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and China Hydrogen Alliance

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Green Hydrogen in China:
A Roadmap for Progress

WHITE PAPER

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Foreword

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Hydrogen can play an important role in accelerating the transition of the energy sector towards net-zero emissions. But it needs to be clean and at scale. The rapid development of hydrogen has become a global priority, and China has incorporated it in its latest national development strategy.

Green hydrogen has a vital role to play in helping China peak and then neutralize its carbon emissions. It is central to the government's ambition to build a green, low-carbon industrial system. And it can contribute towards China's strategic goal of reducing its reliance on fossil fuels. Yet, although China is the world's largest hydrogen producer and consumer, less than 0.1% of the hydrogen it produces is from renewable sources of energy. China Hydrogen Alliance has launched the Renewable Hydrogen 100 initiative that aims to increase the installed capacity of electrolysers to 100 gigawatts by 2030, resulting in a green hydrogen production capacity of roughly 7.7 million tonnes per year.[1]

This paper aims to understand and map out China's pathway towards its 2030 objectives for green hydrogen. It builds on the work of the Accelerating Clean Hydrogen Initiative of the World Economic Forum, which published the *Enabling Measures Roadmaps for Green Hydrogen* for Europe and Japan at the 26th Conference of Parties (COP26) in Glasgow in November 2021.These roadmaps have since been updated with the latest policy developments in both regions.

The roadmap presented in this document for China's green hydrogen industry is the third in the series. It was created by the World Economic Forum and Accenture, in partnership with China Hydrogen Alliance.

Similar to our other roadmaps, we have identified six key barriers, principal among which are cost, demand, infrastructure and standards. Positively, China's abundant sources of renewable energy can amply power its green hydrogen development, and the country's existing 34 million tonnes grey and blue hydrogen industry has created a market that could enable an accelerated expansion of greener alternatives.

China has the potential to commercialize new, clean energy technologies to transform its industrial system and the wider economy. It is our hope that the suite of solutions presented in this paper can, when implemented together, enable China to fully realize its green hydrogen future.

Executive summary

As the world shifts to a trajectory of net-zero emissions, green hydrogen will play an increasingly important role as a low-carbon and flexible form of energy. The global energy crisis provides a strategic opportunity to utilize hydrogen to start reshaping the global energy architecture.

To date, 30 jurisdictions accounting for 70% of global gross domestic product (GDP) have issued state-level hydrogen strategies. In March 2022, China joined the list, publishing its *Medium- and Long-Term Plan for the Development of the Hydrogen Energy Industry (2021-2035)*. Green hydrogen can play an important role in helping China peak, and then neutralize, its carbon emissions. It is vital to China's strategic ambition to build a green, low-carbon industrial system.

As the world's largest hydrogen producer and consumer, China's current hydrogen production is largely grey. Of the 34 million tons of hydrogen that China produced in 2021, 80.3% was produced from fossil fuels, 18.5% from industrial by-production and 1.2% from electrolysis (of this, less than 0.1% from electrolysis powered by renewable energy sources). Demand for green hydrogen is greatly constrained by cost and availability, as its applications are currently limited to a few small pilot projects in the transport sector that account for less than 0.1% of total hydrogen consumption.

China's abundant sources of renewable energy are well placed to power green hydrogen's development. But the industry is nascent and no clear green hydrogen development pathway has been established. The main constraints for the expansion of green hydrogen in China are cost, market demand, infrastructure and industry standards and certification.

Backed by in-depth analysis of China's green hydrogen market, this publication proposes six development goals for China's green hydrogen market, accompanied by key objectives for each goal and 35 enabling measures and recommendations. These centre on building a new energy system and a full supply chain of hydrogen through industrial, regional and global collaborations. The publication draws on the green hydrogen roadmaps for the European Union (EU) and Japan, and, with reference to China's industrial and domestic context, outlines a blueprint to help China deliver on its ambitious green hydrogen vision, with 2030 as the key milestone.

Goal 1: Cost

Key objectives:

– Reduce the cost of electricity in green hydrogen production

– Reduce the cost of electrolysers

The major costs associated with green hydrogen centre on production, transportation and refuelling stations, with production costs the core constraint in scaling the industry. Green hydrogen in China costs 3-5 times more to produce per kg than coal-produced hydrogen.

Meanwhile, blue hydrogen, which uses coal or natural gas in conjunction with carbon capture, utilization and storage (CCUS), is cheaper to produce per unit (currently) and has the potential to produce hydrogen at a low carbon emissions intensity. However, CCUS is not well-established in China and is limited to a few demonstration projects.

Goal 2: Infrastructure

Key objectives:

– Establish unified regulatory standards and procedures

– Reduce the cost of infrastructure investment and expand financing channels

Underdeveloped infrastructure restricts the availability of green hydrogen. Under the Chinese regulatory framework, hydrogen is classified as an energy source as well as a hazardous chemical, which makes developing the industry more complex – hydrogen infrastructure must legally be sited in a chemicals industry park and secure a range of licences. However, regulations differ between jurisdictions. For example, in October 2022, Guangdong province passed interim measures that allow the construction of stations that integrate hydrogen production and refuelling facilities in non-chemical industry parks.

Another obstacle is the high cost of investing in hydrogen infrastructure, along with limited channels to raise finance. In 2021, the hydrogen sector generated just $578 million in investment, compared to $489 billion invested in electric vehicles, which comprise the great majority of capital raised by the new energy vehicle (NEV) sector (that excludes hydrogen-powered vehicles).

Goal 3: Market demand

Key objectives:

– Boost short-term market demand for hydrogen fuel cell vehicles (HFCVs)

– Create multiple end-use application scenarios to drive the large-scale adoption of hydrogen technology

To develop green hydrogen at scale, a breakthrough on supply is not enough – China's markets need policy support to develop more demand-side opportunities. Hydrogen has a wide range of applications – in transport, manufacturing, utilities and construction.

Hydrogen fuel cell vehicles (HFCVs) offer an ideal solution for long-haul, heavy-duty trucking. By 2021, there were 9,000 HFCVs on the road – not enough to support a large-scale industry, but this is expected to change as fuel cell costs fall. Hydrogen is also being piloted in aviation and shipping, though commercialization remains a long-term goal.

Hydrogen also offers significant decarbonization opportunities for iron and steel production, which emits 1-3 tons of carbon dioxide (CO_2) per ton of metal produced. Hydrogen can replace coking coal as a combustion fuel in the smelting process, resulting in water (H_2O) as a by-product instead of CO_2. Other applications include hydrogen energy storage (HES), which entails hydrogen being produced using fuel cells and stored when electrical supply is abundant, to be converted back into electricity when needed.

Goal 4: Industry standards and certification

Key objectives:

– Improve the regulatory system for hydrogen by providing better-structured standards

– Engage multiple stakeholders to develop innovative, high-quality standards

Standards play a pivotal role in the development of hydrogen technology, but standard-setting is too slow to support this fast-growing industry. Despite the publication of Chinese standards that cover the whole supply chain, gaps remain, especially in technical standards for storage, transport and refuelling. Here, China compares poorly to other jurisdictions such as the United States (US) or Japan.

Because of the complexity of the hydrogen value chain, the administrative structure that is responsible for standard setting spans many different ministries and is consequently not best suited for the rapid certification of an emerging industry such as green hydrogen. In practice this means that for certain technology applications, no single administrative body is clearly responsible as of now.

Goal 5: Technology

Key objective:

– Step up proprietary research and development (R&D) across the supply chain to further adapt electrolysis technology to renewable energy sources

Electrolysis is considered the leading green hydrogen-producing technology today. It produces highly purified hydrogen and works well in combination with renewable energy. It therefore enjoys brighter prospects than other types of hydrogen technology, such as those using nuclear energy or photocatalysis (technologies still at the laboratory stage). The electrolysis process relies on electrolysers, of which three types are currently in use: alkaline (ALK), proton exchange membrane (PEM) and solid oxide electrolyser cell (SOEC).

PEM's higher reaction efficiency is well suited to the volatility of wind and solar power. Globally, PEM technology is expected to commercialize rapidly. But China is way behind in this technology. To secure PEM's future, China needs to replace imported components with domestic alternatives.

SOEC recovers waste heat from high-temperature industrial processes, working well in conjunction with photothermal power systems. In China, the experience with SOEC electrolysers is currently limited to laboratory-scale demonstrations.

Goal 6: Evolution and cooperation

Key objective:

– Speed up the development of a national strategy for hydrogen

– Lay the foundation for international cooperation

National-level hydrogen planning is in place, but the development pathway and goals for the hydrogen supply chain are yet to be defined. Other countries have already formulated explicit roadmaps to propel their hydrogen industries, and China risks being left behind. Japan and South Korea are taking the lead in building overseas hydrogen supply systems and sales markets. Japan leads on international cooperation, having recently hosted the Group of Twenty (G20) Clean Energy Ministerial and a special forum on hydrogen.

China started late in this sector, but is now expanding rapidly. Currently, China has the largest hydrogen production capacity worldwide. The blueprint for China's future hydrogen sector development is focused primarily on domestic energy restructuring and carbon neutrality objectives. Additionally, China has witnessed a steady increase in the number of international cooperation projects, more wide-ranging collaborations, diverse partnership models, greater commitment to green hydrogen and more engagement from companies.

Blueprint for the evolution of green hydrogen in China

Given China's ambition to peak carbon emissions by 2030, green hydrogen is destined to play a pivotal role in the country's carbon neutralization. To deliver this new technology at the scale required, China will need to focus on developing the sector through industrial, regional and global collaborations. The key priorities should be:

– Deployment of government policy for balancing supply and demand.

– Improved coordination between provinces to maximize relative strengths and synergies.

– Support for a multilateral approach built on global cooperation in cost, infrastructure and markets.

– Adoption of a China-specific approach to standards and certification.

This publication proposes a roadmap with six goals that China should execute in a series of coordinated actions spread over three phases that accomplish key goals:

Phase 1 - 2023-2024: Supportive policies, demonstration projects, technological breakthroughs, coordination with existing energy supply, application to industry sectors.

Phase 2 - 2024-2027: Technical standards, investment in supply networks, international cooperation, widespread progress.

Phase 3 - 2027-2030: Price and demand targets, energy infrastructure, certification, innovation networks, global participation.

TABLE 1 | **Green hydrogen in China – Goals, objectives and enabling measures**

	Key objectives	Enabling measures
Goal 1 Cost	Reduce the cost of electricity in green hydrogen production Reduce the cost of electrolysers	Implement centralized demonstration projects for hydrogen production from renewable energy sources in areas rich in such resources Formulate policies on special electricity rates for green hydrogen projects Optimize electricity markets to scale up green electricity trading Subsidize the manufacture of green hydrogen equipment Lay down a tax credit policy for green hydrogen Develop efficient high-powered alkaline electrolysers to reduce the capital expenditure
Goal 2 Infrastructure	Establish unified regulatory standards & procedures Reduce the cost of infrastructure investment & expand financing channels	Develop a system for hydrogen administration & designate the competent authorities Accelerate formulation of unified national approval procedures & management standards Encourage local pilot efforts to deregulate hydrogen production & refuelling in non-chemical industry parks Accelerate technological breakthroughs in hydrogen storage & transport, plus domestic production of key components for refuelling stations Promote the construction of integrated hydrogen production & refuelling stations Advocate for the conversion of traditional filling stations into mixed fossil fuel and hydrogen refuelling stations Provide more support for hydrogen infrastructure via financial instruments Accelerate the incorporation of the complete green hydrogen supply chain into green finance standards
Goal 3 Market demand	Boost short-term market demand for hydrogen fuel cell vehicles (HFCVs) Create multiple end-use application scenarios to drive the large-scale adoption of hydrogen technology	Accelerate domestic development of hydrogen fuel cell technology and high-pressure hydrogen storage systems Step up policy support by granting right of way to HFCVs Strengthen public procurement of HFCVs Boost the development of green hydrogen and its applications in industrial production, such as manufacture of iron and steel Explore the coupling of green hydrogen and carbon markets to accelerate the replacement of grey hydrogen across big industrial emitters Promote integration of green hydrogen storage with renewable energy sources, through commercial operating models and demonstration projects Build multiple end-use green hydrogen application scenarios, starting with demonstration projects Distribute industrial demonstration projects in line with local conditions, drive the supply chain by clusters, and scale up applications
Goal 4 Industry standards and certification	Improve the regulatory system for hydrogen by providing better-structured standards Engage multiple stakeholders to develop innovative, high-quality standards	Reflect on the realities and flaws of the hydrogen sector's standards to optimize the standards system Improve top-level planning and execution of standards, while providing policy support, incentives and publicity to promote standardization Pilot local and corporate standards to derive empirical models for promotion and replication Encourage industrial alliances, academic societies, enterprises and other organizations to cooperate and innovate in standard-setting Cooperate in the formulation of international standards
Goal 5 Technology	Step up proprietary research and development across the supply chain to further adapt electrolysis technology to renewable energy sources	Enhance the rapid response capacity of the alkaline hydrogen production system Establish a special fund to finance breakthroughs in new-generation electrolysis technology Define technological development goals and pathways Accelerate China's access to next-generation technology by leveraging universities and participation in global innovation forums Enhance innovation platforms and maximize the role of industrial clusters to incubate and demonstrate key technologies
Goal 6 Evolution and cooperation	Speed up the development of a national strategy for hydrogen Lay the foundation for international cooperation	Refine the national development plan for hydrogen and formulate a roadmap for green hydrogen Develop a long-term mechanism for international cooperation, and connect technology, policy, academia, enterprises and finance with global supply chains Strengthen international cooperation in setting standards for carbon emissions

Introduction: A great mission and a long way to go

Green hydrogen is the optimal solution for net zero

As net-zero carbon emissions become a global goal, energy from hydrogen – which can be low-carbon, flexible, efficient and produced in multiple ways – is becoming an essential means for reshaping the global energy architecture and addressing climate change.

At present, hydrogen can be categorized in different ways, such as by production method or by carbon emissions intensity across the whole life cycle. Depending on production methods, hydrogen can be grey, blue or green. In this publication, green hydrogen refers to hydrogen produced via electrolysis powered by renewable energy sources, including wind, solar, ocean, hydel, geothermal and biomass (Figure 1).

FIGURE 1 **Hydrogen production methods, sources and characteristics**

	Method	Source	Characteristics
Grey hydrogen	Hydrogen is produced by burning fossil fuels	Coal, oil, natural gas and other chemical energy sources	Higher carbon emissions with lower costs; well-established
	Hydrogen results from industrial by-production	Hydrogen extracted from coke oven gas, the chemical fertilizer industry, chlor-alkali and other industrial by-products	
Blue hydrogen	Production of grey hydrogen is combined with carbon capture, utilization and storage	Same source as grey hydrogen, mainly natural gas	Higher carbon emissions with lower costs
Green hydrogen	Hydrogen is obtained by electrolysis of water	Water, renewable energy sources	Low carbon emissions with high costs; limited applications, large-scale adoption needs promotion

Source: Accenture from public data.

Hydrogen is a global priority and now part of China's national planning

> To date, 30 jurisdictions covering 70% of global GDP have announced hydrogen strategies.

The development of hydrogen has become a global priority and has been incorporated into China's national development planning. In addition to climate change, the global energy crisis – aggravated by extreme weather and the Russian invasion of Ukraine – provides a vital strategic opportunity for the development of the hydrogen sector. To date, 30 jurisdictions, encompassing the world's major economies accounting for 70% of global gross domestic product (GDP), have announced state-level hydrogen strategies (Figure 2).[2] Europe, the US, Japan and South Korea are the pioneers.

In March 2022, the National Development and Reform Commission (NDRC) of China and the National Energy Administration jointly issued the *Medium- and Long-Term Plan for the Development of the Hydrogen Energy Industry (2021-2035)*, officially incorporating hydrogen development into China's national development plan and ushering the country's hydrogen sector into a new phase of development.

This plan defines the role of hydrogen in China's energy system and its industrial restructuring and upgrade. Hydrogen is an integral part of China's green and low-carbon energy system and has an important role to play in helping China first peak then neutralize its carbon emissions.[3] The hydrogen industry plan highlights the principle of "building a clean, low-carbon, low-cost and multi-approach hydrogen production system, with a focus on hydrogen production from renewable energy sources and strict controls over hydrogen production from fossil energy sources".

