–based hydrogen production capacity in a number of policies (see Exhibit 2). Furthermore, more than a dozen places in China have introduced policies to reduce constraints for green hydrogen projects, such as allowing green hydrogen production projects to be built outside of chemicals industrial parks and allowing such production without requiring hazardous chemicals safety permissions.[7]

Exhibit 2. **China's provincial green hydrogen planning**

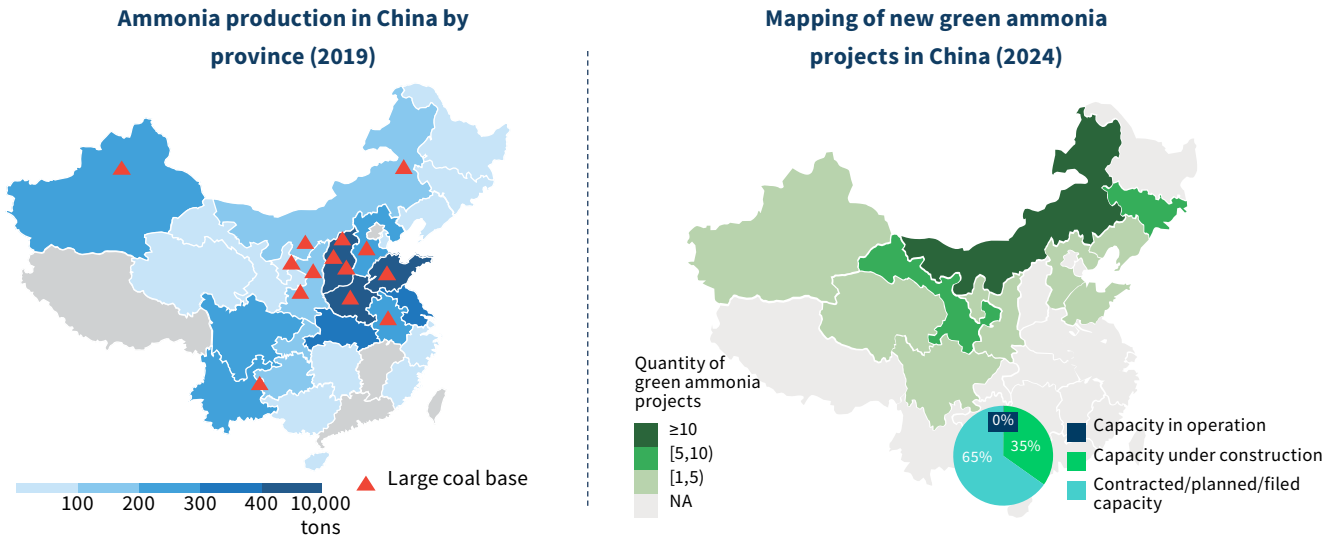
Province	Qty. of policies mentioned	Target of hydrogen production capacity with renewable energy sources	Key cities and districts	Focus areas
Ningxia	9	2025 | 80,000 tons/year	Shizuishan	Chemicals, metallurgy
Qinghai	7	2025 | 40,000 tons/year 2030 | 30,000 tons/year 2035 | 1,000,000 tons/year	/	Metallurgy, chemicals
Inner Mongolia	6	2025 | 500,000 tons/year	Ordos, Baotou, Wuhai	Chemicals, metallurgy
Jilin	6	2025 | 60,000-80,000 tons/year 2030 | 300,000-400,000 tons/year 2035 | 1,200,000-1,500,000 tons/year	Baicheng, Songyuan	Chemicals, metallurgy
Shanghai	5	/	Jinshan	Metallurgy
Shanxi	4	2025 | 200,000 tons/year (Lvliang)	Lvliang, Datong, Changzhi	Metallurgy, chemicals
Henan	4	2025 | 8,000 tons/year (Xinxiang)	Xinxiang, Puyang, Anyang Jiaozuo	Chemicals, metallurgy
Sichuan	4	2025 | 110,000 tons/year (Chengdu) 2030 | 100,000 tons/year (Panzhihua)	Chengdu, Panzhihua	Metallurgy, chemicals
Shaanxi	4	2025 | 130,000 tons/year	Yulin	Chemicals, refinery, metallurgy

RMI Graphic. Source: RMI analysis

Driven by policy and the market, the geographical distribution of ammonia production capacity has expanded from established capacity near large coal bases to new production capacity near renewable energy–rich areas. This illustrates the trend of moving from gray ammonia produced from coal as feedstock to green ammonia with the establishment of a new industry chain of green electricity–green hydrogen–green ammonia. As shown in Exhibit 3, original ammonia production capacity was near coal resources, so its distribution overlapped that of large coal bases, mainly located in East China, Central China, and North China. New ammonia production capacity, however, is close to areas with better wind and solar resources, mainly located in North China, Northeast China, and Northwest China. According to RMI analysis of statistics,[i] the announced green ammonia project capacity in China has exceeded 13 million tons, with the most capacity in Inner Mongolia and Jilin. In terms of project progress, one-third of the planned capacity is under construction; the rest is in signing, planning, filing, and other preparation stages. Nearly half of the projects are 200,000 tons/year or less, with a higher rate of starting construction than larger-scale projects. Inner Mongolia has announced more than 10 green ammonia projects with a planned capacity of over 6 million tons per year, ranking first in both the scale of planned capacity and the number of projects across China.

i RMI statistics based on public information as of June 2024.

Exhibit 3. **Distribution of established and new ammonia production capacity in China**



RMI Graphic. Source: RMI, https://rmi.org/insight/transforming-chinas-chemicals-industry/; EnerScen, https://mp.weixin.qq.com/s/t5S8vAVjERvs7bYYLWl-cg; RMI analysis

1.2 Conventional production process and carbon emissions

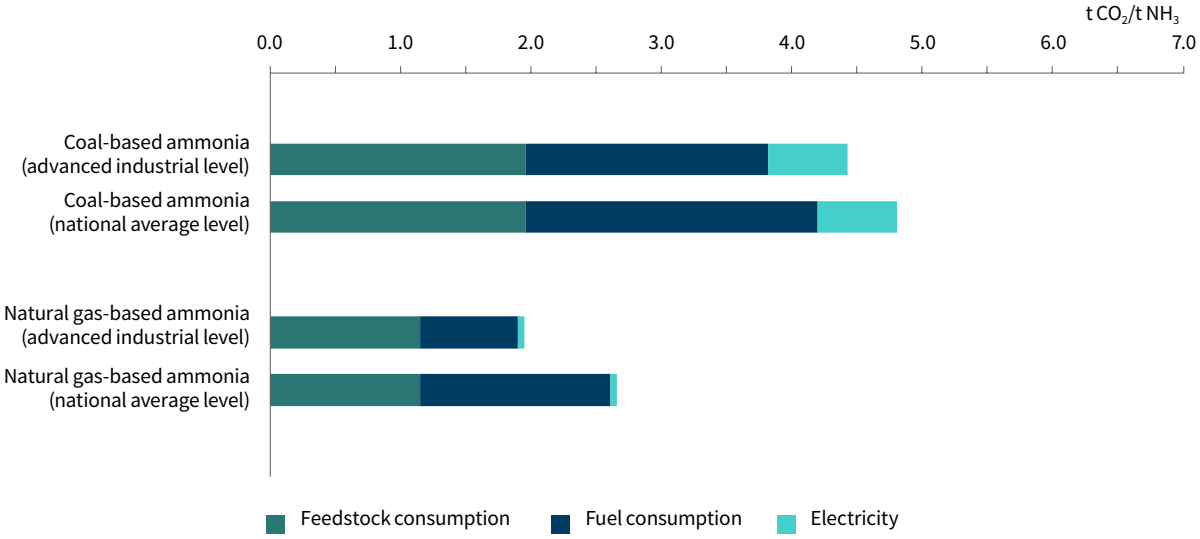
The conventional paths for ammonia synthesis include coal-based and natural gas–based production, with the former having the highest share in China and the latter dominating globally.

The production process of coal-based ammonia includes feed gas production, purification, and ammonia synthesis. Anthracite or pulverized coal and other feedstock are processed and gasified to make feed gas containing carbon monoxide (CO), hydrogen (H_2), and other components. After dust removal and desulfurization to eliminate impurities, the CO in the feed gas is converted into CO_2, and then decarbonized and methanized to obtain pure H_2 and nitrogen (N_2). The mixture of nitrogen and hydrogen in the ratio of 1:3 is compressed at high temperature and high pressure (400°C–500°C, 15 MPa or higher), and directly synthesized to ammonia with catalysts (most commonly iron-based catalysts). Finally, the liquid ammonia is separated from the system through liquidation. The industrial waste heat from the reaction process can be recovered for other processes' heat supply or used for electricity generation for production use, while the remaining power requirement is met by purchasing electricity from the grid.

The production process of natural gas–based ammonia includes feed gas generation, purification, and synthesis as well. First, the natural gas is desulfurized to remove impurities. The gas after pretreatment is converted into the feed gas containing CO, H_2, and N_2 through two-stage pressurized steam conversion. The CO in the feed gas is completely combusted into CO_2 through a conversion reaction, and is then decarbonized and methanized to obtain pure H_2 and N_2. Finally, ammonia is synthesized under the high-temperature and high-pressure catalyst conditions and separated through liquidation. The recovery of waste heat is the same as mentioned above. Compared to the coal-based process, the natural gas–based process offers the following three advantages: (1) natural gas has a lower hydrocarbon ratio (1:4) and produces more effective feed gas for ammonia synthesis; (2) the higher reaction efficiency reduces energy consumption; and (3) fewer impurities and by-products shorten their removal and purification steps.

Based on the fuel and feedstock consumption of the above processes, the process emissions of coal-based and natural gas–based production of 1 ton of ammonia at different technology levels can be calculated with carbon emissions factors published by the Chinese government. As shown in Exhibit 4, the carbon intensity of coal-based ammonia is between 4.4 and 4.8 t CO_2/t NH_3, while that of gas-based ammonia is between 2.0 and 2.7 t CO_2/t NH_3, which is about half of the carbon intensity of the coal-based path and thus can significantly reduce the process emissions. In terms of the emissions structure, CO_2 from feedstock and fuel consumption accounts for more than 85% of the process emissions.

Exhibit 4. **Carbon emissions of coal-based ammonia and natural gas–based ammonia production**

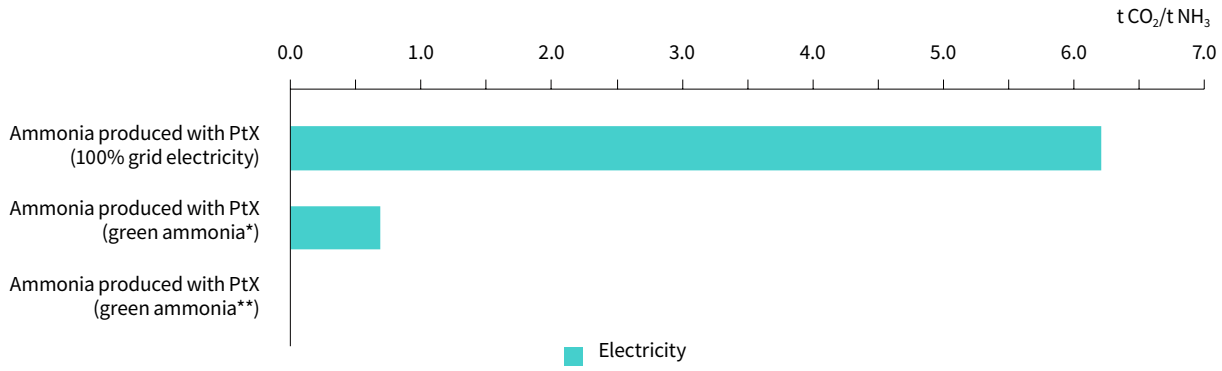


Note: This figure includes only the emissions from the ammonia synthesis process and does not include emissions from upstream raw material extraction, processing, and transport.
RMI Graphic. Source: Banafsheh Jabarivelisdeh et al., **https://www.c-thru.org/wp-content/uploads/2022/12/Ammonia-Technical-Brief-June2022.pdf**; RMI analysis

1.3 Towards green ammonia production

In addition to the conventional process, ammonia can be obtained through power-to-X (PtX), a process that generates products from hydrogen by water electrolysis. This path consists of two stages: water electrolysis and ammonia synthesis. Because the ratio of electricity consumption between the two stages is about 9:1, the total carbon intensity of ammonia synthesis largely depends on how clean the power generation is during the water electrolysis stage. As shown in Exhibit 5, if grid electricity is used in both stages, the carbon emissions of ammonia produced are 6.2 t CO_2/t NH_3, which is significantly higher than the carbon intensity of coal-based ammonia synthesis and thus fails to reduce emissions. If the water electrolysis stage uses green electricity and the synthesis stage still utilizes grid electricity to ensure the stability of the operation, the carbon emissions are reduced by about 85% to 0.7 t CO_2/t NH_3. If both stages utilize green electricity for full electrification, the carbon emissions are reduced by 100%, enabling zero-carbon production of green ammonia. In this report, green ammonia refers to ammonia produced by synthesizing the hydrogen that is generated by electrolyzing water using renewable energy sources such as wind power, with the nitrogen separated from the air.

