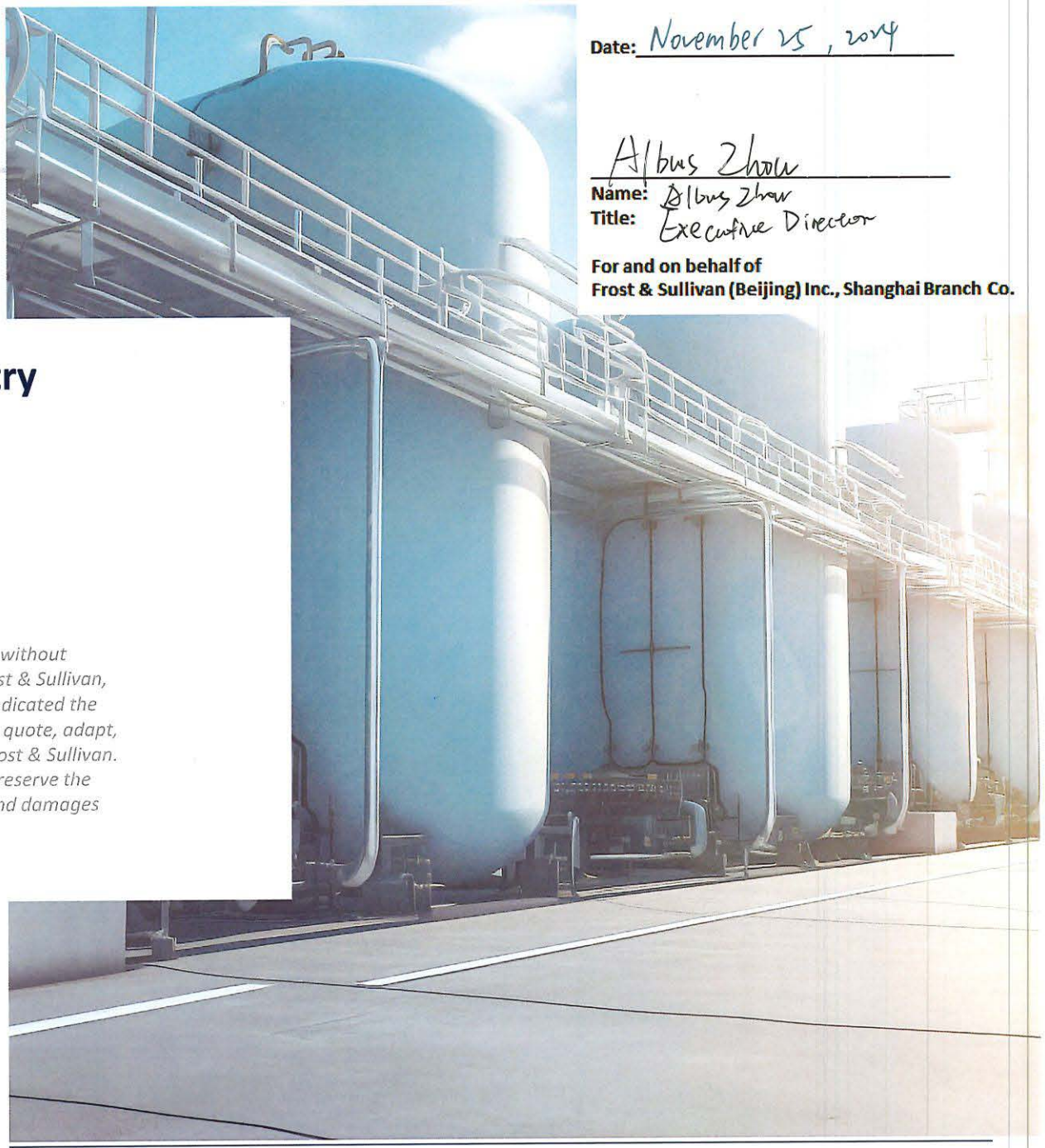


Date: November 25, 2024

Albus Zhou

Name: Albus Zhou
Title: Executive Director

For and on behalf of
Frost & Sullivan (Beijing) Inc., Shanghai Branch Co.

