中国氢能联盟研究院
CHINA HYDROGEN ALLIANCE RESEARCH INSTITUTE

China's Green Hydrogen New Era: A 2030 Renewable Hydrogen 100 GW Roadmap

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About RMI

RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and nongovernmental organizations to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing, People's Republic of China.

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About the China Hydrogen Alliance Research Institute

The China Hydrogen Alliance Research Institute is committed to building a national-level hydrogen industry think tank, focusing on the construction of new digitalization, quality, and ecology infrastructure in the hydrogen industry, and actively promoting the planning and design of hydrogen policies, standards formulation, and project demonstrations in China. Its achievements include the publications *Grow with Hydrogen, White Paper of Hydrogen Industry Report, Hydrogen Big Data*, and *Hydrogen Top Runner Action*; the establishment of China's Hydrogen Standardization Collaborative Innovation Platform and Hydrogen Quality Joint Laboratory; and leading the China-Europe Hydrogen Technology Innovation Special Project of the National Energy Administration.

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Executive Summary

In the context of the “dual carbon” goals,[i] China has launched a comprehensive transition of its energy supply mix and consumption demand toward a clean, low-carbon, and secure energy future and has begun to focus on building a new zero-carbon energy system dominated by renewable energy. Along with the large-scale application of renewable power, renewable hydrogen — a new type of clean energy — will play an irreplaceable role in the decarbonization of hard-to-abate sectors where electrification will not be the only solution, including petrochemicals, steel, heavy road transportation, shipping, and aviation.

Since 2018, several national government departments have addressed the important role of hydrogen in industrial transformation, and local governments have gradually incorporated hydrogen into their phased planning. In March 2022, the official release of the “Medium- and Long-Term Plan for the Development of the Hydrogen Energy Industry (2021–2035)” centered renewable energy–based hydrogen production at the core of long-term development of the hydrogen industry.

To better promote implementation of the plan, this study starts with the current status of China’s hydrogen industry and proposes a target of 100 gigawatt (GW) of cumulative installed capacity of renewable hydrogen by 2030. The target is based on the supply and demand of hydrogen and renewable hydrogen in line with the goal to be carbon neutral by 2060. The main characteristics of renewable hydrogen development in the near and medium term include: region-focused coordinated development, “hydrogen mega base” large-scale development, and gradual replacement through “establishing first and transforming later.”[ii] This study analyzed and set targets for three sectors — chemicals, steel, and transportation — and seven regions — Northeast China, North China, Central China, South China, East China, Northwest China, and Southwest China.

In building the analytical model, this study considered the change in capacity demand of each sector until 2030, the technology and economics of renewable hydrogen production, and the renewable resources of the different regions. The report forecasts the demand for renewable hydrogen consumption in each sector and the output, installed capacity, key development industries, and sources of renewable hydrogen in each region, and it makes recommendations to promote the development of renewable hydrogen industry in support of the “Medium- and Long-Term Plan for the Development of the Hydrogen Energy Industry (2021–2035).”

i In September 2020, China announced climate goals of reaching peak carbon dioxide emissions by 2030 and achieving carbon neutrality by 2060; these are known as the “dual carbon” goals.

ii A “hydrogen mega base” is an area of one or more industry clusters, centered in one city, that has both hydrogen production and use. “Establishing first and transforming later” refers to the green hydrogen development mode that establishes a green hydrogen production and use supply chain first and then phases out gray hydrogen.

The main conclusions and recommendations are:

- Industries and regions in China have the potential to achieve at least 100 GW of accumulated renewable hydrogen capacity installed by 2030, and this will be an important milestone on the way to carbon neutrality by 2060.
- The growth of China's demand for renewable hydrogen by 2030 lies mainly in the replacement of traditional fossil-based hydrogen production in the chemicals sector and new demand created by technological breakthroughs in the steel and transportation sectors.
- Renewable hydrogen production in 2030 will be concentrated in Northwest China, which has rich renewable resources, and in North China and East China, where hydrogen is in high demand from industry.
- It is essential to reduce the cost of various elements in the hydrogen industry through a strong, large-scale demonstration of the hydrogen valley model and by improving renewable hydrogen industry planning for local development conditions.
- China's strategic development of the hydrogen industry requires a phased approach to maximize emissions reduction by using the complementarity of different hydrogen sources.

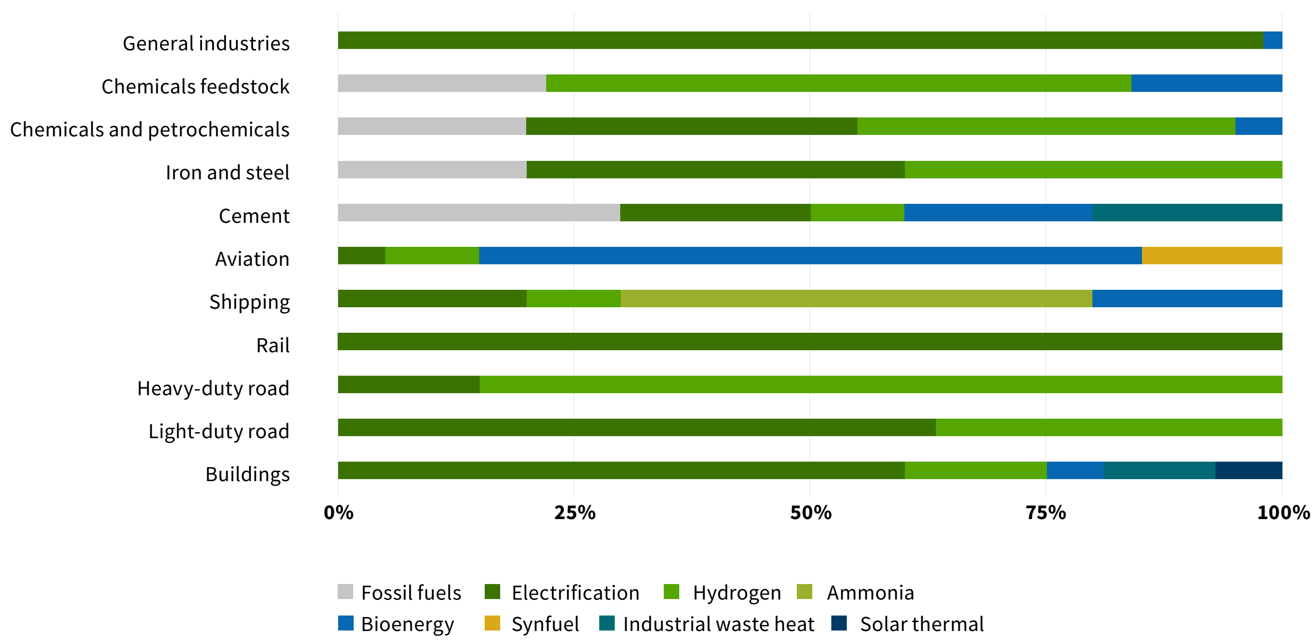
Importance of Hydrogen in China's Energy Transition and Achieving the Dual Carbon Goals

Hydrogen Will Be a Key Element in China's Low-Carbon Energy System in the Future

In September 2020, the Chinese government released the dual carbon goals, ushering in a new era of energy transition and climate change. China's energy structure will continue to transition toward a clean, low-carbon, and secure energy future. In this process, the large-scale supply of renewable power and the full electrification process on the consumption side will be accelerated.

At the same time, heavy industry, shipping, aviation, and other emissions-intensive industries will remain dependent on consumption of fossil energy to a certain extent and will face challenges achieving large-scale renewable power replacement because of technical feasibility and cost. Therefore, the transition path of

Exhibit 1. **Share of final energy demand of different energy sources in sectors under a zero-carbon scenario**



Source: RMI analysis

these sectors will rely on new clean energies such as hydrogen, biomass, and synthetic fuels. According to our research, the share of these new clean energies under the zero-carbon scenario will reach 30%–35%, and the share of hydrogen will account for about 15%–20% (see Exhibit 1, page 7) . Each form of new clean energy, especially hydrogen, will play an important role in China's efforts to achieve the dual carbon goals.

Hydrogen is widely used as a secondary energy source, including as an alternative energy in multiple production and consumption sectors, and it has different applications in heavy industry and the transportation, building, and power industries (see Exhibit 2). The main hydrogen applications are as fuel and feedstock and for carrying energy.

- **Hydrogen is mainly used in such sectors as heavy road transportation, shipping, aviation, and power generation as a fuel.** Hydrogen is flammable, has a high calorific value, leaves only water after combustion, and does not emit greenhouse gases such as CO_2. Compared with traditional fossil fuels such as oil, natural gas, and coal, hydrogen is a clean energy with zero emissions and can be used as fuel for heating or power supply. At present, the use of hydrogen as fuel is still limited globally, mainly owing to the immaturity of the technology, low fuel efficiency of equipment and facilities such as hydrogen turbine, and inadequate infrastructure and policy standards.

- **Hydrogen is mainly used in sectors such as steel and chemicals as feedstock.** Hydrogen is an important industrial gas. As one of the basic elements of many compounds, its strong reducibility is used in many chemical reactions. The chemicals sector uses hydrogen to produce methanol and ammonia, iron smelting uses hydrogen as a reducing agent, and many high-end materials need to use hydrogen in their production processes.

Exhibit 2. **Role of hydrogen in the decarbonization routes of each sector**

Major role
Some role
Small role
No role

		Role of decarbonization options				
		Electricity	Hydrogen	Hydrogen-based fuels	Biomass	Carbon capture and storage (CCS)
Industry	Steel		Direct reduced iron (DRI)			
	Cement	Lower tech readiness	Potential heat source		Heat production	
	Chemicals	Heat production	Heat production and feedstock		Primarily as feedstock	
Transportation	Light road transportation					
	Heavy road transportation		Long-distance freight			
	Shipping	Short-haul only	Short-haul only	Ammonia		
	Aviation	Short-haul only	Short-haul only	Synfuel	Bio jet fuels	
Building					Biogas for heating	
Electricity system			Flexibility options			Higher cost

Related to hydrogen

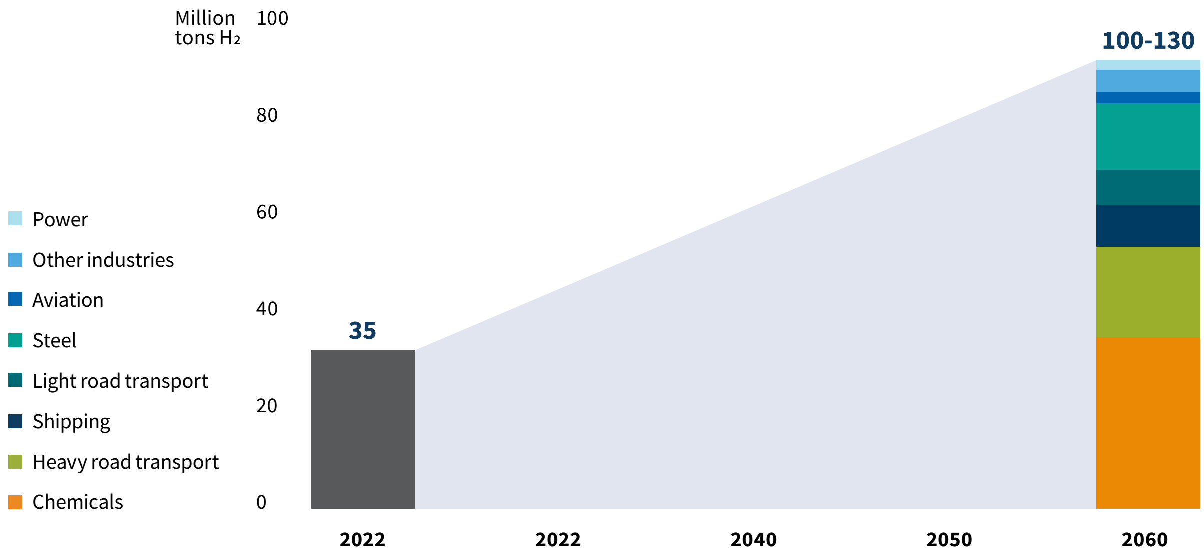
Source: RMI analysis

- **Hydrogen as is mainly used in power storage as an energy carrier.** The storage of liquid or gaseous hydrogen in certain environmental conditions and containers or the conversion of hydrogen into compounds like ammonia may enhance the flexibility of hydrogen used as fuel or feedstock.

Taking into consideration application scenarios, technology costs, and future requirements for China's zero-carbon transition, hydrogen will play a key role in the decarbonization of the chemicals, steel, and heavy road transportation sectors and will gradually expand its applications in shipping, aviation, other heavy industries, and power storage (see Exhibit 2). The research team predicts that by 2060, the demand for hydrogen will increase two to three times compared with demand in 2020, reaching about 100 million to 130 million tons per year (see Exhibit 3), of which renewable hydrogen will account for about 75%–80%, i.e., 75 million to 100 million tons per year.

In other words, the hydrogen supply will be dominated by low-carbon and clean technology paths with only a small amount produced by fossil fuels that will be used in specific, small-scale scenarios. The role of hydrogen and the growth rate of its demand will vary in different industries, but the overall deployment of hydrogen generally will be based on technology and cost, and is expected to be established by 2030 and enter a period of rapid growth after 2035.

Exhibit 3. Hydrogen demand by sector under the zero-carbon scenario



Source: RMI analysis, based on China Hydrogen Alliance Research Institute data of 2020 hydrogen demand

Roles of Hydrogen from Various Sources in Different Phases of the Transition

Hydrogen is unlikely to be obtained directly from nature and instead needs to be produced through different technologies and production processes. At present, the main hydrogen production processes include coal gasification, natural gas and steam methane reforming, industrial hydrogen byproduction, and water electrolysis. So far, hydrogen as a feedstock and intermediate product of chemical production is usually produced by chemical production process, including coal coking gasification, natural gas reforming, and methane coal syngas. Industrial byproduct hydrogen, mainly from coke oven gas, refinery gas, and chlor-alkali flue gas, has become one of the main sources of hydrogen because of its relatively large and stable output.

Hydrogen production by water electrolysis depends on clean energy and has the potential to achieve zero emissions (when 100% renewables are used to power the electrolyzer). To achieve the transition to zero carbon, water electrolysis will be the most important route for hydrogen production and needs to be developed with a higher priority. However, water electrolysis for hydrogen production is still in its initial stage because of the immaturity of the technology, insufficient scaling of the industry, and a much higher cost than that of other hydrogen production routes.

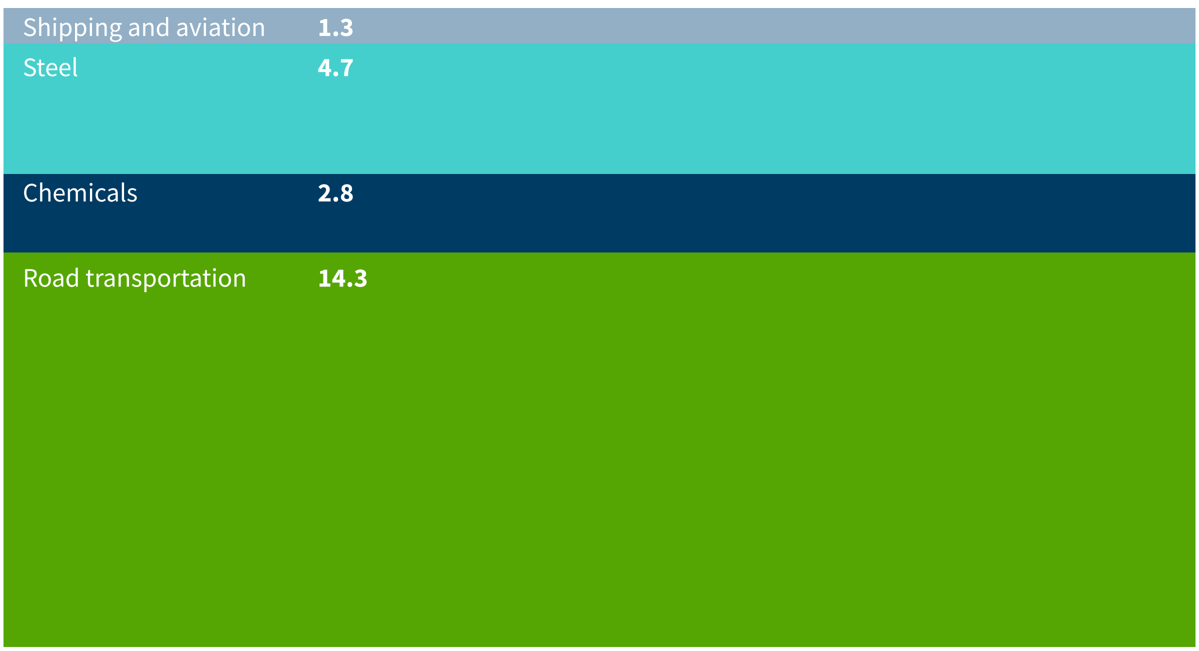
Hydrogen is usually categorized into the following types according to different sources of production:

- **Gray hydrogen:** Hydrogen derived from fossil fuels, such as coal and natural gas, with relatively high emissions but a low cost.
- **Blue hydrogen:** Hydrogen derived from fossil fuels and equipped with carbon capture and storage (CCS) devices that can achieve relatively low emissions.
- **Green hydrogen:** Hydrogen produced by electrolyzers via renewable power, such as solar photovoltaic (PV), wind, or hydroelectric. It can achieve zero emissions, but the current cost is relatively high and has not yet been scaled. Green hydrogen is also called renewable hydrogen.
- **Pink hydrogen:** Hydrogen produced through electrolyzers via nuclear power, which usually can achieve near-zero emissions, but large-scale development is more dependent on the technology and development of nuclear power.