Exhibit 5. **Carbon emissions of PtX-based ammonia synthesis under different sources of electricity**

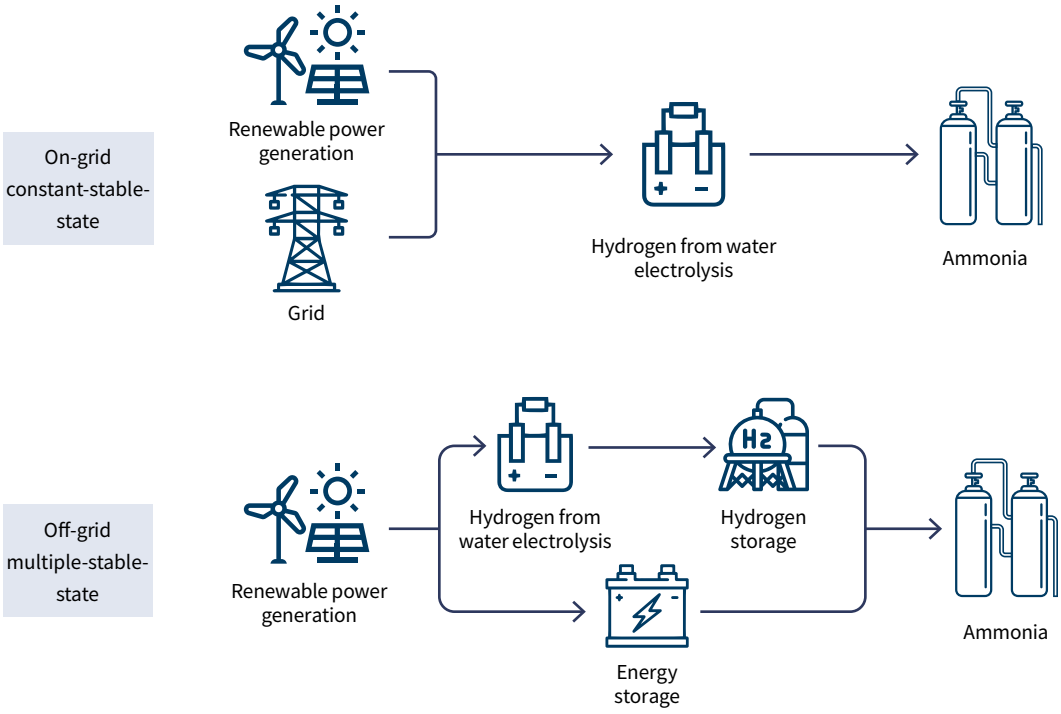


Note: Green ammonia* refers to the ammonia produced from green hydrogen, where green electricity is used only for the hydrogen production, and grid electricity is still used for the synthesis. Green ammonia** refers to the ammonia produced with 100% green electricity in both hydrogen production and synthesis. In addition, the emissions factor for grid electricity used here is 0.5942 kg CO_2/kilowatt-hour (MEE, **https://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/202403/t20240315_1068508.html**), which is the emissions factor for non-fossil electricity excluding market-based trading. This factor may change over time with the progress of electricity market reform and the further increase of renewable energy in installed capacity and power generation capacity in the future.
RMI Graphic. Source: Banafsheh Jabarivelisdeh et al., **https://www.c-thru.org/wp-content/uploads/2022/12/Ammonia-Technical-Brief-June2022.pdf**; RMI analysis

The fluctuation of renewable power generation makes it difficult to directly adapt to a continuous ammonia production process with the conventional Haber-Bosch reaction. Two main solutions are available to deal with the fluctuation (see Exhibit 6): on-grid constant-stable-state solution, which leverages the electricity purchased from the grid to make up for the shortfall in renewable power generation and ensure that the ammonia synthesis plant operates stably at full load; or off-grid multiple-stable-state solution, which is a flexible ammonia synthesis process that ensures the ammonia synthesis plant operates under multiple stable-state load scenarios by equipping the green ammonia production system with a certain scale of energy and hydrogen storage units and dynamically optimizing the load of the plant.

With future gains in low-temperature and low-pressure technology and catalysts, small-scale, distributed green ammonia (DGA) production will be possible and more adaptable to the fluctuation of wind and solar power generation with improved flexibility. DGA production can reduce costs by utilizing a miniaturized Haber-Bosch process with lower operating pressures and temperatures, improved catalyst efficiency, startup and shutdown flexibility, and the ability to simplify the system's need for energy and hydrogen storage.

Exhibit 6. **On-grid constant-stable-state vs. off-grid multiple-stable-state green ammonia systems**



RMI Graphic. Source: RMI analysis

2. Economic Challenges of Green Ammonia Production

Green ammonia is differentiated in production feedstock and plant processes compared with conventional coal- and natural gas–based ammonia. In addition, its production is affected by wind and solar resources, so the cost of green ammonia synthesis should be measured according to resources across geographic locations and the technological routes being adopted.

2.1 Production cost under ideal conditions

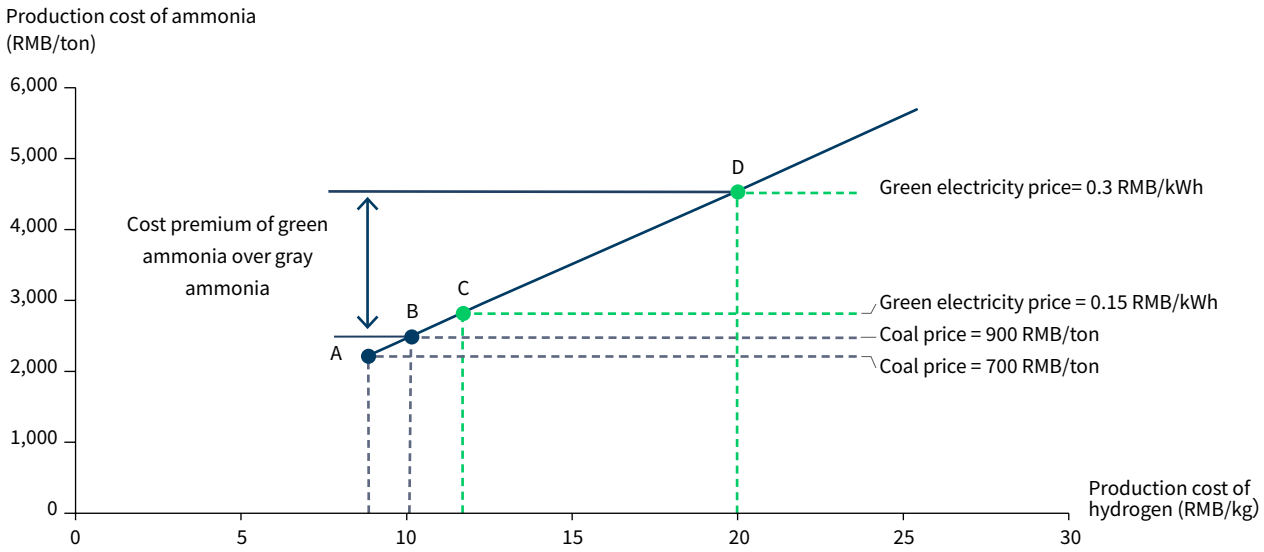
Most of the ammonia in China is gray ammonia produced from coal as feedstock. If the price of raw coal fluctuates between 700 and 900 RMB/ton, the cost of coal-based hydrogen is 9–10 RMB/kg and the resultant production cost of gray ammonia is 2,200–2,500 RMB/ton, as shown in Exhibit 7. The cost of feedstock represents 48%–54% of the total gray ammonia cost, followed by fuel cost (25%–28%).

Under the green ammonia production route, the cost of green hydrogen produced through electrolysis of water with renewable energy is significantly higher than that of gray hydrogen, and it is further increased due to downward price transmission. If the total cost of renewable energy power generation (green electricity price) is 0.15–0.3 RMB/kilowatt-hour (kWh), the cost of green hydrogen produced through the alkaline electrolyzer in the regions with advantageous wind and solar resources is 12–20 RMB/kg under ideal conditions (without the need for energy storage or hydrogen storage due to fluctuating wind and solar).[ii] And the cost of green ammonia produced from green hydrogen rises to 2,920–4,600 RMB/ton, which is 1.2–2.1 times the cost of coal-based ammonia.

The cost of hydrogen production is the main reason for the price discrepancy between gray and green ammonia. As shown in Exhibit 7, if the cost of hydrogen could be reduced by 1 RMB/kg, the cost of producing 1 ton of ammonia could decrease 190 RMB. Because the price of green hydrogen greatly depends on the price of green electricity, the utilization of lower-cost green electricity is the key to reducing the cost of green ammonia production. Under the above ideal scenario, which does not consider the fluctuations of wind and solar power generation, cost parity between green and gray ammonia can only be achieved when the cost of green hydrogen production is less than 10 RMB/kg. This means that the price of green electricity must be less than 0.12 RMB/kWh.

ii Take the wind and solar resources in Ordos of Inner Mongolia as an example. The annual effective utilization hours of solar and wind power generation in this region are about 1,600 and 2,305, respectively, totaling about 3,905 hours.

Exhibit 7. **Production costs comparison of gray and green ammonia**



Note: Key assumptions: (1) The production of coal-based ammonia runs in the on-grid constant-stable-state route for 8,000 hours per year. (2) The production of green ammonia runs in the off-grid constant-stable-state route for 3,905 hours per year, with reference to Inner Mongolia for bundled output hours of wind and solar power. The off-grid constant-stable-state route does not need storage and is therefore an ideal scenario. (3) The green electricity price refers to the end-use electricity cost.
RMI Graphic. Source: RMI analysis

2.2 Impacts of stable production on cost

In a real situation, the fluctuation of renewable energy sources does not match the continuous ammonia production model. Producing green ammonia continuously and stably with fluctuating renewable energy sources requires additional cost compared with the above-mentioned ideal green ammonia scenario. Both the on-grid constant-stable-state route and off-grid multiple-stable-state route as discussed above will bring additional cost.