Confidential

Global and China Hydrogen Industry

Independent Market Research

To: REFIRE

FROST & SULLIVAN (BEIJING) INC., SHANGHAI BRANCH CO.
弗若斯特沙利文(北京)咨询有限公司上海分公司

—1961-2021—
FROST & SULLIVAN
沙 利 文 60周年
60th ANNIVERSARY

FROST & SULLIVAN
沙 利 文

Scope

The project scope is defined as follows:

Research Period	• Historical Year: 2018-2022 • Base Year: 2023 • Forecast Year: 2024E-2028E
Research Coverage and Methodology	• Global and China Market • Include both primary research and secondary research.
Service Scope and Assumptions	• Global and China Hydrogen Industry • Frost & Sullivan's projection on the size of each of the related markets is based on the assumption that (i) the overall global social, economic, and political environment is expected to maintain a stable trend over the next decade; (ii) during the forecast period, related key industry drivers are likely to continue driving growth in China, and global market; and (iii) there are no extreme force major event or industry regulations by which the market situation may be affected either dramatically or fundamentally.

Agenda

Overview of Hydrogen Industry

Definition and Importance of the Hydrogen Industry

The Importance Analysis of Hydrogen Industry

Definition

- Hydrogen energy is considered to be one of the cleanest, most efficient, and renewable energy sources. As an energy medium, it has the advantages of being able to have zero emissions during the energy conversion process, high efficiency, high energy density and storable on large scale, and therefore has gained more and more attention and applications in the energy field. Meanwhile, hydrogen energy is a high-quality energy source that is easy to produce and widely used. The development of hydrogen energy is of great significance to ensuring national energy security, optimizing the energy structure, promoting clean energy transformation and achieving China's goal of "carbon peaking by 2030 and carbon neutrality by 2060" in the future.
- The whole industrial chain related to hydrogen energy is the hydrogen industry.

Environmentally Friendly

- Hydrogen energy is a zero-carbon emission energy source, and its combustion produces only water vapor, making it a truly green energy source. Compared to fossil fuels, the use of hydrogen energy can effectively reduce the amount of carbon dioxide in the atmosphere, reducing the risk of the greenhouse effect, which is of great significance for the protection of the environment.

Energy Security

- The abundant reserves of elemental hydrogen are the basis for its great role in the energy sector. Hydrogen production by electrolysis of water using renewable energy sources such as solar and wind power will be the mainstream. Raw materials are more available and the production process is more environmentally friendly. Developing the hydrogen industry is expected to help China break away from dependence on a single fossil fuel and reduce energy security risks.

Promoting Economic Development

- The rise of the hydrogen industry will drive the development of related industries and create more employment opportunities. From production, storage, and transportation to application, the hydrogen industry chain involves many fields, including but not limited to equipment manufacturing, infrastructure construction, and logistics. This will inject new vigor into economic development and promote industrial upgrading and transformation.

Source: Frost & Sullivan

Overview of Hydrogen Industry

Analysis of the Advantages of Hydrogen Energy (1/2)

Analysis of the Advantages of Hydrogen Energy

High Natural Content Of Elemental Hydrogen

Hydrogen is the most abundant element in the universe, occupying 75 percent of the mass of the universe. On Earth, hydrogen is also extremely abundant and exists in the air almost all around us. This abundance provides us with unlimited possibilities and opportunities, making it possible to access hydrogen energy resources without geographic restrictions. Hydrogen energy resources have great advantages over other resources in terms of availability, storage, and transportation. It is not subject to geological changes, political risks, environmental impacts, etc., as some mineral resources are.

High Heating Value

Hydrogen has a higher heating value than that of conventional fuels. This means that each gram of hydrogen can release a large amount of energy when burned, capable of meeting the needs of a wide range of equipment. In comparison, petrol has a calorific value of about 42 MJ/g, and gas has a heating value of about 46 MJ/g, and these conventional fuels are dwarfed by hydrogen. Hydrogen's high calorific value gives it a significant advantage in energy conversion and utilization. With hydrogen energy, equipment can generate power or heat at higher efficiencies, resulting in lower energy consumption and emissions.

Eco-friendly

The process of producing and using hydrogen is extremely eco-friendly. Firstly, renewable energy sources such as solar energy and wind energy can be used in large quantities in the generation of hydrogen, and the use of these energy sources helps to slow down greenhouse gas emissions and protect the ecological environment. Secondly, the combustion product of hydrogen is only water, without any residual pollution to the environment.