The plan frames the requirements for green hydrogen development against the following target deadlines:

- **By 2025**, to establish a hydrogen supply system that ensures hydrogen is consumed close to where it is produced, whether as an industrial by-product or from renewable energy sources. The aim is to produce 50,000 hydrogen fuel cell vehicles (HFCVs) with sufficient hydrogen refuelling stations.[4] The target for renewable energy-based hydrogen production capacity is 100,000-200,000 tons per year, achieving CO_2 emissions reductions of 1-2 million tons per year.
- **By 2030**, there should be wide application of hydrogen produced from renewable energy sources, which will robustly support the country's decarbonization goals, with a focus on decarbonizing mobility and then industry.
- **By 2035**, hydrogen from renewable sources should account for a significantly higher proportion of consumption at end-points or by end-users, playing a vital role in supporting the transition towards green energy.

FIGURE 2 **Global hydrogen strategies by jurisdiction, 2017-22**

Source: China Hydrogen Alliance, Accenture analysis.

> In 2021, China produced 34 million tons of hydrogen, but less than 0.1% came from electrolysis powered by renewable energy sources.

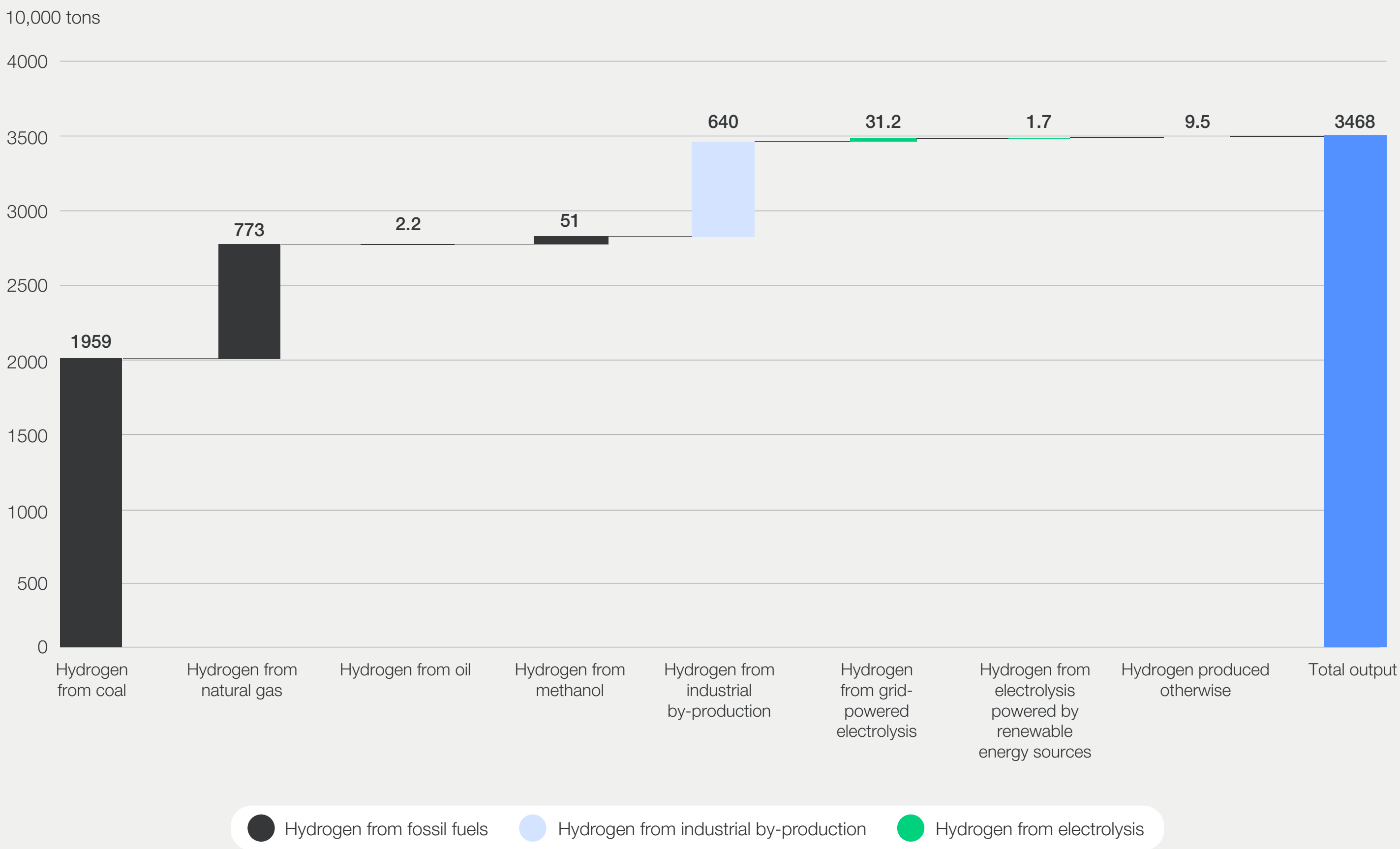
China needs a clear hydrogen development pathway

As the world's largest hydrogen producer and consumer,[5] China's current hydrogen production is dominated by fossil energy-based methods and supplemented by industrial by-production, with a relatively small amount of hydrogen produced from electrolysis.

In 2021, China produced 34.68 million tons of hydrogen, of which 80.3% was produced from fossil fuels, 18.5% from industrial by-production, and 1.2% from electrolysis (of this, less than 0.1% was from electrolysis powered by renewable energy sources) (Figure 3).

While China's consumption of hydrogen is relatively large, the demand for green hydrogen is greatly constrained by cost and availability, as its applications are limited to a few small pilot projects in the transport sector that account for less than 0.1% of total hydrogen consumption countrywide (Figure 4).

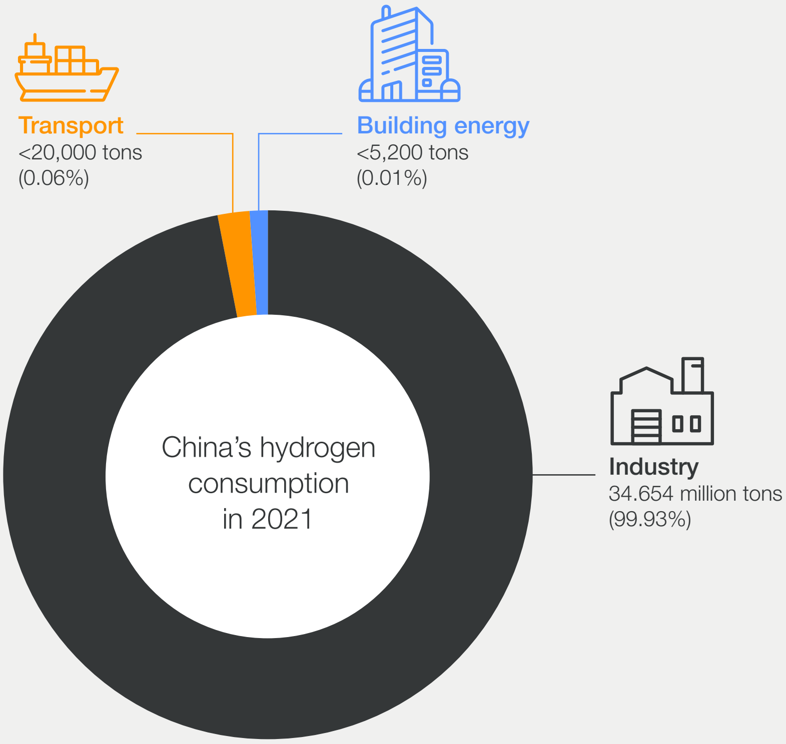
FIGURE 3 **Hydrogen production in China by energy type, 2021**



Source: China Hydrogen Alliance, Accenture analysis.

Given China's abundant sources of renewable energy, green hydrogen is one of the most promising energy sources for its future. Though China's top-level plan for hydrogen energy has been formulated, no precise, phased and measurable development goals or paths have been established yet. This paper is a roadmap that aims to define these green hydrogen development goals, determine the best pathways towards realizing them, and help China deliver on its ambitious green hydrogen vision.

FIGURE 4 | **China's hydrogen consumption, 2021**



Source: China Hydrogen Alliance, Accenture analysis.

Six development goals for China's green hydrogen market

At present, the global hydrogen market is at a nascent stage, with countries and regions facing similar risks and opportunities. This paper follows the green hydrogen development framework used for the EU and Japan roadmaps developed by the World Economic Forum and Accenture. Based on the central assumption that sufficient renewable energy is available, the report proposes and analyses six development goals for China's green hydrogen market and the accompanying objectives (see below and Figure 5).

Subsequent chapters present each goal in detail, analysing existing challenges and proposing a total of 35 enabling measures to overcome the challenges in achieving each goal. The report concludes with a three-phase timeline from 2023-2030 to deliver on these goals.

The six green hydrogen development goals and their key objectives are:

Goal 1: Cost

– Reduce the cost of electricity in green hydrogen production.

– Reduce the cost of electrolysers.

Goal 2: Infrastructure

– Establish unified regulatory standards and procedures.

– Reduce the cost of infrastructure investment and expand financing channels.

Goal 3: Market demand

– Boost short-term market demand for HFCVs.

– Create multiple end-use application scenarios to drive the large-scale adoption of hydrogen technology.

Goal 4: Industry standards and certification

– Improve the regulatory system for hydrogen by providing better-structured standards.

– Engage multiple stakeholders to develop innovative, high-quality standards.

Goal 5: Technology

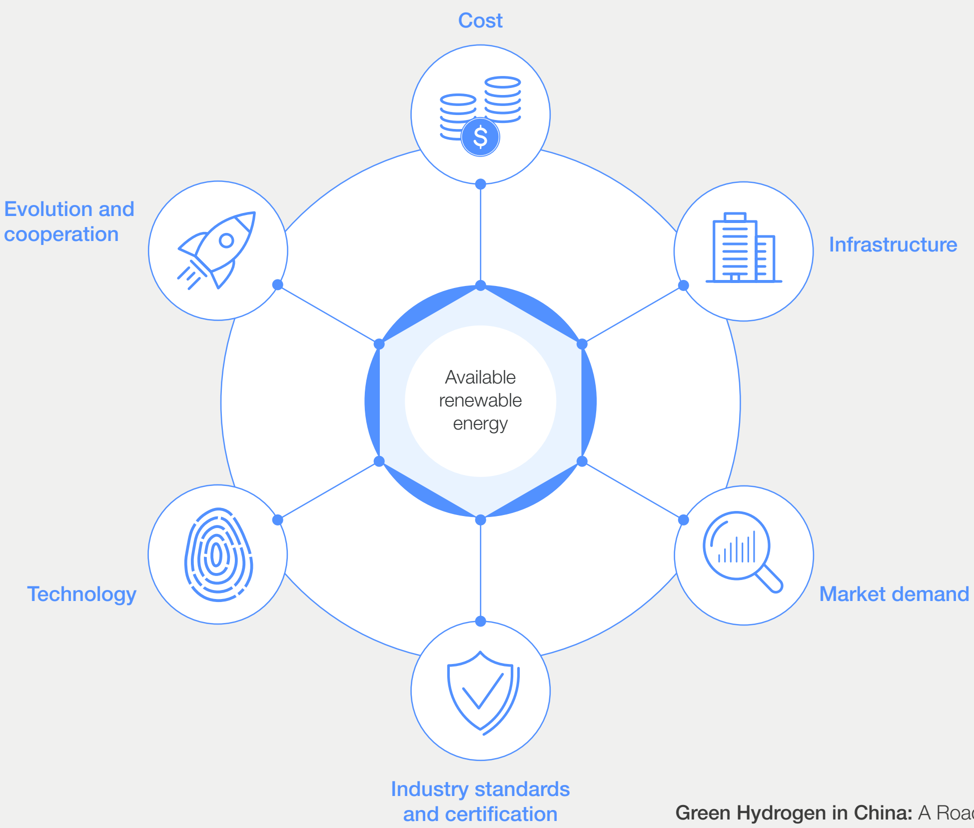
– Step up proprietary R&D across the supply chain to further adapt electrolysis technology to renewable energy sources.

Goal 6: Evolution and cooperation

– Speed up the development of a national strategy for hydrogen.

– Lay the foundation for international cooperation.

FIGURE 5 **Six development goals for China's green hydrogen market**



Goal 1

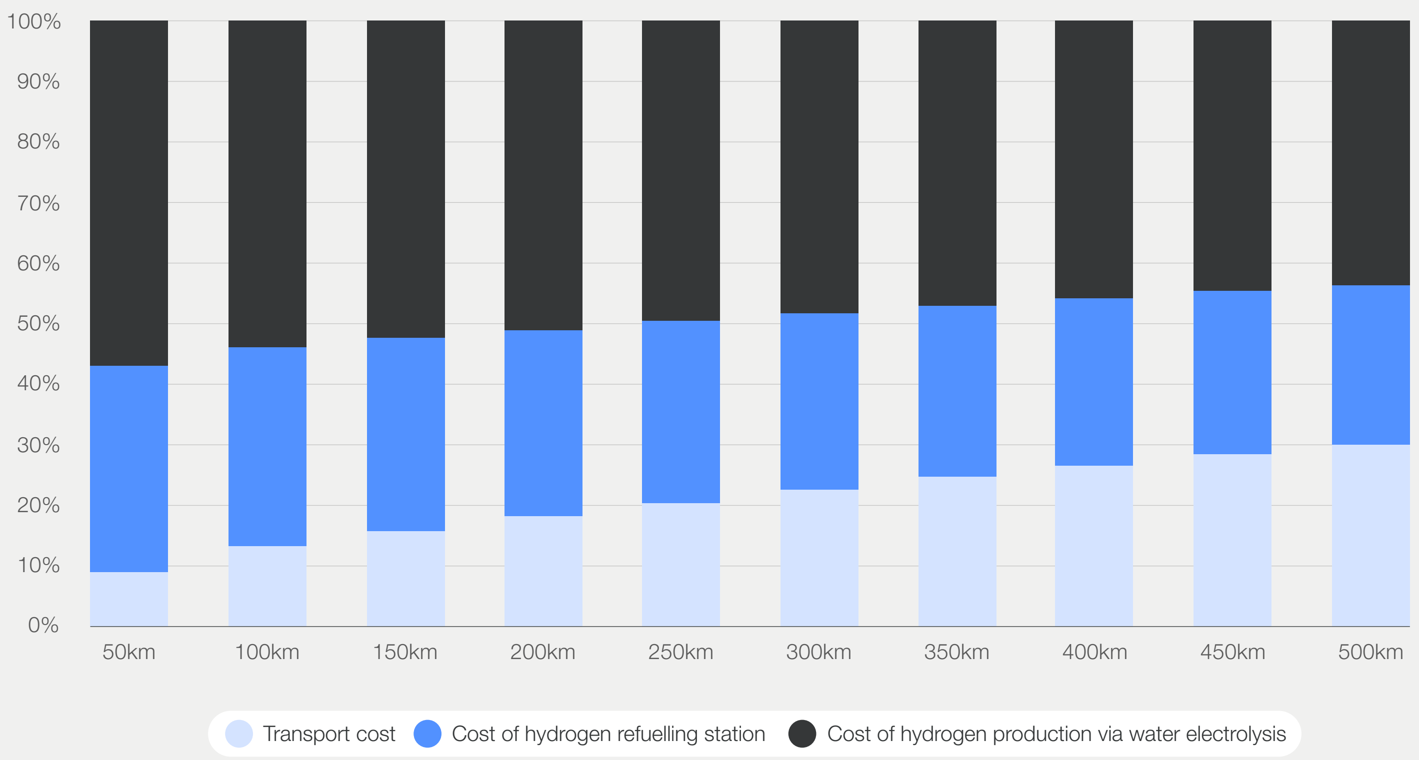
Cost

1.1 Production cost is a core constraint in scaling up green hydrogen

The cost components of green hydrogen can be broken down into production, transportation and refuelling stations. Of these, it is the production process that embodies the highest cost and presents one of the principal challenges on the supply side.

Green hydrogen is produced from electrolysis of water powered by renewable energy. Production of this type of hydrogen currently costs CNY 33.9-42.9/kg ($4.92-6.23/kg),[6] assuming that production runs at full load for 7,500 hours annually and electricity prices average CNY 0.5/kWh ($0.07). As shown in Figure 7, even taking into account the fluctuating price of raw materials, the production cost of green hydrogen is on average at least three times that of coal-produced hydrogen (CNY 6.8-12.1/kg, $0.99-1.76),[7] and considerably more than hydrogen produced by either natural gas (CNY 7.5-24.3/kg, $1.09-3.53) or as an industrial by-product (CNY 9.3-22.4/kg, $1.35-3.25).