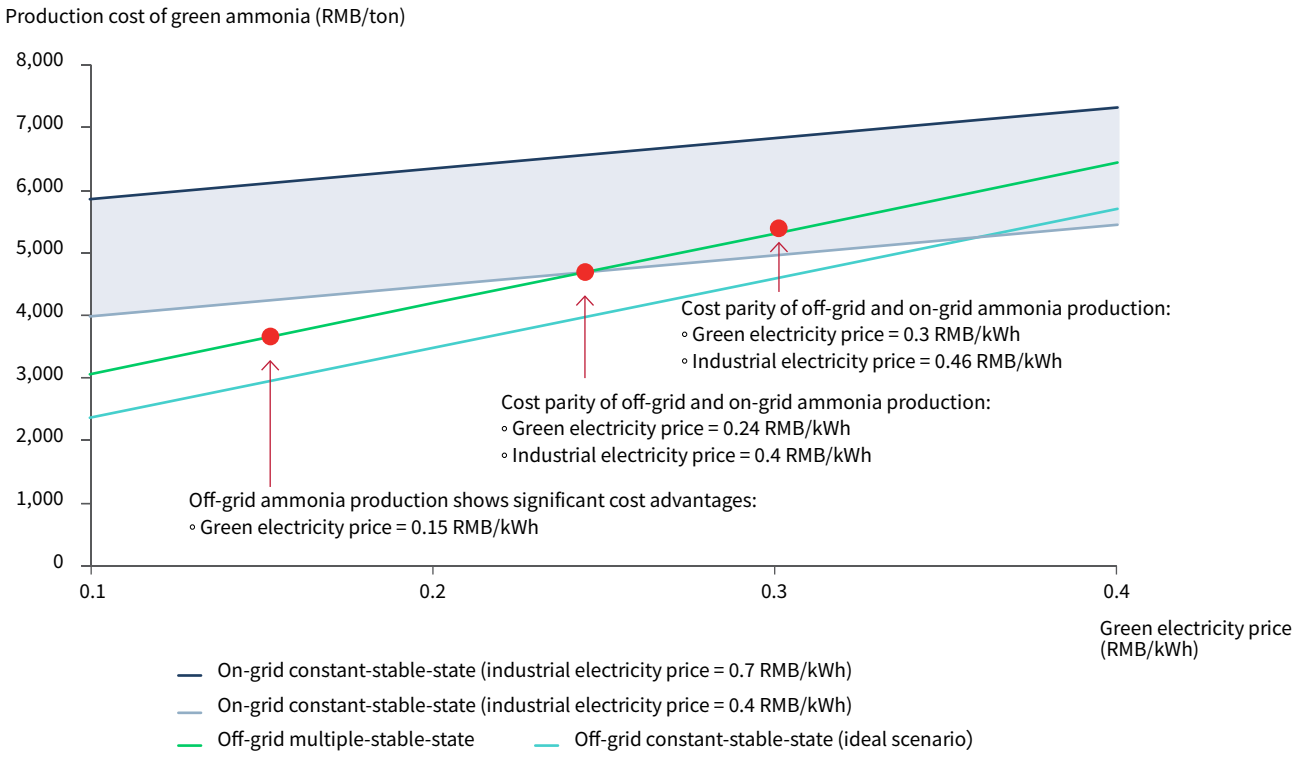
Take the abovementioned regions with advantageous wind and solar resources as an example. If a new ammonia plant with a designed capacity of 200,000 tons/year and operating for 8,000 hours per year is built, the green electricity can only satisfy 49% of its power demand when the on-grid constant-stable-state process is adopted, so the remaining 51% has to be purchased from the grid to ensure stable production. When the off-grid multiple-stable-state process is adopted, additional storage facilities for energy and hydrogen must be deployed for the flexible adjustment of the ammonia plant based on wind and solar power generation conditions. As is seen from the flexible multiple-stable-state ammonia production plan proposed by a project under construction in China, the optimal stable-state load adjustment cycle is eight hours, and the optimal scale of hydrogen storage is 350,000 standard cubic meters of low-pressure hydrogen storage tanks.[8] In addition, the requirement for PV storage in Inner Mongolia specifies the storage ratio of 15%.[9] At the current technology level and conditions, the unit price of week-length hydrogen storage using low-pressure tanks is 2 RMB/kg,[10] and the unit price of electrochemical energy storage is 0.3 RMB/kWh.[11] Based on the above assumptions, the costs of green ammonia production using the on-grid constant-stable-state route ("on-grid green ammonia") and off-grid multiple-stable-state route ("off-grid green ammonia") at different green electricity prices and grid agent's purchase price of electricity ("industrial electricity price") under the fluctuation of renewable power generation are calculated, as shown in Exhibit 8.

With fluctuation of wind and solar power generation, the costs of on-grid and off-grid green ammonia are both higher than that in the ideal scenario. The premium for off-grid green ammonia mainly comes from the additional cost of energy and hydrogen storage, which represents about 15%–20% of the total cost, while the premium for on-grid green ammonia comes from the additional cost of purchasing electricity from the grid, so it varies from 15% to 65% depending on the level of industrial electricity prices.

From the perspective of economics, whether off-grid or on-grid green ammonia should be prioritized at present depends on the renewable resource endowment and existing regional foundations of the industry and power system. For areas with abundant renewable resources and low green electricity prices (below 0.24 RMB/kWh, such as Xinjiang, Ningxia, Inner Mongolia, and other western provinces), off-grid green ammonia offers significant cost advantages. Specifically, when the green electricity price is 0.15 RMB/kWh, the cost of off-grid green ammonia is 15% and 40% lower than that of on-grid green ammonia in areas with low and high industrial electricity prices, respectively, so it is appropriate to maximize the advantages of renewable resource endowment in these areas by selecting the off-grid route to develop green ammonia. In areas less rich in renewable resources, the costs of off-grid and on-grid green ammonia are closer to each other due to high green electricity prices. In this case, lower industrial electricity prices, if available, would help on-grid green ammonia offer cost advantages. For example, if the green electricity price is 0.3 RMB/kWh, which is lower than industrial electricity price at 0.46 RMB/kWh, the cost of on-grid green ammonia will decrease to below that of off-grid green ammonia. Therefore, green ammonia production with on-grid electricity supplies could be the transition route in these regions.

Given future cost evolving trends, the price advantage of off-grid green ammonia over on-grid green ammonia will be further expanded based on the assumption that green electricity prices are decreasing as technology advances and the market matures. According to Exhibit 8, in regions with low industrial electricity prices (0.4 RMB/kWh), if the green electricity price is reduced from 0.3 to 0.1 RMB/kWh, the production cost of off-grid green ammonia will shift from 356 RMB/ton higher than that of on-grid green ammonia to 927 RMB/ton lower, showing improved cost advantage over time. In regions with high industrial electricity prices (0.7 RMB/kWh), the cost advantage of off-grid green ammonia will increase from 1,521 to 2,804 RMB/ton. Therefore, the off-grid multiple-stable-state route is more economical and promising for green ammonia synthesis with the fluctuating power generation of wind and solar PV in the long term.

Exhibit 8. **Production costs of different green ammonia routes with wind and solar power generation**



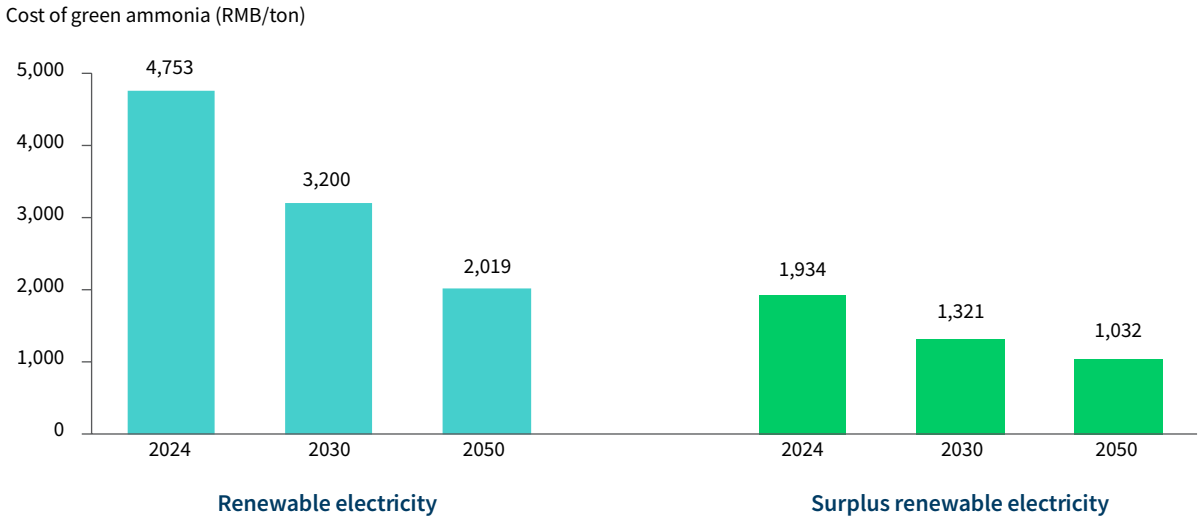
RMI Graphic. Source: RMI analysis

2.3 Impacts of utilizing surplus electricity on cost

Because the cost of renewable electricity has a decisive impact on the cost of green ammonia, using surplus electricity will significantly reduce the cost of electricity for green ammonia production and thus increase cost competitiveness. The scenario of utilizing surplus renewable electricity for green ammonia production is measured based on the assumption that the cost of surplus renewable electricity can reach zero under ideal conditions.[iii] As shown in Exhibit 9, under the current conditions, the cost of green ammonia production using the off-grid multiple-stable-state path was projected to decrease in 2024 from 4,753 RMB/ton (based on a renewable electricity price of 0.25 RMB/kWh) to 1,934 RMB/ton (based on a surplus renewable electricity price of 0), which is lower than that of gray ammonia, which is in the range of 2,200–2,500 RMB/ton, and offers economies for large-scale promotion.

iii In the ideal scenario, the cost of surplus electricity is assumed to be 0. However, the cost of surplus electricity could be higher due to factors such as the limited availability of abandoned wind and solar power generation, fixed investment cost for power-generating facilities, grid reserve capacity, and cost of power transmission and distribution.

Exhibit 9. **Costs of off-grid multiple-stable-state green ammonia production (with renewable electricity and surplus renewable electricity)**



Note: Key assumptions: (1) The total cost of renewable electricity is 0.25, 0.18, and 0.1 RMB/kWh for 2024, 2030, and 2050, respectively. (2) The cost of surplus renewable electricity is zero.
RMI Graphic. Source: RMI analysis

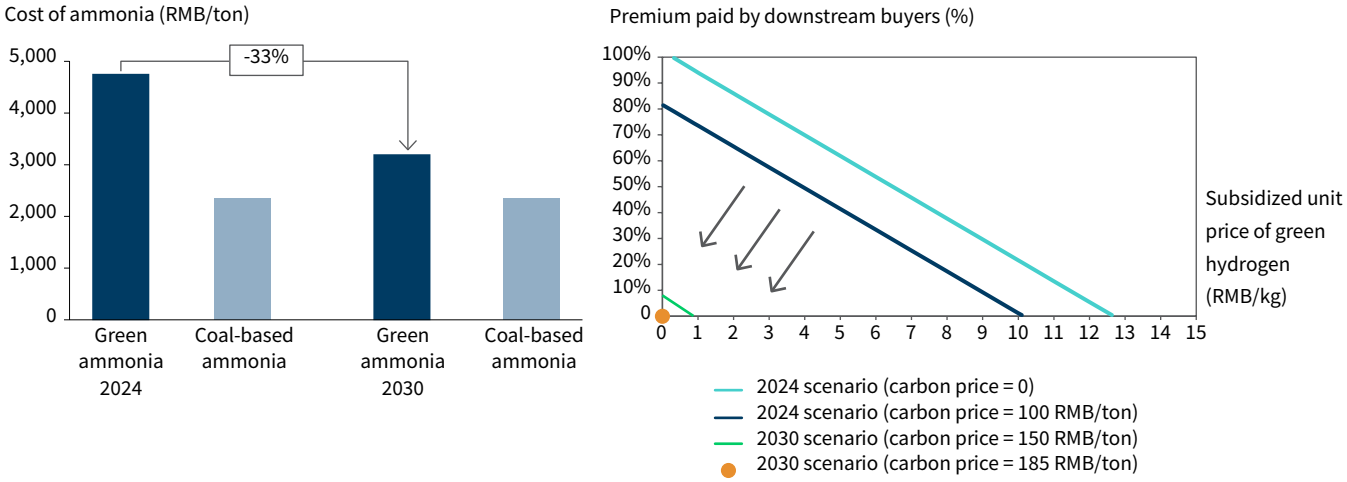
3. Boosting Multiple Use Cases: Driving Cost Reduction and Closing Gaps

In China, ammonia is mainly used in three major use cases: agriculture, industry, and energy carrier. Among them, 70% of ammonia is used in agriculture, and nearly 30% is used in industry. In terms of specific application scenarios, green ammonia faces the problem of excessively high cost compared with conventional paths for both existing agricultural use and emerging scenarios such as power generation and shipping. Taking the above off-grid multiple-stable-state solution for green ammonia production and its application as an example, this section analyzes the trends of the drivers over time, including the policy required, the carbon market, and the downstream premiums, based on the cost after replacement with green ammonia in diverse application scenarios. The aim is to provide reference for solutions that effectively help bridge the cost gap and accelerate the deployment and development of green ammonia.