Source: Frost & Sullivan

Overview of Hydrogen Industry

Analysis of the Advantages of Hydrogen Energy (2/2)

Analysis of the Advantages of Hydrogen Energy

Various Application Scenarios

Hydrogen can be used in a wide range of applications. In the field of transportation, FCEV has good business potential; in industrial production, hydrogen can be used in industries such as industrial gas, synthetic ammonia, coke, etc., which has great economic value.

In power generation and storage, the nature of large-scale, long-period hydrogen storage provides a new path to address the imbalance between power supply and demand. The fuel cell power generation solution has strong competitiveness in future stationary power supply. In addition, because hydrogen fuel cells can be grid-independent, they also serve as an well-recognized option to offer secure power supply for critical load functions such as data centers, telecommunications towers, hospitals and emergency response systems.

Scalable Storage

Scalable storage of hydrogen energy is an intrinsic part of complete energy chains, starting from energy generation to end-use. Hydrogen can either be stored underground in deep geological formations, preferably in rock salt formations, or on a large scale. Alternatively, it could be stored in above-ground containments on a large scale whenever the geological situation is not suitable. The possibility of scalable storage of hydrogen power provides opportunities for more convenient usage.

Hydrogen is storable on large scale.

High Energy Density

An advantage is hydrogen's energy density. Diesel has an energy density of 45.5 megajoules per kilogram (MJ/kg), slightly lower than gasoline, which has an energy density of 45.8 MJ/kg. By contrast, hydrogen has an energy density of approximately 120 MJ/kg, almost three times of diesel or gasoline.

1 kg of hydrogen, used in a fuel cell to power an electric motor, contains approximately the same energy as a gallon of diesel.

Source: Frost & Sullivan

Overview of Hydrogen Industry

The Importance of China's Green Energy Industry

Hydrogen Energy Industry Standard System Construction Guidelines (2023 Edition)		
Issuing Authority	**Release Date**	**Main Comments**
National Standards Commission National Development and Reform Commission Ministry of Industry and Information Technology Ministry of Ecology and Environment Ministry of Emergency Management National Energy Administration	Aug. 2023	The guideline specifies the key tasks of domestic and international hydrogen energy standardization in the past three years and systematically builds a standard system for the whole industrial chain of hydrogen energy production, storage, transmission, and use. The guideline covers five sub-systems, including foundation and safety, hydrogen preparation, hydrogen storage and transmission, hydrogen refueling, and hydrogen energy application. The guideline aims to implement the top-level design on the development of the hydrogen energy industry and give full play to the role of industry in regulating and leading the development of the hydrogen energy industry.

- **In the area of hydrogen storage and transportation**, it mainly includes basic requirements for hydrogen storage and transportation such as hydrogen compression, hydrogen liquefaction, blending of hydrogen and natural gas, solid hydrogen storage materials, standards for hydrogen storage and transportation equipment such as containers, cylinders, pipelines, etc., as well as hydrogen storage and transportation systems, and the promotion of the formulation and revision of standards related to safe and efficient hydrogen storage and transport.
- **In the area of hydrogen refueling**, it mainly includes standards for hydrogen refueling station equipment, systems, and operation, and safety management, and promotes the formulation and revision of standards related to the safe, reliable, and efficient development of hydrogen refueling stations.
- **In terms of hydrogen energy application**, it mainly includes hydrogen energy conversion and utilization equipment and parts such as fuel cells, hydrogen internal combustion engines, hydrogen boilers, and hydrogen gas turbines. As well as standards for hydrogen energy application in the fields of transport, energy storage, power generation, and nuclear industry, and to promote the formulation and revision of hydrogen energy-related new technologies, new processes, new methods, and safety-related standards.