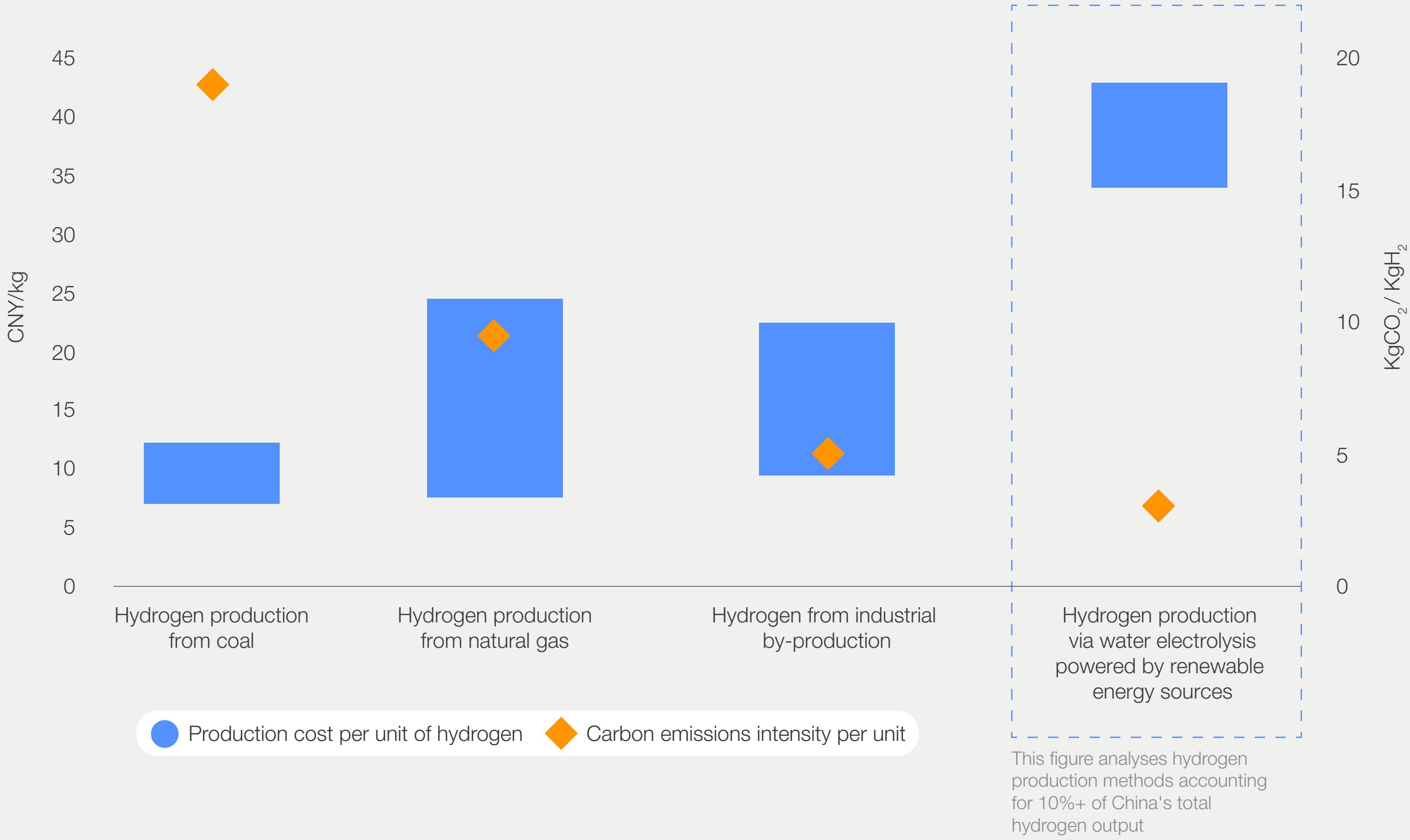
FIGURE 6 **Cost composition of green hydrogen, by transport distance**



Notes: 1. Transport cost is calculated at 20 megapascal (MPa) for different transport distances. 2. Cost of hydrogen production via electrolysis is calculated using the alkaline electrolyser method for a production size of 1,000 Normal cubic metre per hour (Nm3/h), year-round operation time of 2,000 hours, electricity consumption of 5 kilowatt-hour (kWh) for 1 Nm3 of hydrogen produced, and photovoltaic electricity price of CNY 0.3/kWh. 3. Cost calculation includes the annual depreciation and amortization of operating and investment costs.

Source: Literature review and Accenture analysis.

FIGURE 7 | **Cost and carbon emissions intensity of hydrogen, by production method (fossil fuels vs renewables)**



Source: EV100_Plus, Accenture analysis.

> **Green hydrogen in China costs on average at least three times more to produce per kg than coal-produced hydrogen.**

> **China's net-zero goals are not only aimed at reducing emissions, they are also important in reducing reliance on fossil fuels.**

The competitiveness of green hydrogen is undermined not only by lower-cost grey hydrogen produced from fossil fuels or as an industrial by-product, but also by blue hydrogen, whose production is accompanied by emissions reduction through carbon capture, utilization and storage (CCUS).

Given that green hydrogen is better aligned with low-carbon pathways over the long term than either grey or blue hydrogen, it is imperative to drive down the price of green hydrogen production to make it more cost-effective for commercial use.

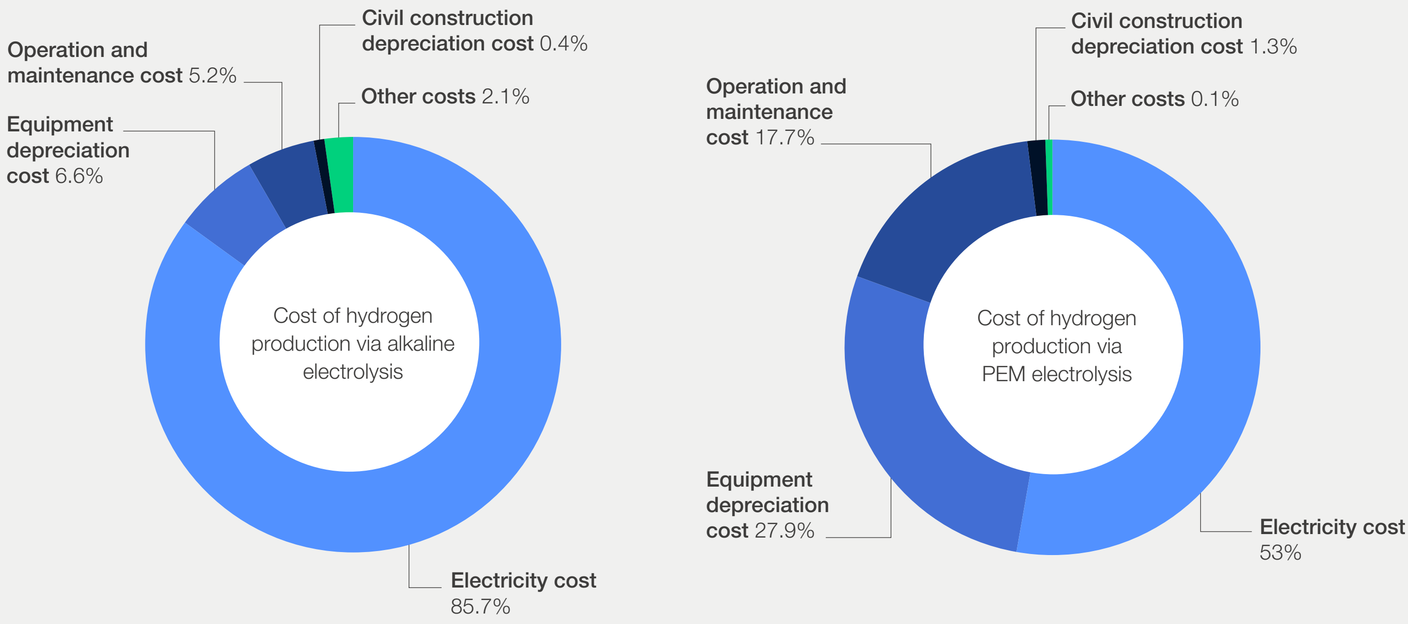
In addition to the climate benefits of green hydrogen, two other compelling reasons exist for investing in scaling up this technology.

First, China's net-zero goals are not only aimed at reducing emissions, they also aim to guarantee future energy security by diversifying the structure of the country's energy mix away from its reliance on fossil fuels. While blue hydrogen can play a short-term role in the transition towards cleaner energy, its production methods still use fossil fuels and CCUS. By contrast, green hydrogen meets China's goal of constantly increasing the proportion of non-fossil energy consumption[8] and offers a reliable replacement for import-dependent oil and natural gas resources.

Second, CCUS technology is not yet well-established and has not been widely promoted across China, except for a few demonstration projects. There are also questions around carbon capture rates in the blue hydrogen production process.

There are currently two viable electrolysis processes for green hydrogen production: alkaline electrolysis and proton exchange membrane (PEM) electrolysis. Chapter 6 explores the comparative advantages of each technology in more detail. For now, the main point to note is that while each technology is at a different stage of commercial development and scale, one thing is in common: very high usage of electricity (see Figure 9). The costs of electricity and electrolytic cells represent the two largest costs for both types of technology.

FIGURE 8 | Cost structure of green hydrogen production (alkaline vs PEM electrolysis)



Note: Hydrogen production via alkaline electrolysis is calculated against a production size of 1,000 Nm3/h, with an electrolyser cost of CNY 2,500/kW; Hydrogen production via PEM electrolysis is calculated against a production size of 200 Nm3/h, with an electrolyser cost of CNY 14,000/kW.

Source: EV100_Plus, Accenture analysis.

Key objectives under this goal

- Reduce the cost of electricity in the green hydrogen production process.
- Reduce the cost of electrolysers.

1.2 Enabling measures for reducing cost

Implement centralized demonstration projects for hydrogen production from renewables in areas rich in such resources

Supported by large wind and photovoltaic power generation bases,[9] centralized projects for hydrogen production using renewable energy can open up access to large-scale, low-cost renewable energy, thus bringing down costs. When the price of renewable energy drops to below CNY 0.15/kWh ($0.02) – compared to the current average of CNY 0.5/kWh ($0.07) – the cost of green hydrogen production can be reduced to less than CNY 15/kg ($2.18) in the existing technology context, making it economically viable.[10]

Formulate policies on special electricity rates for green hydrogen projects

With supportive policies in place to reduce electricity rates, low-cost green hydrogen can become an option for urban clusters currently limited by a lack of local hydrogen sources and costly hydrogen storage and transport. For example, to build itself rapidly into "a metropolis of green hydrogen", Chengdu priced electricity at CNY 0.15-0.20/kWh for green-powered hydrogen production projects across the city.[11] The city of Shenzhen has also introduced supportive policy measures, such as providing cheaper power for hydrogen production during trough hours.

Optimize electricity markets to scale up green electricity trading

China should explore how market mechanisms can optimize cross-regional hydrogen production. The challenge arises because the infrastructure to transport hydrogen by pipeline from where it is produced to where it is consumed is very expensive. The solution is to produce green hydrogen in locations where its consumption is the highest, which in turn means transmitting renewable power to those production sites. For example, the north of China generates a lot of renewable electricity but has less demand for green hydrogen; meanwhile, in eastern and central regions of China, the opposite is the case. Green electricity trading can encourage the transfer of green power from the regions where it is generated to the industrial centres that need it to produce green hydrogen. Doing this requires implementing large-scale green electricity trading and improvements to trading mechanisms.

Subsidize the manufacture of green hydrogen equipment

Subsidies for the R&D of new green production equipment will speed up the development of green hydrogen installations and bring down the costs of investment in green hydrogen projects and facilities.

Lay down a tax credit policy for green hydrogen

A tax credit policy dedicated to green hydrogen would drive down the costs of investment in new projects. China can learn from the Inflation Reduction Act adopted by the US Congress in 2022, which contains the world's first clean hydrogen tax credit policy.[12] This new regulation offers both an investment tax credit, which can cover part of the upfront cost of constructing new facilities for clean hydrogen production, and a production tax credit (based on the output of clean hydrogen).[13]

Develop efficient high-powered alkaline electrolysers to reduce the capital expenditure

The electrolytic bath or electrolyser is a key device to produce green hydrogen. However, the process of scaling up green hydrogen development is hampered by the technology and cost of electrolysers. Technology for the alkaline electrolyser, which forms the basis for most hydrogen production in China, has already been localized, bringing its price down to less than CNY 3,000/kW ($436) compared to the original cost of CNY 6,000-8,000/kW ($872-1,163) when using imported technology. The costs of land and equipment used in hydrogen production will be further reduced as smaller eletrolysers with larger output are rolled out.

CASE STUDY

China Huaneng Group – a leader in large-scale, high-efficiency electrolysers

China Huaneng Group is one of the five major power generators in China. In 2005, the group built a dedicated laboratory for hydrogen and fuel cell technology as a supporting platform for R&D into new technologies. During the 14th Five-Year Plan period (2021-2025), Huaneng plans to build five to eight green hydrogen industrial parks to promote the application of efficient, large-scale facilities for electrolytic hydrogen production. It also plans to develop and demonstrate new electrolytic hydrogen production technologies using intermittent renewable energy sources.

As one of the key hydrogen projects under Huaneng's 14th Five-Year Plan, the innovative Pengzhou project to produce hydrogen via electrolysis is a vital component in Chengdu's quest to build itself into a model metropolis for the green hydrogen sector. It is also the first large-scale project for hydrogen production via electrolysis in southwest China.

Goal 2

Infrastructure

2.1 Underdeveloped infrastructure restricts availability of green hydrogen

Hydrogen infrastructure includes hydrogen production stations, storage and transportation facilities, and refuelling stations along the supply chain. However, research conducted for this report reveals a common perception that underdeveloped hydrogen infrastructure in China has hindered the availability of hydrogen, especially green hydrogen.

Under the Chinese regulatory framework, hydrogen is classified as both an energy source and a hazardous industrial chemical, making it harder to develop the necessary infrastructure. For the time being, only local regulations apply on the construction of hydrogen infrastructure – and the review, approval and acceptance procedures vary greatly, as does the competence of local authorities in this specialized area. It is common practice to manage hydrogen in accordance with its dual attributes of "energy" and "hazard". However, as it is treated as a hazardous chemical, hydrogen infrastructure of any kind is legally required to be situated in a chemical industry park and must secure the necessary licences for hazardous chemical production and operation.

As chemical industry parks are mostly located in sparsely populated suburbs, hydrogen projects risk being located far away from their end-consumers. In fact, most existing HRSs depend on offsite hydrogen supply. Remote storage and long-distance transportation add to the invisible cost of hydrogen and create potential traffic hazards, hampering the promotion and application of green hydrogen. Ideally, hydrogen refuelling stations (HRSs) would have their own onsite hydrogen production facilities. However, as noted above, this would require the complicated process of designating the land as "industrial" to permit production, as well as "commercial" to permit the sale of hydrogen.[14]

Furthermore, the management of hydrogen as both energy source and hazardous chemical requires separate review, approval and inspection processes and regulations, which dampens the enthusiasm of anyone looking to construct hydrogen infrastructure. To build a hydrogen refuelling station, for example, the review and approval process examines issues related to land use, project establishment, planning, construction, installation and acceptance. To add to the complexity, the regulations governing reviews and approvals differ from one local government to another and even from one department to another. After a project is accepted, stations in different places will be subject to different regulations governing their operation. Some regions require station owners to have two licences (the Hazardous Chemical Business Licence and the Hydrogen Cylinder Refuelling Licence), while other regions refer to the operating rules governing natural gas filling stations.[15]

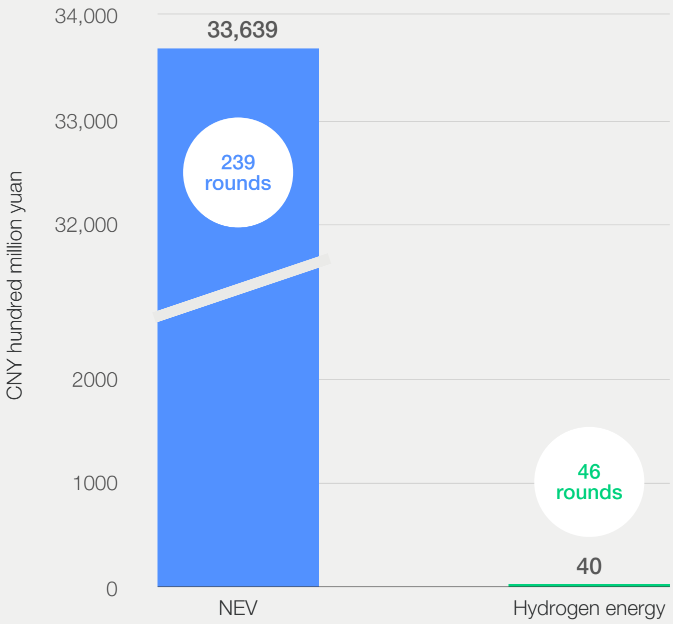
In 2021, investment in the hydrogen sector totalled just $578 million, compared to $489 billion of investment into the new energy vehicle sector.