3.1 Scenario 1: Ammonia for agricultural use

Agriculture is the main application scenario for ammonia. Among the current downstream demands, urea and ammonium nitrate account for 55% and 10%, respectively, and can be used to produce nitrogen and phosphorus fertilizers. The left figure of Exhibit 10 shows the premiums of green ammonia production cost over the conventional path in the agricultural application scenario at present and by 2030. The current production cost of off-grid green ammonia is 4,753 RMB/ton, which is about two times that of the conventional coal-based ammonia cost (2,350 RMB/ton). As technology advances and conversion efficiency improves in renewable power generation, hydrogen production through electrolysis of water, energy storage, hydrogen storage and the production cost of green ammonia is expected to decline by 33% to 3,200 RMB/ton by 2030. Because this cost is still higher than that of coal-based ammonia by 850 RMB/ton, green ammonia cost parity will not be achieved in agricultural applications. If relying on technological advancement and large-scale development alone to reduce the cost of green ammonia, the cost parity between green ammonia and gray ammonia is expected to be achieved between 2040 and 2045.

Exhibit 10. **Cost trends of green ammonia in agricultural scenario (left) and policy and market instruments' role in achieving cost parity (right)**



RMI Graphic. Source: RMI analysis

Agriculture is critical to food security. To promote the adoption of green ammonia with higher cost in this sector, policy support can be leveraged to open the market in the early stage. As the cost of green ammonia decreases, a reasonable reduction and phaseout mechanism of the subsidy should be in place, so that the transition is driven by market-oriented measures such as the carbon market. The current available cost reduction measures mainly include subsidies for green hydrogen production and applications. For example, Jilin, Ningdong, and other places have introduced subsidy policies for different segments along the green hydrogen supply chain. The national carbon emissions trading market covers only the power generation, iron and steel, cement, and electrolytic aluminum industries, and the chemicals industry is still under assessment and has not yet been included. At the downstream buyer level in the agricultural sector, fluctuations in the price and supply of fertilizer will further affect food security because fertilizer is inherently an agricultural necessity. That makes the price of fertilizer more rigid, and the downstream willingness and degree of acceptance of the premium of green fertilizer are both lower under China's fertilizer supply and price stabilization policy.

As shown in the right figure of Exhibit 10, if green ammonia is produced with the current technology, its promotion in the agricultural sector still needs a larger subsidy (12–13 RMB/kg for green hydrogen) to achieve parity with coal-based ammonia. If coal-based ammonia is included in the carbon market in the near future, the green hydrogen subsidy required for parity can be reduced to 9–10 RMB/kg at the current carbon market trading price of 100 RMB/t CO_2 and the downstream acceptable green premium of 5%. It is expected that by 2030, technological advances and scale-up will help cut the cost of green ammonia production by 33%. Although this cost is still higher than that of conventional coal-based ammonia, if at that time the ammonia industry is included in the carbon market and the carbon price is higher than 185 RMB/ton, cost parity of green ammonia can be achieved without the subsidy and the premium paid downstream. Therefore, the shift from a policy-led to a market-led mechanism is expected to accelerate the adoption of green ammonia in the agricultural sector.

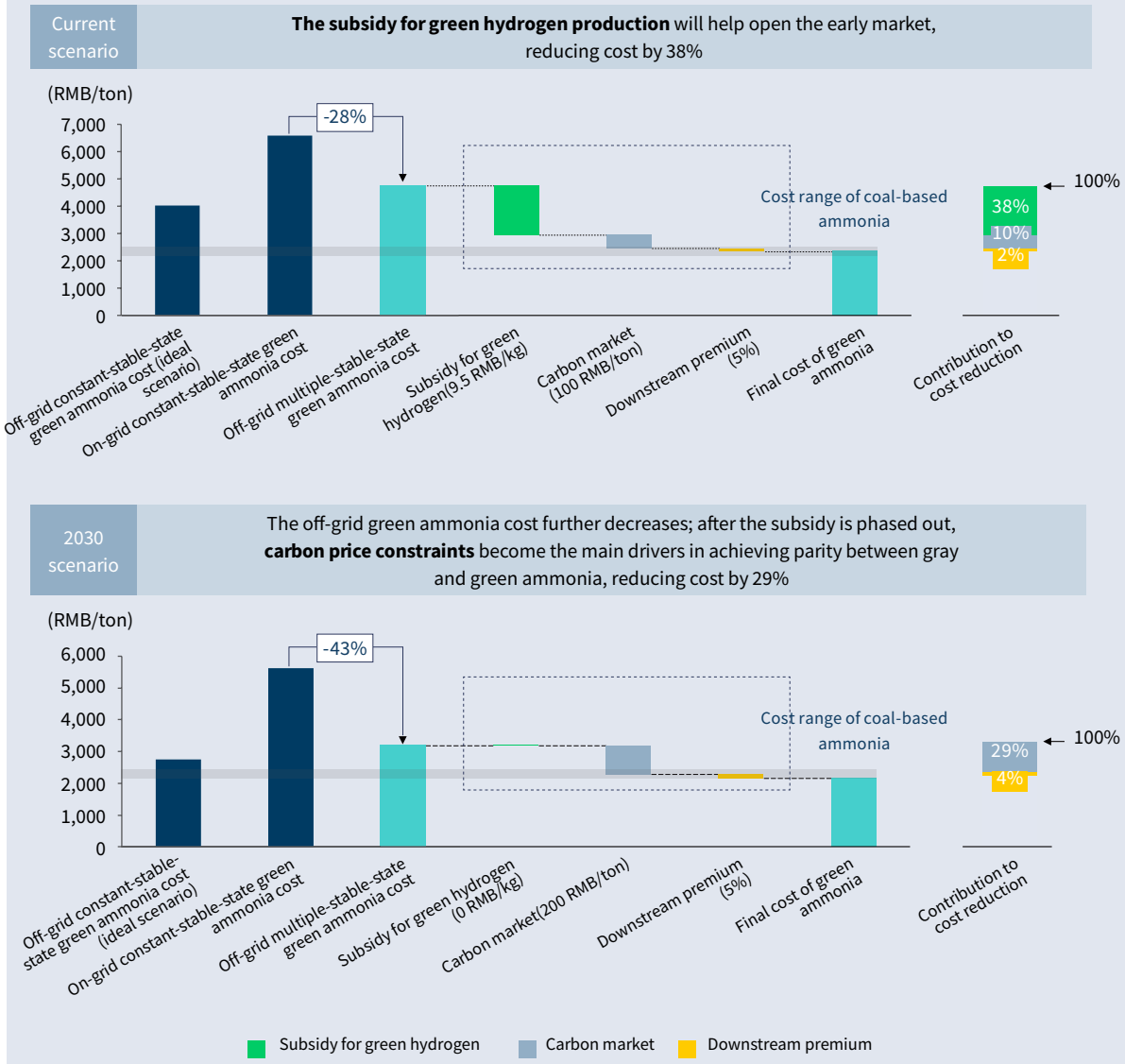
Synergy of multiple factors to drive cost reduction including policy support, downstream willingness to pay premium, and carbon market price signal

The calculation results of green ammonia's cost parity under the current and 2030 scenarios are shown in Exhibit 11, and are based on the assumptions that ammonia will be included in the carbon market for trading in the near future, and downstream buyers could accept a relatively low level of green premium — 5% higher compared with coal-based ammonia production, which is benchmarked with production cost at 2,350 RMB/ton.

At present, the core driver to achieve green ammonia parity in agriculture is early-stage subsidy. The current cost of off-grid green ammonia is 4,753 RMB/ton, and the cost gap between green and gray ammonia could be narrowed by 481 RMB/ton due to the difference in their carbon intensity when the carbon market trading price is at 100 RMB/t CO_2. Assuming the premium paid by the downstream buyers is 5%, the cost gap is further narrowed to 118 RMB/ton. In this case, if the subsidy to players along the green hydrogen supply chain is 9.5 RMB/kg, the cost of green ammonia could further decrease by 1,805 RMB/ton. Therefore, the ultimate cost of green ammonia could reach 2,350 RMB/ton, which is in the parity range with gray ammonia with certain cost competitiveness. Analyzing the contribution of each measure shows that the green hydrogen subsidy in this scenario reduces the cost by 38% compared to the initial cost (100%), while the carbon market and downstream premium reduce the cost by 10% and 2%, respectively.

By 2030, the subsidy is expected to be phased out, enabling green ammonia cost reduction to be carbon market oriented. Because the 2030 scenario assumes an initial cost of 3,200 RMB/ton and that the carbon price will increase to 200 RMB/t CO_2 due to the gradual inclusion of industries in the carbon market and active trading, the carbon price can narrow the cost gap between green ammonia and coal-based ammonia by 914 RMB/ton. The cost reduction is 118 RMB/ton if the premium paid by the buyer is maintained at 5%, and the final cost of green ammonia is 2,157 RMB/ton. This is slightly lower than the cost of coal-based ammonia, enabling green ammonia to offer better cost competitiveness. At that time, the contribution ratio of each measure will change as follows: the carbon market will take the largest share at 29%, the downstream premium will be 4%, and the green hydrogen subsidy will be phased out.

Exhibit 11. **Collaborative cost reductions from subsidy, carbon market, and downstream premium affordability under the current and 2030 scenarios**



RMI Graphic. Source: RMI analysis

Calculations for the domestic cases of Jilin and Ningdong

Exhibit 12. The role of subsidy policy in driving green ammonia toward parity under the current and 2030 scenarios

	Jilin	Ningdong
Output hours of wind and PV (hr)	3,551	3,339
Green hydrogen price (RMB/kg)	17.9	18.1
Cost of off-grid multiple-stable-state green ammonia (RMB/ton)	4,769	4,782
Subsidy policies issued for green hydrogen	For projects with an annual production of more than 100 tons of green hydrogen, the subsidy in the first year is 15 RMB/kg (base) and will be provided for three consecutive years in a way that decreases year by year (80% of the base in the second year and 60% in the third year), with a cap of RMB 5 million each year.	For chemicals projects that replace fossil-based hydrogen with green hydrogen in Ningdong Base, local finance provides subsidy for hydrogen use at 5.6 RMB/kg upon identification with a cap of RMB 5 million per year and up to three years.
Subsidized unit price of green hydrogen (RMB/kg)	15 (1st year, up to 333 tons of green hydrogen/year) 12 (2nd year, up to 417 tons of green hydrogen/year) 9 (3rd year, up to 556 tons of green hydrogen/year) 0.27 (200,000 tons of multiple-stable-state green ammonia, 18,549 tons of hydrogen/year)	5.6 (up to 893 tons of green hydrogen/year) 0.27 (200,000 tons of multiple-stable-state green ammonia, 18,549 tons of hydrogen/year)
Subsidized price of green ammonia (RMB/ton)	4,718 (actual subsidy) 1,868 (max. subsidy without cap)	4,731 (actual subsidy) 3,667 (max. subsidy without cap)

RMI Graphic. Source: Jilin Provincial People's Government, **https://xxgk.jl.gov.cn/szf/gkml/202212/t20221205_8643380.html**; Ningdong Base Management Committee, **https://www.nationalee.com/newsinfo/6865031.html**; RMI analysis

Domestic subsidy policies are already in place for the production and utilization of green hydrogen. For example, as shown in Exhibit 12, Jilin Province provides three consecutive years of subsidy for projects with an annual production of at least 100 tons of green hydrogen. Starting at 15 RMB/kg in the first year, the subsidy declines every year (80% in the second year and 60% in the third year). Ningdong Energy and Chemical Industry Base subsidize chemicals projects that replace gray hydrogen with green hydrogen at 5.6 RMB/kg, with a cap of RMB 5 million per year for a single enterprise and up to three years.