To achieve the ambitious goal of carbon neutrality, it is necessary to promote the large-scale application of hydrogen and fully realize the substitution of renewable hydrogen for fossil energy in other fields such as heavy industry. Analysis of the scale of applications of hydrogen in various industries and the overall energy structure under the zero-carbon scenario shows that more than 20 billion tons of emissions reductions could be achieved between 2020 and 2060 by using hydrogen. The transportation, steel, and chemicals sectors would account for about 15.6 billion tons, 4.7 billion tons, and 2.8 billion tons of the reductions, respectively (see Exhibit 4).

Renewable hydrogen will become a major zero-carbon feedstock in the transportation, steel, and chemicals sectors. In addition, the establishment of the hydrogen industry chain can also fully promote economic growth and industrial development, creating market output value of about 1.6 trillion renminbi (RMB) and infrastructure investment space of more than 1 trillion RMB, based on total capital investment and operating expenses.

Exhibit 4. **Cumulative emissions reduction of hydrogen applications by sector, 2020–2060 (100 billion tons)**



Source: RMI analysis

China is the world's largest producer and consumer of hydrogen, but most of the hydrogen produced and consumed comes from fossil fuels. Hydrogen production in China was about 35.33 million tons in 2021, mainly from the petrochemical, chemical, and coking industries, with 57.06% from coal, 21.90% from natural gas, 18.15% from industrial byproducts, 1.42% from water electrolysis, and 1.47% from other sources.[iii]

Given the current limitations in technology and scale of hydrogen production by water electrolysis and the development status of renewable energy in China, it is difficult to achieve a significant increase in the proportion of renewable hydrogen production in a short time. Therefore, it is necessary to make use of the complementarity of hydrogen from different sources in stages to maximize the emissions reduction effect of hydrogen and create a better foundation for renewable hydrogen in the strategic development of hydrogen overall in China.

- **Short term: focus on diverse applications, while considering competitiveness and cleanliness.** Given the low cost and relatively large yield of fossil-based hydrogen and byproduct hydrogen, these hydrogen sources can more effectively drive the large-scale development of hydrogen consumption in the short term, cultivate upstream and downstream industrial chains of hydrogen, and pave the road for the promotion and application of green hydrogen while reducing the full life-cycle cost.

- **Medium term: gradually build a renewable-based hydrogen supply system.** Based on the gradual improvement of infrastructure and the industrial chain, the cost of renewable hydrogen will approach that of hydrogen production from fossil energy. Currently, it is necessary to guide and encourage production and application through strengthened market mechanisms and policy measures, and gradually realize the transition toward renewable hydrogen use in various applications.

- **Long term: achieve the integration of renewable hydrogen and the power sector with a comprehensive breakthrough.** With the further optimization of cost and improvements in technology, it is necessary to continue to develop the industrial chain, optimize the environment of renewable hydrogen production and consumption, then promote the application of renewable hydrogen in key industries to fully realize the replacement of fossil energy by renewable hydrogen in heavy industry and long-distance transportation.

iii Information provided by the China Hydrogen Alliance Research Institute for the purpose of this research.

“Renewable Hydrogen 100” within China’s General Policy and Industrial Context

National Hydrogen Plan as the Blueprint for Industry

In the past few years, state and local governments have stepped up efforts to formulate strategic planning for the hydrogen industry. In April 2020, the National Energy Administration (NEA) officially included hydrogen as a form of energy in the Energy Law of the People’s Republic of China (Draft for Comments), clarifying the role of hydrogen in China’s energy system.[1] At the same time, all provinces have incorporated hydrogen development into their 14th five-year plans (FYPs) and 2035 vision plans, which established the policy and industrial framework for hydrogen development.

In March 2022, the People’s Republic of China (NDRC) and the NEA jointly issued the “Medium- and Long-Term Plan for the Development of the Hydrogen Industry (2021–2035).” It further clarified the role of hydrogen in China’s energy system and its importance in the green and low-carbon transition of the economy toward the goal of carbon neutrality by 2060. The development direction of hydrogen with renewable hydrogen as the core has been emphasized, and overall planning has been completed from the perspective of the whole industrial chain, including production, storage, transportation, and infrastructure, highlighting the major role of the market and providing an action guide for the high-quality development of the hydrogen industry.[2]

Based on the strategic development of China’s hydrogen industry, the plan established phased development targets for 2021–2035, including:

- By 2025, a relatively complete set of policies for the development of the hydrogen industry should be written. Progress should be made in the technology of clean energy–based hydrogen production, transportation, and storage. A hydrogen supply system should be established with industrial byproducts and renewable-based production as the main sources. The plan also set several quantified targets, including 50,000 operating fuel cell vehicles, 100,000 to 200,000 tons of renewable-based hydrogen production per year, and 1 million to 2 million tons of CO_2 emissions reduction per year.

- By 2030, a relatively complete technology innovation system of the hydrogen industry and a clean energy–hydrogen production and supply system should be established. Renewable-based hydrogen production should be widely promoted to support the realization of the carbon peaking goal.

- By 2035, a hydrogen energy industrial system should be formed. A diverse hydrogen application environment, covering transportation, energy storage, and industry, should be established. The share of hydrogen production from renewables should be significantly increased in final energy consumption, with renewable hydrogen playing an important role in supporting the green energy transition and development.

On this basis, the plan proposed four specific tasks for the development of China's hydrogen industry in the future:

- **Build an innovation system to support the high-quality development of the hydrogen industry.** Around the core technology route of the hydrogen industry, the "Medium- and Long-Term Plan" proposes that efforts should be made to promote R&D of hydrogen fuel cell (HFC), renewable-based hydrogen, as well as core technologies in hydrogen production, storage, and transportation, and to develop a technical support platform for industrial innovation and a talents cultivation mechanism.

- **Coordinate development of hydrogen infrastructure.** Plan for infrastructure, focusing on production and based on how development of the industry is progressing. Select the optimal technical pathway of hydrogen production according to location of resources. Prioritize the use of industrial byproduct hydrogen and encourage nearby consumption. At the same time, actively promote pilot and demonstration projects of hydrogen production from renewable energy sources. Set up hydrogen production bases in areas with larger-scale hydrogen consumption, and gradually promote the systematic planning of storage and transportation and the hydrogen refueling network.

- **Steadily promote diverse demonstration applications of hydrogen.** Identify transportation, energy storage, distributed power generation, and industrial applications as core application scenarios. Explore and establish cost-effective application models of hydrogen in each scenario, and gradually establish large-scale development through pilot demonstration projects.

- **Speed up and improve a system of policies and institutions to support development of the hydrogen industry.** Starting from industrial standards and specifications, efforts should be made to systematically improve the supporting policies for the large-scale production and consumption of hydrogen and renewable hydrogen at the national and local levels. Set and strictly implement standard hydrogen production, storage, transmission, and use systems, and actively experiment on the preferential tariff policy for hydrogen production from renewable power, the market price of hydrogen storage, and the trading mechanism.

The "Medium- and Long-Term Plan" created a blueprint for the long-term development of China's hydrogen industry and facilitated the deployment, promotion, and application of the industrial chain of hydrogen, especially renewable hydrogen, in the next stage.

First, the plan maps out how to develop clean and low-carbon hydrogen sources. The principle of clean and low-carbon development has been established, with emphasis on developing hydrogen production from renewable energy. It includes strictly controlling hydrogen production from fossil energy and setting green and low-carbon development targets for the hydrogen industry. Technical tasks related to hydrogen production from renewable energy improve and accelerate hydrogen conversion efficiency from renewable energy and the scale of hydrogen production from a single unit. The plan recommends the following:

- Coordinate and promote the construction of a clean, low-carbon, and low-cost hydrogen production system.

- Prioritize the use of industrial byproduct hydrogen in areas where coking, chlor-alkali, and propane dehydrogenation industries are clustered.

- Prioritize the demonstration of hydrogen production by renewable energy in areas rich in solar, wind, and hydro resources.

- Establish a policy and institutional guarantee system for supporting green and low-carbon development of hydrogen.

- Study and explore policies for preferential power prices for hydrogen production from renewable energy to promote the optimization of a clean and low-carbon standard system.

Second, the plan attaches great importance to demonstrations of diverse applications of hydrogen. Demonstrations of hydrogen applications will be promoted in an orderly manner in the transportation sector, with emphasis on the applications of HFCs in medium- and heavy-duty vehicles. Demonstrations of HFC applications in the shipping and aviation industries should be explored. Demonstrations of hydrogen applications in the energy storage field should be carried out to explore and cultivate a new integrated application model of wind, solar, and hydropower plus hydrogen energy storage. Diverse applications in the power generation sector should be coordinated to deploy distributed heat and power cogeneration facilities for HFCs, taking local conditions into consideration, and to carry out demonstrations of integrated microgrids of hydrogen and power. Applications of hydrogen in the industrial sector should explore the demonstration of replacing fossil energy with hydrogen production from renewable energy in industries such as ammonia, methanol, refining, and coal to oil and gas.

Finally, the plan creates an unprecedented opportunity for the development of hydrogen, moving toward a period of large-scale demonstrations and rapid development of the core application scenarios. The plan provides quantified targets for hydrogen development for the first time, emphasizes the importance of building an industrial system, encourages local governments to formulate supportive policies and design infrastructure, and establishes the main role of the market, thus opening up space for multiple industries to independently carry out technological R&D and the application of pilot demonstrations. The plan identifies transportation, storage, distributed power generation, and industrial applications as core uses of hydrogen, and renewable hydrogen (green hydrogen) as the key development objective. The plan also encourages the exploration of effective development models in hydrogen production and applications and actively promotes industries and regions to carry out large-scale pilot demonstrations and become accelerators for the development of the whole industry.

With increasing the share of renewable hydrogen production as the ultimate goal, the plan aims to improve the technology and infrastructure along the hydrogen production chain and create opportunities for the large-scale application of renewable hydrogen by supporting policy measures, helping to accelerate development of the hydrogen industry after 2035, and contributing to the carbon neutral goal by 2060.

Beyond the plan, the development of the hydrogen industry still needs further detailed guidelines and specifications. First, based on the quantified near-term targets in the plan, further medium- and long-term renewable hydrogen production and installation targets on region and sector levels should be clearly defined and closely linked to the carbon neutrality goal.

Second, given the guiding principles of the plan to promote high-quality industrial development and coordinated infrastructure build-out and to avoid herd behavior, new development goals are needed that are tailored to each region, taking into account each area's resources and industrial characteristics and strengthening the focus and breakthroughs of regional and local industrial development.

Finally, given the plan's directives to promote a variety of hydrogen applications, the impact of cost reduction should be evaluated in large-scale commercial hydrogen applications. The scaled development of pilot demonstrations in each application scenario should be aligned with the cost of hydrogen production and application. Targets for medium- and long-term applications of hydrogen, especially renewable hydrogen, should be set to encourage the hydrogen industry to enhance its competitiveness.

Setting the 100 GW Renewable Hydrogen Capacity by 2030 Target to Drive Rapid Application of Green Hydrogen in Industries

The development of China's domestic hydrogen industry generally is in its initial stage. The supporting policy systems in various industries and regions are incomplete. The pilot and demonstration projects in various fields have yet to reach economies of scale. Incentive policies and mechanisms and financial support for hydrogen and renewable hydrogen applications are by far still insufficient. At the same time, in key development areas of hydrogen and renewable hydrogen, individual companies already are conducting major pilot projects. But business cooperation between upstream and downstream industrial chains and players has not been established and the scale effect of demonstration projects cannot be achieved.

In 2060, the total annual production of hydrogen is expected to exceed 100 million to 130 million tons, at least 75%–80% of which will be supplied by renewable sources. Based on this, the research team is proposing a target framework for renewable hydrogen production and installation in the transition period ending in 2030. In September 2021, the research team launched the Renewable Hydrogen 100 initiative and proposed that the installed capacity of renewable hydrogen electrolyzers in China could reach 100 GW by 2030.

Guided by the medium- and long-term carbon neutrality goal, the target is based on the current development of China's hydrogen industry and is in line with the "Medium- and Long-Term Plan." Given the potential of renewable hydrogen to meet the increasing demand for hydrogen and gradually replace fossil fuels for hydrogen production, the optimization of technologies and costs, and the improvement of infrastructure development, the target is expected to provide a forward-looking reference for the development of policy and industry.

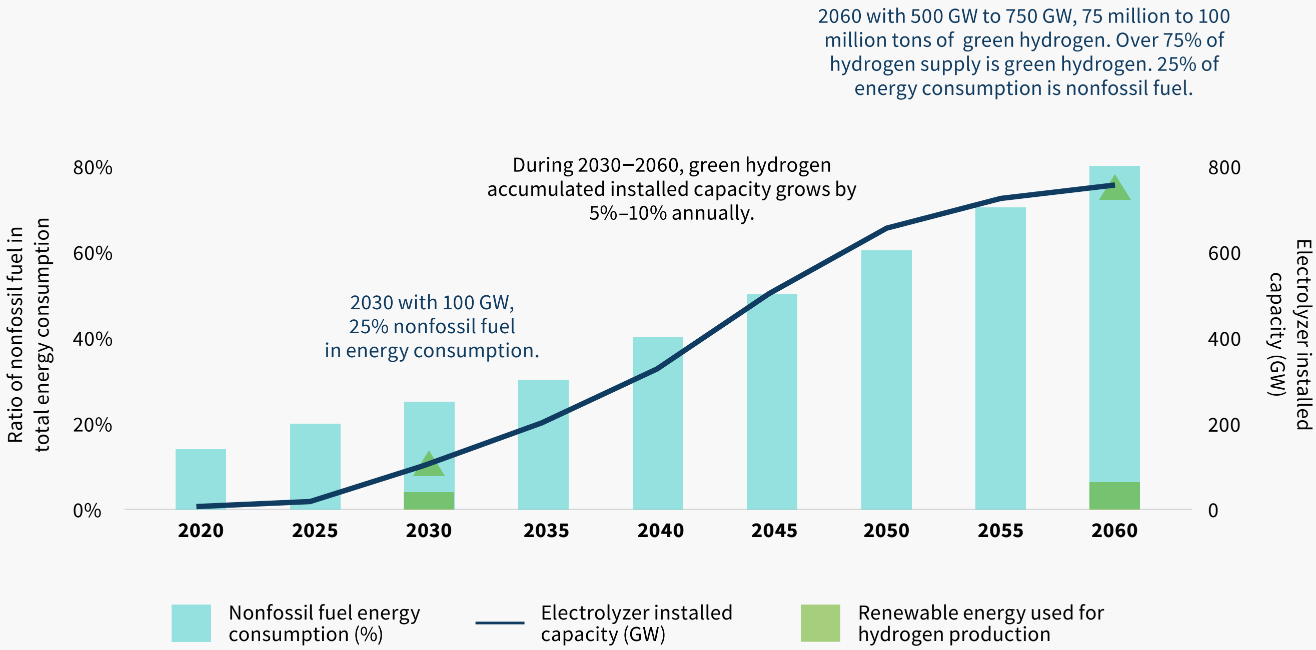
The 100 GW installed capacity target is guided by the goal of carbon neutrality by 2060

The target of 100 GW of renewable hydrogen installed capacity in 2030 takes into account the needs of China's energy structure transition and the development of the country's hydrogen industry under the carbon neutral scenario. In terms of renewable energy supply, the share of nonfossil energy in China's primary energy consumption mix is expected to exceed 25% by 2030, and the total installed capacity of wind and solar power will reach 1.6 terawatts (TW) to 2 TW. Assuming hydrogen production by water electrolysis is deployed at the rate of 5%–10% of the renewables capacity, the installed capacity of renewable hydrogen is expected to reach 100 GW.