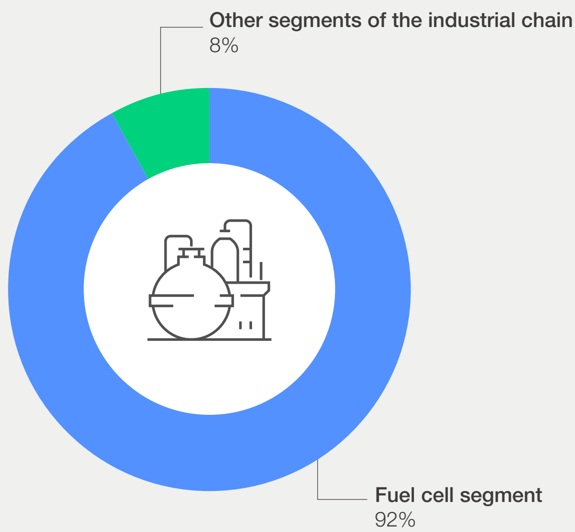
Another obstacle to hydrogen infrastructure construction is the high investment cost, along with the limited channels available to raise finance. Capital investment in the facility building alone incurs high costs. An average investment of CNY 12-15 million ($1.7-2.2 million), excluding the land cost, is expected for a fixed 35 MPa (megapascal) HRS with a daily refuelling capacity of 500 kg, or CNY 20 million ($2.9 million) for a station with a capacity of 1,000 kg (three times the cost of an equivalent conventional filling station).[16] The infrastructure to bring the hydrogen to the refuelling station would also need investment, estimated to be about CNY 4-6 million/km ($580,000-870,000), which is 2-3 times the cost of a natural gas pipeline.[17]

Financing channels for hydrogen infrastructure are also limited. The industrial supply chain for hydrogen is long and China's hydrogen sector is only at the initial stage of commercialization, so it is hard for a single enterprise to possess the technology and capital required for a sectoral transition to clean hydrogen. The overall financing available to the hydrogen industry remains small. In 2021, the new energy vehicle (NEV) sector witnessed 239 rounds of financing for electric vehicles,[18] with a total capitalization of CNY 3,363 billion ($489 billion). By contrast, the hydrogen sector recorded just 46 rounds of financing totalling CNY 3.98 billion ($578 million) – one-thousandth the scale of investment in the NEV sector.

At the same time, the majority of the investment in the hydrogen sector goes into developing hydrogen fuel cells, leaving other segments of the hydrogen industry with even less finance (see Figure 10).

FIGURE 9 **Distribution of investment capital across China's hydrogen energy sector, 2022 (Q1-2)**





Source: EV100_Plus, Accenture analysis.

Key objectives under this goal

- Establish unified regulatory standards and procedures.
- Reduce the cost of infrastructure investment and expand financing channels.

2.2 Enabling measures for infrastructure

Develop a system for hydrogen administration and designate the competent authorities

The government's *Medium- and Long-Term Plan for the Development of the Hydrogen Energy Industry (2021-2035)* defines, for the first time, the strategic importance of hydrogen as an energy source within China's wider national development policy. This is of great benefit in easing the development of China's hydrogen sector. On this basis, local governments should be able to designate the competent authorities; appoint administrative functions to take charge of the production, storage, transport and industrial applications of hydrogen; refine the relevant management rules, laws and regulations; and optimize the corresponding business environment.

Guangdong province has blazed a trail as the province with the greatest number of hydrogen refuelling stations. In 2018, it published the *Opinions on Accelerating the Innovation and Development of the NEV Industry*, which stipulated that the provincial bureau of housing and urban-rural development would be responsible for the "management system and construction standards for the design, construction and operation of hydrogen refuelling stations". The document also identified the scope of official duties, the review and approval procedures, and the relevant roles for the authorities administering land, planning, development and reform, fire service, work safety supervision, environmental protection, civil air defence and other government departments, and has greatly contributed to the construction and adoption of HRSs in Guangdong.

Accelerate formulation of unified national approval procedures and management standards

A unified national approval and acceptance process, along with a set of management standards for hydrogen infrastructure, is needed to address existing disparities in local policy and ensure the orderly development of the green hydrogen industry. Nationally agreed procedures will simplify approvals for refuelling stations and advance the overall planning of trans-regional, long-distance and large-scale infrastructure, such as hydrogen pipelines.

Encourage local pilot efforts to deregulate hydrogen production and refuelling in non-chemical industry parks

In October 2022, Guangdong's bureau of housing and urban-rural development published the *Interim Administrative Measures of Guangdong Province for Hydrogen Refuelling Stations Serving Fuel Cell Vehicles*, which allow the construction of stations that integrate hydrogen production and refuelling facilities in non-chemical industry parks. Other regions have followed suit in order to speed up the construction of hydrogen infrastructure.[19]

Given that it will take time for national policies to come into being, in the short term, local governments should be encouraged to pilot their own policy measures, "loosening" policy restrictions step by step in a way that ensures safety while allowing the clean energy capacity of hydrogen to fulfil its potential.

Accelerate technological breakthroughs in hydrogen storage and transport, as well as domestic production of key components for refuelling stations

Hydrogen is usually stored and transported in liquid or gaseous forms. Moving hydrogen as a high-pressure gas will remain the dominant means of transport in China over the short to medium term. However, the pressure levels at which gaseous hydrogen is stored and transported in China are far below global standards. For example, the typical hydrogen transportation capacity for a Chinese vehicle is about 260-460 kg, compared to 1,000-1,500 kg per vehicle in other parts of the world. China urgently needs innovation in technology, materials and processes in order to increase the gaseous hydrogen storage pressure in cylinders.

At the same time, it would be prudent to pursue pilot projects in hydrogen transport pipelines, combined with a variety of different storage and transport options, for instance low-temperature liquid state, solid state, cryogenic and high-pressure state, and organic liquid state.

In respect of refuelling stations, China needs to accelerate its proprietary R&D to enable the domestic production of core installations and key components of HRSs, such as compressors and gas fillers, so as to reduce the infrastructure cost.

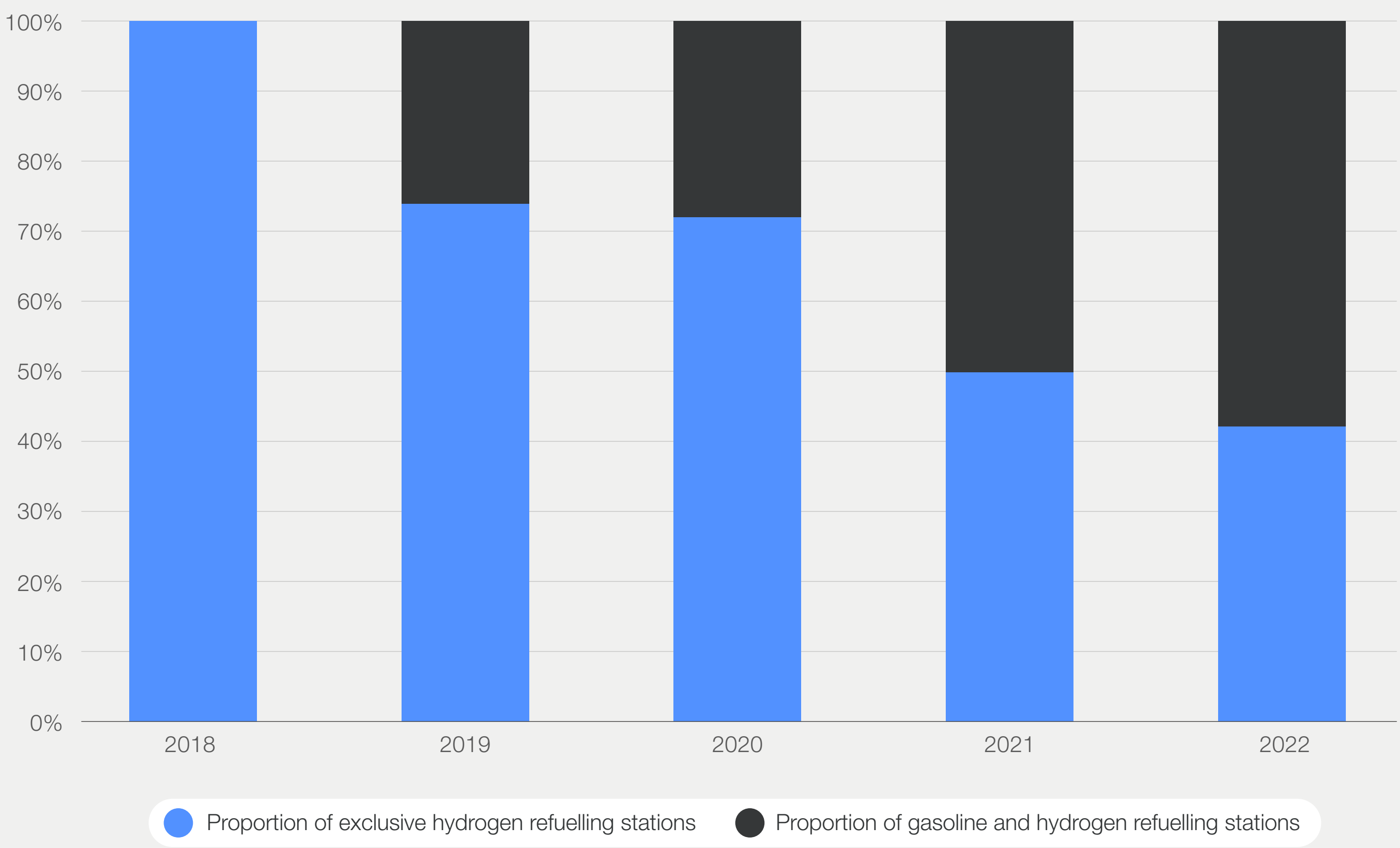
Promote the construction of integrated hydrogen production and refuelling stations

The storage and transport infrastructure necessary for a large-scale hydrogen industry is unlikely to be implemented in the short term, given the constraints of both technology and cost. At this point, the most effective solution is to integrate hydrogen production and refuelling infrastructure in single locations. This approach saves trailer transport and time spent loading and unloading, reducing transport costs and transit safety risk. These factors will in turn help cut the cost of hydrogen for end-users as well as eliminate the risk of transporting hydrogen by road.

Advocate for the conversion of traditional filling stations into mixed fossil fuel and hydrogen refuelling stations

One of the most effective ways to rapidly install hydrogen refuelling stations is to build HRSs alongside existing traditional (i.e. fossil fuel) filling stations. Traditional filling stations in China have the potential to be converted into mixed fossil fuel and hydrogen refuelling stations. This dodges the problems involved in the construction of a new HRS, such as land planning and administrative approval and acceptance. Meanwhile, since the large-scale promotion of fuel cell vehicles (FCVs) has led to decrease in the number of petrol- and diesel-powered vehicles, the modification of filling stations into HRSs can revitalize the assets of these filling stations and improve land-use efficiency.

FIGURE 10 **Proportion of filling stations that offer hydrogen exclusively compared to stations that offer both hydrogen and fossil fuels**



Source: Blue Book on the Development of China's Hydrogen Refuelling Station Industry, 2022; Accenture analysis.

Figure 11 demonstrates that, out of the total number of fuel stations with the capability of hydrogen refuelling, the proportion of stations that offer exclusively hydrogen compared to stations that offer both hydrogen and fossil fuels has risen from 0% in 2018 to nearly 60% today. In 2021, the State-owned Assets Supervision and Administration Commission of the State Council issued the *Guidance on Promoting the Quality Development of Central Enterprises to Achieve Carbon Peaking and Carbon Neutrality*, explicitly encouraging conventional filling stations to build integrated transport and energy service stations that cater to vehicles powered by petrol, diesel, electricity or hydrogen.

“ Traditional filling stations in China have the potential to be converted into mixed fossil fuel and hydrogen refuelling stations.

Provide more support for hydrogen infrastructure via financial instruments

Taking into consideration the characteristics and structure of the hydrogen industry, the demand for capital to build HRSs and hydrogen transport pipelines can be fulfilled through, for example, green bonds, syndicated loans and financial leasing, coupled with market mechanisms that the government has introduced to promote reduction in carbon emissions. Other financial instruments that can be introduced include special green credit channels for core enterprises in the hydrogen supply chain, innovative intellectual property pledge loans,[20] and investment-loan linkage mechanisms for hydrogen.

Accelerate the incorporation of the complete green hydrogen supply chain into green finance standards

In July 2020, the European Union published the EU taxonomy for sustainable activities, which encompasses and classifies the entire green hydrogen supply chain, including the manufacture of hydrogen production and utilization equipment, and hydrogen storage for power generation.[21] China can draw on the EU taxonomy – as well as additional documentation on green finance standards, such as the *Catalogue of Guidance on Green Industries* (2019) and the *Catalogue of Green Bond-Supported Projects* (2021) – to speed up the creation of its own taxonomy for the hydrogen industry, allowing it to incorporate projects from the full hydrogen supply chain in its catalogue of green finance standards.

CASE STUDY

China Energy builds the first complete supply-chain project for green hydrogen

As one of the country's top five power generators, China Energy Investment Corporation (China Energy) facilitated the inception of the China Hydrogen Alliance in 2018 and the Hydrogen Energy Technology Company in 2019. As part of this ambitious expansion into the hydrogen sector, in September 2022, a subsidiary of China Energy started the construction of a 620-megawatt (MW) solar photovoltaic power project in the Ningdong Energy and Chemical Industry Base. The Ningdong base, located in the small autonomous region of Ningxia in north-central China, is a demonstration zone for carbon emissions reduction technology using renewables-based hydrogen – the first of its kind in the region.

The project consists of an electrolysis plant to produce green hydrogen, a solar power plant that supplies the renewable energy needed to power the electrolysers, a series of hydrogen refuelling stations (HRSs) and, finally, hydrogen-powered heavy trucks that use the hydrogen thus produced. The infrastructure is expected to be completed and put into operation by the end of 2023, featuring 100% green hydrogen production and application. Some of the green hydrogen produced will be supplied to the coal-to-oil project of Ningxia Coal Industry Company as an alternative energy source, and the rest will go to HRSs to refuel hydrogen-powered heavy trucks for transporting coal between distant thermal power plants and coal mines.

The ultimate project plan is to build a centralized photovoltaic power station of 4,000 MW and an off-grid photovoltaic DC system of 960 MW, equipped with facilities for hydrogen production via electrolysis with an annual output of around 30,000 tons, plus more than 20 HRSs.

On completion, the project will be the largest green hydrogen production and consumption base in China, supporting operations along the whole hydrogen supply chain, including hydrogen production powered by renewable energy, green hydrogen use in the coal-chemical industry, hydrogen storage and transport, hydrogen refuelling, and hydrogen-powered vehicles. The Ningdong project will serve as a model for reducing carbon emissions using green hydrogen.

Goal 3 Market demand

3.1 China's new markets for green hydrogen need policy support to reach their potential

Hydrogen fuel cells offer an ideal solution to power long-haul, heavy-duty commercial vehicles along fixed routes.

At present, green hydrogen accounts for less than 0.1% of total hydrogen consumption in China. Constraints on growth include the cost and technology associated with production, storage and transportation. However, to develop green hydrogen into a large-scale industry, a breakthrough purely on the supply side is not enough – China needs to develop more demand-side opportunities.

Hydrogen has a wide range of applications as a secondary or alternative energy source, for example in the transport, manufacture, utilities and construction industries.