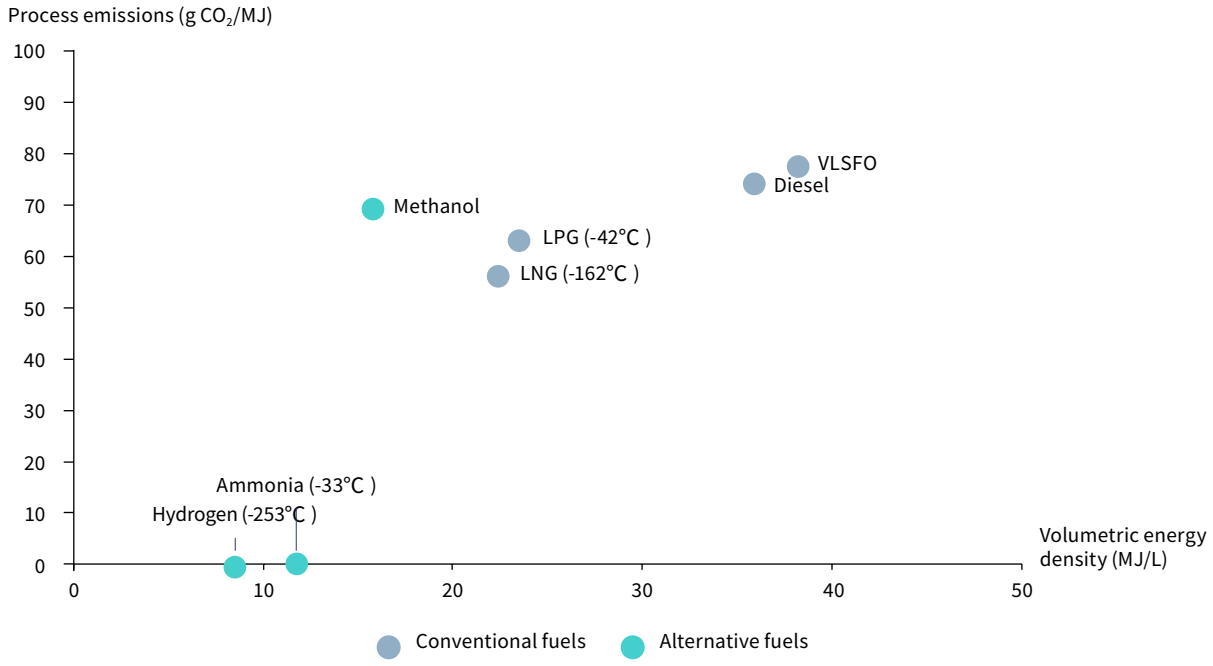
Although all relevant subsidy policies mention a larger subsidy, it is still difficult to cover the demand for subsidy of large-scale green ammonia projects due to caps on the total amount of subsidies. According to the calculation of wind and solar resources in Jilin and Ningdong, the current production costs of off-grid green ammonia there are 4,769 and 4,782 RMB/ton, respectively. If the subsidy for green hydrogen is 15 and 5.6 RMB/kg, the post-subsidized green ammonia prices will be 1,868 and 3,667 RMB/ton. However, because the policies introduced in both places have set a total subsidy cap of RMB 5 million, the subsidy can only reduce the cost of green ammonia to 4,718 and 4,731 RMB/ton if the annual output is about 100,000 tons of ammonia, leading to limited cost reduction. The cap on the total subsidy favors small-scale green ammonia plants. For example, under the current policy in Jilin, the subsidy of 15 RMB/kg can support up to 333 tons/year of green ammonia production, while in Ningdong the subsidy of 5.6 RMB/kg can support up to 893 tons/year. In China, the scale of typical ammonia plants is above 10,000 tons, so the subsidy cap makes it difficult for large-scale green ammonia projects to receive the degree of subsidy support mentioned in the policy.

3.2 Scenario 2: Ammonia as maritime fuel

Clean alternative liquid fuels represented by green hydrogen and its derivatives such as green ammonia and green methanol have received extensive attention in the context of the decarbonization of the global maritime industry. As shown in Exhibit 13, alternative fuels including hydrogen, ammonia, and alcohols have a lower volumetric energy density than conventional fuels such as very-low-sulfur fuel oil (VLSFO) and diesel. Volumetric energy density is a key measure for comparing the properties of maritime fuels, which indicates that alternative fuel storage containers must be two to four times the volume of conventional fuels' to achieve comparable volumetric energy for a given distance of transportation.[iv]

Despite the lower volumetric energy density, alternative fuels can significantly reduce carbon emissions during use. For example, green hydrogen and green ammonia emit zero carbon dioxide in the combustion process because these fuels do not contain carbon elements. At the same time, the application of alternative fuels in the fuel cell vessel improves the efficiency of energy conversion. Traditional fuel (such as VLSFO, liquefied natural gas [LNG], and liquefied petroleum gas [LPG]) engines are internal combustion engines that convert the thermal energy generated from the combustion of fuel into mechanical energy, causing a certain amount of heat loss, which reduces the efficiency of energy conversion. Alternative fuels (hydrogen, ammonia, and methanol) can be used in the internal combustion engine or fuel cell. For example, an ammonia-powered ship that adopts a direct ammonia-to-electricity solid oxide fuel cell (SOFC) power system can directly convert chemical energy to electric energy at an efficiency of 50%–60%, which is 10% higher than that of the traditional internal combustion engine.[12]

Exhibit 13. **Properties of liquid fuel for maritime transportation**

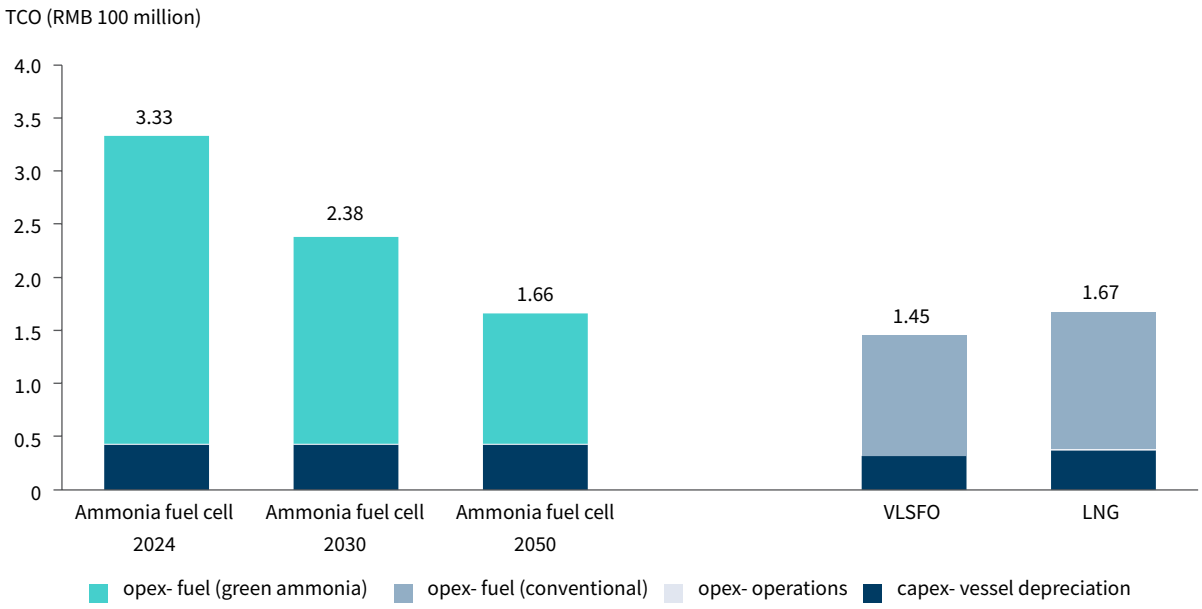


RMI Graphic. Source: mtu, **https://www.mtu-solutions.com/cn/zh/stories/marine/how-does-shipping-go-green.html**; Guangdong Provincial Department of Ecology and Environment, **https://gdee.gd.gov.cn/attachment/0/483/483550/3836527.pdf**; RMI analysis

iv Process emissions in shipping are also referred to as tank-to-wake emissions, indicating the emissions that result from the on-board fuel as the vessel navigates the water.

For the shipping industry, total cost of ownership (TCO) is a key indicator that measures all the economic inputs of a vessel over its entire life cycle, including the present value of the initial investment annuity, fuel cost, and operating expenses. Therefore, it is also widely used to compare the economics of different vessels. As measured in Exhibit 14, the current TCO for ammonia fuel cell vessels is RMB 333 million, while the TCOs for conventional VLSFO and LNG vessels are RMB 145 million and RMB 167 million, respectively, making the TCO of ammonia-powered vessels 2.3 times that of VLSFO vessels and 2 times that of LNG vessels. The high cost of ammonia fuel cell vessels is attributed to two main reasons. First, the production of ammonia fuel cell vessels requires special designs for ammonia engines, fuel storage tank safety, and so on, so the cost of construction (capital expenditures) is higher, 1.5 times that of VLSFO vessels. Second, fuel cost has a decisive impact on vessel TCO, accounting for 80%–90% of the TCO of vessels with different power sources. The current unit energy cost of green ammonia being higher than that of conventional fuels further increases the total cost of ammonia fuel cell vessels. As the cost of green ammonia declines, the TCO of ammonia fuel cell vessels could fall to RMB 238 million and RMB 166 million by 2030 and 2050, and eventually equalize with the cost of LNG vessels around 2050, but still be higher than that of VLSFO vessels. Relying on technology to drive cost reduction alone will postpone parity beyond 2050.

Exhibit 14. **TCO comparison of vessels with different liquid fuels**



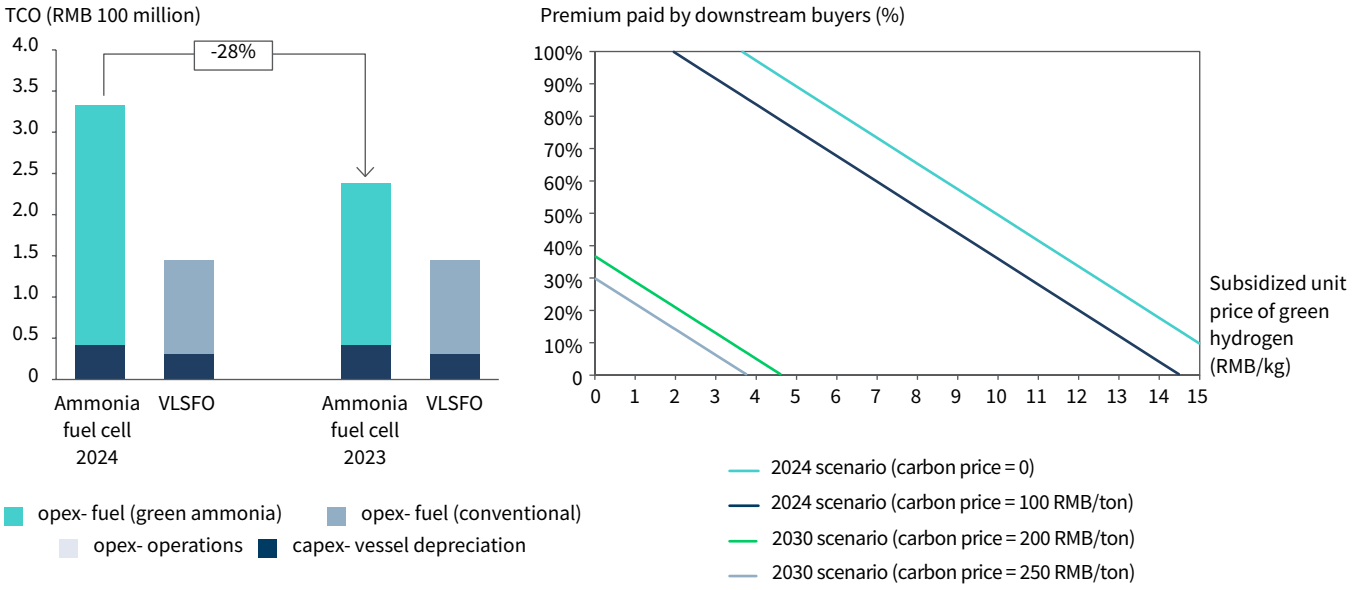
Note: Key assumptions: (1) Ammonia fuel cells are SOFCs with a service life of 25 years and a capex of 0 salvage value on a straight-line depreciation method. (2) The green electricity prices for 2024, 2030, and 2050 are 0.25, 0.18, and 0.1 RMB/kWh. (3) The unit prices of VLSFO and LNG are 4,544 and 6,000 RMB/ton, respectively.