In terms of demand for the hydrogen industry, the share of hydrogen in the overall energy system under the carbon neutral scenario is about 15%–20%. Assuming the proportion of renewable hydrogen exceeds 70%, its installed capacity should reach at least 500–750 GW by 2060 (see Exhibit 5). An installed capacity of renewable hydrogen of at least 100 GW in 2030 could meet the market demand for renewable hydrogen in 2060 and conform to the development laws of the industry and market. This assessment is based on the development trend of the renewable hydrogen industry technology and cost-effectiveness, and maintaining an annual growth rate of about 7% for the additional installed capacity of renewable hydrogen from 2030 to 2060.

Given that the hydrogen industry is still in its early stages and the industry chain is not yet fully established because of the high cost of each segment, the establishment of a forward-looking target could accelerate the growth of the industry from 1 GW to 100 GW. This would provide sufficient cost-effectiveness and scale effect for the hydrogen industry and the overall energy decarbonization without costs being a burden to the society as a whole.

Exhibit 5. **Development of renewable hydrogen capacity under 100 GW scenarios**



Source: RMI analysis

At present, both the quantity and scale of hydrogen production projects from water electrolysis are increasing in the world. The energy mix used for hydrogen production is turning clean. The Asia-Pacific region is gradually becoming a leader in renewable hydrogen projects development. According to the research team, at the end of 2021, 217 water electrolysis projects with a total capacity of 372 MW were completed worldwide.

The solar-powered water electrolysis hydrogen production demonstration project in Ningxia, now in operation, is one of the world's largest green hydrogen production projects in terms of single unit capacity. Chinese domestic companies have planned 161 renewable hydrogen production projects. Twelve of these projects are operational, with a total hydrogen production capacity of about 23,100 tons per year, and 22 projects are under construction.

State-owned enterprises (SOEs), such as China Energy, Sinopec, and SPIC, have accelerated the development of the whole hydrogen energy industry chain and set up "mega base" projects (those with large-scale hydrogen production capacity that are connected to nearby demand) in areas with rich wind and solar resources, such as Inner Mongolia, Ningxia, Xinjiang, and Jilin. The SOEs will play an important role in the development of China's hydrogen industry and help the industry reach a turning point in the overall market.

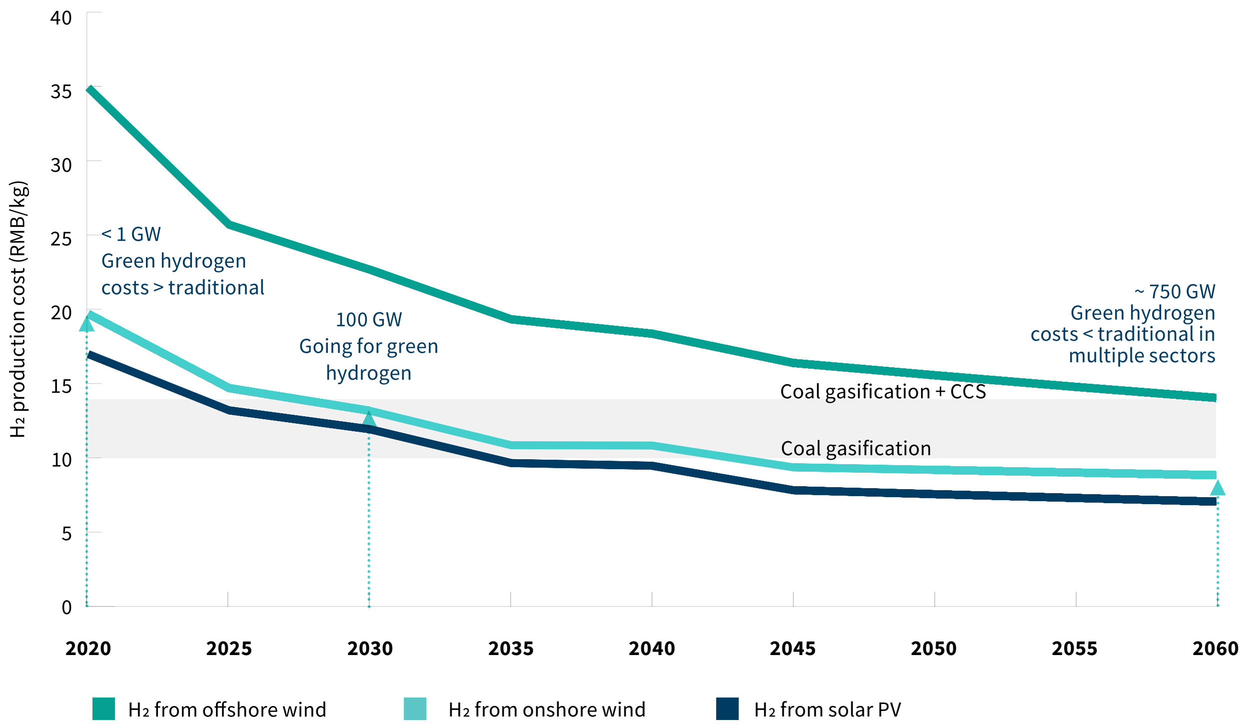
Although demand for hydrogen in China still will be mainly from traditional industries in 2030, we can project that 10 years of accelerated development are expected to result in a deepening of supply-side structures, optimized production capacity, increased replacement of renewable hydrogen in the chemicals sector, and the gradual emergence of renewable hydrogen in the steel, transportation, and energy storage sectors. The total demand for hydrogen in 2030 will reach 37 million to 40 million tons, and the supply of renewable hydrogen will reach about 7.7 million tons by the time the total installed capacity of renewable hydrogen reaches 100 GW. Between 2030 and 2060, China will expand the scale of the renewable hydrogen industry at an annual growth rate of 5%–10%, meeting the market demand of a zero-carbon economy and reaching 100 million to 130 million tons of hydrogen supply and 75 million to 100 million tons of renewable hydrogen supply in 2060.

The 100 GW target to drive scaled development and cost reduction

The target of 100 GW renewable hydrogen installed capacity in 2030 takes into consideration changes in the hydrogen industry chain between now and 2030, especially changes in the economics of renewable hydrogen, and it reflects the importance of the renewable hydrogen economy and cost reduction.

At present, the cost of hydrogen production from coal and industrial byproducts is 10–12 RMB per kg, and the cost of renewable hydrogen is 20–25 RMB per kg (see Exhibit 6, page 19). Only by fully improving the cost competitiveness of renewable hydrogen can the shift from gray and blue hydrogen to renewable hydrogen be realized. Expansion of the industrial scale, especially the rapid increase of installed capacity, is the most effective way to reduce the cost. As the scale of electrolyzers expands to 100 GW, the investment cost of alkaline electrolyzers in China will decrease from 2,000 RMB per kilowatt (kW) in 2020 to 1,500 RMB per kW in 2030. At the same time, thanks to the continued reduction of the cost of renewable power, the average total cost of hydrogen production from renewable power is expected to drop to 13 RMB per kg, which is competitive with the cost of hydrogen production from fossil energy.

Exhibit 6. **Relationship between the renewable hydrogen capacity and hydrogen production cost**



Source: Analysis by RMI and China Hydrogen Alliance Research Institute

From the perspective of various industries at the application end of renewable hydrogen, the target of 100 GW installed capacity may quickly reduce the investment cost of equipment and infrastructure and accelerate the process of renewable hydrogen to reach cost parity with and eventually replace fossil energy in heavy industry, long-distance transportation, and other fields.

Our analysis shows that the required cost parity of renewable hydrogen is about 10 RMB per kg for direct reduced iron (DRI) hydrogen in the steel sector, 14 RMB per kg for ammonia, 8 RMB per kg for methanol in the chemicals sector, 18 RMB per kg for commercial vehicles in the transportation sector, 5 RMB per kg for aviation and shipping, and 10 RMB per kg for power generation. Reaching 100 GW installed capacity by 2030 may reduce the end-use cost of renewable hydrogen to 13 RMB per kg, which is close to the required cost parity in most application scenarios. This is an important foundation for the large-scale application of renewable hydrogen on the consumer side, as well as a cornerstone for accelerating the formation of a clean and stable hydrogen supply and achieving the promotion and application of renewable hydrogen under the goal of carbon neutrality by 2060.

The installed capacity target of renewable hydrogen may help address the economic gap between the potentially huge market demand and the current high cost of renewable hydrogen products, providing market confidence to achieve the 2035 hydrogen goal and steadily progress to the goal of carbon neutrality by 2060, reducing short-term uncertainties, and providing verified data for long-term financing.

The 100 GW target also takes into account the development cycle of large heavy industry projects. To fully realize the long-term emissions reduction effect of hydrogen, strategic planning should occur 5 to 10 years before the expected commissioning of technology projects, and the scale should gradually expand from demonstration projects. China's renewable hydrogen industry is in its infancy, and the development cycle is expected to be prolonged owing to the complex technologies and processes required in the large-scale application of green hydrogen in various industries. To validate key projects and achieve stable large-scale installation, 2030 will be a key time for China's renewable hydrogen industry.

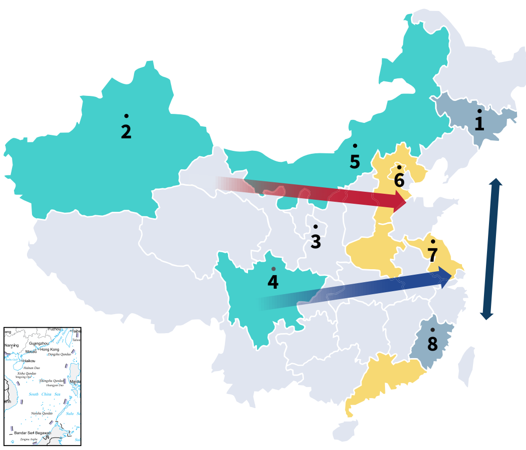
This report creates a roadmap for the implementation of the 100 GW renewable hydrogen capacity target. It proposes three major renewable hydrogen development models for the next 10 years, namely region-focused coordinated development, large-scale development with mega bases, and gradual replacing by "establishing first and breaking later." In addition, it offers a systematic analysis and breakdown of the 100 GW renewable hydrogen capacity from two perspectives: regional distribution of renewable hydrogen production and hydrogen demand of main hydrogen-consuming industries.

The report also lays out the characteristics of renewable hydrogen installed capacity in each region by 2030 and offers development recommendations on four topics — policy, demonstration, infrastructure, and technology — in accordance with the strategic direction of the hydrogen development plan. The report extends and responds to the strategic planning and objectives of the "Medium- and Long-Term Plan" and supplements and supports aspects not covered by the plan, such as regional large-scale development. At the same time, the report suggests how to further implement the three key tasks of technological innovation, infrastructure layout, and diverse demonstration applications proposed in the plan.

Renewable Hydrogen 100 by 2030 Development Model Outlook

Demand will drive development of the hydrogen industry, and the supply and demand network will be driven by industrial build-out, technological and economic progress, security constraints, and resource planning and optimization. **Region-focused coordinated development, large-scale development with mega bases, and gradual replacement by "establishing first and breaking later"** will be the three important models of renewable hydrogen development in the next decade. They will help achieve cross-regional and cross-category overall planning and coordinated development of the hydrogen industry and even the whole energy system (see Exhibit 7).

Exhibit 7. **Examples of existing and potential green hydrogen mega bases**



Fuel cell vehicle demonstration city cluster
Yangtze River Transport supply chain
Coastal transport and maritime trade supply chain
Northern rail and pipeline supply chain

1		**Northeast base**: wind power, biomass hydrogen production + pipeline hydrogen mixing
2		**Xinjiang base**: wind and solar based hydrogen production + new electric power demonstration area
3		**Ningdong base**: photovoltaic hydrogen + green chemical industry
4		**Sichuan base**: hydroelectricity hydrogen production + green ammonia synthesis + green shipping
5		**Inner Mongolia base**: wind and solar based hydrogen + green chemical industry
6		**North China base**: wind power hydrogen + green transportation + green steel
7		**East China base**: hydrogen production from offshore wind power + green transportation + international trade
8		**South China base**: hydrogen production from offshore wind power + green transportation + international trade

Source: China Hydrogen Alliance Research Institute analysis

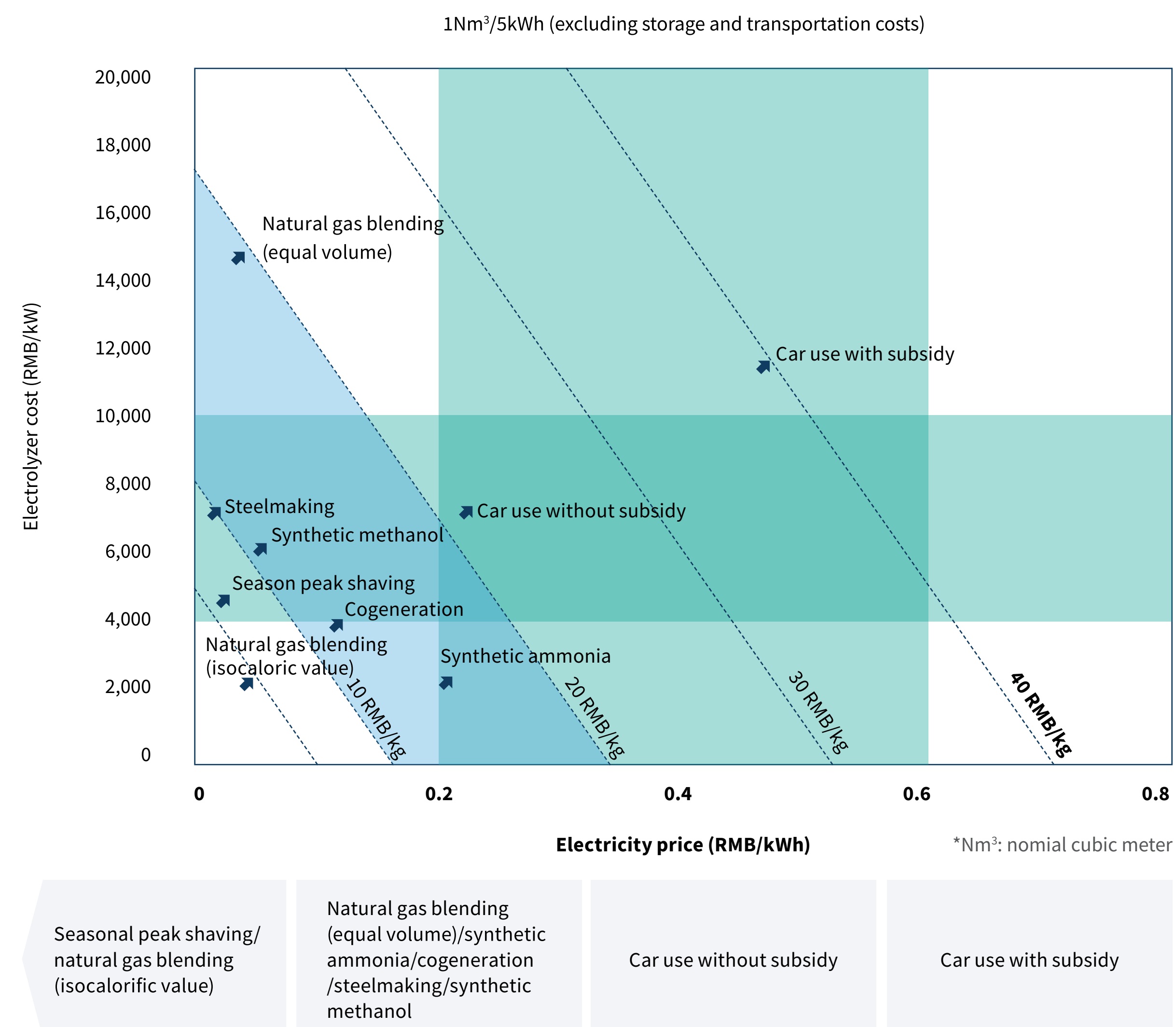
Region-Focused Coordinated Development

The cost bottleneck of long-distance transportation and large-scale storage of hydrogen is difficult to resolve in the short term, and the distribution of hydrogen production resources and the levels of technological economics across different hydrogen use cases vary significantly. Inner Mongolia, Hebei, and Henan have independently explored regional development models of hydrogen production and use by successively releasing project lists of integrated demonstrations of hydrogen production by wind and solar in 2021, and pilots of integrated use of source, grid, load, and storage of power, plus multi-energy complementary development. By 2030, development of the hydrogen industry will be dominated by regional hubs and supplemented by short-distance, point-to-point models.