In the transport sector, for instance, where electric propulsion is unsuitable for long-haul and heavy-duty commercial trucking due to the weight of batteries, their limited endurance capacity and the time taken to recharge, hydrogen offers an appropriate alternative. Hydrogen fuel cells – with their high energy density, low kerb weight, fast refuelling and resistance to low temperatures – offer an ideal solution to power long-haul, heavy-duty commercial vehicles along fixed routes.

In China, the transport sector is currently the key end-user of green hydrogen. The technology offers an important decarbonization solution for transport, which, unlike other sectors such as manufacturing, is relatively price-insensitive on the demand side. As of 2021, a total of 9,000 hydrogen fuel cell vehicles (HFCVs) plied on Chinese roads, with sales that year running to just 1,596 units,[22] not enough to support large-scale industrial application or charging facilities. However, with the cost of hydrogen fuel cells predicted to fall, the technology is likely to become more popular. Meanwhile, hydrogen is being piloted in other transport sectors such as aviation and shipping, though its commercialization remains a long-term goal.

Hydrogen offers significant decarbonization opportunities for manufacturing industries – especially iron-and-steel production, which emits between one and three tons of CO_2 for every ton of metal produced. China is the world's largest producer and consumer of iron and steel. Confronted with such high carbon emissions, along with ambitious decarbonization goals, the country has an urgent task to reshape this industry along a new, low-carbon pathway. Hydrogen can replace coking coal as a combustion fuel in the iron-ore smelting process, resulting in H_2O as a by-product instead of CO_2. Currently the main source of hydrogen is coke oven gas,[23] but as the cost of producing green hydrogen falls, it is expected to become one of the key solutions for reducing carbon emissions in many more industrial applications.

Hydrogen also plays a key role in the chemicals industry. It is an important raw material in ammonia synthesis, methanol synthesis, petroleum refining and the coal chemical industry. In view of the cost, the hydrogen used in China's chemicals sector is mostly produced through conventional pathways such as natural gas reforming and coal gasification. However, the constant decline in costs all along China's green hydrogen supply chain and the emerging interest in zero-carbon industrial solutions suggest that the use of green hydrogen will keep rising in the chemicals sector.

Specific application scenarios for hydrogen in the utilities and construction sectors include HES (hydrogen energy storage) and HCNG (hydrogen-enriched compressed natural gas). HES technology takes advantage of fluctuating electricity generation. When electrical power is abundant, hydrogen is produced via electrolysis to convert intermittent fluctuations and surplus electric energy into hydrogen for storage. When electrical output from other sources is insufficient, hydrogen is converted back into electricity using fuel cells or other power generation facilities and fed back into the grid.

Compared with a variety of other energy storage technologies, HES is suitable for large-scale, long-cycle energy storage. According to the China Electricity Council, by the end of 2021, the country's installed energy storage capacity had reached 42.66 GW, of which the installed capacity of new-type energy storage was 6.27 GW,[24] accounting for less than 15% of the total. Of this new-type energy storage, 90% is in the form of electrochemical energy storage. In China, hydrogen storage is still a newcomer and generating projects with high profits is not yet feasible – so the wide-scale use of green hydrogen as a means of storing energy remains a long-term goal.

HCNG, a mixture of hydrogen and compressed natural gas (CNG) in varying proportions, is used as an alternative to natural gas and transmitted through existing natural gas pipelines. HCNG can improve engine combustion efficiency and reduce oxynitride pollution and CO_2 emissions. In China, however, HCNG faces multiple challenges, such as lack of technological advances, high cost and the absence of a decarbonization effect. Its popularization will therefore take time.

FIGURE 11 | **Comparison of major technology pathways to energy storage in China**

		Mechanical energy storage	Large-scale energy storage by peak cutting and trough filling	Thermal energy storage	Electromagnetic energy storage	Chemical energy storage
Form of application		Pumped storage Compressed air energy storage Flywheel energy storage	Battery energy storage*	Molten salt storage	Superconducting energy storage Supercapacitor energy storage	Hydrogen energy storage Natural gas energy storage
Technological maturity		High	High	Medium	Low	Low
Performance	**Energy storage capacity**	Gigawatt level	Kilowatt to megawatt level	Megawatt level	Kilowatt to megawatt level	Megawatt to gigawatt level
	Energy density	Low	High	Moderate	Low	Very high
	Energy storage efficiency	70%-85%	60%-95%	50%-90%	80%-98%	30%-80%
	Energy storage cycle	Months-long	Weeks-long	Weeks-long	Days-long	Year-long
	Response time	Seconds to minutes	Hundred milliseconds	Weeks to hours	Milliseconds	Minutes
	Life span	30-60 years	2 years	30 years	100,000 times, 30 years	10,000 hours
	Cost	CNY 1,000-6,000/kW	CNY 2,000-3,000/kW	CNY 500-4,000/kW	/	CNY 20,000-50,000/kW
Advantages		Technological maturity Large power and energy capacity Long life span Low operating cost	Technological maturity Fast response High construction flexibility	High thermal storage volume	Fast response Long life span	High storage energy volume Long storage cycle
Disadvantages		Slow response High requirements for infrastructure	High cost Occasional heating problems	High thermal storage volume Limited application scenarios	Low energy density High investment cost Inherent self-discharge loss	Low efficiencyHigh cost High requirements for infrastructure
Applicable scenarios		Large-scale energy storage by peak cutting and trough filling	Peak load and frequency regulation	Peak load regulation, direct use of thermal energy	/	Large-scale, long-cycle energy storage

Source: Public data, Accenture analysis.

Key objectives under this goal

- Boost short-term market demand for hydrogen fuel cell vehicles (HFCVs).
- Create multiple end-use application scenarios to drive the large-scale adoption of hydrogen technology.

3.2 Enabling measures to create market demand

Accelerate domestic development of hydrogen fuel cell technology and high-pressure hydrogen storage systems

While a large proportion of the HFCV engine system can be made locally in China, some of its hydrogen cell materials (e.g. catalyst, carbon paper and high-strength carbon fibre) are still dependent on imports. In addition, high-pressure hydrogen storage technology – necessary to penetrate the long-haul commercial vehicle market – remains a bottleneck for China's FCVs.

China urgently needs to make progress in cylinder manufacturing technology – the lower-pressure 35 MPa Type III cylinder still dominates, while the more attractive Type IV hydrogen cylinder is still at the R&D stage. China is also heavily dependent on the import of cylinder valves, which hinders the localization of high-pressure hydrogen storage technology. As such, it is important that both upstream and downstream suppliers work together to develop alternatives. They should also consider partnering with high-performing foreign companies for joint innovation.

Step up policy support by granting rights of way to HFCVs

In China, central and local governments have issued development goals and supportive policies to promote the widespread application of hydrogen-fuelled vehicles (see Figure 12). However, most of the policies focus on subsidies for vehicle purchase, operation and maintenance, rather than on granting rights of way. Many large cities in China have strict regulations on the routes and times of day permitted for the circulation of large transportation vehicles. Opening up these rights of way would greatly incentivize enterprises to purchase and use hydrogen-powered vehicles, and upcoming policy is expected to do so. Specifically, it should allow reasonable times of day to permit their commercial operations and reduce constraints on road access and drive timings.

Strengthen public procurement of HFCVs

In September 2020, the Chinese government announced incentives for "demonstration cities" to invest in HFCVs.[25] Cities have responded to the call with the public procurement of hydrogen-fuelled buses. However, the volume of such purchases remains small, since detailed information on the incentives has not yet been released, while the price paid so far is low – sometimes not even enough to cover the production costs of the manufacturer. To boost the HFCV market, state-level guidance should be put in place, with detailed incentives developed and disclosed. Local governments should cooperate and encourage related industries to achieve economies of scale, so as to drive market demand and bring down HFCV prices.

Boost the development of green hydrogen and its applications in industrial production, such as manufacture of iron and steel

Fostering the green hydrogen chemical industry and hydrogen metallurgy technologies would further boost the green hydrogen sector while enabling industries such as iron and steel to decarbonize. In hydrogen metallurgy, it is difficult to replace the existing coke-powered blast furnace-basic oxygen furnace (BF-BOF) process with a green hydrogen application. Further technological advances are necessary, and China's supply-side reforms since 2015 have helped. In view of its industrial development stage, China should, in the short term, focus on the promotion and application of hydrogen-based, green chemical and metallurgical processes across sites with the capacity to transition incrementally.

Explore the coupling of green hydrogen and carbon markets to accelerate the replacement of grey hydrogen across big industrial emitters

China initiated its national cap-and-trade system (national carbon market) in 2021, encompassing 2,225 key emitters in the power generation sector. The system aims to expand its coverage to other industries subject to emissions controls – especially the petrochemicals, chemicals, and iron and steel industries – and improve the pricing mechanism. China should develop carbon footprint detection and identification to cover the whole life cycle of hydrogen, and explore ways to combine it with the Chinese Certified Emission Reduction (CCER) system. Furthermore, China should give full play to the price signalling role of the carbon market, quantify the benefits of green hydrogen in emissions reduction and accelerate the restructuring of hydrogen supply, so that green hydrogen can become competitive in various applications.

Promote the integration of green hydrogen storage with intermittent renewable energy sources

As China's energy restructuring progresses, the role of renewables in its electrical power architecture is accelerating. Yet in northwest China, which boasts ample renewable energy sources, renewable energy power stations are not operating to full capacity. Much of the power they generate ends up being wasted because of limited local consumption capacity and the slow construction of transmission infrastructure.

The government should therefore consider the use of green hydrogen in energy storage and peak-load regulation at upstream power stations and grids. It should also consider granting hydrogen producers composite power rates or auxiliary service compensations. In addition, the merits and defects of different technology pathways should be considered when energy storage systems are configured at new-energy power stations, since hydrogen storage could be used to replace electrochemical storage for power stations that need large-scale, long-term energy storage. To accelerate uptake, the government should build demonstration projects for green hydrogen storage.

Build multiple end-use green hydrogen application scenarios, starting with demonstration projects

China should develop feasible green hydrogen schemes for existing scenarios in construction and other sectors, such as HCNG technology in response to natural gas shortage in cities. Pilots and demonstrations set good examples by developing advanced technology pathways and business models, accumulating design, construction and operation capabilities, and generating replicable and extendable project experience for large-scale applications to promote deep decarbonization.

Distribute industrial demonstration projects in line with local conditions, drive the supply chain by clusters, and scale up applications

The government should coordinate its approach to planning with a coherent distribution of demonstration projects based on the supply capacity, industrial base and market demand of each jurisdiction. China should seek to avoid the "bandwagon effect", as already seen in the planning and layout of HFCV projects, which feature inefficiencies such as overlapping infrastructure at multiple sites and vehicle supply that is mismatched with actual transport capacity. Instead, industrial clusters should be encouraged, because they are likely to boost mass production, can more effectively amortize the costs of R&D and production, and hence encourage more investment in the green hydrogen industry.

FIGURE 12 | **Local government support for hydrogen fuel cell vehicles**

Support coverage

Place	Innovation and R&D	Key components	Infrastructure - Hydrogen refuelling stations	Terminal application - Vehicles	Ecology of the industry
Daxing district, Beijing	Reward for innovation platforms Subsidies for R&D on chosen topics and standards	Sourcing subsidies	/	Vehicle purchase subsidies Operation subsidies	Subsidies for incorporation Rent subsidies Financing subsidies Subsidies for exchanges
Daxing district, Beijing and Zibo city, Shandong province	Incentives for the invention of the first set of facilities or components Incentives for outcome commercialization	/	Construction subsidies Operation subsidies	Vehicle purchase subsidies Hydrogen storage and transport	Subsidies for project implementation Investment subsidies
Shanghai	Incentives for outcome commercialization Incentives for R&D according to the point redemption scheme	Incentives for R&D put into production	Construction subsidies Operation subsidies	Incentives for whole-vehicle production Incentives for vehicle operation	/
Fuzhou, Fujian province	Supporting subsidies for scientific research projects R&D subsidies	/	Construction subsidies Operation subsidies	Incentives for vehicle operation Vehicle purchase subsidies Traffic deregulation	“Case-specific deliberation” for major investment projects
Foshan, Guangdong province	/	/	Construction subsidies Operation subsidies	Vehicle purchase subsidies Subsidies for swaps to HFCV Incentives for green operation Subsidies for highway toll Urban traffic right of way	/
Huangpu district, Guangzhou city, Guangdong province	Policy support for certified R&D institutions Policy support for national, provincial and municipal projects	/	Construction subsidies Operation subsidies	/	Support for putting down roots through investment Support for trade associations Support for industrial parks Discount loans

Zhangjiakou, Hebei province	Incentives for innovation platforms Subsidies for R&D of standards Incentives for outcome commercialization	Incentives for R&D put into production	Operation subsidies	Vehicle purchase subsidies Operation subsidies	Support for green hydrogen projects Setting up a comprehensive supervision platform
Zhengzhou, Henan province	Incentives for innovation platforms	Incentives for R&D put into production	Construction subsidies Operation subsidies	Incentives for whole-vehicle R&D and production Operation subsidies	Subsidies for project implementation Discount loans for enterprises
Puyang, Henan province	ncentives for innovation platforms Incentives for intellectual property rights Incentives for invention of first set of facilities or components	/	Construction subsidies	Incentives for vehicle R&D Operation subsidies	Subsidies for enterprises swapping to hydrogen energy “Case-specific deliberation” for major projects

CASE STUDY

"Hydrogen into Households" – A world-class demonstration project

On 16 April 2021, the Ministry of Science and Technology (MOST) and the provincial government of Shandong signed the Framework Agreement on the Joint Implementation of the Science and Technology Demonstration Project for Hydrogen into Households. This made Shandong the first (and so far only) demonstration province for large-scale hydrogen applications.

"Hydrogen into Households" is one of the key R&D programmes under the national 14th Five-Year Plan, and the MOST Hydrogen Energy Technology package sets out details regarding its implementation. It aims to develop hydrogen supply systems by paving the way for the construction of supporting facilities such as hydrogen refuelling stations (HRSs) and boosting hydrogen-related industries.

Over its five-year implementation period (2021-2025), the programme will focus on "building one hydrogen energy highway, two hydrogen energy ports, three popular science bases, four hydrogen energy parks and five hydrogen energy communities". By delivering pure hydrogen through pipelines, it will help demonstrate the viability of hydrogen applications in a variety of scenarios, including industrial parks, community buildings, transport and mobile energy consumption, ports and highways. The project will give birth to China's first hydrogen freeway corridor and first demonstration base for 10,000 sets of integrated hydrogen supply installations.

By 2025, the project's green hydrogen supply capacity is expected to reach 150 tons per day. The fuel cell co-generation system for thermal and electrical energy will cover 12,000 households, and 6,000 hydrogen fuel cell vehicles (HFCVs) will be put into use. Project investment will exceed CNY 10 billion ($1.45 billion), which will help attract a 10-fold investment across the hydrogen industry.

The progress so far includes:

- 29 special policies issued for the hydrogen industry; two national standards, nine local standards and two group standards formulated and released.
- 22 HRSs completed, with the first high-speed HRS in China put into operation.
- 848 FCVs put into use, and over 30 dedicated fuel-cell bus lines put into operation.
- Siting and scheme design work concluded for four green industrial parks featuring zero-carbon hydrogen energy.

Goal 4

Industry standards and certification

4.1 Standard-setting is too slow to support the fast-growing hydrogen industry

Poor communication and slow decision-making have hampered the standardization of the hydrogen supply chain.

Standards play a pivotal role in the development of new technologies, which is why the international community, especially developed economies, are attaching great importance to green hydrogen and hydrogen energy standards. At present, the standardization and certification system for China's hydrogen industry has been established but is not functioning optimally.[26]

China's system for hydrogen standards addresses eight key sub-systems (see Figure 13), as per the China National Institute of Standardization:

1. Foundation and management of hydrogen energy
2. Hydrogen quality
3. Hydrogen safety
4. Hydrogen engineering
5. Hydrogen production and purification
6. Hydrogen storage, transport and refuelling
7. Hydrogen energy applications
8. Hydrogen-related inspection and testing[27]

However, despite the publication of standards covering the whole hydrogen supply chain, gaps remain, especially regarding sub-systems 6 and 7 above. For example, in the case of hydrogen storage, transport and refuelling, although China has recently issued standards such as the *Group Standards for Compressed Hydrogen Storage Cylinders for Vehicles* and the *Technical Specifications for Hydrogen Refuelling Stations*, few technical standards for transport have been established, while the design standards for long-distance hydrogen pipeline transport are yet to be developed. In contrast, the US has established requirements for the design, installation and use of hydrogen piping systems in different application scenarios. Regarding the application of hydrogen, China's standards focus mainly on the technical aspects of HFCVs, while technical standards for other application scenarios are still under planning.