RMI Graphic. Source: RMI analysis

Accelerating international recognition and compatibility of green ammonia standards and certifications can improve the willingness of the shipping industry to pay the green premium as a downstream industry, thus propelling the scale-up of green ammonia in the industry. Despite the current high cost, the significance of green ammonia for decarbonizing shipping makes it possible for ship owners to pay a higher green premium at an early stage to fuel the operation of ammonia-powered ships. As shown in Exhibit 15, when the carbon price is 0–100 RMB/ton, the parity between ammonia-powered vessels and VLSFO vessels can only be achieved if a green premium of 115%–130% is paid by the downstream. This premium will drop to 30%–40% by 2030 when the carbon price is 200–250 RMB/ton. In July 2024, the world's first green ammonia pricing under the green ammonia certification compliant with the EU's Renewable Energy

Directive (RED II) was awarded to Germany's Hydrogen Derivatives Import Program, with the winning price at a premium of more than 1.9 times that of conventional ammonia.[13] This international example shows that compliance with green product standards has a significant effect on monetizing the environmental benefits of green ammonia. Receiving a green premium under the standard framework system will play a critical role in bridging the cost gap of green ammonia and in deploying ammonia-powered vessels in the maritime sector. Therefore, China sees great importance in jointly establishing a global green ammonia market for the low-carbon transition of the ammonia industry. The construction of a scientific, rigorous, and effective standard system that is internationally recognized and compatible will greatly support the creation of a green ammonia market that offers a differentiated premium.

Exhibit 15. **Cost trends of the green ammonia in the maritime fuel scenario (left) and policy and market instruments' role in achieving cost parity (right)**



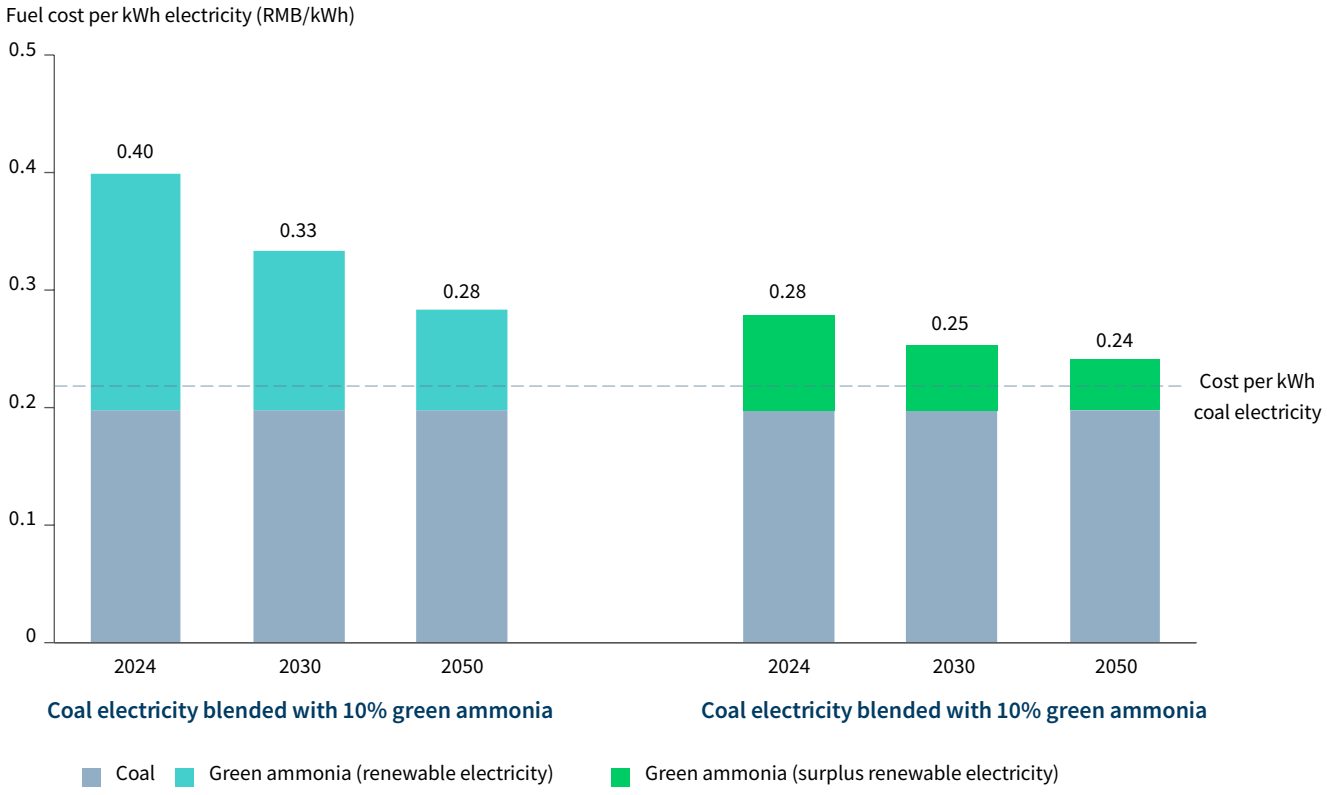
RMI Graphic. Source: RMI analysis

3.3 Scenario 3: Blending ammonia for power generation

The power industry has been included in the carbon market for trading. From 2022 to 2024, the domestic carbon market price increased from 60 to 100 RMB/ton, and power enterprises, especially coal power units, urgently need to reduce carbon emissions. Blending ammonia for power generation is one of the three major low-carbon power generation technology routes for coal power generation defined in the *Action Plan for Low-Carbon Transformation and Construction of Coal-based Power Generation (2024-2027)*,[14] including biomass-blended burning, green ammonia–blended burning, and carbon capture, utilization, and storage. Green ammonia–blended burning offers potential for emissions reduction compared to existing coal power units. The calorific value per unit of ammonia is two-thirds that of coal, and the amount of ammonia consumed to provide the same calorific value is greater than the amount of coal consumed. As shown in Exhibit 16, the fuel cost per kWh of the ammonia blended power generation route is measured based on the amount of the fuel required to provide the same calorific value, using the green ammonia–blended burning ratio of 10% suggested by the policy. The fuel costs per kWh using green ammonia produced with renewable electricity are RMB 0.40, 0.33, and 0.28 by 2024, 2030, and 2050, respectively. If green ammonia is produced with surplus electricity (assume surplus electricity price at 0)

as suggested by the policy, the fuel costs per kWh can be reduced to RMB 0.28, 0.25, and 0.24 due to the lower cost of electricity, but are still higher than that of coal power (0.22 RMB/kWh). Parity will be achieved later than 2050 through technology-driven cost reduction.

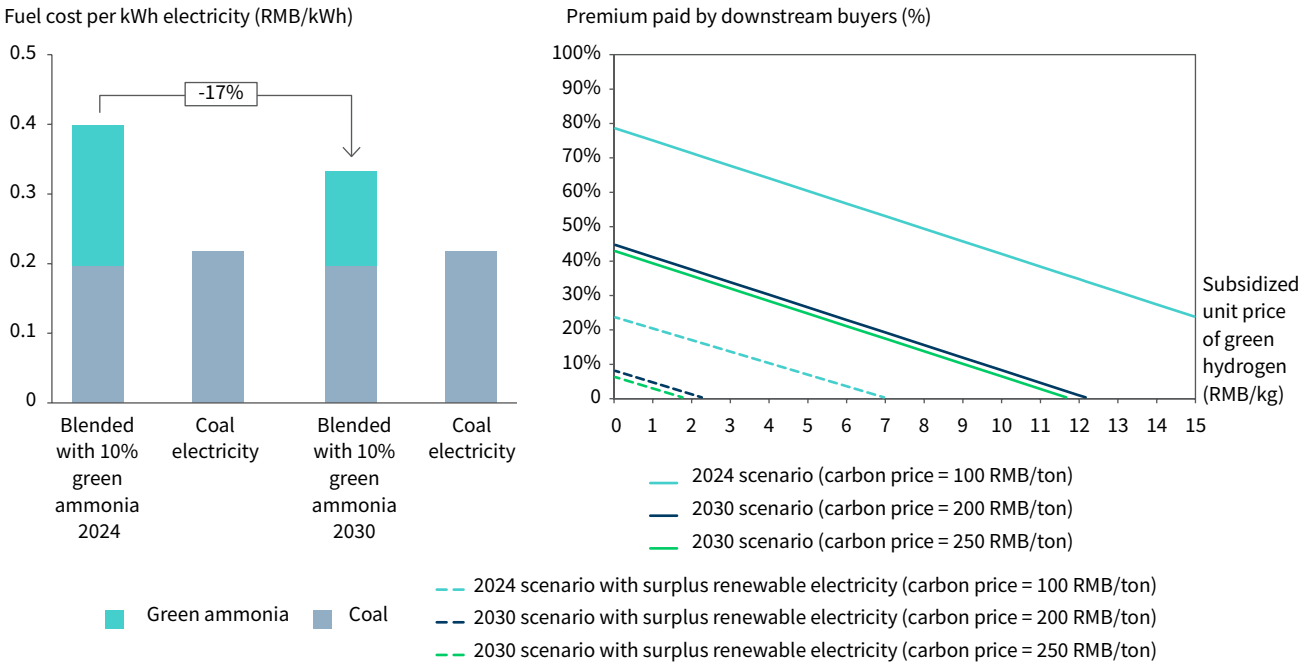
Exhibit 16. **Fuel cost per kWh for 10% green ammonia–blended power generation**



Note: Key assumptions: (1) The coal price is 800 RMB/ton. (2) Blending of 10% green ammonia is measured by calorific value ratio, (i.e., 10% of the calorific value of coal electricity is replaced with green ammonia). (3) The green electricity prices for 2024, 2030, and 2050 are 0.25, 0.18, and 0.1 RMB/kWh, and the price of surplus renewable electricity is assumed to be 0. (4) The technical parameters and costs of electrolysis, hydrogen storage, and electrochemical energy storage are decreasing over time.
RMI Graphic. Source: RMI analysis

Reducing the cost of green ammonia production through the advantageous low price of surplus renewable electricity is the key to achieving parity in ammonia blended for power generation. Although the power sector has already been included in the carbon market, due to the high cost of green ammonia compared to coal, parity between blending ammonia and coal power generation is still achieved only with extensive subsidies for green hydrogen (>15 RMB/kg) or downstream premiums (80%), showing high reliance on non-technology-driven cost reduction factors. Even as the cost of green ammonia declines with technological advancement, the subsidy required to green hydrogen will remain as high as 12 RMB/kg by 2030, and the challenge to parity is significant. However, if surplus renewable electricity can be utilized, the need for cost reduction instruments will be significantly reduced. As shown in Exhibit 17, under the assumed technology cost and carbon price, the cost difference between producing green ammonia using surplus renewable electricity and the conventional path further narrows with reduced needs for subsidies and for the proportion of premium paid by downstream buyers (moving to the lower left in the right figure of Exhibit 17). When the cost of surplus renewable electricity is zero, the green hydrogen subsidy required to achieve parity of blending ammonia for power generation decreases to 7 RMB/kg at present and to 2 RMB/kg by 2030, thus greatly reducing the difficulty.

Exhibit 17. **Cost trends of blending ammonia in power generation scenarios (left) and policy and market instruments' role in achieving cost parity (right)**



RMI Graphic. Source: RMI analysis

3.4 Outlook of green ammonia in multiple use cases

The cost premium of the green ammonia production route over the conventional route and the trigger of the cost reduction measures required for parity show different features in the three application scenarios of green ammonia. As shown in Exhibit 18, in the agriculture sector where the premium is the lowest, the production cost of green ammonia is 102% higher than that of coal-based ammonia at present and 36% higher by 2030, and can rely on technological advancement to achieve parity in 2040–2045. Through the carbon market and the premium paid by downstream buyers, green ammonia in the agricultural scenario is expected to be free of subsidy by 2030 at the earliest, when it could transition to a market-driven growth model. The premium in the maritime fuel scenario is comparatively high, with ammonia-fueled vessels currently costing 129% more than VLSFO ones. Parity will not be achieved until beyond 2050 if relying on technological advancement alone. However, with the premium paid in the downstream and the carbon market, parity can be achieved earlier, by around 2040. Compared with these two scenarios, blending ammonia for power generation shows greater uncertainty, and it will be difficult to achieve parity by 2050 through cost reductions if only utilizing green ammonia produced with renewable electricity. In this scenario, it is crucial to reduce the cost of green ammonia production by relying on the advantageous low cost of surplus renewable electricity.