Source: Frost & Sullivan

Overview of Hydrogen Industry

Favorable Policies/Regulations Regarding China's Hydrogen Industry

Release Date	Issuing Authority	Policies	Comments
Jul, 2024	The State Council	The Guidance on Accelerating the Comprehensive Green Transformation of Economic and Social Development	• The guidance proposes that, by 2030, the scale of the energy-saving and environmental protection industry will reach about 15 trillion yuan; the proportion of non-fossil energy consumption will be raised to about 25%; the carbon emission intensity per unit of transported volume of operational transport vehicles will decrease by about 9.5% compared to the year 2020; and the annual utilization volume of bulk solid waste will reach about 4.5 billion tons, etc.
Apr. 2024	The Standing Committee of the National People's Congress	The Energy Law of the People's Republic of China (Draft)	• This is the foundational and overarching legal draft in the field of energy in China, which clarifies that hydrogen energy is included as a part of the energy sector. The law stipulates provisions for improving the energy planning system, perfecting the systems for energy development and utilization, strengthening the construction of the energy market system, enhancing the energy reserve system and emergency mechanisms, promoting energy technology innovation, and intensifying supervision and management.
Mar, 2024	National Energy Administration	Guiding Opinions on Energy Work (2024)	• The government encourages the release of new policies that accelerate the development of the hydrogen energy industry, promote hydrogen technology innovation and industrial development in an orderly manner, carry out hydrogen energy demonstrations projects, focus on hydrogen production from renewable energy sources, and expand the application scenarios of hydrogen energy

Source: Frost & Sullivan

Overview of Hydrogen Industry

Favorable Policies/Regulations Regarding China's Hydrogen Industry

Release Date	Issuing Authority	Policies	Comments
Dec, 2023	National Development and Reform Commission	Guiding Catalogue for Industrial Structure Adjustment (2024)	• This catalog is an important guide for all levels of government in China to allocate resources and guide investment. This catalog is divided into three categories: encouragement, restriction, and elimination • Under this catalog, various operations or items in relation to the hydrogen industry, including hydrogen storage, applications of hydrogen technology, hydrogen production through renewable methods, hydrogen fuel engines, etc., are categorized under the encouraged category of industries.
Aug. 2023	Standardization Administration	Guide on the Establishment of Standards on Hydrogen Energy Industry	• The guide has established a standard system for the whole industry, covering hydrogen production, storage, transportation, and application. • The guide divides the standards from five perspectives, technology, equipment, system, safety, and testing • The guide consists of 20 sub-systems and 69 tertiary sub-systems.
Jun, 2023	**National Energy Administration (NEA)**	**The Blue Book on the Development of New Power Systems**	• **The government encourages breakthroughs in key technologies applicable to renewable energy electrolysis for hydrogen production, including proton exchange membrane (PEM) and high-temperature solid oxide electrolysis. Efforts are underway to conduct research and development on critical technologies in hydrogen storage, transportation, and refueling, as well as in fuel cell equipment and system integration. By the year 2030, the proportion of non-fossil energy consumption is targeted to reach 25%**
Oct. 2021	State Council	Action Plan for Upgrading Carbon Dioxide Peaking Before 2030	• The action plan carries out the research and development of technical standards for hydrogen production, storage, transportation, refueling, and diversified applications of hydrogen energy, to support the development of the whole industrial chain. The proportion of renewable energy in newly constructed channels shall, in principle, not be less than 50%. • The file focuses on renewable energy hydrogen production, hydrogen production by water electrolysis, and fuel cell systems. • By 2030, the proportion of newly added vehicles powered by new energy and clean energy is expected to reach around 40%. The carbon emission intensity per unit of turnover for operational vehicles is targeted to decrease by approximately 9.5% compared to the levels in 2020. The comprehensive energy consumption per unit of turnover for the national railway is aimed to decrease by around 10% from the levels in 2020.