In terms of hierarchy, global best practice divides standards into national and industrial, with industrial standards typically outnumbering national standards. For example, in Japan and the US, the industrial standards for hydrogen outnumber national standards by a ratio of 3 and 4, respectively. The reason is that in both countries, industry standards play the role of supplementing, refining and extending national standards. Although China's hydrogen standards are composed of national, industrial, local and group standards, its industrial standards amount to only one-third the number of national standards, representing an obvious disproportion.

As for the standards setting body, the Standardization Administration of the People's Republic of China (SAC) is responsible for the formulation of China's national standards for hydrogen technology. The corresponding industry standards are established by the relevant government bodies, such as the National Energy Administration (NEA), the Ministry of Industry and Information Technology (MIIT) and the Ministry of Housing and Urban-Rural Development (MoHURD). However, this structure is not best suited for the rapid certification of an emerging industry such as hydrogen that spans many different sectors.

On the one hand, the SAC can only formulate a limited number of national standards every year – with all kinds of standards queuing up for issuance, waiting times are long. On the other hand, the hydrogen sector is an inter-disciplinary, cross-industry technical frontier, with upstream and downstream functions – such as production, storage, transport and application – that are subject to different competent authorities. Some of these functions have multiple administrators, while some technical domains lack clear, competent authorities and standard-setting bodies. As a result, poor communication and slow decision-making have hampered the standardization of the hydrogen supply chain.

FIGURE 13 | China's standards system for hydrogen

Universality ⟷ Creativity

	National standards	Industrial Standards	Local standards	Group standards
Foundation and management	4 items			
Hydrogen quality	6 items			
Hydrogen safety	19 items	4 items		China Industrial Gases Industry Association
Hydrogen engineering	2 items	9 items		
Hydrogen production and purification	9 items	6 items		
Hydrogen storage, transport and refuelling	10 items	2 items	Shanghai, Guangdong, Shandong, etc. are setting local standards	Enterprises engaged in hydrogen energy
Application of hydrogen energy	14 items	1 items		
Hydrogen-related testing	37 items	8 items		
	101 items in total	30 items in total		

Source: Open data, Accenture analysis.

Key objectives under this goal

- Improve the regulatory system for hydrogen by providing better-structured standards.
- Engage multiple stakeholders to develop innovative, high-quality standards.

4.2 Enabling measures for standards and certification

Reflect on the realities and flaws of the hydrogen sector's standards to optimize the standards system

The coverage of technical standards for sub-systems 6 (hydrogen storage, transport and refuelling) and 7 (application of hydrogen) should be extended. In terms of hydrogen infrastructure, it is necessary to accelerate the formulation and revision of standards for hydrogen production from renewable energy sources, the inspection and testing of high-pressure hydrogen storage vessels, solid hydrogen storage, hydrogen liquefaction facilities, liquid hydrogen storage and transport facilities, and key HRS facilities (e.g. hydrogen compressors, hydrogenators, pipe fittings and valves).

As for sub-system 7, relevant standards should be added to the hydrogen energy application field on an ongoing basis to keep up with innovation and expansion, so as to ensure the smooth transition of the hydrogen industry from demonstration level to wide-scale application.

Improve top-level planning and execution of standards, while providing policy support, incentives and publicity to promote standardization

The Chinese government bodies that set standards need to establish more effective top-level planning for creating standards for the hydrogen sector, while clearly identifying the standard-setting organizations responsible for each setting. The government should offer more policy support and incentives for standardization, including financial subsidies, while making standard-setting practices uniform and transparent, so that the entire system of standards can develop at a faster pace. In addition, a publicity campaign should be launched to promote the role of standards among a broader audience.

Pilot local and corporate standards to derive empirical models for promotion and replication

The Chinese authorities must encourage and support local government bodies to pioneer local and group standards, especially in areas not covered by national standards. This could provide a solution to the backlog of national standards.

Encourage industrial alliances, academic societies, enterprises and other organizations to form platforms to cooperate and innovate in standard-setting

Industrial alliances and academic societies – with their access to test data and practical experience – should be mobilized to participate in the development of technical standards for China's hydrogen industry. Enterprises, industry players, academics and standard-setters should cooperate through multistakeholder platforms to facilitate dialogue and work together to develop high-quality standards.

In the US, for example, the American National Standards Institute (ANSI) and the Standards Development Organization (SDO) work together to establish the standardization system for hydrogen technology. ANSI is responsible for the coordination and management of the standardization process and authorizes the establishment of the national standards for hydrogen technology. However, ANSI is not engaged in the formulation of any specific content for the standards, as this falls under the remit of the SDO, which comprises academic societies and industrial alliances.

Academic societies in the US convene international seminars to obtain cutting-edge research that can form the foundation for standard-setting. They blaze a trail for US hydrogen standards to expand overseas. Meanwhile, the country's industrial alliances leverage resources to conduct testing and produce experimental data on a massive scale. Since they are well-attuned to the commercial market, industrial alliances are best placed to garner the latest test results from the industry, keep abreast of its development trends, and set the cornerstones for the hydrogen standard-setting work that is urgently needed.[28]

Cooperate in the formulation of international standards

China's hydrogen enterprises, academic societies and industrial alliances can take the initiative to join the committee of the International Standardization Organization (ISO) to contribute to the formulation of international standards. This may be advantageous in two ways. First, it could enable China to draw on advanced global practices to inform and streamline its hydrogen standard-setting journey. Second, it could speed up the convergence of China's standardization system with international standards, paving the way for technology exchanges and international trade in hydrogen.

Goal 5

Technology

5.1 China has mature alkaline electrolysis technology and is now exploring the new generation of hydrogen production processes

Electrolysis is considered the hydrogen-producing technology with the most potential. It produces highly purified hydrogen and works well in combination with renewable energy. It therefore enjoys brighter prospects than other types of hydrogen technology, such as those using nuclear energy or photocatalysis (technologies still at the laboratory stage). The electrolysis process relies on electrolysers, of which three types are currently in use: alkaline (ALK), proton exchange membrane (PEM) and solid oxide electrolyser cell (SOEC).

ALK electrolysis is cheaper than PEM or SOEC. As a mature technology with a high output per electrolyser, ALK is used mainly to generate hydrogen by using electricity from the grid. The equipment is comparatively cost-efficient because it can be manufactured domestically, its key performance indicators are close to world-class standards, and a complete supply chain is in place and in good shape. However, ALK requires a stable power supply, so although it is the preferred method for producing green hydrogen, the efficiency of the process suffers when renewable power supplies fluctuate. To maintain its status as a core hydrogen production technology, ALK players need to further lower their costs and ensure their technology is compatible with renewable energy systems at a large scale.

PEM electrolysis outshines ALK in operational flexibility and reaction efficiency. It is able to maintain a standby mode at minimum power levels and is well suited to the high volatility and intermittency of wind and photovoltaic power. As a result, PEM is more suitable for a future electrical power mix that depends on renewable energy, and the technology is expected to be developed and commercialized rapidly. However, China must catch up with world-leaders in PEM, in terms of technology maturity, device scale, service life and cost-effectiveness. China depends largely on imports of key components for its domestic PEM electrolytic tanks, including the principal raw materials for the proton exchange membrane and precious metal catalyst materials, such as iridium and titanium-based materials. To secure PEM's future development, China must substitute imports with domestic alternatives all along the supply chain.

As for SOEC electrolysis, its power consumption is less than that of ALK and PEM because it recovers waste heat arising from high-temperature industrial processes. Consequently, the technology is more suited to operate in conjunction with photothermal power systems that generate high-temperature, high-pressure steam.[29] In China, the experience with SOEC electrolysers is currently limited to laboratory-scale demonstrations.

FIGURE 14 | Performance characteristics of China's three approaches to hydrogen production by electrolysis

	Alkaline	Proton exchange membrane	Solid oxide electrolyser cell
Technology maturity	Large-scale application	Small-scale application	Early commercial stage
Operating temperature	70-90°C	70-80°C	70-90°C
Current density	0.2-0.4 A/cm2 (Ampere per centimetre squared)	1.0-2.0 A/cm2	1.0-10.0 A/cm2
Hydrogen production per set	0.5-1000 Nm3/h (Normal metre cubed per hour)	0.01-500 Nm3/h	/
Energy consumption of electrolyser	4.5-5.5 kWh/Nm3 (Kilowatt-hour per normal metre cubed)	3.8-5.0 kWh/Nm3	2.6-3.6 kWh/Nm3
Conversion efficiency of system	60-75%	70-90%	85-100%
Lifetime of system	10-20 years	10-20 years	/
Start-stop (SS) speed	Hot SS: minute level Cold SS: >60 minutes	Hot SS: second level Cold SS: 5 minutes	SS: slow
Dynamic responseability	Stronger	Strong	Weaker
Power quality requirement	Stable power supply	Stable or fluctuating power supply	Stable power supply
Range of load regulation	15-100% rated load	0-160% rated load	/
System operation and maintenance (OM)	Complex and high-cost OM as corrosive liquid is involved in the operation	Simple and low-cost OM as non-corrosive liquid is involved in the operation	Currently focused on technical research, without OM demand
Floor area	Larger	Smaller	/
Price of electrolyser	CNY 2,000-3,000/kW (made in China) CNY 6,000-8,000/kW (imported)	CNY 7,000-12,000/kW	/
Blend with renewable energy sources	Applicable to power systems with stable power supply and large-scale installed capacity	Applicable to power generation systems using renewable energy sources with fluctuations	Applicable to photothermal power generation systems discharging high-temperature, high-pressure steam

Key objective under this goal

– Step up proprietary R&D across the supply chain to further adapt electrolysis technology to renewable energy sources.

5.2 Enabling measures for technology

Enhance the rapid response capacity of the ALK hydrogen production system

To make the ALK process more adaptive to renewable energy, China can take a multi-pronged approach, such as enhancing the rapid response capacity of the hydrogen production system, improving the power efficiency of large-scale hydrogen production from electrolysis, and controlling the way the ALK system couples with the power supply. China should develop the software needed to conduct the whole-process simulation analysis of modular systems for large-capacity hydrogen production from electrolysis, including the design and operation sections.

Establish a special fund to finance breakthroughs in new-generation electrolysis technology

The government should move fast to set up a special fund to finance technological advancements in collaboration with leading labs and academic institutes. The promising PEM technology should be the research focus in the short term, along with the search for other new electrolysis technologies, such as SOEC and anion exchange membrane (AEM) electrolysis.

Europe has set an example. In 2005, the European Commission invested € 2.6 million to fund the three-year GenHyPEM project, specializing in the research of PEM electrolysis technology. The project crew consisted of 11 universities and institutes in France, Germany, Russia, the US and other countries, aiming to develop a PEM electrolyser with high current density, high working pressure and high electrolytic efficiency.

Define technological development goals and pathways

The government can guide capital and resource investment by setting clear technological development goals and pathways. In 2014, the European Union put forward three development goals for hydrogen production via PEM electrolysis, as follows:

- First, meet the hydrogen demand for transport through distributed PEM electrolysis systems suitable for large-scale HRSs.
- Second, meet industrial-purpose hydrogen demand by producing PEM electrolysers with a generation capacity of 10/100/250 MW.
- Third, meet the demand for large-scale energy storage, including hydrogen power generation at peak hours, with hydrogen used as a household gas source and fuel for large-scale transport, with plans to phase-in PEM and phase-out ALK in water-electrolytic hydrogen production.

Accelerate China's access to next-generation technology by leveraging universities and participation in global innovation forums

China should leverage the research capacities of universities and scientific research institutes to accelerate the pooling and commercialization of next-generation hydrogen technologies through industry-academia collaboration centred on forward-looking and disruptive technologies. Connections should be built with the International Association for Hydrogen Energy (IAHE) and other relevant international organizations to facilitate China's participation in international academic exchanges and forums, as well as in the joint R&D and industry-wide application of universal and key hydrogen technologies.

Universities and research institutes should create more opportunities to strengthen joint projects with partners from countries or regions taking a lead in hydrogen technologies. Such cooperation projects could also be extended into additional countries or regions. In this way, China could play a more effective role in global supply and innovation chains for hydrogen.

Enhance innovation platforms and maximize the role of industrial clusters to incubate and demonstrate key technologies

China should focus on key technologies within the hydrogen sector, establish a hierarchy of platforms for diversified innovation, and support universities, research institutes and enterprises in building cutting-edge interdisciplinary platforms. At the same time, the country should integrate quality innovation resources across the industry, and encourage the construction of hydrogen industry incubators (e.g. demonstration zones in industrial clusters) to support the development and engineering of key technologies.

Goal 6

Evolution and cooperation

6.1 Top-level planning has not yet defined the development path for the hydrogen supply chain

The evolution of the green hydrogen sector in China has been accelerating ever since its inclusion in the *Report on the Work of the Government of the Two Sessions* in 2019. In March 2022, the release of the government's *Medium- and Long-Term Plan for the Development of the Hydrogen Energy Industry (2021-2035)* put the development of hydrogen on the national strategy agenda, delivering an immediate stimulus to the hydrogen industry as a whole. Nevertheless, when considering the evolution of hydrogen in other major global economies, it is clear that China still has a long way to go, especially regarding the development of green hydrogen.

FIGURE 15 | Roadmaps for the development of hydrogen energy across major economies

The United States

September 2022

Department of Energy's National Clean Hydrogen Strategy and Roadmap (draft)*

* The US released the final strategy and roadmap in early June. This report does not analyse the document.

- The roadmap provides a snapshot of hydrogen production, storage, transport and use in the US, and explores the potential for **clean hydrogen*** to contribute to the country's decarbonization and economic development.
- Its **target** is to increase clean hydrogen production to 10 million tons per year by 2030, 20 million tons per year by 2040 and 30 million tons per year by 2050.
- It sets **three key directions:** (1) Target strategic, high-impact uses of clean hydrogen. This will ensure that clean hydrogen is utilized in the highest value applications (where limited deep decarbonization alternatives exist); (2) Reduce the cost of clean hydrogen; and (3) Focus on regional networks. This includes regional clean hydrogen hubs to enable large-scale clean hydrogen production and end-use in proximity.

Germany

July 2021

The Hydrogen Action Plan 2021-2025

June 2020

National Hydrogen Strategy

- The action plan analyses the growth estimates for the hydrogen economy up to 2030 and proposes 80 measures for the effective implementation of Germany's National Hydrogen Strategy, including **green hydrogen acquisition**.
- Hydrogen, **especially green hydrogen produced from renewable sources**, is identified as a prerequisite for Germany to become carbon neutral by 2050, by enabling the phase-out of thermal and nuclear power generation.

Japan

March 2019

The Strategic Roadmap for Hydrogen and Fuel Cells

- This roadmap **defined specific technological development projects**, with respective **goals** set for **each domain**.
- It aims to put 200,000 fuel-cell vehicles into operation by 2025 and 800,000 by 2030, supported by the refuelling network of 900 hydrogen refuelling stations, about nine times the current number.

European Union

February 2019

Hydrogen Roadmap Europe: A Sustainable Pathway for the European Energy Transition

- This roadmap identified hydrogen as an essential element in achieving Europe's decarbonization goals and projected that it would contribute to large-scale decarbonization across the construction, transport and manufacturing industries. Hydrogen was predicted to account for 25% of Europe's total energy demand by 2050.
- Milestones were established as follows: by 2030, the transport sector would expect a fleet of 3.7 million passenger fuel-cell vehicles and 500,000 fuel-cell light commercial vehicles, with about 45,000 fuel-cell trucks and buses put into operation, and around 570 diesel trains replaced by fuel-cell trains.

Notes: * Compared with green hydrogen, clean hydrogen covers a wider range. According to China's Standards and Certification for Low-carbon Hydrogen, Clean Hydrogen and Hydrogen from Renewable Energy Sources, clean hydrogen refers to hydrogen that produces no more than 4.9 kilograms of carbon dioxide for each kilogram of hydrogen produced in its life cycle, while green hydrogen is subject to the requirements for production sources in addition to the carbon emissions ceiling.

Source: Public data, Accenture analysis.

In terms of hydrogen planning at the national level, the top-level planning is in place. However, the setting of goals to develop the supply chain and the design of a roadmap for green hydrogen have not yet been completed. Countries that are more established in the hydrogen field have already formulated clear, strategic roadmaps to implement their goals in the grey, blue and green hydrogen sectors (see Figure 16).