Exhibit 18. **Outlook for green ammonia across application scenarios**

Application scenario	Agriculture (existing application)	Clean shipping fuels (emerging application)	Ammonia-blended power generation (emerging application)	
Conventional path	Coal-based ammonia	Very-low-sulfur fuel oil	Coal electricity	
Green ammonia path	Green electricity-green hydrogen-green ammonia	Ammonia fuel cell	Power generation blended with 10% green ammonia (renewable electricity)	Power generation blended with 10% green ammonia (surplus renewable electricity)
Cost of conventional path	2,350 RMB/ton	145 million RMB/year	0.22 RMB/kWh	Power generation blended with 10% green ammonia (surplus renewable electricity)
Cost of green ammonia path (premium compared with conventional path) by 2024	4,753 RMB/ton (102%)	333 million RMB/year (129%)	0.40 RMB/kWh (83%)	0.28 RMB/kWh (28%)
Cost of green ammonia path (premium compared with conventional path) by 2030	3,200 RMB/ton (36%)	238 million RMB/year (64%)	0.33 RMB/kWh (52%)	0.25 RMB/kWh (16%)
Time to parity through technology-driven cost reduction	Small-scale production by 2040 Large-scale production by 2045	Later than 2050	Later than 2050	Later than 2050
Downstream premiums (%)	5%	10%	10%	10%
Green hydrogen subsidy required for parity by 2024 (carbon price = 100 RMB/ton)	9.5 RMB/kg	13 RMB/kg	18.5 RMB/kg	4 RMB/kg
Estimated earliest time to parity (green premium paid in the downstream, joint cost reduction through carbon market trading, subsidy completely phased out)	2030 (no premium paid by downstream buyers)	Around 2040	Later than 2050	2030

RMI Graphic. Source: RMI analysis

All three application scenarios see both opportunities and challenges in replacing the conventional ammonia production route with green ammonia.

Agriculture

Green ammonia is expected to reshape the production capacity deployment of the ammonia and fertilizer industries while helping overcome the seasonal shortage of fertilizer production. In terms of industrial location, green ammonia can lead the shift of ammonia and fertilizer production capacity from coal- and natural gas–rich areas to renewable resource–rich ones. Take Northeast China as an example. Green ammonia is expected to offer the opportunity for localized fertilizer production because the local traditional ammonia production capacity is limited by fossil resources and the scale of agriculture and the demand for fertilizers are large, making it a net inflow region for fertilizers. Seasonally, green ammonia can be used as an alternative source to help overcome ammonia fluctuations to produce fertilizers. Traditional ammonia production could be restricted or reduced due to the ensured supply of coal and gas during the heating season. Northeast China has a cold winter and a long heating season with a high demand for fossil energy, which potentially consumes the same fossil fuels as ammonia production. If the ample wind and solar resources in Northeast China (especially the wind resource in winter) can be utilized, there will be new opportunities to utilize green ammonia as a supplementary feedstock for fertilizer production in winter.

However, in the traditional agricultural application scenario, the domestic market has sufficient ammonia production capacity with limited profitability of downstream fertilizer production, so the weak motivation of enterprises for technological substitution may become a challenge in large-scale application.

Maritime fuel

Methanol- and ammonia-based fuels are expected to decarbonize the shipping industry; green ammonia has significant advantages over methanol in terms of industrial base and future costs. Compared with ammonia-fueled vessels, methanol-fueled vessels have an advantage in ordered quantity and the number in use due to the variety of paths to clean fuel production and the maturity of engine technology and marine standards. By June 2024, global orders for methanol-powered vessels and the number in operation were 234 and 35, compared with only 25 and 1 for ammonia-powered vessels.[15] However, ammonia synthesis technology is mature and the industrial base is developed enough to meet the demand for large-scale vessel fueling. In addition, ammonia synthesis only needs water as the feedstock, whereas green methanol production also needs CO_2. Looking ahead, green ammonia will offer better economics because CO_2 captured from the industrial process may not be recognized as a green source. Thus, CO_2 may need to be obtained using direct air capture, which will make green methanol's cost increase significantly.

Challenges to green ammonia as a maritime fuel include immature ammonia engine and fuel cell technologies, chemical toxicity of ammonia, and a higher level of safety for ammonia-fueled vessels due to the risk of fuel leakage and material corrosion.

Blending ammonia for power generation

The application of green ammonia in the retrofit of coal power units may bring stable, expected demands, while technological breakthroughs in the proportion of blended ammonia will offer the potential for growth of the applications. There are long-term demands for the decarbonization of coal power plants. It is expected that coal power plants will still represent 34% and 8% of the total installed capacity of the power system and coal power generation will represent 45% and 5% of the national power generation capacity

by 2030 and 2060.[16] Blending ammonia for power generation is one of the three major technologies for the low-carbon transformation of coal power plants that have been identified by the current policy, creating a favorable situation for green ammonia's demand and application. Technically, the current policy proposes an ammonia blending ratio of 10%, while domestic engineering trials have verified the feasibility of a 35% blending ratio. It can be foreseen that the technology breakthrough with a higher ammonia blending ratio will bring greater demand for green ammonia.

However, different from agriculture and maritime fuel, which utilize green ammonia as the main decarbonization route, power companies under the coal power plant decarbonization and transformation guidance would have biomass-blended burning; carbon capture, utilization, and storage; and other relatively mature and competitive low-carbon technology options besides ammonia blending, which is facing challenges that cause uncertainty in future applications, including low total energy efficiency and technical difficulties in exhausted gas pollutant control.

4. Global Practices and Implications

Countries and regions have gained valuable experiences and lessons through their distinctive projects promoting the development of the green hydrogen and green ammonia industries across the world. These projects are not only the effective integration of technological innovation and policy support, but also provide reference and implication for the development of the green ammonia industry in China.

4.1 Yara — Joint efforts of subsidy, certification, and value chain collaboration

Yara is a large Norwegian international fertilizer company, and its clean ammonia division, Yara Clean Ammonia, is the world's largest ammonia distributor committed to seizing growth opportunities in low-emissions fuels for shipping and power generation, low-carbon food production, and industrial ammonia, while boosting the global development of clean ammonia. With 15 vessels, Yara Clean Ammonia operates the world's largest ammonia network, and it has access to 18 ammonia terminals as well as multiple ammonia production and consumption sites around the world.

Yara Clean Ammonia's representative project is the green retrofit of a gas-fired ammonia plant in Pilbara, Western Australia, one of the world's largest ammonia production facilities with a production capacity of 840,000 tons of ammonia per year and a market share of approximately 20% of the global ammonia trade. In 2022, Yara Pilbara partnered with the international energy company ENGIE to construct a demonstration project of green ammonia transformation that includes a 10 megawatt (MW) electrolyzer, 18 MW solar PV and battery storage, and a green hydrogen plant with 640-ton annual capacity at ENGIE's site to provide green hydrogen for the ammonia plant. The project started production in 2022 and began supplying green hydrogen to the ammonia plant in 2024.

The early success of the project was mainly attributed to subsidy, certification, and cooperation of stakeholders across the value chain:

- Government subsidy: The Yara Pilbara project received AUD 42.5 million from the Australian Renewable Energy Agency Renewable's Hydrogen Deployment Funding Round, and AUD 2 million from the Renewable Hydrogen Fund of the Western Australian government. This financial assistance greatly supported the deployment and development of the project at the early stage, improving the economics of green ammonia production.

- Green certification: The Yara Pilbara plant was the first green ammonia project to be certified by the Australian Smart Energy Council's Zero Carbon Certification Program for its commitment to produce renewable ammonia with the electricity from on-site solar PV, creating a demonstration for the industry.

- Long-term offtake agreements: In 2024, Yara signed long-term offtake agreements with India-based energy companies Acme Cleantech and AM Green to import renewable ammonia that meets the

requirements of the EU RFNBO and RED II. The establishment of the renewable ammonia certification scheme and the long-term offtake agreements have helped increase green ammonia producers' confidence, reducing supply chain risk.

- Early tie-ups with downstream shipping and power generation companies: In 2021, Yara signed a memorandum of understanding with JERA, Japan's largest power generation company, to collaborate on the production, delivery, and supply chain development of ammonia produced from natural gas and green ammonia for zero-emissions thermal power generation in Japan. In 2023, Yara built the world's first clean ammonia-fueled container ship, Yara Eyde. It will be the first vessel to sail an emissions-free route between Norway and Germany, expected in mid-2026. The expansion of downstream application scenarios is generating new demands for green ammonia.

4.2 Talus — A distributed development model

Talus Renewables is an innovative US-based company specializing in the development and promotion of renewable energy technologies for sustainable development in the agricultural and industrial sectors. The company has made significant progress in DGA production, particularly in miniaturizing the traditional Haber-Bosch process to fit into small-scale, modular production facilities. Talus Renewables optimizes the traditional Haber-Bosch process by reducing operating pressures and temperatures and improving catalyst efficiency for small-scale production. The process is designed as a containerized module that can be easily transported and installed to meet the needs of single farms or small cooperatives, while effectively integrating with renewable energy sources such as wind and solar power for 100% green production.

Compared with conventional centralized ammonia synthesis, DGA introduces the following opportunities to downstream agricultural production:

- Reduced supply chain risk: With distributed ammonia production, the fertilizer supply chain shifts from multimodal transportation across thousands of miles to "the farm community's backyard," offering higher reliability and significantly lower cost. Simplifying supply chain logistics protects consumers from geopolitical instability and uncertainty across transportation.

- Enhanced fertilizer price stability: By decoupling ammonia production from the fluctuation of natural gas price and coupling it to the fixed annual cost of renewable electricity, DGA production reduces the pressure on farmers from fluctuating ammonia prices and ensures that farmers are able to purchase fertilizer at a more stable and affordable cost.

- Operational benefits of renewable electricity integration: Traditional ammonia production technologies must continuously maintain and operate at high temperatures and pressures. When these processes move from a steady supply of fossil raw materials to an intermittent supply of renewable electricity, they should be provided with energy storage, which adds cost and complexity. The advanced small-scale ammonia production processes could be operated more flexibly and allow for adjustment in production in response to changes in renewable energy supply, providing possibilities for cost reduction and system simplification.

4.3 NEOM— Large-scale production

The NEOM Green Hydrogen Company (NGHC), a joint venture between ACWA Power, Air Products, and NEOM, will integrate up to 4 GW of solar and wind energy to build the world's largest green hydrogen plant by 2026. The plant will produce up to 650 tons of green hydrogen per day in the form of green ammonia with an annual production capacity of 1.2 million tons of green ammonia to provide cost-effective solutions for the global transportation and industrial sectors. It is expected to reduce 5 million tons of CO_2 emissions per year. The plant is currently under construction at Oxagon in NEOM of Saudi Arabia.

As the world's largest green ammonia project to date, the success of the NEOM project can be summarized as follows:

- Large-scale green financing: The project has a total value of US$8.4 billion and received US$6.1 billion of nonrecourse financing provided by 23 local, regional, and international banks and financial institutions. The nonrecourse financing structure of the project has been certified by S&P Global (as a second-party opinion provider) as compliant with the Green Loan Principles, and is one of the largest project financings implemented under the Green Loan framework.

- Exclusive offtake agreement and international market expansion: NGHC has entered into an exclusive 30-year offtake agreement with Air Products that covers all green ammonia produced at the plant. This will unlock the economic potential of renewable energy throughout the value chain. The project focuses on developing international markets, particularly those countries and regions that are actively pursuing energy transition and carbon neutrality goals. It has signed long-term supply agreements with a number of countries and companies in Japan, South Korea, and Europe to meet their demand for green ammonia and hydrogen.

- International advanced technology collaboration: NEOM's collaboration with Air Products and ACWA Power leverages their technology and experience in industrial gases and renewable energy to ensure the technical advancement and feasibility of the project. NGHC has entered into an engineering, procurement, and construction agreement with Air Products, which is the designated contractor and systems integrator for the entire facility.

- Financial and policy support: The government has invested in the construction of large-scale solar and wind power generation facilities to ensure that the NEOM project receives a stable, low-cost supply of renewable energy. The Saudi government has provided income tax exemptions to companies that are part of the NEOM project, reducing their tax burden and increasing their profits. An import tariff exemption is implemented for key equipment and technology used in the green ammonia project, reducing the initial investment cost of enterprises.

From the above three projects, the following conclusions can be drawn (see Exhibit 19):

- First, financial support is the basis for the success of green ammonia projects. In the above projects, the government provided financial support through the provision of green hydrogen subsidy, tax exemption, and support for early green financing of the projects, which can help improve the economics of early green ammonia projects.