- ## Cost of hydrogen storage and transportation will influence initial cross-regional scaled coordination

Considering the strong uncertainty of early demand of hydrogen, the availability of long-distance and large-capacity hydrogen pipelines is unlikely, and the storage and transportation costs of other technical routes are mostly higher than 10 RMB per kg when the distance exceeds 500 km. For industrial applications, given the related storage and transportation costs, hydrogen replacement is viable only when the power price for hydrogen production is lower than 0.1 RMB per kW hour and the equipment cost is lower than 4,000 RMB per kW, thus resource availability and technical level requirements are almost burdensome. For transportation applications, given the high acceptable cost level, the combined low cost of hydrogen production in resource-rich areas and short-distance storage and transportation may be cost-effective. For example, it may be economic to produce hydrogen in wind- and solar-rich regions like Ulanqab and Zhangjiakou and transport it to the Beijing-Tianjin-Hebei region (see Exhibit 8).

Exhibit 8. **Acceptable hydrogen cost levels by end use**

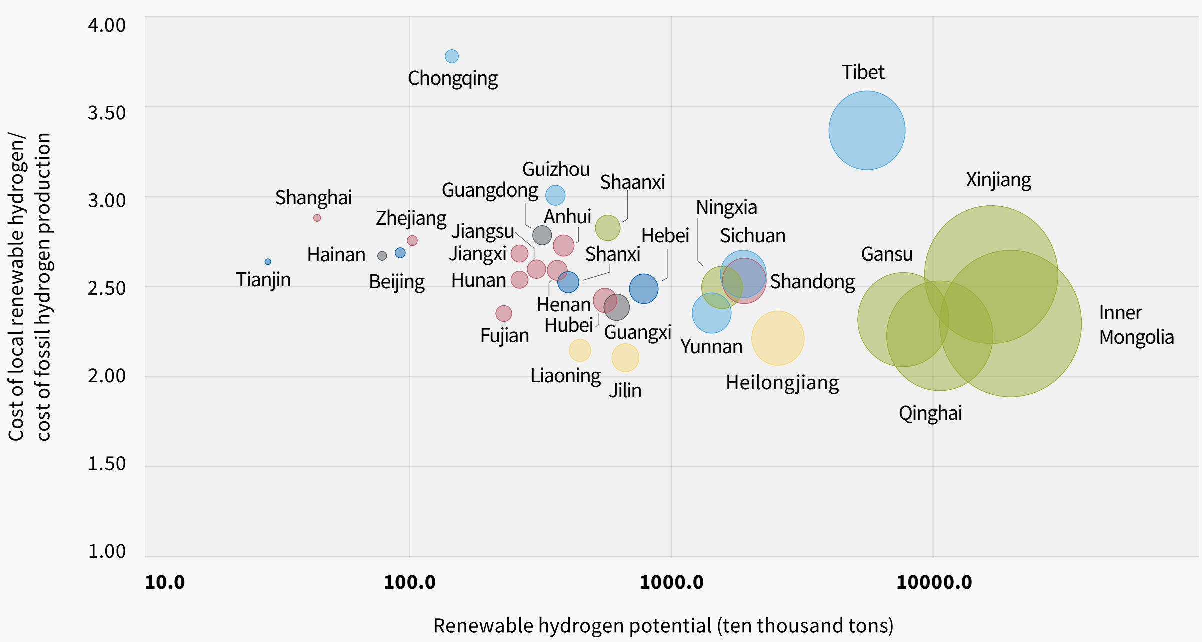


Source: China Hydrogen Alliance Research Institute analysis

- **Differences in renewable resources conditions will drive the differentiation of regional development**

Northeast China, North China, Northwest China, and Southwest China are rich in renewable resources, thus the cost difference between renewable hydrogen and traditional hydrogen production routes is small, making multiple applications economical. In contrast, East China and Central China regions are relatively short of renewable resources, and the high demand for power leads to a premium on green electricity, while the cost of offshore wind power is not yet achieving parity. This makes the cost of renewable hydrogen much higher than the cost of traditional hydrogen production routes, which affects the increase in regional demand (see Exhibit 9).

Exhibit 9. **Cost and scale of renewable hydrogen production by region**

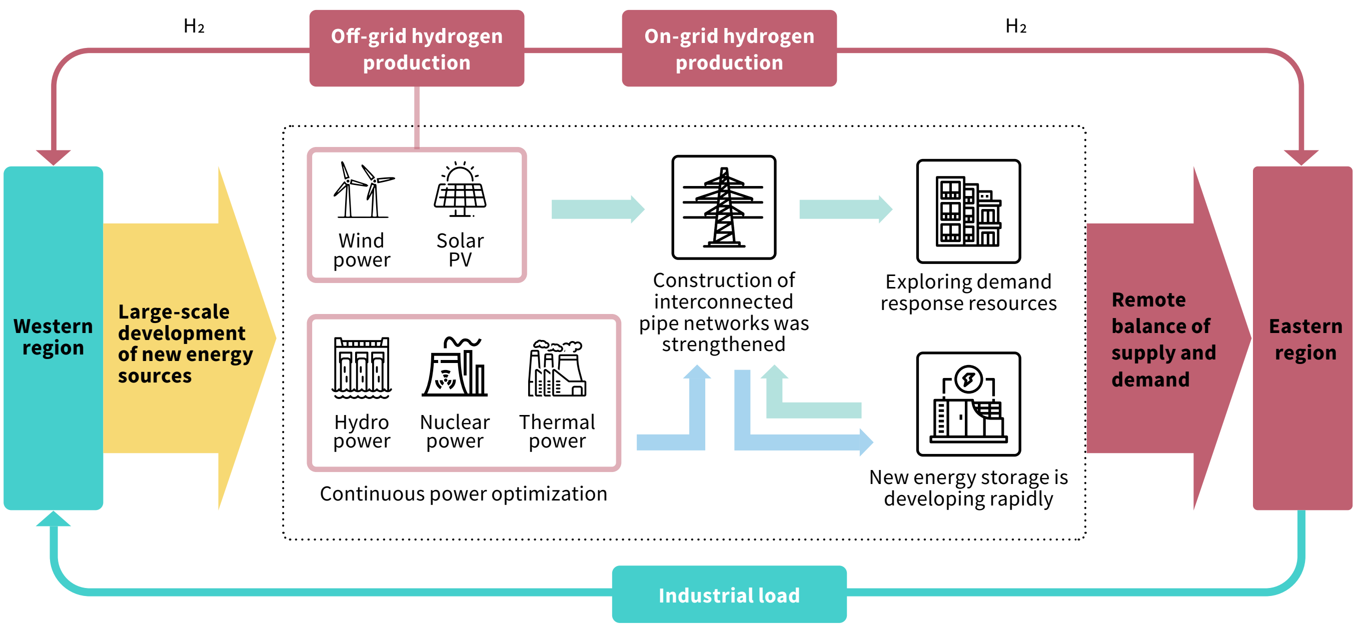


Source: China Hydrogen Alliance Research Institute analysis

- ### Flexible energy demand drives intra-region cooperation

The coordinated development of modern energy systems and in-depth development of renewable energy bases may further strengthen the regional demand for combined development of hydrogen and power. Within individual new energy bases, power to hydrogen (to power) can be used as a nearby alternative measure to flatten power fluctuation. In the whole grid, power to hydrogen (to power) can also be used as an option for power supply and demand balance in a larger range and longer time scale, with higher penetration of variable renewable energy. As technology matures and economics improve over the long term, power to hydrogen (to power) can replace part of the supportive role of a coal-fired fleet to help adjust renewables, leveraging its complementary characteristics with a larger range of other power sources to play a role in the supply and demand balance of the whole grid (see Exhibit 10).

Exhibit 10. **Integrated development of hydrogen production from electrolyzer with energy base loads**



Source: China Hydrogen Alliance Research Institute analysis

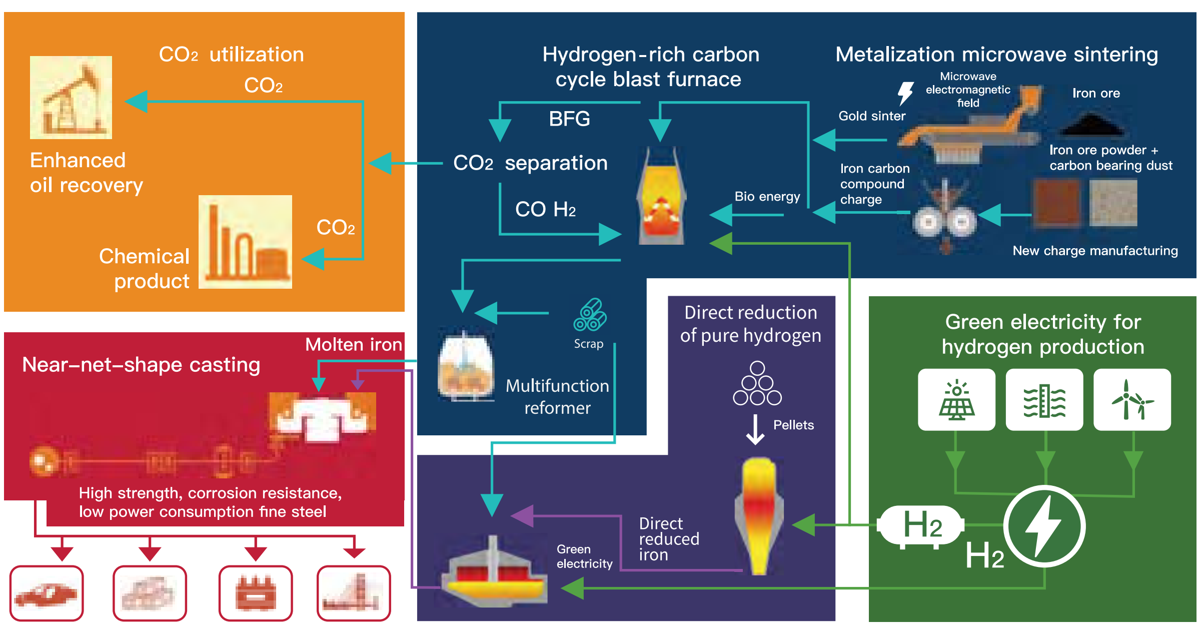
Large-Scale Development with Mega Bases

In the long run, technological breakthroughs and cost reductions in production and applications are keys to achieving large-scale promotion of hydrogen, while the initial stage before 2030 is more dependent on cost reductions brought by scale effect. Given the distribution of hydrogen production capacity and the location of related industries in China, large-scale development and application of renewable hydrogen in the form of mega bases not only makes full use of local resources and enhances the guarantee for renewable hydrogen development, but also empowers hydrogen development in all segments of the value chain. The "Plan to Deploy Large-Scale Wind and Solar Bases Mainly in Deserts, Gobis, and Barren Lands"[3] issued by the NDRC and NEA, and the "Notice on the Establishment of Integrated Plan of Renewable Energy along Major Rivers"[4] issued by the NEA, can provide support for the development of mega bases of wind, solar, hydro, thermal, and storage, as well as a solution for the large-scale development of hydrogen.

• Existing industry configuration paves the road for mega base developmen

Northwest China, North China, Northeast China, and Southwest China together account for nearly 65% of hydrogen production capacity in China and have the potential and space to achieve large-scale hydrogen source substitution. The new energy system will not only reshape the energy system, but also reconstruct the industrial system. With abundant renewable resources, these regions will become the sites of such zero-carbon industries as green chemicals and hydrogen metallurgy. A new industrial model supported by a green, stable, and reliable energy system can be built by fully coordinating renewable energy, energy storage, and hydrogen and dynamically combining the production and use of green energy in zero-carbon mega industrial bases (see Exhibit 11).

Exhibit 11. **Development model of hydrogen-based, zero-carbon industrial parks**

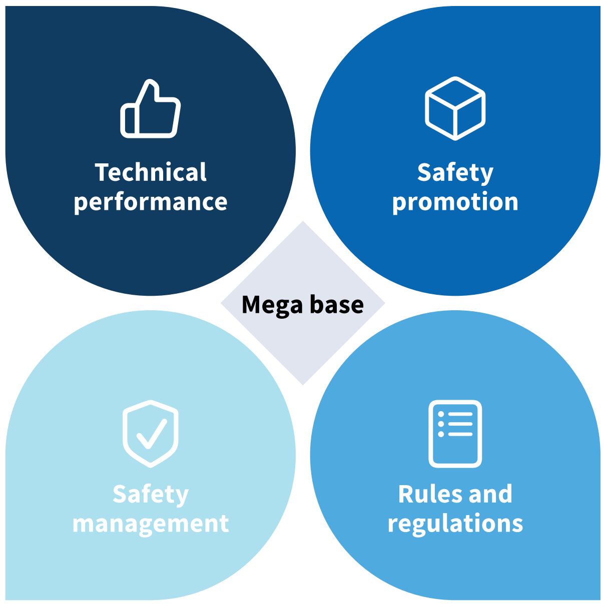


Source: China Hydrogen Alliance Research Institute analysis

- ### Mega base model maximizes the guarantee for safe hydrogen development

The mega base model may increase the overall awareness of project risks among project developers; design institutions; engineering, procurement, and construction integrators; and key product component suppliers. It also helps local regulatory authorities effectively explore safety specifications, gain relevant experience, and continuously scale up demonstrations in an orderly manner (see Exhibit 12).

Exhibit 12. **Explore safe hydrogen development through mega bases**



Source: China Hydrogen Alliance Research Institute analysis

- **Mega bases provide support for industrial development from multiple value chains**

Globally, as the hydrogen industry matures, hydrogen demonstration projects are becoming increasingly comprehensive to cover multiple value chains. The mega base model of local consumption of renewable hydrogen in production attracts support from policy and financing resources; it also is open to a wide range of partnerships and cooperation, smoothing channels for supply and use of hydrogen and making project development more likely. The International Energy Agency also proposed multiple value chains for development of the hydrogen industry because development of one value chain will reduce costs and encourage innovation in others. Value chains within the same region can play synergistic roles with one another. For example, truck fleets in industrial clusters and transport corridors can reduce overall costs with the advantage of greater scale (see Exhibit 13).