The international trade in hydrogen is still in the exploratory stages and the necessary mechanisms have not yet been established. Japan and South Korea – despite insufficient domestic resources – are taking the lead in building overseas hydrogen supply systems and sales markets. When it comes to international cooperation, Japan has stepped up in recent years as a leading country in the hydrogen sector. For instance, it hosted a Clean Energy Ministerial and a special forum on hydrogen at the G20 Ministerial Meeting in 2019. It formulated cooperation strategies for developed countries, resource suppliers and China, as part of its goal to lead the evolution of the global hydrogen market.

China started late in this sector, but is currently in a period of rapid expansion. Although the country has the largest hydrogen production capacity worldwide, its current blueprint for the sector is centred on domestic energy restructuring in support of its carbon peaking and carbon neutralization goals. Hence, China has embarked on industrial planning and positioning for the sector in a way that is different from other major economies. Nevertheless, the past few China International Import Expo (CIIE) editions have witnessed trends such as a constant increase in the number of international cooperation projects, more wide-ranging collaborations, diverse partnership models, greater commitment to green hydrogen and more engagement from companies.

FIGURE 16 **International cooperation on hydrogen at the China International Import Expo (CIIE)**

Trends in international cooperation in hydrogen	CIIE 2020 and 2021	CIIE 2022
Increase in number of cooperation projects	Relatively few cooperation projects signed	Cooperation projects signed outnumbered those in 2020 and 2021 combined
Broadening coverage of cooperation	Cooperation mainly centred on the hydrogen user end (especially in the field of transport)	Enriched cooperation at the hydrogen user end and increased cooperation in the chemicals industry
Extension of cooperation patterns	Procurement undertaken through imports	Extensive upstream and downstream cooperation
"Green hydrogen" becoming a hotspot of cooperation	Less cooperation on green hydrogen; less concern about the "colour" of hydrogen	More cooperation projects on green hydrogen
More foreign companies engaging for in-depth cooperation	International giants such as Air Products, Panasonic and Linde the only participants	Cooperation agreements involving leading companies such as Thyssenkrupp and Siemens for the first time at CIIE, with existing and emerging partnerships going hand in hand
China transitioning from government-led to corporate-led cooperation	Local governments the main signatories of international agreements on hydrogen	More Chinese companies taking the initiative to engage in international hydrogen cooperation

Key objectives under this goal

- Speed up the development of a national strategy for hydrogen.
- Lay the foundation for international cooperation.

6.2 Enabling measures for evolution and cooperation

Refine the national development plan for hydrogen and formulate a roadmap for green hydrogen

China should refine its national strategic plan and roadmap for the development of hydrogen by drawing on world-class foreign practices. To achieve its hydrogen goals, China should also develop a technology roadmap, timetable and key tasks to sustain high-quality growth of the sector. The country should incorporate green hydrogen into all its emissions reduction and green development efforts, as well as guiding and encouraging cross-regional cooperation, multi-sector applications of hydrogen and the sustainable development of the sector.

Develop a long-term mechanism for international cooperation, and connect technology, policy, academia, enterprises and finance with global supply chains

The Belt and Road Initiative encompasses 85% of the countries that have issued hydrogen strategies, paving the way for China's entry into international hydrogen cooperation. China should strive for broader cooperation with these countries and also with other major players across the globe on hydrogen technology research, definition of standards, leading practices and sector financing, in order to jointly promote the development of the hydrogen industry.

Strengthen international cooperation in setting standards for carbon emissions

The European Union's carbon border adjustment mechanism (CBAM), which is expected to come into force from 2026 onwards, will extend the scope of its carbon tax to hydrogen and some other industries. This means that future hydrogen trade between China and the EU will be linked to the carbon emissions quota-based pricing of the EU, and the convergence of emissions standards for hydrogen will become an inevitable part of such trade.[30] China has already promulgated the *Standard and Evaluation of Low-Carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen*,[31] but this is only a group standard and needs to be aligned with the standards of other jurisdictions, such as the EU and Japan.

Blueprint for the evolution of green hydrogen in China

Coordinating the development of green hydrogen

Green hydrogen is still undergoing early-stage expansion in China, with the sector aiming to build a new energy system and a complete supply chain for hydrogen. Given the government's stated ambition to peak national carbon emissions by 2030, green hydrogen is destined to play a pivotal role during the country's carbon neutralization phase. However, to deliver this new technology at the scale required, China will need to focus on developing its green hydrogen sector through industrial, regional and global collaborations.

Some key priorities stand out, as detailed below:

- Deployment of government policy for balancing supply and demand.
- Improved coordination between provinces to maximize relative strengths and synergies.
- Support for a multilateral approach built on global cooperation in cost, infrastructure and markets.
- Adoption of a China-specific approach to technology, standards and certification.

Deploying government policy for balancing supply and demand

The downstream market needs large-scale, low-cost green hydrogen supply, while equally, the projects and infrastructure supplying that green hydrogen need consistent downstream demand. This "chicken and egg" scenario between supply and demand can only be resolved through concerted efforts along every section of the supply chain to scale up green hydrogen.

Given the irreplaceable role of government policy in promoting the industry, the policy focus should be based on a coherent overall plan tied to clear development goals. This plan should ensure that the phase-out of existing energy sources only happens after a breakthrough in green hydrogen is achieved, so that China's energy industry can evolve in an orderly manner.

Improving coordination between provinces to maximize relative strengths and synergies

As the sources of renewable energy are not usually based near energy hubs, China's provinces need to align across each section of the supply chain to avoid the potentially redundant construction of low-level hydrogen projects. Since almost all provinces have their own hydrogen aspirations outlined in their 14th Five Year Plans, they will need to work together based on their comparative advantages. By lifting barriers to trade, each province can contribute towards strengthening the elements essential to the success of the sector, such as policy, standards, technology and promotion.

Provinces will need to coordinate to maximize their relative strengths in industrial structure, resource endowment, scientific research, talent and market prospects. They will also need to generate synergies across policy, standards, technology, markets and other core factors, and remove obstacles to industrial development, such as regional blockades and local protectionism. Regional coordination will generate new growth, guided by national policies, led by key cities and sustained by leading enterprises.

Supporting a multilateral approach built on global cooperation in cost, infrastructure and markets

The world has ushered in a new era of industrial and technological revolution focused on green, low-carbon growth, in which China is playing an increasingly essential role. China's renewable energy installations account for one-third of the world's total. The country is also home to half of the wind power and 80% of the photovoltaic components worldwide. For seven years running, China has been the world's largest investor in renewable energy.[32]

Consequently, Chinese hydrogen companies, academics and industry platforms should participate in the global hydrogen market through collaboration and project-based exchanges. Global cooperation in hydrogen is not only a necessary obligation in terms of climate action, it is also a positive step towards the coordinated development of the economy, society and sectors such as energy, security and many others. It is in China's interest to pursue a multilateral approach in its green hydrogen endeavour, in order to achieve a win-win outcome, especially in relation to global standards, technological innovation and trade.

China, the EU and Japan share the aspiration to grow their green hydrogen sectors, and their interests converge in terms of the three key factors essential for the scale-up of hydrogen – cost, infrastructure and markets. The EU hopes to lower the cost of electricity in hydrogen production, while Japan is focusing on investment in electrolysers as it depends on hydrogen imports. China is investing across the full value chain, with a particular focus on creating industrial parks.

Adopting a China-specific approach to technology, standards and certification

Where China differs from the EU and Japan is in technology, standards, certification and progress – China has chosen ALK technology for the large-scale production of green hydrogen from renewable energy sources, as these are stable and abundant in the country. For green hydrogen production dependant on more volatile sources of renewable energy, it has chosen PEM technology.

China's hydrogen development is different from other countries' due to its industry standards and certification system, which are subject to Chinese-style administration. The country should, in the initial stage, develop its own standards for hydrogen safety, engineering, production, purification and testing for a small number of local hydrogen models. Greater collaboration between provinces and regions is needed to ensure that hydrogen development across the country takes a unified direction, that hydrogen-based applications grow and expand, and hydrogen technology advances apace. This collaboration will in turn drive a growing demand for common technical standards governing hydrogen production from renewables, hydrogen storage and refuelling, and hydrogen applications.

In October 2022, the National Energy Administration (NEA) issued the *Summary of Industry Standards Setting Programs for the Energy Sector 2022*, of which 11 are related to hydrogen. These include standards for pipelines and cylinders that store and transport compressed hydrogen, hydrogen storage systems at power stations, and HCNG transportation – as well as standards for green hydrogen production.

All these efforts will help accelerate the formulation of industry standards.

FIGURE 17 | Summary of China's green hydrogen development goals and enabling measures

Technological development, R&D and innovation

Standards and certification

Market and finance

Matching supply and demand

The flags denote areas where the EU and Japan have similar enabling measures

Cost

Reduce the cost of electricity in green hydrogen production

- 1a. Implement centralized demonstration projects for hydrogen production from renewable energy sources in areas rich in such resources
- 1b. Formulate policies on special electricity rates for green hydrogen projects
- 1c. Optimize electricity markets to scale up green electricity trading

Cost

Reduce the cost of electrolysers

- 2a. Subsidize the manufacture of green hydrogen equipment
- 2b. Lay down a tax credit policy for green hydrogen
- 2c. Develop efficient high-powered alkaline electrolysers to reduce the capital expenditure

Infrastructure

Establish unified regulatory standards and procedures

- 3a. Develop a system for hydrogen administration and designate the competent authorities
- 3b. Accelerate formulation of unified national approval procedures & management standards
- 3c. Encourage local pilot efforts to deregulate hydrogen production & refuelling in non-chemical industry parks

Infrastructure

Reduce the cost of infrastructure investment and expand financing channels

- 4a. Accelerate technological breakthroughs in hydrogen storage and transport, plus domestic production of key components for refuelling stations
- 4b. Promote the construction of integrated hydrogen production and refuelling stations
- 4c. Advocate for the conversion of traditional filling stations into mixed fossil fuel and hydrogen refuelling stations
- 4d. Provide more support for hydrogen infrastructure via financial instruments
- 4e. Accelerate the incorporation of the complete green hydrogen supply chain into green finance standards

Technology

Step up proprietary R&D across the supply chain to further adapt electrolysis technology to renewable energy sources

- 5a. Enhance the rapid response capacity of the alkaline hydrogen production system
- 5b. Establish a special fund to finance breakthroughs in new-generation electrolysis technology
- 5c. Define technological development goals and pathways
- 5d. Accelerate China's access to next-generation technology by leveraging universities and participation in global innovation forums
- 5e. Enhance innovation platforms and maximize the role of industrial clusters to incubate and demonstrate key technologies

Technological development, R&D and innovation | Standards and certification | Market and finance | Matching supply and demand

The flags denote areas where the EU and Japan have similar enabling measures

Market demand

Boost short-term market demand for hydrogen fuel-cell vehicles

- 6a. Accelerate domestic development of hydrogen fuel cell technology and high-pressure hydrogen storage systems (EU)
- 6b. Step up policy support by granting right of way to HFCVs
- 6c. Strengthen public procurement of HFCVs (EU, Japan)

Market demand

Create multiple end-use application scenarios to drive the large-scale adoption of hydrogen technology

- 7a. Boost the development of green hydrogen and its applications in industrial production, such as manufacture of iron and steel (EU)
- 7b. Explore the coupling of hydrogen and carbon markets to accelerate the replacement of grey hydrogen across big industrial carbon emitters (EU, Japan)
- 7c. Promote integration of green hydrogen storage with renewable energy sources, through commercial operating models and demonstration projects
- 7d. Build multiple end-use green hydrogen application scenarios, starting with demonstration projects (EU, Japan)
- 7e. Distribute industrial demonstration projects in line with local conditions, drive the supply chain by clusters, and scale up applications (EU, Japan)

Industry standards and certification

Improve the regulatory system for hydrogen by providing better-structured standards

- 8a. Reflect on the realities and flaws of the hydrogen energy sector's standards to optimize the standards system
- 8b. Improve top-level planning and execution of standards, while providing policy support, incentives and publicity to promote standardization

Industry standards and certification

Engage multiple stakeholders to develop innovative, high-quality standards

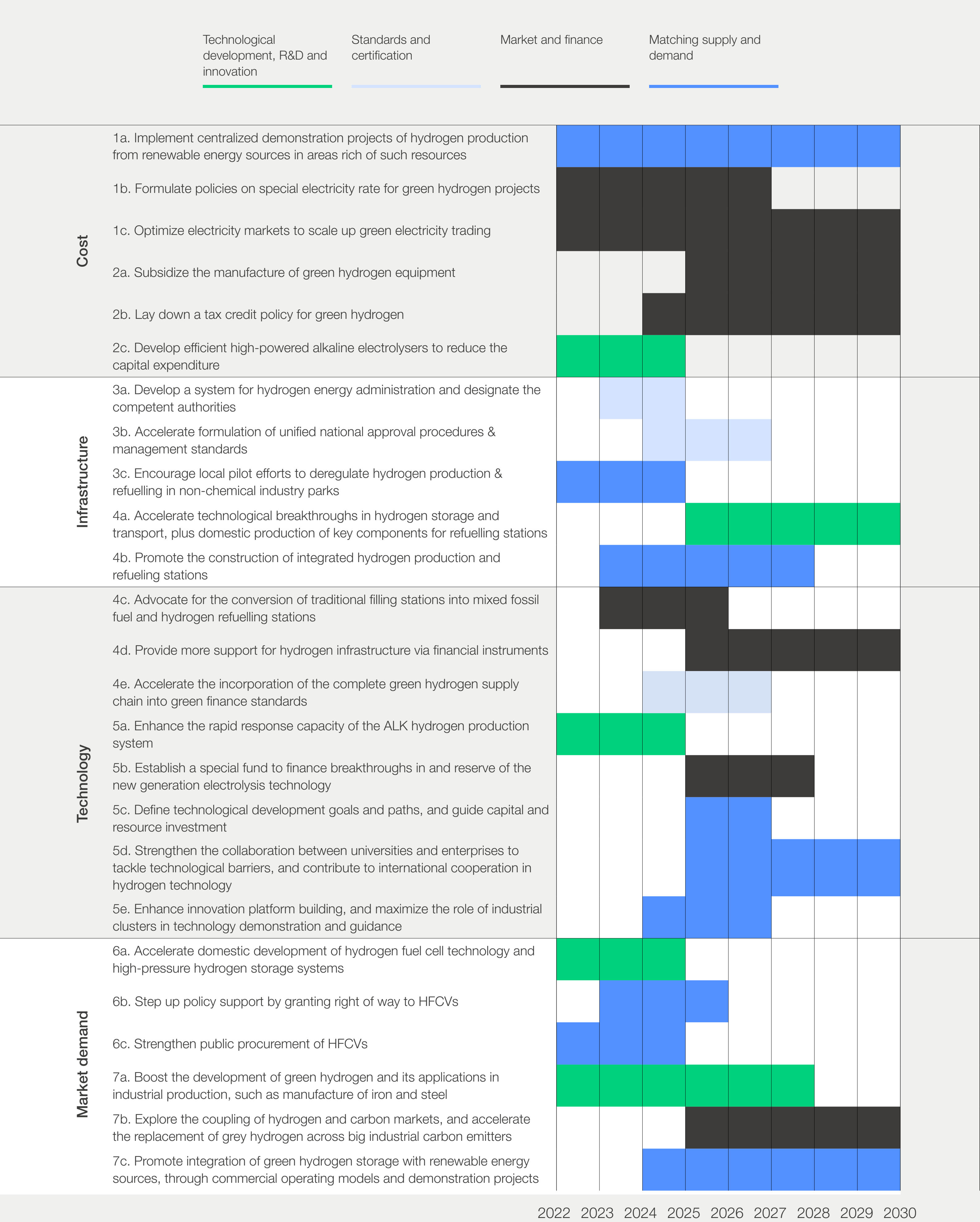
- 9a. Pilot local and corporate standards to derive empirical models for promotion and replication
- 9b. Encourage industrial alliances, academic societies, enterprises and other organizations to cooperate and innovate in standard-setting
- 9c. Cooperate in the formulation of international standards