- Second, the buyer's willingness to offtake is an important basis for enhancing the expectation of stable, long-term returns from green ammonia projects. For early projects that still have a green production premium, signing exclusive offtake agreements or long-term supply agreements can convey confidence in stable production and supply to the upstream production side, helping enhance long-term stable development across the supply chain.

- Third, the development of downstream application scenarios is critical to steadily expanding market demand for green ammonia. In addition to the traditional fertilizer industry, the applications of ammonia blended for power generation, ammonia-powered shipping, and other emerging areas will increase demand for green ammonia.

- Fourth, the establishment of product standards and certification systems for green hydrogen and green ammonia will provide essential guidance to the industry and help monetize the environmental value of green products.

- Fifth, to better adapt to the fluctuation of renewable energy, the innovative low-temperature, low-pressure Haber-Bosch process with advanced catalysts that enables flexible start–stop of green ammonia production will play a key role in matching renewable electricity on a larger scale and further reducing the cost of green ammonia.

Exhibit 19. **Implications from global green ammonia projects**

Category	Measures	Result	Case 1: Yara (Norway)	Case 2: Talus (US)	Case 3: NEOM (Saudi Arabia)	Domestic situation
Financial support	Government provides subsidy for green hydrogen, tax exemption, and support for early green financing of projects	Enhance economics of green ammonia	✓	✓	✓	★★ Many provinces have issued subsidy policies for green hydrogen
Buyers' willingness to to offtake	Sign exclusive offtake agreements and long-term supply agreements with buyers	Enhance the expectation for long-term revenue stabilization of green ammonia project	✓	✓	✓	★ Weak demand among buyers to offtake
Downstream application	Expand green ammonia application scenarios in fertilizer, shipping, power generation, and other sectors	Expand green ammonia market demand	✓	✓	✓	★ Mature applications in fertilizer; applications in shipping and power generation are still being explored
Standard setting	Establish green hydrogen and green ammonia product standards	Lead the development of green ammonia industry	✓	✓		★★ Group standard for green hydrogen already in place; standards for green hydrogen and derivatives are under development
New process	New innovative low-temperature, low-pressure Haber-Bosch process and new catalysts	Flexible start-stop for better adaptability to renewable energy fluctuations		✓		★ Small-scale demonstration application

Note: ★ Early stage; ★★ Positive progress; ★★★ Mature

RMI Graphic. Source: RMI analysis

5. Recommendations

The low-carbon development of the ammonia industry is crucial not only to the chemicals industry's decarbonization, but also to the low-carbon transition of many industries in its application scenarios. On the one hand, as an important derivative of green hydrogen, green ammonia can address storage, transport, and consumption of renewable energy sources through the green electricity–green hydrogen–green ammonia conversion, enabling the coupling of renewable energy systems with conventional power systems. On the other hand, as an important basic chemical and energy carrier, green ammonia will provide a feasible path to the green transition of fertilizer, shipping, power generation, and other related industries in the downstream market, contributing to the decarbonization paths and prospects in the industrial, transportation, and power generation sectors.

Due to factors such as the high cost of renewable electricity and the need to adapt continuous production of ammonia to fluctuations in renewable power generation, the current production cost of green ammonia is still high compared to conventional options. Innovative cost-sharing mechanisms combined with maximum roles of technology iteration, policy support, carbon markets, and downstream premiums are essential to accelerating green ammonia's path to cost parity.

With the above analysis, this report provides recommendations for the following three levels:

Policy level: Create policies that support the development of the green ammonia industry and examine the incorporation of green ammonia into the green energy system as quickly as possible; keep the green electricity–green hydrogen–green ammonia chain smooth on the supply side; and foster the application of green ammonia in agriculture, shipping, and electricity scenarios on the consumption side.

- Because green ammonia is both a chemical product and an energy source, incorporate it into green energy policy systems and strategies as quickly as possible to create favorable conditions for its utilization as an emerging energy source. Create policies that support the development of the green ammonia industry, leverage the advantages of domestic upstream and downstream industry integration and diverse application scenarios at a certain scale, and prioritize the market-oriented approach to guide and drive the development of the green ammonia industry.

- Focus regional and project planning on gradually promoting partial and high-proportion replacement of fossil energy consumption with green power, green hydrogen, and green ammonia based on local conditions and its industrial basis. Locate new green ammonia projects as close as possible to wind and solar power generation bases to create favorable conditions by accessing low-cost renewable electricity. For existing coal- and gas-based ammonia plants, encourage the gradual blending of green hydrogen to transition from gray ammonia to green ammonia.

- Develop support plans for specific application scenarios and ensure cross-scenario policy convergence. For example, in the agricultural scenario concerning food security, the downstream premiums should not be overemphasized at the beginning. Consideration can be given to setting up an appropriate subsidy introduction mechanism and a subsidy phaseout mechanism that match the cost reduction from technology iteration so as to transition from subsidy-driven to market-driven. For shipping

scenarios in which cost parity is expected later but with high demand for decarbonization, stakeholders should cultivate the market for a long time and coordinate policy support, carbon market, green premium, and other measures in the short, medium, and long term.

Industry level: Promote the green ammonia standard certification system and its international recognition and compliance and jointly create a global market while propelling the innovation and breakthrough of flexible ammonia synthesis, distributed ammonia production, and other technologies and models.

- Establish a standard and certification system for green ammonia, green fertilizer, and green fuel as early as possible, accelerate the in-depth integration of the hydrogen market and the carbon market, advance the green value certification of the entire industry chain of green hydrogen and green ammonia, establish a complete life-cycle carbon emissions accounting system for green hydrogen and green ammonia, and incentivize the scale-up of the green hydrogen and green ammonia industries through the value of carbon. Promote the establishment of the coupling and mutual recognition system for green electricity-green certification–green ammonia to facilitate the development of green ammonia as a green hydrogen–based energy source.

- Enable the mutual recognition and compliance of domestic and international green ammonia standards and participate in and contribute to the creation and development of the global green ammonia market. Facilitate the creation of a differentiated market based on decarbonization attributes, increase the recognition of the green premium by all stakeholders in the upstream and downstream of the green ammonia industry chain, and strive for a market mechanism that incentivizes decarbonization of green ammonia's production and utilization.

- For technological innovation, improve the overall technological level of the green ammonia industry by advancing technologies such as new catalysts, low-temperature and low-pressure synthesis methods, and flexible processes to better adapt to production with a high proportion of renewable electricity. For model innovation, actively explore and practice the DGA production model according to local conditions beyond the traditional centralized development model.

Enterprise level: Set clear transition goals and green ammonia development plans, enhance collaboration across the industry chain, and pinpoint early application opportunities of green ammonia in the downstream.

- For internal development planning, map carbon emissions at the enterprise and main process levels, align with industry goals and set enterprise's own carbon reduction strategy and goals, and actively prepare for inclusion in the national carbon market. At the same time, propel the low-carbon transition for the existing ammonia production capacity by replacing with clean energy, conducting green electricity and green certificate trading, and constructing renewable power generation projects while preparing for talent acquisition.

- For external cooperation, actively establish early partnerships including power generation enterprises, storage and transport enterprises, fertilizer producers, and ports, and promote the development of the green ammonia industry by facilitating long-term offtake agreements and innovative cooperation models.

Endnotes

1 Ammonia Technology Roadmap, International Energy Agency, 2021, **https://www.iea.org/reports/ammonia-technology-roadmap**.

2 National Bureau of Statistics, **https://data.stats.gov.cn/easyquery.htm?cn=C01&zb=A0E0H&sj=2022**.

3 Yalin Xiong et al., "Demand for Hydrogen in China's Ammonia Industry under the 'Dual Carbon' Goals and Carbon Reduction Path," 2022, **https://esst.cip.com.cn/CN/PDF/10.19799/j.cnki.2095-4239.2022.0364?token=3ad32ad293a74aeb8091a97770a0e702**.

4 "Implementation Guidelines for Energy Conservation, Carbon Reduction, Transformation and Upgrading of Ammonia Industry," NDRC, MIIT, MEE, and NEA, 2022, **https://www.ndrc.gov.cn/xwdt/tzgg/202202/t20220211_1315447.html**; "Implementation Plan for Carbon Peaking in the Industrial Sector," MIIT, NDRC, and MEE, 2022, **https://www.gov.cn/zhengce/zhengceku/2022-08/01/content_5703910.htm**.

5 National Bureau of Statistics, **https://data.stats.gov.cn/easyquery.htm?cn=C01&zb=A0E0H&sj=2022**.

6 "Implementation Guidelines for Energy Conservation, Carbon Reduction, Transformation and Upgrading of Ammonia Industry," NDRC, MIIT, MEE, and NEA, 2022, **https://www.ndrc.gov.cn/xwdt/tzgg/202202/t20220211_1315447.html**; "Implementation Plan for Carbon Peaking in the Industrial Sector," MIIT, NDRC, and MEE, 2022, **https://www.gov.cn/zhengce/zhengceku/2022-08/01/content_5703910.htm**; "State Administration for Market Regulation, NEA, Special Action Plan for Energy Conservation and Carbon Reduction in Ammonia Industry," NDRC, MIIT, and MEE, 2024, **https://www.ndrc.gov.cn/xxgk/zcfb/tz/202406/t20240607_1386767.html**; "Implementation Plan for Accelerating the Application of Clean and Low-Carbon Hydrogen in the Industrial Sector," MIIT, NDRC, and NEA, 2024, **https://www.miit.gov.cn/jgsj/jns/wjfb/art/2024/art_94d97ac212a3495b82f2a0a352ce2ddd.html**.

7 "Policies in Many Places Loosen: Green Hydrogen Production Outside Chemical Parks Is Allowed," HEIPA, 2024, **https://cn-heipa.com/newsinfo/7337474.html**

8 Xu Ji et al., "Flexible Multiple-Stable-State Process of Ammonia Synthesis for Renewable Energy Uncertainty," 2024, **https://jjmjs.com.cn/article/doi/10.13226/j.issn.1006-6772.CN23122701**.

9 "Several Policies of Inner Mongolia Autonomous Region to Support the Development of New Energy Storage (2022-2025)," People's Government of Inner Mongolia Autonomous Region, 2022, **http://www.sntyq.gov.cn/sntyq/zwgk/zfxxgk/fdzdgknr/zfwj0/zfwj/f365ba6ad2fd4eaab04b8567c2120bc5/index.html**.

10 Transitioning China's Industries: Creating Clusters for Large-scale Green Hydrogen Integration, RMI, 2024, **https://rmi.org.cn/insights/transitioning-chinas-industrial-sectors-creating-clusters-for-large-scale-green-hydrogen-integration/**.

11 "Cost Down Keywords: A Brief Analysis on the Lifecycle Cost of Electricity for Energy Storage," InfoLink, 2024, **https://www.infolink-group.com/energy-article/cn/energy-storage-topic-key-cost-reduction-ess-life-cycle-lcoe-fundamentals**.

12 A Pathway to Decarbonise the Shipping Sector by 2050, IRENA, 2021, **https://www.irena.org/Publications/2021/Oct/A-Pathway-to-Decarbonise-the-Shipping-Sector-by-2050**.

13 Oscar Pearce, "Fertiglobe Success in H_2Global Pilot Auction Marks Milestone in Renewable Ammonia Supply for EU," Ammonia Energy Association, 2024, **https://ammoniaenergy.org/articles/fertiglobe-success-in-h2global-pilot-auction-marks-milestone-in-renewable-ammonia-supply-for-eu/**.

14 "Action Plan for Low-Carbon Transformation and Construction of Coal-Based Power Generation (2024-2027)," NDRC and NEA, 2024, **https://www.ndrc.gov.cn/xxgk/jd/jd/202407/t20240716_1391684.html**.

15 Maritime Forecast to 2050, DNV, 2024, **https://www.dnv.com/maritime/publications/maritime-forecast/**.

16 Outlook for China Energy and Electricity Development, State Grid Energy Research Institute, 2022.

RMI, CPCIF.HEC, *Advancing Green Ammonia Economics: Towards Decarbonization of China's Chemicals Industry*, 2025, **https://rmi.org/insight/advancing-green-ammonia-economics-towards-decarbonization-of-chinas-chemicals-industry/**

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RMI Innovation Center
22830 Two Rivers Road
Basalt, CO 81621

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