Exhibit 13. **Global "hydrogen hubs" to explore integrated and ecological development model**

USA
- ACES, Utah
- Port of Los Angeles, Shore Power Project, California

Chile
- Hydrogen Infrastructure Project

UK
- HyNet North West England
- BIG HIT Orkney Islands

Netherlands
- HEAVENN
- Hydrogen Delta
- H2 Proposition Zuid-Holland/Rotterdam
- Port of Amsterdam region

Germany
- H2Rivers/H2Rhein-Neckar
- HyBayern
- Norddeutsches Reallabor
- eFarm
- Hyways for Future

Spain
- Green Hysland Mallorca
- Basque Hydrogen Corridor

France
- Auvergne-Rhône-Alpes Hydrogen Valley
- Normandy Hydrogen Plan
- Hydrogen Territory Burgundy Franche Comté
- CEOG, French Guiana

Japan
- FH2R Fukushima

China
- Five Demonstrative City Clusters
- Ningdong Hydrogen Pilot Zone
- Ordos Green Hydrogen City

Italy
- South Tyrol Hydrogen Valley

Austria
- WIVA P&G

Oman
- Oman Green Hydrogen and Chemical Sector

Australia
- Neoen Crystal Brook
- Energy Park
- Eyre Peninsula Gateway

Thailand
- Phi Suea House

Europe (IPCEI)
- Blue Danube
- Black Horse
- Green Octopus
- Green Crane
- Sines Industrial Hub

Denmark
- HyBalance

Source: Analysis by China Hydrogen Alliance Research Institute and RMI

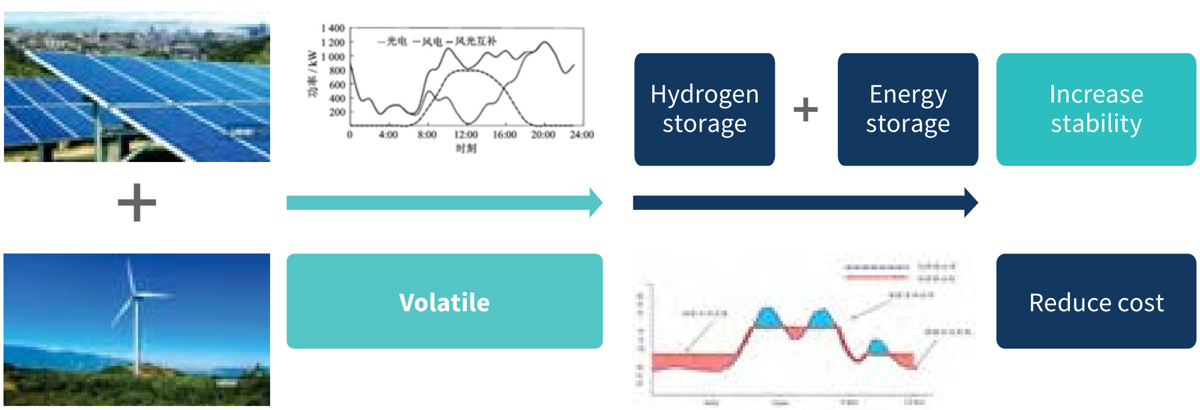
“Establishing First and Transforming Later” to Accelerate Decarbonization of Hydrogen Source Mix

With the release of the dual carbon goals, the development of the clean hydrogen supply chain has been formally established, but the optimization of the hydrogen source structure still needs to follow market rules and “establish first and transform later.” Industrial byproduct hydrogen can play a transitional role in the initial stage and will gradually be replaced by renewable hydrogen in the later stage. Some regions rich in industrial byproduct hydrogen resources will provide support during the transition because they have the advantages of low cost, convenient transportation, and stability. With advances in technology and a decrease in the cost of clean power, renewable hydrogen will become the major newly installed source of hydrogen production capacity by 2030.

- **Renewable hydrogen alone cannot meet the demand in the initial stage**

The fluctuation of renewable energy generation is one of the main factors that limit the stable and continuous supply of renewable hydrogen. Crude oil refining, chemical production, and metal smelting are continuously operating industrial processes that need a constant hydrogen supply of more than 8,000 hours per year. Currently, most individual solar PV power stations operate between 1,000 and 2,000 hours annually, and onshore wind farms, between 2,000 and 3,000 hours, with a lot of fluctuation. Even if a complementary wind and solar model is considered, hydrogen production from grid power is still required to provide greater stability and to ensure a continuous supply of hydrogen from water electrolysis. Otherwise, large-scale power storage or hydrogen storage will be required, but this would lead to a significant decline in cost-effectiveness (see Exhibit 14).

Exhibit 14. **Large-scale power storage or hydrogen storage may lead to a decline in cost-effectiveness**



Source: China Hydrogen Alliance Research Institute analysis

- **Industrial byproduct hydrogen may play a transitional and supportive role**

In a diverse supply situation, technology route selection depends on the applicability, economic, energy efficiency, and environmental benefits of hydrogen at different stages of development. There is a large quantity of industrial byproduct hydrogen, and it is widely distributed. High purity byproduct hydrogen is produced in industries such as chlor-alkali, ethane cracking, and propane dehydrogenation, which have the potential to provide low-cost and beneficial distributed hydrogen sources for the early development of the hydrogen industry, especially in East China with its advanced chemicals industry. In the chlor-alkali industry alone, about 850,000 tons of byproduct hydrogen can be collected annually. Although some chlor-alkali producers recycle it, the recycle rate is only about 60%, leaving nearly 300,000 tons of available byproduct hydrogen each year.

- **The falling cost of technology is driving renewable hydrogen into the mainstream**

After years of development, the cost of wind and solar power is at parity with thermal power and continues to decline. At the same time, water electrolysis–to–hydrogen technology has great potential. The cost reduction potential of alkaline water electrolyzer is expected to be about 20%, and that of using proton exchange membranes is expected to reach 40%. The cost of related hydrogen production equipment will decrease rapidly, thanks to technological progress and scale effects, improving hydrogen's economic competitiveness in multiple applications. **With the decrease of power generation costs and the iteration of technology,[iv] hydrogen from renewables will gradually expand its market application scope and become the mainstream technology route of the future's hydrogen production system.**

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iv "Iteration of technology" refers to the advancement of technology through successive upgrades.

Renewable Hydrogen 100 Regional Development Paths

Given China's vast and varied geography, as well as regional differences in industry and availability of renewable hydrogen resources, the next step was to analyze the consumption demand and production capacity needs for renewable hydrogen by sectors and regions. This analysis identified demand features and key development areas that will help in the writing of supportive policies and the deployment of industries. It focused on three key sectors (chemicals, steel, and transportation) and seven main regions (North China, East China, Central China, South China, Northeast China, Northwest China, and Southwest China).[v]

By 2030, the installed capacity of electrolyzers in China will reach 100 GW, and the total demand for renewable hydrogen will reach 7.7 million tons per year. The chemicals sector will have the largest demand for renewable hydrogen, followed by transportation and steel. In the early stage of renewable hydrogen development, the economic advantages of combined regional production and consumption of renewable hydrogen will be obvious, as industry users are highly sensitive to cost and convenience of use, and the cost bottleneck of storage and transportation cannot be solved in the short term. The local demand in Northwest China and North China will be strong, and they will lead in terms of regional installed scale, followed by East China and South China.

v The regions include the following areas:

- North China: Beijing, Tianjin, Hebei Province, Shanxi Province
- East China: Shandong Province, Shanghai, Jiangsu Province, Zhejiang Province, Anhui Province, Jiangxi Province, Fujian Province, Taiwan*
- Central China: Henan Province, Hubei Province, Hunan Province
- South China: Guangdong Province, Guangxi Zhuang Autonomous Region, Hainan Province, Hong Kong Special Administrative Region*, Macau Special Administrative Region*, South China Sea Islands*
- Northeast China: Heilongjiang Province, Jilin Province, Liaoning Province
- Northwest China: Xinjiang Uygur Autonomous Region, Inner Mongolia Autonomous Region, Shaanxi Province, Ningxia Hui Autonomous Region, Gansu Province, Qinghai Province
- Southwest China: Chongqing, Tibet Autonomous Region, Yunnan Province, Guizhou Province, Sichuan Province

Note: The areas indicated by an asterisk (*) are not included in this analysis due to lack of information.

Analysis of the Scale of Renewable Hydrogen in Different Sectors

By 2030, renewable hydrogen is expected to be used in large-scale demonstrations of applications in the chemicals, steel, and transportation sectors.[vi] Hydrogen applications in the chemicals sector will still mainly be concentrated in high hydrogen consumption processes, such as ammonia, methanol, and refining. In the steel sector, hydrogen applications will mainly be concentrated in the extensive deployment of hydrogen steelmaking projects by leading steelmakers. In the transportation sector, hydrogen will be applied to a certain proportion of heavy freight, light and medium logistics vehicles, buses, mining machinery, port machinery, and cleaning vehicles. The transition to renewable hydrogen will mean significant changes in the locations of applications in different industries.

- ### Chemicals

In the chemicals sector, this study focuses on three upstream chemicals subindustries that are most closely related to hydrogen supply and demand: petroleum refining, ammonia, and methanol. At present, China's chemicals sector is still an energy-intensive and high-emissions sector, with fossil fuels as the main energy source and raw material. As the main production segment of the petrochemicals industry, petroleum refining has a large demand for hydrogen. Almost all large refineries have on-site hydrogen production equipment and use natural gas reforming or coal gasification as the main hydrogen supply source. The production of ammonia and methanol in China uses coal and coal gasification to produce hydrogen in the traditional way.

With the introduction and implementation of environmental protection policies and access restrictions, hydrogen-based green chemicals will transform the chemicals sector. Since the 13th Five-Year-Plan, several provinces with advanced energy and chemicals sectors, including Shandong, Inner Mongolia, and Shaanxi, have gradually tightened the approval and management of new energy-intensive chemicals projects, driven by government targets for energy consumption and energy intensity.

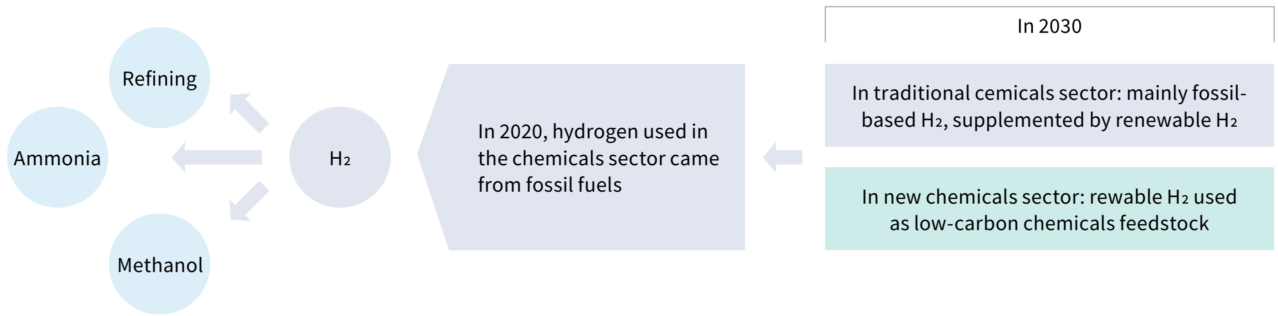
In February 2022, the NDRC, the Ministry of Industry and Information Technology (MIIT), the Ministry of Ecology and Environment (MEE), and the NEA jointly issued the "Notice on Issuing the 'Implementation Guidelines for Energy Conservation and Carbon Reduction Transformation and Upgrading in Key Areas of High Energy-Consuming Industries.'"[5] It includes specific implementation guidelines for chemicals industries, including oil refining, the coal chemicals, and ammonia. It calls for upgrading and transforming green processes and technology, strengthening relevant cutting-edge technologies, and accelerating the elimination of outdated equipment and technology that are not in line with the green and low-carbon transition.

vi Power generation and energy storage will be important applications of hydrogen in the future, but compared with other sectors that are already using hydrogen, the application of hydrogen in the energy sector, especially in the power sector, has not been carried out on a large scale. As a substitute for or supplement to existing energy sources, hydrogen will face great technical and economic challenges in these sectors and will still be in the demonstration and exploration period over the next decade, with large-scale commercial applications unlikely. As a result, hydrogen use in the energy and power sectors will not have a significant impact on renewable hydrogen demand in 2030.

The application of hydrogen as energy storage faces the challenge of lack of reliable hydrogen storage and transportation solutions, and the application feasibility of hydrogen energy storage is far from that of other mature storage options (traditional pumped storage and electrochemical storage, etc.). Power generation from hydrogen, especially hydrogen turbines, is suitable for the transformation of gas-fired power generation facilities. However, the ratio of gas-fired power in China is extremely low and limited by the maturity of equipment, so power generation from hydrogen is costly and has a low application potential in China. Hydrogen fuel cell power generation is only suitable for very small-scale distributed emergency power needs or as a power supply in remote areas, with application cases and scale relatively limited.

In the future, applications of renewable hydrogen in the chemicals sector will mainly mean replacing nonrenewable hydrogen in existing traditional processes and the use of renewable hydrogen in modern chemicals production. Due to the technology complexity of chemical projects, the need for large investments, and the long development cycle of modern chemicals projects, applying renewable hydrogen as a raw material on a large scale requires the upgrade of multiple production lines, resulting in high costs and risk in the short term. In the next decade, applications of renewable hydrogen mainly will mean replacing traditional fossil-based hydrogen production in traditional technological processes and piloting a small number of new renewable hydrogen chemicals projects that have relatively mature conditions (more advanced technologies and better cost-effectiveness). Since the new chemicals processes adopt different technologies from existing and traditional production paths, and existing projects are difficult to transform, renewable hydrogen is only suitable for new projects (see Exhibit 15).

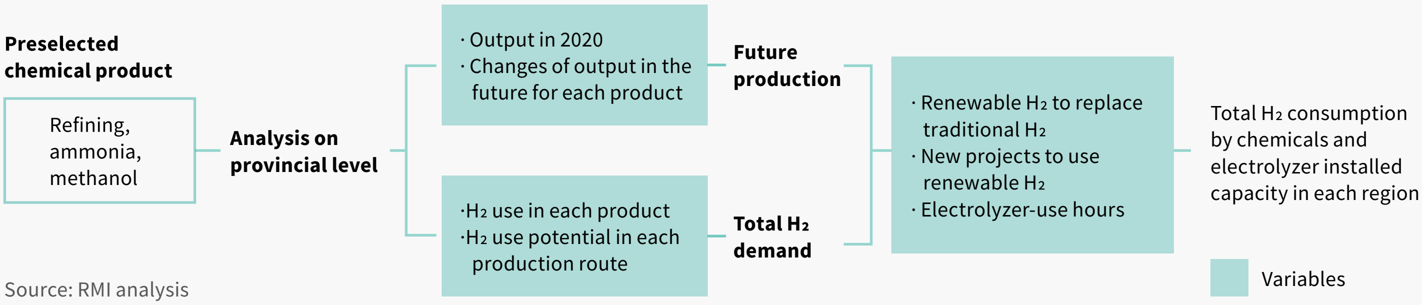
Exhibit 15. Hydrogen use in the chemicals sector in 2030



Source: RMI analysis

This report analyzes the demand for renewable hydrogen in refining, ammonia, and methanol, based on a comprehensive assessment of the demand for hydrogen and the feasibility of renewable hydrogen substitution in each region in 2030. Refinery products include a combination of gasoline, diesel, and other products, and the demand for hydrogen is related to the product structure and total output, while the demand for hydrogen per unit of ammonia and methanol is relatively clear. At the same time, considering the technical economies of scale of each subindustry and the regional availability of renewable hydrogen, the replacement and incremental development models of renewable hydrogen do vary in different subindustries and regions. Based on an analysis of product output and the development models, we analyzed the demand for hydrogen use and installed capacity of renewable hydrogen in the chemicals sector in 2030 (see Exhibit 16).

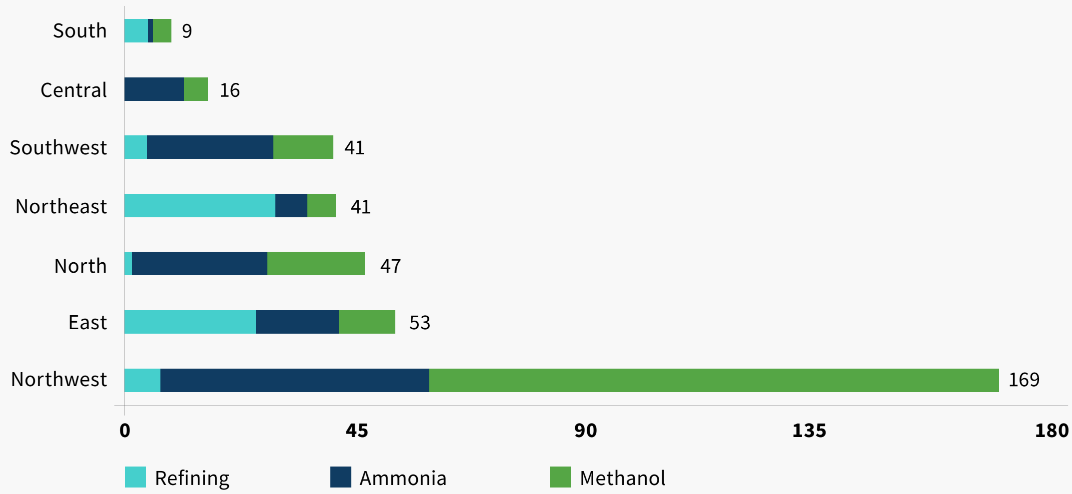
Exhibit 16. Hydrogen demand in the chemicals sector in 2030



Source: RMI analysis

According to estimates, the total renewable hydrogen consumption in the chemicals sector will reach 3.76 million tons in 2030, making it the largest renewable hydrogen demand market in China (see Exhibit 17). In particular, Northwest China will become the largest consumer of renewable hydrogen in the chemicals sector because of its advantages in renewable power resources, followed by East China, Northeast China, and Southwest China.