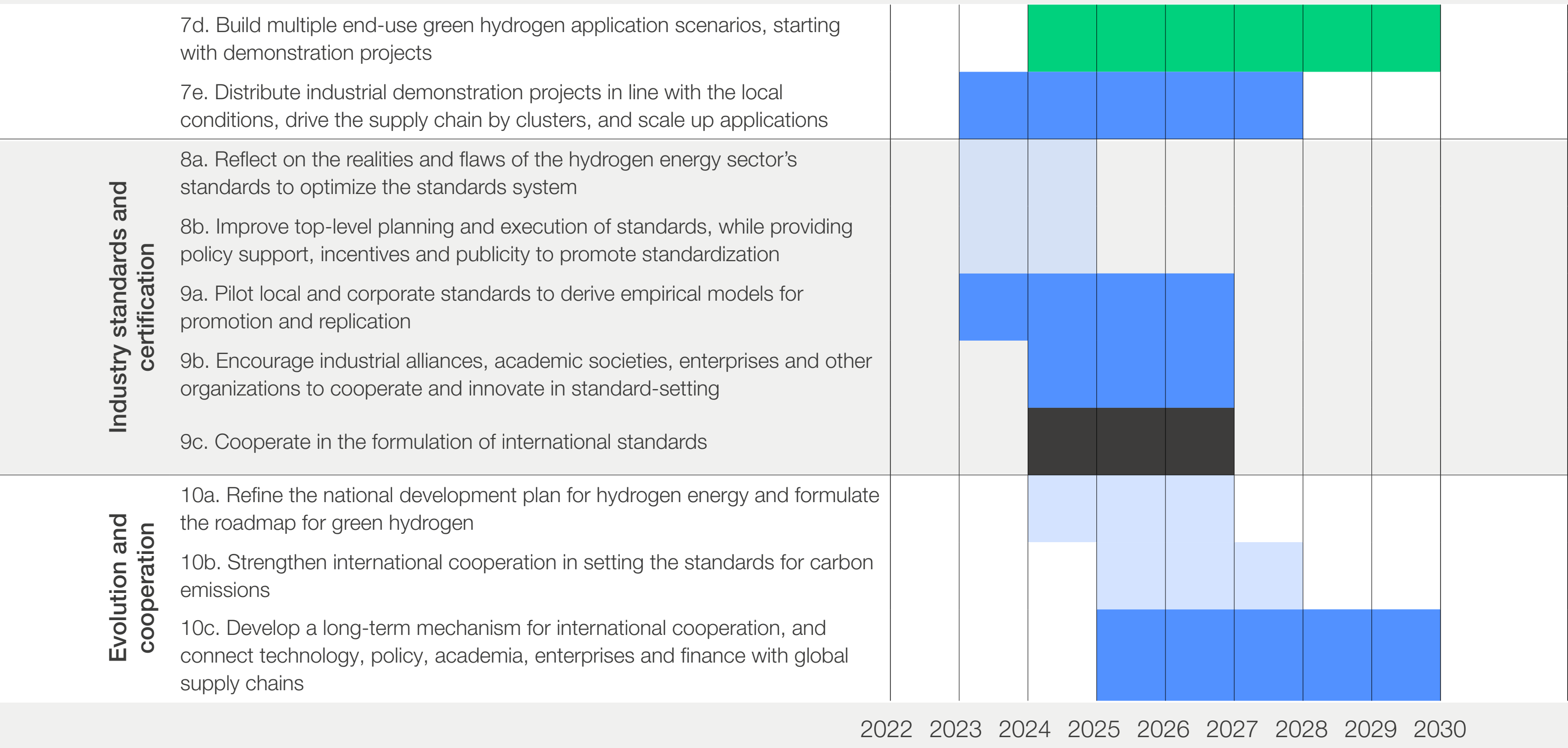
Evolution and cooperation

Speed up the development of a national strategy for hydrogen

- 10a. Refine the national development plan for hydrogen energy and formulate the roadmap for green hydrogen
- 10b. Strengthen international cooperation in setting the standards for carbon emissions
- 10c. Develop a long-term mechanism for international cooperation, and connect technology, policy, academia, enterprises and finance with global supply chains (EU, Japan)

FIGURE 18 | **Enabling measures: Road mapping**





Outlook 2030: China’s pathway to green hydrogen

The release in March 2022 of the government’s medium- and long-term plan for the hydrogen industry fires the starting gun for China’s race to develop green hydrogen. The government has defined the end of this decade as the deadline for the country to peak its carbon emissions, so 2030 marks the start of in-depth decarbonization across multiple industries. This in turn will initiate a new phase of large-scale green hydrogen development.

Keeping in mind the 2030 milestone, this report proposes a roadmap for measures to enable the development of China’s green hydrogen industry, broken down into three phases, detailed below:

– Phase 1: 2023-2024

– Phase 2: 2024-2027

– Phase 3: 2027-2030

Phase 1: 2023-2024

- **Supportive policies:** China will adopt policies to support the long-term development of the green hydrogen industry, including fiscal and tax incentives and subsidies for the supply chain.
- **Demonstration projects:** Government support will lead to more demonstration projects, bringing down the cost of hydrogen storage and transport.
- **Technology breakthroughs:** More breakthroughs will be made in core technologies, especially the R&D of hydrogen and fuel cells.
- **Coordination with existing energy supply:** The government will coordinate the storage of wind, photovoltaic and hydrogen generation, and couple hydrogen with other existing energy production and storage.
- **Application to industry sectors:** Coordination will pave the way for applying hydrogen to the transportation, heating, chemicals and metallurgical industries, thereby improving energy efficiency and reaping its accompanying economic and social benefits.

Phase 2: 2024-2027

- **Technical standards:** China will develop a full-scale technical standards system for hydrogen, covering infrastructure design, construction and certification, and consisting of national, industrial, regional, associational and corporate standards.
- **Investment in supply networks:** The country will develop technologies for the long-haul transport and large-scale storage of hydrogen, and invest in more infrastructure to sustain an integrated hydrogen supply network across regions and countrywide.
- **International cooperation:** To deliver an integrated supply network, it will be vital to attract international investment. This will require open-mindedness and practicality in technical and industrial innovations.
- **Widespread progress:** By the end of this phase, green hydrogen applications will be flourishing at multiple sites.

Phase 3: 2027-2030

- **Price and demand targets:** The cost price of hydrogen produced from renewable energy sources will reach CNY 15/kg ($2.18), the storage and transport price per hundred kilometres will range from CNY 5-10/kg ($0.73-1.45), and the price at HRSs will be from CNY 30-35/kg ($4.36-5.09). Demand for green hydrogen will reach around 5-8 million tons.
- **Energy infrastructure:** Over 5,000 HRSs will be built across the country, forming a well-functioning network.
- **Certification:** China will develop a comprehensive framework of standards and certification for the hydrogen sector.
- **Innovation networks:** The country will create state-level engineering and research centres, and centres for technical and manufacturing innovation in leading enterprises, universities and colleges. The role of this innovation network will be to make breakthroughs in key technologies along the supply chain, by defining multiple sectoral goals that align with China's top-level hydrogen plan, along with creating roadmaps to achieve those goals.
- **Global participation:** China will seek pragmatic cooperation with foreign players in hydrogen technology and industrial innovation, and play a significant role in hydrogen development around the globe.

Conclusion

With the government's announcement of the *Medium- and Long-Term Plan for the Development of the Hydrogen Energy Industry (2021-2035)* in March 2022, the growth of hydrogen's value chain has been incorporated into China's national development plan. Hydrogen is consequently assuming an ever more critical role in China's energy system. Above all, green hydrogen – which provides significant decarbonization potential for industries such as transportation, manufacturing, utilities and construction – is a top priority for China to deliver on its commitment to carbon neutrality by 2060.

However, despite this growing attention on green hydrogen, challenges around cost, infrastructure and demand prevent it from making significant contributions to China's energy transition. As a result, green hydrogen currently makes up a tiny fraction of the country's hydrogen production and consumption.

The national plan has framed high-level strategic goals for green hydrogen, with 2035 as the date by when hydrogen from renewable sources should form a significant proportion of terminal energy consumption. But a precise, phased and measurable pathway for green hydrogen development has not yet been proposed. Clear development objectives, detailed planning and dedicated policies are needed to facilitate the kinds of value-chain collaboration that can promote large-scale, orderly development of the sector.

This report proposes a roadmap for China's green hydrogen development, defined by six key barriers and goals – related to cost, infrastructure, market demand, industry standards and certification, technology, and evolution and cooperation. To deliver on these goals, the report offers 35 enabling measures, to be executed in three phases from now until 2030. This blueprint for action is further informed by cross-cutting themes, such as the supportive role of government policy, coordination between provinces, an approach built on global cooperation, as well as a China-specific approach to standards.

Over the next 18 months, practical steps to take down this pathway include government support for demonstration projects and policy incentives for industry sectors to adopt green hydrogen. These measures will, in turn, generate the breakthroughs in cost, infrastructure and demand that are needed to accelerate the growth of this exciting, new energy technology.

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1. Leigh Collins, *China should install100GW of green hydrogen by 2030', says Beijing-supervised body*, Recharge, https://www.rechargenews.com/energy-transition/china-should-install-100gw-of-green-hydrogen-by-2030-says-beijing-supervised-body/2-1-1071599, 2021.
2. Wan Yanming, Xiong Yalin and Wang Xueying, *Strategic analysis of hydrogen energy development in major countries*, https://esst.cip.com.cn/EN/Y2022/V11/I10/3401, 2022.
3. International Energy Agency, *Hydrogen Industry Development Plan 2021-2035*, https://www.iea.org/policies/16977-hydrogen-industry-development-plan-2021-2035, 2023.
4. A hydrogen fuel-cell vehicle (HFCV) uses the same kind of electric motor to turn the wheels that a battery-electric car does. But it is powered not by a large, heavy battery but by a fuel-cell stack in which pure hydrogen (H_2) passes through a membrane to combine with oxygen (O2) from the air, producing the electricity that turns the wheels plus water vapour. See John Voelcker, Hydrogen Fuel-Cell Vehicles: Everything You Need To Know, https://www.caranddriver.com/features/a41103863/hydrogen-cars-fcev/.
5. Statista, Energy & Environment, "Hydrogen consumption worldwide in 2020, by country" and "Global hydrogen use 2020, by country, published by N. Sönnichsen", https://www.statista.com/statistics/1292403/global-hydrogen-consumption-by-country/.
6. Chinese yuan converted to US dollars using the 3 April 2023 rate of 0.145583. Source: www.XE.com.
7. China EV100, *Report on the Development of Hydrogen Energy Industry in China 2020*, October 2020.
8. State Council, *Action Plan for Carbon Dioxide Peaking Before 2030*, October 2021.
9. *The Opinions on Improving the Systems, Mechanisms and Policy Measures for the Transition to Green and Low-carbon Energy* jointly issued by the NDRC and NEA propose "to facilitate the building of energy supply systems dominated by clean and low-carbon energy, as well as to accelerate the construction of large-scale wind power and photovoltaic bases, especially in desert, gobi and desolate areas." At the end of 2021, NEA issued a *Notification on the Selection of Proposed Second Series of Projects for Large-scale Wind Power and Photovoltaic Bases Mainly Located in Desert, Gobi and Desolate Areas*, further requiring that "the threshold for an individual project shall not be less than 1 million kW."
10. Interview with China Hydrogen Alliance, compiled by Accenture.
11. Chengdu Municipal People's Government, *Policy Measures for Energy Structure Optimization for Green and Low-carbon Urban Development*, June 2022.
12. Compared with green hydrogen, clean hydrogen covers a wider range. According to China's *Standards and Certification for Low-carbon Hydrogen, Clean Hydrogen and Hydrogen from Renewable Energy Sources*, clean hydrogen produces no more than 4.9 kilograms of carbon dioxide in its entire life cycle for each kilogram of hydrogen produced, while green hydrogen is subject to the requirements for production sources in addition to the carbon emissions ceiling.
13. Monahan Katherine and Marisa Beck, *Hydrogen tax credits in the U.S. Inflation Reduction Act*, Canadian Climate Institute, https://climateinstitute.ca/publications/hydrogen-tax-credits-in-the-u-s-inflation-reduction-act/, 2023.
14. Interviews with industry insiders, compiled by Accenture.
15. TrendBank and ZDHS, *Blue Book on the Development of China's Hydrogen Refuelling Station Industry 2022*, July 2022.
16. China EV100, *Report on the Development of Hydrogen Energy Industry in China 2020*, October 2020.
17. Ibid.
18. New energy vehicles (NEVs) refer to vehicles that use unconventional vehicle fuels as their power source. NEVs are divided into pure electric vehicles, extended-range electric vehicles, plug-in hybrid vehicles, and non-plug-in hybrid vehicles. Pure electric vehicles – including battery-electric vehicles (BEVs) and solar-powered vehicles – are completely powered by electricity. In the China context, NEVs do not usually include vehicles powered by hydrogen or hydrogen fuel cells.
19. In the "Two Sessions" held in March 2023, China's National People's Congress representatives noted that hydrogen is still managed as a hazardous chemical in the country. However, to develop the hydrogen industry, it is recommended that hydrogen used as energy and hydrogen used as an industrial raw material be treated separately, so that projects to produce, store and utilize hydrogen as an energy source are not treated as chemical or hazardous chemical projects.
20. Intellectual property pledge financing refers to a financing method in which an enterprise obtains loans from a bank that evaluates its property rights in legally owned patents, trademarks and copyrights as collateral. Intellectual property pledge financing can alleviate the difficulty and high cost of financing for enterprises to a certain extent, and obtain necessary funding through the "light assets" of intellectual property. This can help technology-based small- and medium-sized enterprises to solve financial shortfalls caused by the lack of real estate by using intellectual property pledges as collateral.
21. EV100_Plus, Hydrogen Energy Center of China EV100 and Central University of Finance and Economics, *Building a Hydrogen Finance System in line with the Carbon Peaking and Carbon Neutralization Goals*, 2022.
22. China EV100, *Report on the Development of Hydrogen Energy Industry in China 2020*, October 2020.
23. China Metallurgical News, *Realities and Challenges Regarding Hydrogen Metallurgy Technology*, 29 August 2022.

24. The *Development and Enforcement Plan for New-type Energy Storage under the 14th Five-Year Plan* issued by the NEA stipulates that "new-type energy storage refers to energy storage mainly in the form of power output in addition to pumped storage".

25. Five ministries of the state announced incentives for FCV demonstration cities, replacing the previous policy of large subsidies for FCV purchases. A demonstration city shall be able to, within four years, "promote more than 1,000 FCVs that meet the relevant technical metrics, with an average operating distance of over 30,000 km covered by hydrogen use per vehicle."

26. According to the definition of the Standardization Law of the People's Republic of China, standards refer to technical requirements that need to be unified in fields such as agriculture, industry, service industry and social undertakings. Standards include national standards, industry standards, local and group standards, and enterprise standards. National standards refer to standards adopted and publicly released by national institutions, and are divided into mandatory and recommended standards. Industry and local standards are recommended standards. Group standards are independently formulated and released by groups in accordance with the standard development procedures established by the group, and are voluntarily adopted. On December 29, 2020, the "Standards and Evaluation of Low Hydrocarbon, Clean Hydrogen, and Renewable Energy Hydrogen" proposed by the China Hydrogen Alliance was officially released and implemented.

27. "Review of Hydrogen Standards for China", https://www.e3s-conferences.org/articles/e3sconf/pdf/2019/44/e3sconf_icaeer18_03032.pdf.

28. Shi Wenbo, Cai Chunming, Li Dewei, Ono Kei and Zhang Jianbo, *ISO/IEC: Comparisons between the Standardization Systems for Hydrogen Energy Technology in the US, China, and Japan and the Recommendations*, Chemical Industry and Engineering Progress, https://hgjz.cip.com.cn/EN/Y2022/V41/I12/6275, 2022.

29. China EV100, *Report on the development of hydrogen energy industry in China 2020*.

30. China Energy News, *CBAM: Legislation passed at the first reading in the European Parliament*, 2022.

31. Wei Liu, Yanming Wan, Yalin Xiong and Pengbo Gao, "Green Hydrogen Standard in China: Standard and Evaluation of Low-Carbon Hydrogen, Clean Hydrogen, and Renewable Hydrogen", in *Hydrogen Sourced from Renewables and Clean Energy: A Feasibility Study of Achieving Large-scale Demonstration*, edited by Y. Li, H. Phoumin and S. Kimura, pp. 211-24, Economic Research Institute for ASEAN and East Asia, https://www.sciencedirect.com/science/article/abs/pii/S0360319921042737, 2022.

32. Xie Zhenhua, *Great Changes in the World: Symbiosis and Restructuring*, International Financial Forum (IFF), 2 December 2022.

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