Source: Frost & Sullivan

Overview of Hydrogen Industry

Favorable Policies/Regulations Regarding China's Hydrogen Industry

Release Date	Issuing Authority	Policies	Comments
Sep. 2022	National Development and Reform Commission (NDRC)	Guiding opinions of the State Council on accelerating the green and low-carbon development of Inland Waterway Ships	• By 2025, the breakthrough in key technologies for green power such as hydrogen fuel cells will be acquired. The research and development of technologies and equipment such as marine hydrogen fuel cell power systems, hydrogen storage systems, and refueling systems will have been strengthened. Hydrogen fuel cell power technology will have been explored for applications such as passenger ships, and the use of green hydrogen produced by electrolysis of water from solar and other renewable energy sources will have been encouraged.
Mar. 2022	**National Development and Reform Commission**	**The Medium and Long-term Plan for Hydrogen Industry (2021-2035)**	• **The plan analyzes the current development situation of China's hydrogen industry and clarifies the strategic positioning, overall requirements, and development goals of the industry. The importance of hydrogen is increased.** • From a domestic perspective, China is the world's largest hydrogen producer, with an annual hydrogen production of approximately 33 million tons, of which around 12 million tons meet industrial hydrogen quality standards. China leads globally in renewable energy installed capacity, positioning itself with significant potential in providing clean and low-carbon hydrogen.
Mar. 2022	**National Development and Reform Commission**	**The Medium and Long-term Plan for Hydrogen Industry (2021-2035)**	• By 2025, the fleet of fuel cell vehicles is expected to reach approximately 50,000, with the deployment and construction of a number of hydrogen refueling stations. The production of hydrogen from renewable energy sources is targeted to reach 100,000 to 200,000 tons per year, becoming a significant component of the newly added hydrogen consumption and resulting in a reduction of carbon dioxide emissions by 1 to 2 million tons per year.
Jan. 2022	**National Energy Administration, NDRC**	**The 14th Five-Year Plan (FYP) for a Modern Energy System**	• During the 14th FYP period, the annual average growth in R&D funding for energy is targeted to exceed 7%, with approximately 50 breakthroughs expected in key technology areas. To achieve a non-fossil energy consumption share of 25% by 2030, further substantial increases are expected.

Source: Frost & Sullivan

Overview of Hydrogen Industry

Favorable Policies/Regulations Regarding China's Hydrogen Industry

Release Date	Issuing Authority	Policies	Comments
Nov. 2021	National Energy Administration, Ministry of Science and Technology	The 14th Five-Year Plan (FYP) on Scientific and Technological Innovation in the Energy Sector	• This plan includes targets such as (i)conduct research on critical technologies for integrating, structurally designing, and precision manufacturing high performance, long-lasting proton exchange membrane fuel cell (PEMFC)stacks, (ii) achieve breakthroughs in key solid oxide fuel cell (SOFC)technologies, master system integration optimization design, and understand operational characteristics and load response patterns, (iii) enhance critical technologies such as stack stacking and power amplification for molten carbonate fuel cells (MCFC) and acquire expertise in integrated design for molten carbonate fuel cells ranging from hundred-kilowatt to megawatt levels, and (iv) demonstrate the application of stationary fuel cell power generation and distributed energy supply in various scenarios.
Oct. 2021	The state council	Notice by the State Council of the Action Plan for Carbon Dioxide Peaking Before 2030	• The plan encouraged the application of hydrogen, natural gas, and other renewable energy in transportation fields, highlighting the importance of hydrogen energy in carbon dioxide peaking.
Oct. 2021	NDRC, National Energy Administration, MOF, Ministry of Natural Resources, Ministry of Ecology and Environment, Ministry of Housing and Urban-Rural Development, Ministry of Agriculture and Rural Affairs, China Meteorological Administration, National Forestry and Grassland Administration	The 14th Five-Year Plan for the Development of Renewable Energy	• This plan (i) promotes hydrogen production from renewable energy and promotes large-scale utilization of hydrogen, and (ii) aims to achieve a proportion of new energy-electricity consumption exceeding 70%.