Exhibit 17. Demand for renewable hydrogen in the chemicals sector by region in 2030 (10, 000 tons/year)

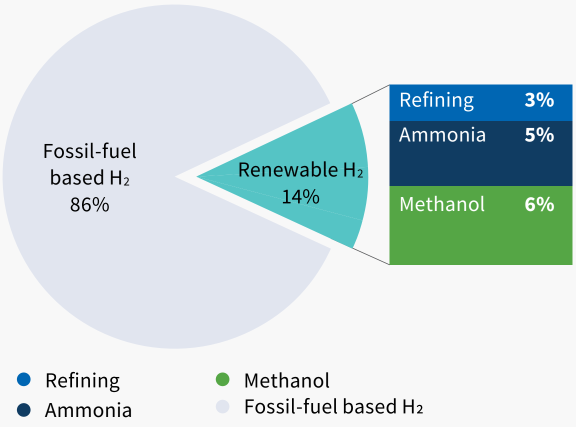


Source: RMI analysis

Based on an assessment of such factors as production process, feedstock, technology, and economics, renewable hydrogen has the potential to be an important low-carbon alternative feedstock in refining, ammonia, and methanol production (see Exhibit 18, page 34). By 2030, the largest demand for renewable hydrogen in the chemicals sector will come from methanol production, followed by synthetic ammonia and refining.

Exhibit 18. **Renewable hydrogen demand in the chemicals sector in 2030**

	Total	Refining	Ammonia	Methanol
Renewable hydrogen application	Replacing gray H_2, newly added green H_2	Green hydrogen used for refining, replacing gray hydrogen	Production capacity alternatives	Renewable hydrogen in chemicals
Renewable hydrogen consumption (million tons/year)	3.76	0.73	1.38	1.65
2020–2030 Production variation	–	Stable	Stable	About 20% increase



Source: RMI analysis

The methanol production industry is expected to keep growing and to become stable by 2030. In China's methanol industry, demand for renewable hydrogen is expected to reach 1.65 million tons per year, and the average renewable hydrogen application rate is expected to reach 20%. At present, the domestic methanol industry is oversupplied, with significant regional differences,[vii] and the raw material structure is highly dependent on coal, making the industry vulnerable to the impact of low-cost methanol abroad.

In the future, emerging applications, such as methanol to olefin or propylene, and methanol fuel, are expected to drive the growth of methanol downstream consumption. The integration and upgrading of production capacity may also improve competitiveness. Given that it is difficult to obtain approval for new coal-to-methanol projects, the production of green methanol from renewable hydrogen will increase methanol output in the future, with related projects being gradually established in the Northwest China and Southwest China (such as the Liquid Sunshine demonstration project). In 2030, Northwest China will be the largest production base of methanol in China.

Production capacity for ammonia synthesis will be more concentrated, equipment will be replaced and upgraded, and demand for renewable hydrogen will be further transferred to areas rich in renewable resources. By 2030, the demand for renewable hydrogen is expected to reach 1.38 million tons per year. Because of the distribution of coal resources and industrial bases, China's current ammonia production capacity is mainly concentrated in Shandong, Henan, Shanxi, Hubei, and Jiangsu. The overall slow growth of demand for downstream products such as urea is leading to the saturation of supply and demand in the northern markets, but new capacities have been planned in Anhui, Hubei, Henan, Fujian, and other provinces in recent years.

vii At present, methanol production capacity in the Northwest accounts for more than half of the country's total and is mainly used to produce downstream olefin and other products, whereas methanol in East China is in short supply and needs to be imported from the Northwest.

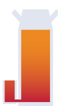
In the future, ammonia producers in Southwest China and Northwest China are expected to take the lead in responding to policy guidance to carry out technological transformation and merger and reorganization, reducing energy consumption and speeding up industrial optimization and adjustment through renewable hydrogen replacement. At the same time, ammonia has the potential to expand as a safer and more transportable hydrogen carrier.[6] Northeast China, which has the capacity to export ammonia, will promote the expansion of ammonia production and make it an important means of large-scale consumption of renewable resources.

Total refinery production is expected to remain unchanged by 2030, with renewable hydrogen demand expected to reach 730,000 tons per year. Because of the upstream raw material supply and distribution of industrial bases and downstream consumer markets, the current distribution of refineries is concentrated in the eastern coastal area. By 2030, with the promotion of the dual carbon goals and related industry policies,[7] new energy replacement will accelerate in the transportation sector, but total demand for petrochemical products will not increase significantly. So while the commissioning of large integrated refining and chemical units will increase capacity, some smaller independent refineries will be phased out or merged, leading to a future refinery output similar to the current level. The cost of renewable hydrogen in refining is higher than the current cost of fossil-based hydrogen.[8] However, with the overall upgrading of China's petrochemicals industry and increasingly clear policy signals, the penetration of renewable hydrogen will increase steadily in refineries in the Southwest China, Northwest China, and Northeast China, given favorable factors such as the emissions reduction effect of capacity replacement, implementation of major projects, and the falling cost of renewable hydrogen.

- **Steel**

The steel sector is one of the most carbon intensive, and it is under significant pressure to decarbonize. Emissions in the sector account for about 7.2% of the global total.[9] Rapid decarbonization of the steel sector is particularly important in China, which produced 1.03 billion tons of crude steel in 2021, accounting for about 53% of the world's total crude steel output.[10] Coke currently is used as the main reducing agent in China's steel production. Fuel combustion produces the necessary high temperatures and coke reaction process, but it also creates carbon emissions. Electrifying the current process to avoid these emissions would be difficult, and neither improving efficiency nor recycling waste steel will help. However, replacing coke with renewable hydrogen using electric furnaces in a process called "direct reduction" will be a critical and promising way to completely decarbonize the steel sector.[11]

Exhibit 19. Technology classifications and pros and cons of hydrogen metallurgy

Technology	Illustration	Statement	Emissions reduction potential*	Technology readiness levels (year)	Pilot project	Advantages	Limitations
H_2 blast furnace (BF)		Inject reducing gas with high H_2 content through top of BF	20%	5–9	Bayi Steel's H_2-rich carbon recycle BF; Thyssenkrupp's BF ironmaking with coal replaced by H_2	Low transformation cost, more economical, increases production	Limited emissions reduction potential; technically hard to achieve full-hydrogen steelmaking
H_2 direct reduced iron (DRI)		Increase share of H_2 in gas-based shaft furnace DRI	95%	6–8	HBIS H_2-rich gas DRI; Arcelor Mittal's DRI project in Germany	High emissions reduction potential, more international experience	Difficult for renovation, lack of fundamental technology
H_2 smelting reduction		Inject H_2-containing gas to smelting reduction process	95%	5	Jianlong Saisipu Hydrogen-Based Smelting Reduction Project	High emissions reduction potential	Difficult transformation, lack of fundamental technology, fewer international experiences

*Emissions reduction potential will be maximized with zero-carbon power, which means DRI combines with an electric arc furnace, and smelting reduction combines with a converter.
Source: RMI analysis

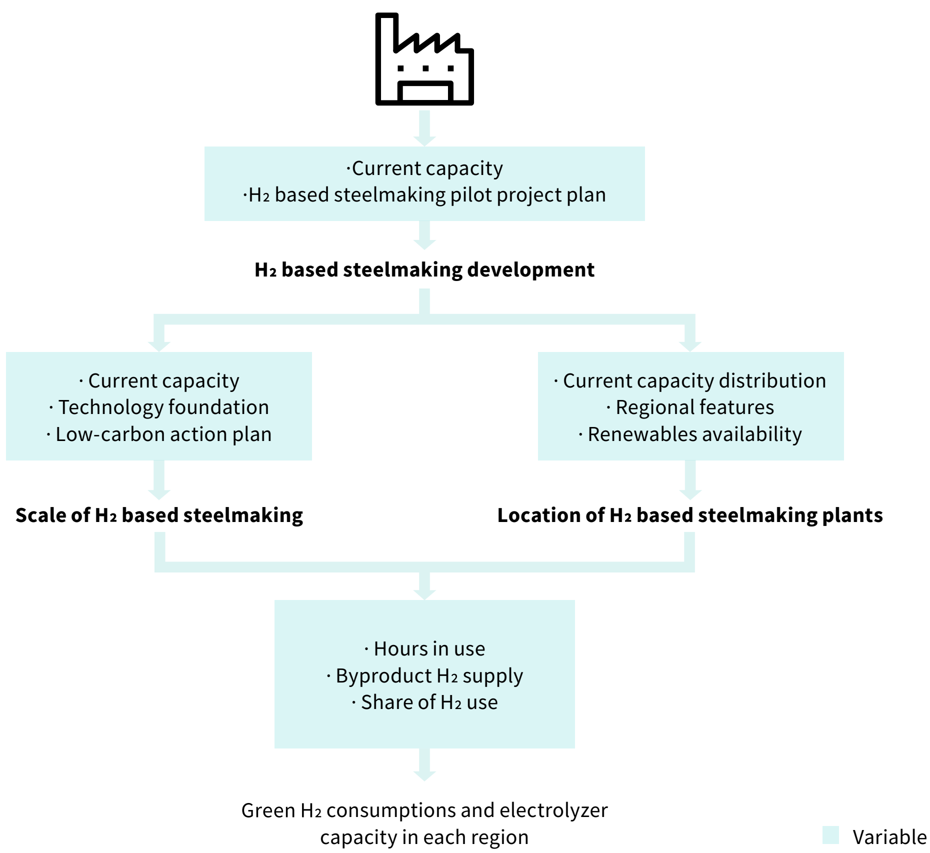
Exhibit 20. Recently announced hydrogen-based steelmaking projects

Steelmaker	Location	Technology	Capacity (10kt)	H_2 source
Baowu-Bayi Steel	Urumqi, Xinjiang	Hydrogen-rich BF	R&D stage	—
Baowu-Zhanjiang Steel	Zhanjiang, Guangdong	H_2-rich, gas-based shaft furnace	2×100	Byproduct H_2, clean H_2
HBIS	Zhangjiakou, Tangshan, Handan, Hebei	H_2-rich, gas-based shaft furnace	3×120	Byproduct H_2, RH
JISCO	Jiayuguan, Gansu	Hydrogen DRI	R&D stage	—
Jianlong Group	Wuhai, Inner Mongolia	H_2 smelting reduction	30	Byproduct H_2
Rizhao Steel	Rizhao, Shandong	Hydrogen DRI	50	Byproduct H_2
Jinnan Steel	Linfen, Shanxi	Hydrogen injection in BF	300	Byproduct H_2

Source: RMI analysis based on public information

The use of renewable hydrogen in the steel sector is focused on the production process of new capacity, with industry leaders showing the way. The main applications for hydrogen metallurgy can be divided into three categories, as shown in Exhibit 19, page 36. An evaluation of factors such as new capacity of steelmakers by 2030, plans to develop hydrogen metallurgy technology, as well as the capacity distribution, technical basis, action plan, and local attributes of each company,[viii] shows that hydrogen metallurgy capacity is mainly coming from leading industry players, and several large-scale hydrogen metallurgy bases will be formed.[12] Hydrogen metallurgy technology pilot projects of various large domestic steelmakers are shown in Exhibit 20, page 36. Based on this analysis, this study estimated the capacity scale and regional location of hydrogen metallurgy projects, and the renewable hydrogen consumption and demand of electrolyzer capacity in different regions by taking into account the regional use hours of electrolyzers and the supply of byproduct hydrogen (see Exhibit 21).[ix]

Exhibit 21. Analysis of hydrogen demand in the steel sector in 2030



Source: RMI analysis

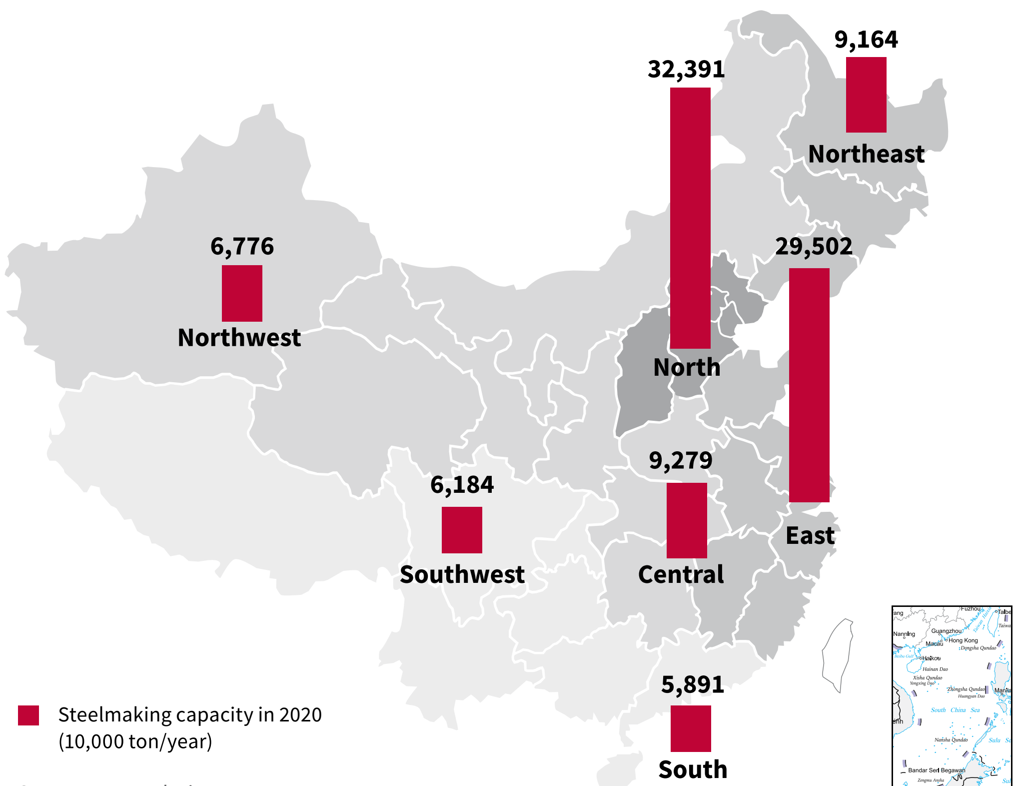
viii In March 2022, the guideline on the development of the steel industry jointly issued by two ministries and one commission supported the development of hydrogen metallurgy action plans by local governments and companies. The carbon neutralization roadmaps announced by large steel companies such as Baowu and HBIS consider hydrogen steelmaking an important technological approach to low-carbon metallurgy.

ix In March 2022, the guideline on the development of the steel industry jointly issued by two ministries and one commission supported the development of hydrogen metallurgy action plans by local governments and companies. The carbon neutralization roadmaps announced by large steel companies such as Baowu and HBIS consider hydrogen steelmaking an important technological approach to low-carbon metallurgy.

China's hydrogen metallurgy capacity in 2030 will be an estimated 43.47 million tons, accounting for about 4.5% of the country's total metallurgy capacity. Hydrogen consumption in the sector will be about 1.74 million tons, of which renewable hydrogen will be 940,000 tons, accounting for about 54%, with the rest of the demand met by industrial byproduct hydrogen. The location of hydrogen-based ironmaking capacity will be different from that of today's ironmaking capacity. At present, the geographic distribution of China's steelmakers is closely related to factors such as the distribution of iron ore and coke resources, transportation conditions, market demand, and labor and industrial bases, with production capacity mainly concentrated in North China and East China, such as in Hebei, Jiangsu, Liaoning, Shandong, and Shanxi.

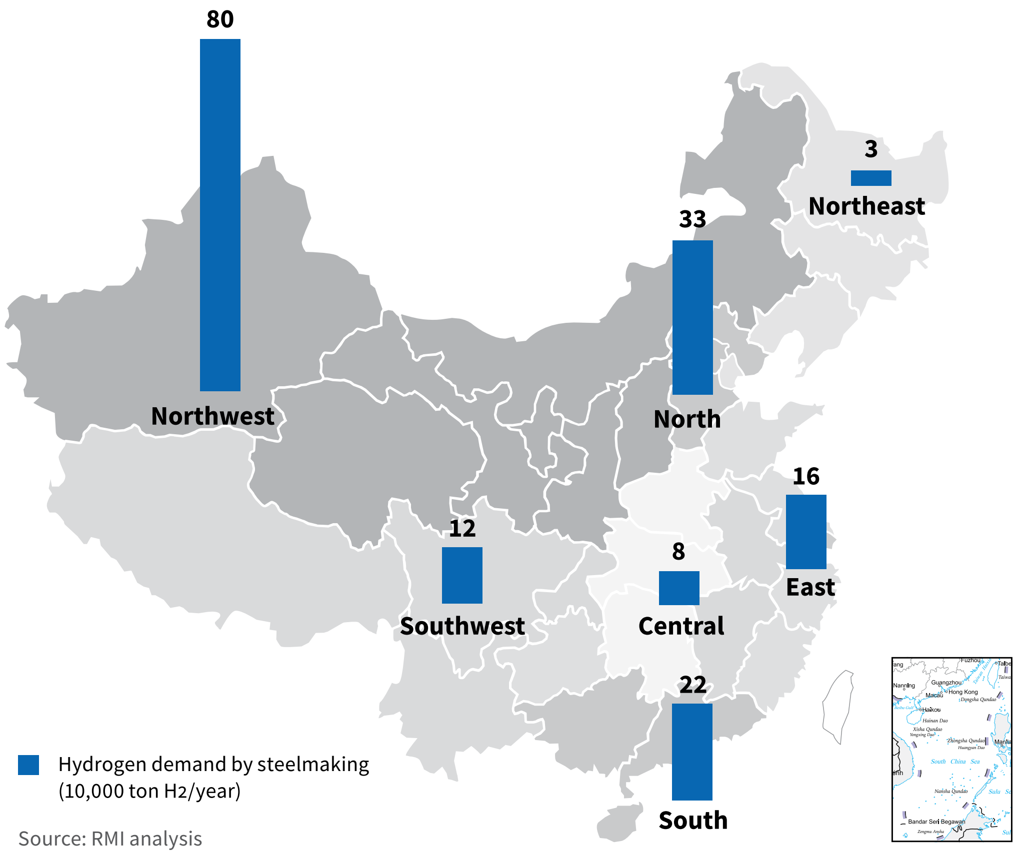
In the future, steelmakers will tend to deploy hydrogen-based ironmaking projects in regions rich in renewable hydrogen resources to reduce the cost of hydrogen storage and transportation. Northwest China will become the most important base for the development of hydrogen-based ironmaking, and its hydrogen metallurgy capacity will account for 46% of the region's total steelmaking capacity in 2030. South China will also have the comparative advantage of developing hydrogen metallurgy. As shown in the Exhibits 22 and 23, the steel sector, especially the renewable hydrogen metallurgy industry, in East China and North China will be transferred to the Northwest to some extent.

Exhibit 22. **Steelmaking capacity in China in 2020**



Source: RMI analysis

Exhibit 23. **Hydrogen consumption in steelmaking in China in 2030 (10,000 ton H_2/year)**



Source: RMI analysis

- ## Transportation

With cost reductions brought by technological breakthroughs and scale effect, HFC vehicles can achieve accelerated penetration in some applications, and the scale of hydrogen used in the transportation sector will gradually increase. New energy vehicles (including battery electric vehicles [EVs] and HFC vehicles) are among the most important ways for road transportation in China to achieve carbon neutrality in the future. Continuous technology advancements, increase in energy density, and cost reduction have made power batteries suitable and competitive in passenger vehicles and some commercial vehicles.[13]

Compared with the power battery, promotion of HFC vehicles is under greater pressure. At present, HFC vehicles are being promoted where requirements for range and stability are high, such as heavy-duty trucks, cold chain logistics, intercity buses, urban buses, and port and mining vehicles.[14] In some parts of northern China, where cold weather limits EVs, HFC vehicles also have the potential to work in taxis and official vehicles. As national and local policies and industrial support for HFC vehicles continue to deepen, "3+2" HFC vehicle demonstration city clusters have been identified nationwide,[x] including the Shanghai, Guangdong, Beijing, Henan, and Hebei city clusters. Twenty-four provinces in China have announced hydrogen or HFC development plans, and other provinces are also considering or developing them.

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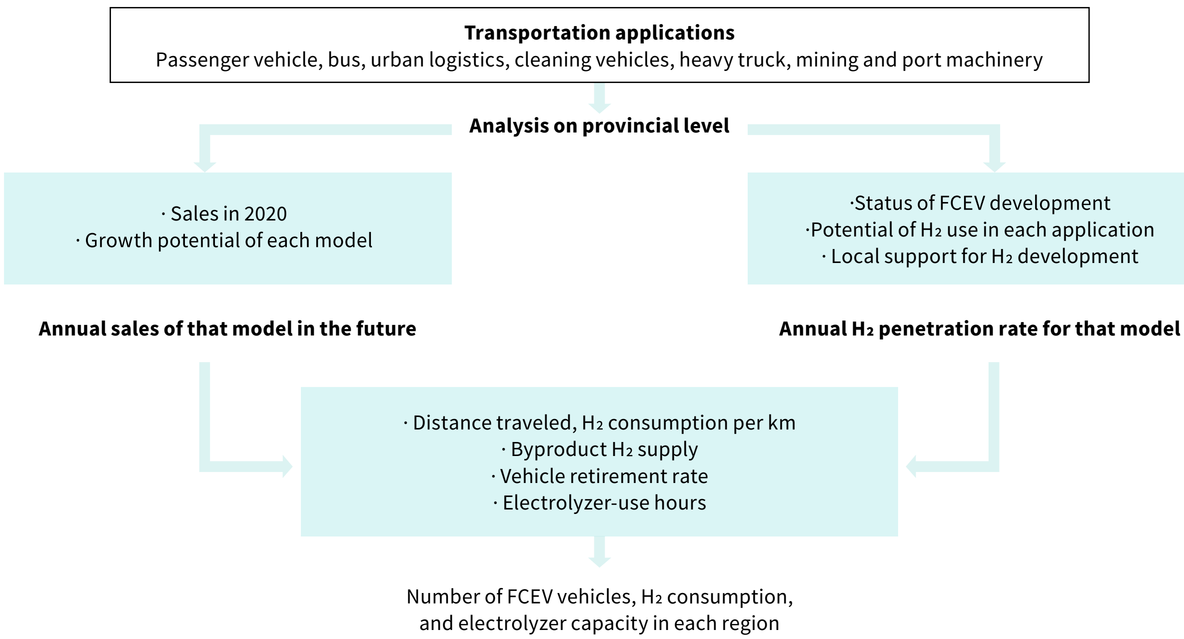
x "3+2" is China's national hydrogen fuel cell vehicles demonstrative city clusters, in which "3" means the three clusters of nearby cities approved in the first tier, including the Beijing, Shanghai and Guangdong clusters, and "2" means two city clusters approved in the second tier, including the Hebei and Henan clusters. All these clusters will have more hydrogen vehicles pilot operations and supporting policies.

Given the highly dispersed nature of the transportation sector and its wide-ranging geography, the demand for renewable hydrogen by HFC vehicles in different regions can be calculated according to the vehicle ownerships in each province. By selecting seven transportation applications, including passenger vehicles (e.g., taxis and official vehicles), buses, urban logistics vehicles, sanitation vehicles, heavy-duty trucks, mining machineries, and port machineries, taking provinces as units and based on market space and technical and economic analysis of each application, the regional sales of each vehicle model and penetration of HFC vehicles in 2020–30 were estimated. By considering factors such as driving mileage, hydrogen consumption per unit mileage, industrial byproduct hydrogen supply, auto scrappage, and electrolyzer utilization hours, this study forecast the regional hydrogen demand in the transportation sector and electrolyzer capacity requirement in 2030 (see Exhibit 24).

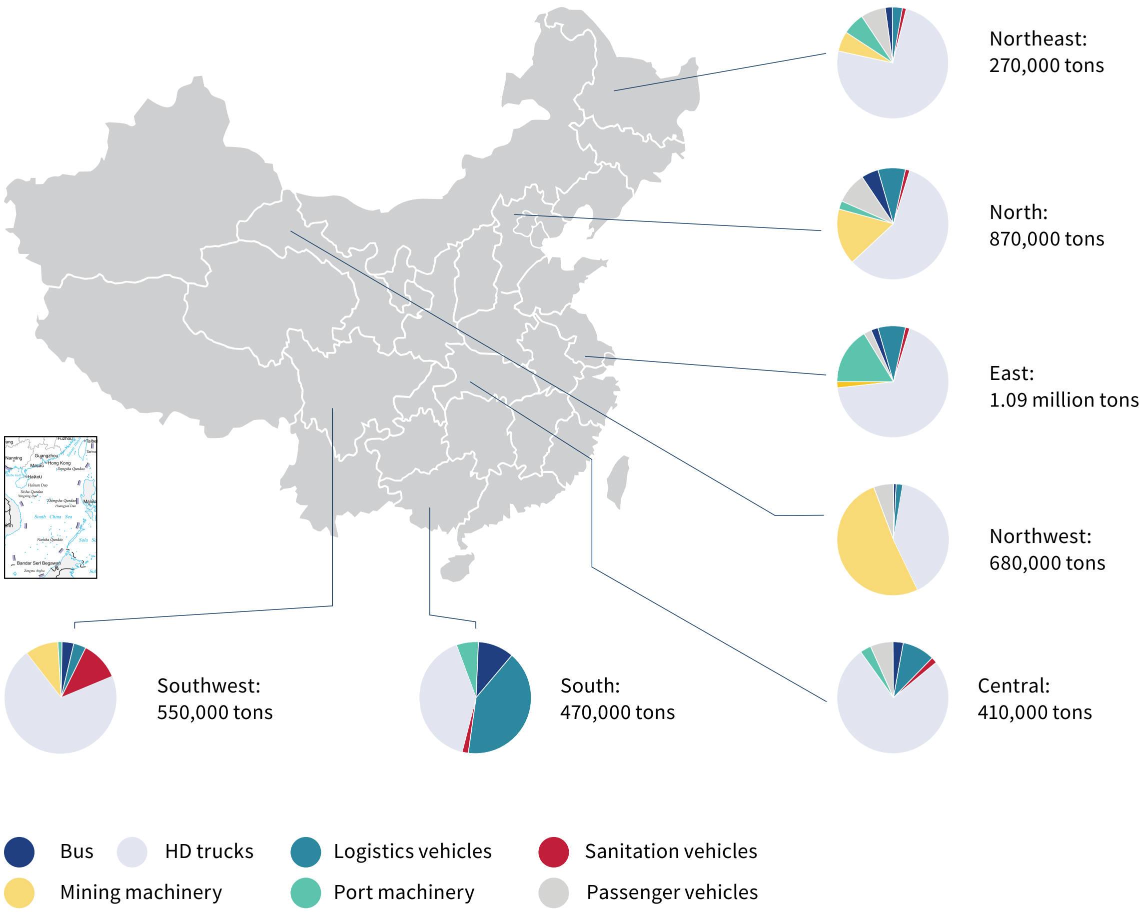
Exhibit 24. **Hydrogen use in the transportation sector in 2030**



Source: RMI analysis

The number of HFC vehicles in China is estimated to reach 620,000 by 2030, with a total hydrogen consumption of 4.34 million tons per year (see Exhibit 25, page 41), of which 3.01 million tons will be renewable hydrogen and the rest will be met by industrial byproduct hydrogen. Within all applications, HFC heavy-duty trucks will be the fastest developed, with the ownership expected to reach 280,000 by 2030. The development of HFC vehicles will be relatively balanced among different regions. Development will be rapid in East China, North China, and South China in the early stage, which is strongly correlated with regional economic development levels, transportation demand, and local support for HFC vehicles and the hydrogen industry. In the later stage, the accelerated development in Northwest China and Northeast China will be consistent with the compatibility of HFC vehicles in cold and heavy-duty applications.

Exhibit 25. **Distribution of hydrogen consumption in the transportation sector in 2030**



Source: Analysis by RMI and China Hydrogen Alliance Research Institute

Outlook on Regional Development of Renewable Hydrogen Capacity

Considering such factors as speed of the transition of traditional industries, availability of natural resources, and renewable hydrogen use levels, the regional distribution of China's renewable hydrogen capacity in 2030 will show the following features:

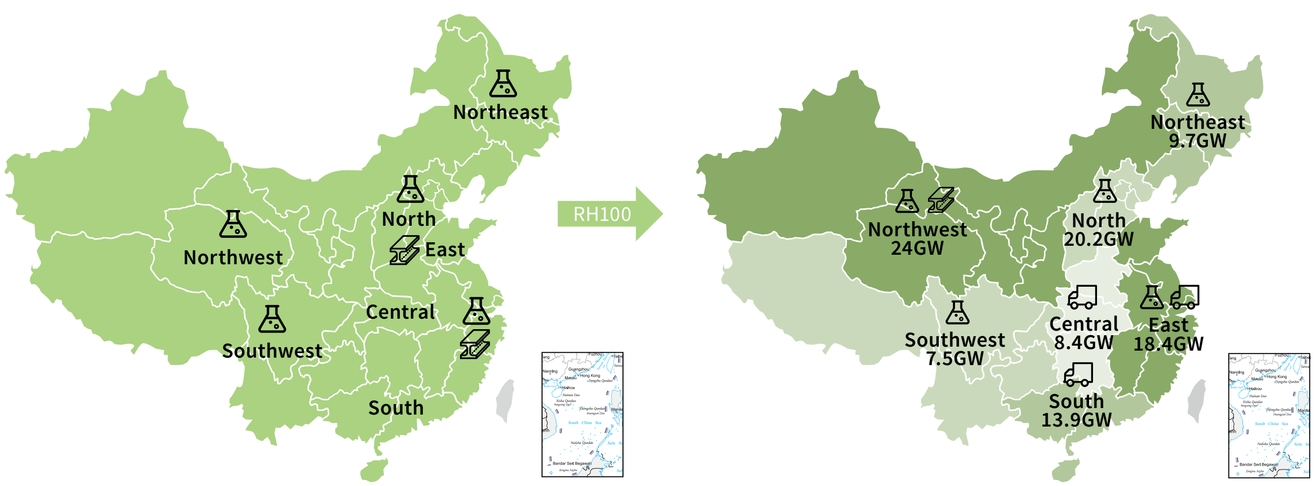
- Regions where the demand for transitioning and upgrading traditional industries matches the natural availability of renewable resources will become important development bases for renewable hydrogen, with relatively large installed capacity and low-cost renewable hydrogen, including Northwest China, Southwest China, and Northeast China. Focusing on large-scale applications in these regions with concentrated loads, local hydrogen production could be carried out by using abundant and cost-competitive wind and solar resources, supplemented by byproduct hydrogen, to meet the needs of different applications.

- In regions like the eastern coastal areas, with advanced industrial bases, dense populations, and limited renewable resources, the cost of large-scale production of renewable hydrogen is high, and the development of the hydrogen industry will be supported by industrial byproduct hydrogen plus distributed hydrogen production plus short-distance transportation. In the initial stage, based on the cost-effectiveness of each hydrogen source, high-quality byproduct hydrogen resources will be used as a transitional route, and the production of renewable hydrogen by small-scale and distributed stations, such as integrated hydrogen production and refueling stations, will be an important supplement.

- In regions with local advantages in but uneven distribution of renewable resources, the accelerated penetration of renewable hydrogen could be achieved by centralized hydrogen production plus medium-distance transportation. In northern North China, for example, Sinopec is planning to build a 400-kilometer pipeline from Ulanqab to Beijing. The model can promote the coupling of hydrogen with existing energy resources to improve resource use efficiency and minimize the cost of hydrogen production. It also can meet the economic requirements of applications in the transportation sector through mid-distance transportation.

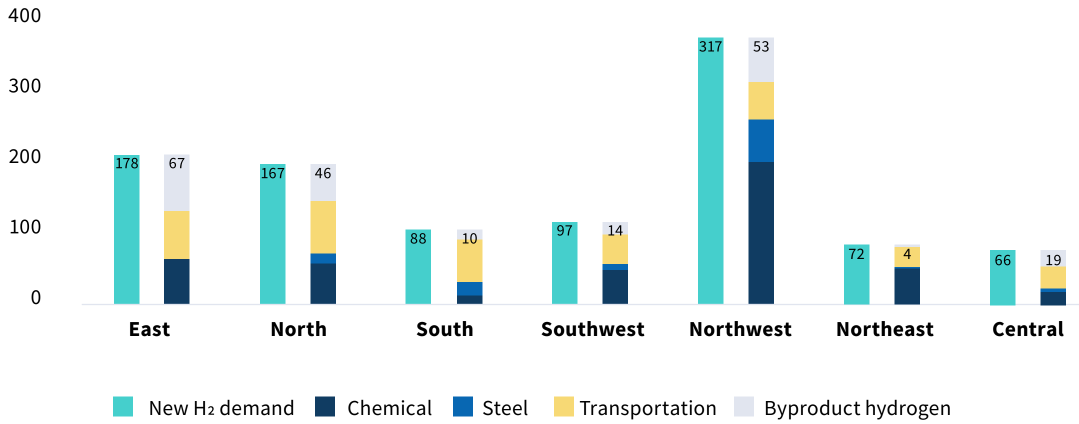
The detailed regional distribution of industries and the corresponding renewable hydrogen capacity are illustrated in Exhibits 26 and 27.

Exhibit 26. **Distribution of traditional industries in 2020 and renewable hydrogen capacity in 2030**



Source: Analysis by RMI and China Hydrogen Alliance Research Institute

Exhibit 27. **Renewable hydrogen consumption by region in 2030 (10,000 tons/year)**



Source: Analysis by RMI and China Hydrogen Alliance Research Institute

- ### Northwest China: Integrated development driven by resource advantages

The Northwest region has significant advantages in resource conditions and consumption demand. The rich fossil fuel, metal mineral, land, and solar and wind resources coupled with moderate power demand are making this region an ideal place for renewable power–based hydrogen production bases. These bases cannot only meet the needs of heavy industries for low-cost, zero-carbon transition, but also to a certain extent optimize the structure of production and application of renewable power. Driven by the transition of heavy industries and the full development of renewable power, Northwest China is expected to become the largest renewable hydrogen production and application base in China. Therefore, this study predicts that 24 GW electrolyzers will be built in Northwest China by 2030, with renewable hydrogen output reaching 2.64 million tons per year.

To meet this target, Northwest China needs to fully make use of industrial byproduct hydrogen and accelerate the deployment of renewable hydrogen based on the existing industrial structure, transforming into a modern, comprehensive low-carbon industrial zone. Both national and local governments should increase incentives for low-carbon transition of heavy industries and application of renewable hydrogen in this region and promote the comprehensive development of renewables-based hydrogen production by means of preferential tariff and financial support for project development and construction.

- ### Northeast China and Southwest China: Coordinated development of chemicals transition and renewable energy

Northeast China and Southwest China are China's most important development bases for the chemicals sector, including refining and ammonia. Facing challenges such as intensified downstream competition, rising raw material prices, and accelerated low-carbon transition, these regions should replace traditional raw materials with cleaner versions and original byproduct hydrogen with renewable hydrogen to promote the energy transition. Given the abundance of wind and solar resources in Northeast China and hydropower resources in Southwest China, it will be beneficial economically to replace traditional production capacity with hydrogen production from renewable power. Based on the end-use demand of various industries, it is estimated that 10 GW and 7 GW of electrolyzers will be built in Northeast China and Southwest China, respectively, by 2030, with renewable hydrogen outputs reaching 1.21 million tons and 820,000 tons per year.

To achieve this goal, national and local government support for renewable hydrogen production is needed. Incentives for the production and application of renewable hydrogen are also needed to further narrow the cost gap between renewable hydrogen and hydrogen from natural gas or byproduct hydrogen from the chemicals sector and to fully realize the gradual replacement of byproduct hydrogen with renewable hydrogen.

- **North China and South China: Simultaneous development in the steel and transportation sectors**

The development of the hydrogen industry in North China and South China is expected to have two focuses: fuel cells in demonstration city clusters and pilot projects led by pioneering steelmakers. By 2030, green hydrogen production bases will be built in North China and South China, which have advantageous local power resources. These bases will serve hydrogen steelmaking and metallurgy bases, led by large steelmakers such as HBIS and Baowu, and HFC vehicle industry and demonstration project clusters around core regions like Beijing-Zhangjiakou and Guangzhou-Foshan. North China and South China need to build 20 GW and 14 GW of electrolyzers by 2030, respectively, with renewable hydrogen outputs reaching 1.21 million tons and 780,000 tons per year.

To achieve this goal, it is necessary to build a hydrogen supply chain network covering key regions and centered on regions with local resource advantages, strengthen support for the development of the whole regional hydrogen industry chain, and quickly form a supply and demand network for large-scale use of renewable hydrogen.

- **East China and Central China: Focus on breakthroughs in the transportation sector**

The development of the hydrogen industry in East China and Central China is mainly concentrated in the Yangtze River Delta city clusters and the Shandong, Henan, and Wuhan regions. Based in the Shanghai demonstration city cluster, East China will deploy HFC vehicles in port transportation, logistics, and public transportation, forming a large-scale application base of renewable hydrogen. Shandong province can carry out comprehensive demonstrations in the transportation and chemicals sectors in combination with the Hydrogen to 10,000 Households demonstration program. In the near future, provinces need to make large-scale use of industrial byproduct hydrogen and carry out demonstration projects with renewable hydrogen. In the long term, they should produce renewable hydrogen with the development of offshore wind resources.

Demand for transportation in the densely populated provinces of Central China, the country's transportation hub, will continue to grow. Zhengzhou was selected in the second batch of demonstration city clusters, while Wuhan has a mature automobile industry base and is planning to develop a hydrogen industry of 100 billion RMB to become the world capital of hydrogen vehicles.

According to the analysis, East China and Central China need to build 18 GW and 8 GW of electrolyzers by 2030, respectively, with renewable hydrogen outputs reaching 1.1 million tons and 470,000 tons per year. (see Exhibit 28, page 45).

Exhibit 28. **Summary of regional development of renewable hydrogen capacity**

	Demand by sector	Renewable hydrogen supply	Potential solutions for regional storage and transportation	Major challenges	Renewable hydrogen installed capacity in 2030 (GW)	Renewable hydrogen production in 2030 (10,000 tons)
East China	Transportation and chemicals	Offshore wind to H_2, small-scale wind and solar to H_2	Tank trucks and regional pipelines	Rich industrial byproduct H_2, with low demand for new capacity in the region	18.4	110
North China	Transportation and steel	Wind to H_2	Tank trucks and regional pipelines		20.2	121
South China	Transportation	Hydro and offshore wind to H_2	Tank trucks	High green power cost	13.9	78
Southwest China	Chemicals	Hydro to H_2	Tank trucks and regional pipelines	Decentralized new projects	7.5	82
Northwest China	Steel and chemicals	Large-scale wind and solar to H_2	Regional pipelines and pilot liquid H_2	Huge investment required	24	264
Northeast China	Chemicals	Wind and solar to H_2 mega base	Regional pipelines	Long distance between supply and demand	9.7	68
Central China	Transportation	Hydro to H_2	Tank trucks	Limited green power resources	8.4	47

Source: RMI analysis

It should be noted that, as of 2021, the installed capacity of electrolyzers for hydrogen production in China was less than 1 GW, and most of them were pilot or demonstration projects. The overall cost of renewable hydrogen is high, and no large-scale commercial projects have been implemented. In addition, the total electrolyzer manufacturing capacity in China is lower than 5 GW.

An important part of realizing 100 GW of renewable hydrogen installed capacity in 2030 is encouraging industry participants to form a stable expectation of future market demand and trends. Achieving this requires analyzing and selecting the path to achieve carbon peak goal in all industries and taking advantage of key decision points to support the expansion of electrolyzer manufacturing capacity, steadily increasing electrolyzer manufacturing capacity and installed capacity by 2025.

At the same time, leading players should further reduce the cost of renewable hydrogen production through technological progress and economies of scale and seize early opportunities in the potential renewable hydrogen consumption market. As the economics of the whole renewable hydrogen industry chain improves, the investment return of the low-carbon transition using renewable hydrogen will be higher than other paths, and renewable hydrogen installations will accelerate rapidly with the strong demand for applications.

Suggestions for the Next Stage of Development

China has the potential at the national and regional levels to meet the target of 100 GW of renewable hydrogen capacity by 2030, but at the same time, more effective measures need to be taken to solve the challenges. Under the guidance of the “Medium- and Long-Term Plan,” we offer the suggestions below to more effectively promote the large-scale development of the hydrogen industry and renewable hydrogen, reduce cost while improving the industry system, unleash the development potential of hydrogen and renewable hydrogen, lead the long-term development of the hydrogen industry, and achieve the dual carbon goals.

Further Develop the National Target of Renewable Hydrogen Capacity as Well as Regional Production and Consumption Goals

Building on the “Medium- and Long-Term Plan,” development goals for renewable hydrogen installed capacity in 2030 and 2060 as well as production and consumption targets in different regions and sectors will be further studied and determined. Based on the goals and general development strategy in the plan, we recommend more research on the long-term development roadmap of the hydrogen and renewable hydrogen industry under the guidance of the goal of carbon neutrality by 2060. We also recommend clarifying the role of hydrogen in China’s overall energy system and identifying key milestones in the renewable hydrogen transition and the demand for production and installed capacity.

Based on the roadmap, targets for installed capacity and production of renewable hydrogen in 2030 should be proposed, in line with the growth rate of scaled development and cost-effectiveness trends. Production and consumption targets of renewable hydrogen by regions and sectors in 2030 should be identified, taking into account regional levels of resources and how developed technologies are in in major hydrogen-using industries. Companies in all regions and industries should be encouraged to set their own targets for renewable hydrogen consumption.

Carry out Hydrogen Mega Base Scaled Demonstrations to Drive a Rapid Decline in Costs in the Hydrogen Value Chain

Strengthen multilevel cooperation to establish hydrogen valley demonstration projects and jointly develop a renewable hydrogen economy. In addition to increasing policy support from the central government for mega base demonstration projects, effort should be made to fully mobilize local governments, using regional advantages to strengthen the policy and financial support for hydrogen valley demonstration projects. As the main shareholder in the large-scale development of the hydrogen industry, central SOEs should leverage their advantages in capital resources, infrastructure construction capacity, and coordination capacity to break through technological barriers by combining the introduction of foreign technology with independent R&D, making full use of internal market and superior resources to deploy large-scale application demonstrations. Different central SOEs should enhance cooperation; promote rational use of superior resources in various segments of production, storage, transportation, and refueling; and speed up the development and commercialization of hydrogen-based products, creating and expanding new markets by leveraging strengths of different players.

Private companies should use their advantages of flexibility and innovation, and join central SOEs leveraging their resources and markets , to break through core technologies and promote industrial development. Cooperation among central and local governments, central SOEs, and central and private companies can help promote the hydrogen industry to achieve technological upgrading, scale expansion, market expansion, and cost reduction as soon as possible.

Governmental authorities should research, develop, and apply hydrogen technologies and equipment according to relevant demonstration projects, breaking bottlenecks of key technologies. The advantages of the new nationwide system should be used to continuously implement supportive policy systems to facilitate the demonstration and application of first-of-its-kind technologies and equipment in the hydrogen industry. With the support of third-party industrial institutions, the "top runner" program should be planned and implemented in the hydrogen industry to enhance the efficiency of governance and accelerate the establishment of a standard system for innovative technology development, helping China's hydrogen equipment and technologies move from a "follower" to a "parallel runner" and finally to a "top runner." Third-party, high-quality public service platforms and training bases should be built for inspecting and testing hydrogen system equipment; improving and enhancing service levels for the testing, certification, and application of hydrogen equipment and technologies; and accelerating the commercialization of the hydrogen industry.

Deeply analyze the operation of mega base projects, summarize and refine best practices, and form a reference model. Efforts should be made to locate regional representatives of renewable hydrogen and mega base demonstration projects to conduct field research and analysis of project operations. This research and analysis should identify key factors in the success of the projects, main challenges, and the development direction for the next phase, forming best practice cases through summarizing, refining, and creating replicable development models of renewable hydrogen projects that can be referenced.

Improve the Local Supportive Policy Framework for the Hydrogen Industry to Accelerate Construction of Renewable Hydrogen Projects

Under the guidance of the national hydrogen plan, local support policies for the hydrogen and renewable hydrogen industry should be formulated, taking into consideration local conditions. Local government departments should create a systematic top-level plan for hydrogen and renewable hydrogen development, identify the development direction and route of hydrogen and renewable hydrogen in the region, and specifically formulate and issue industrial development goals and special plans for hydrogen and renewable hydrogen. Mechanisms for hydrogen facilities to participate in the power and carbon markets should be clarified. Regions with favorable conditions should accelerate the introduction of preferential tariff and policy supports for hydrogen production from renewable energy, further improve the time-of-use tariff mechanism, and encourage hydrogen production from curtailed renewable power and valley hours power.

Access conditions and trading mechanisms for hydrogen facilities to participate in spot markets, auxiliary services, and medium- and long-term trading in various power markets should be studied and created to facilitate hydrogen entering and participating in various power markets. Methodologies for calculating carbon reductions in clean and low-carbon hydrogen projects should be developed to explore coordinated development of hydrogen with the national carbon trading market.

Increase policy support for the development of renewable hydrogen projects and improve the incentive mechanism for low-carbon and clean hydrogen projects. Local governments should continue to implement fiscal, financial, tax, and land policies supporting hydrogen development. These policies include loan discounts, tax reductions, inclusive financial services, preferential allotment of land, and investment subsidies for key components or projects in the hydrogen industry. Financial institutions are encouraged to use policies such as the carbon emissions reduction support tool of the Central Bank to carry out innovations in hydrogen-related green financial products and increase credit support for low-carbon and clean hydrogen projects.

To formulate policies in support of technological innovation in the hydrogen industry, companies, and research institutes should increase investment in and encourage technological breakthroughs in basic materials, core technologies, and key components of hydrogen and fuel cells through technical cooperation, talent introduction, and the establishment of industrial funds.

Efforts should be made to formulate incentives for low-carbon and clean hydrogen use and hydrogen-based energy storage projects. For new energy-based hydrogen production projects that implement gray hydrogen replacement and new energy storage, appropriate preference can be given in areas such as competitive configuration, project approval (registration), grid interconnection, system scheduling and operation arrangements, guaranteed use hours, and compensation assessments for auxiliary power services. The introduction of a low-carbon and clean hydrogen quota mechanism should be studied in the chemicals and steel sectors, and companies can receive incentives to phase out high-emissions technology and equipment by selling the quota.

Prioritize talent cultivation in the hydrogen industry. Talent cultivation in the hydrogen industry should be in line with the dual carbon goals. Coordinated innovation in administration, production, academics, research, and applications should be vigorously promoted based on major national science and technology missions, innovation platforms, and college education. This will help to achieve balanced development of talents in fields including basic research, applied basic research, technology innovation, achievements transfer, and support services in the hydrogen industry, guaranteeing talent and professional support for the development of the hydrogen industry in China.

Integrate the Hydrogen Industry and Expert Resources to Promote the Establishment of Industrial Technology Standards

Establish industry and local platforms and formulate and implement industry and group standards according to relevant technical standards involved in the "Medium- and Long-Term Plan." Efforts should be made to actively implement the development of hydrogen technology and safety-related standards, accelerate the establishment of a special system for the formulation of hydrogen and renewable hydrogen technology standards, and raise the importance of relevant technical standards. The formulation of guiding principles and opinions for hydrogen and renewable hydrogen technology standards should be accelerated to provide guidance and direction for industry-related companies to achieve core technology breakthroughs and promote China's technical standards as a global leader.

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