Source: Frost & Sullivan

Overview of Hydrogen Industry

Favorable Policies/Regulations Regarding China's Regional Hydrogen Industry

Release Date	Issuing city/province	Policies	Comments
Aug. 2024	Shaanxi Province	Notice on Supporting the Development of Distributed Photovoltaics, Hydrogen Refueling Stations, and Hydrogen Vehicle Travel on Highways	• The Shaanxi Provincial Government announced that hydrogen fuel cell vehicles equipped with ETC devices will be fully exempt from highway tolls within the province starting from September 1.
Aug. 2024	Jilin Province	Notice on Implementing Discounts for Hydrogen Vehicles on Jilin Province Highways	• From September 1, 2024, hydrogen vehicles registered in Jilin Province equipped with ETC devices will be exempt from toll fees when traveling between toll stations on highways within Jilin Province with in 2 years.
Jul. 2024	Shanxi Province, Lüliang City	Several Policy Measures (Trial) to Promote the Development of the Hydrogen Energy Industry in Lüliang City	• Hydrogen vehicle toll fees will be reduced or exempted, road access will be granted to hydrogen vehicles, and for hydrogen vehicles weighing 12 tons or less, an off-peak travel policy will be implemented within urban areas.
Jun, 2024	Hong Kong	Strategy of Hydrogen Development in Hong Kong	• the Government has formulated the Hydrogen Strategy to address the technical challenges in the six major areas of safety, suitable technologies, infrastructure, cost effectiveness, capacity building and public acceptance, as well as the unique situation of Hong Kong.
May, 2024	Ordos, Inner Mongolia	Notice from the Ordos Municipal Transportation Bureau on Issuing the Implementation Plan for Toll Fee Subsidies for Hydrogen Energy Vehicles	• Starting from June 1, 2024, the first full subsidy policy for hydrogen energy vehicle toll fees in Inner Mongolia will be officially implemented. Hydrogen vehicles traveling through toll stations within Ordos City will have the full toll fee refunded in the following month after verification. The trial period for this policy is from June 1, 2024, to June 1, 2026.
Apr. 2024	Sichuan Province	Sichuan Province Further Promotes Action Plan for the Development and Popularization of the Hydrogen Energy Industry Chain (2024-2027)	• Across the province, relax restrictions on urban access for hydrogen fuel cell vehicles. Hydrogen-powered vehicles equipped with ETC devices will be exempt from toll charges on expressways in our province. The funds required for the exemption will be borne by the provincial finance.

Source: Frost & Sullivan

Overview of Hydrogen Industry

Favorable Policies/Regulations Regarding China's Regional Hydrogen Industry

Release Date	Issuing city/province	Policies	Comments
Feb. 2024	Shandong Province	Notice on the Temporary Exemption of Highway Tolls for Hydrogen Vehicles	• Starting from March 1, 2024, hydrogen vehicles equipped with ETC devices on provincial highways will be exempt from highway tolls for a trial period of two years. Upon expiration, adjustments will be made based on the implementation results.
Sep. 2023	Shandong Province	Notice on the Pilot Demonstration and Construction of Energy Green and Low Carbon Transition	• Encourage the development of wind power and photovoltaic power generation to produce hydrogen, and cultivate new modes of renewable energy development and utilization; actively promote the research and demonstration of nuclear energy desalination, nuclear energy to produce hydrogen, and so on.
Sep. 2023	Foshan	Foshan Peak Carbon Implementation Programme	• Strengthen the construction of hydrogen energy infrastructure. Promote the expansion of hydrogen energy demonstration and application, promote the agglomeration of elements of the hydrogen industry, cultivate and introduce advantageous backbone enterprises, realize the hydrogen industry to strengthen and supplement the chain, and create a hydrogen industry platform in the Greater Bay Area.
Aug. 2023	Zhangjiakou	Action Plan for Accelerating the Construction of Fuel Cell Vehicle Demonstration and Application Urban Cluster in Zhangjiakou City (2023-2025)	• By the end of 2023, a total of 765 fuel cell vehicles will be promoted, and by the end of 2025, the cumulative promotion is targeted to reach 1,130 or more fuel cell vehicles. During the demonstration period, the hydrogen production cost in our city is expected to decrease to below 30 RMB per kilogram. The city plans to establish no fewer than 14 hydrogen refueling stations.
Jun. 2023	Hebei Province	Measures of Hydrogen Industry Safety Management in Hebei Province	• Regulations on the Safety Management of Hydrogen Product Production, Storage, Transportation, Filling, and Utilization in the Administrative Region of Hebei Province.

Source: Frost & Sullivan

Overview of Hydrogen Industry

Favorable Policies/Regulations Regarding Global Hydrogen Industry

- **The overseas market for hydrogen energy presents a vast potential.**
- **Numerous countries are strategically positioning themselves in the hydrogen energy sector.** Firstly, against the backdrop of carbon reduction, hydrogen energy is a crucial decarbonization method, so many countries have been involved in such an industry. Secondly, some nations face energy security concerns and cannot sustain themselves solely on fossil fuels, relying on imports. Hydrogen, with widely distributed and abundant raw materials, offers an effective solution to those countries with energy challenges. Additionally, countries with abundant renewable resources, such as wind and solar power, can achieve low-cost hydrogen production, as seen in regions like the Middle East, North Africa, and Australia, further driving the development of the hydrogen industry overseas.
- **The hydrogen industry encompasses a lengthy value chain, providing extensive market opportunities.** The entire industry chain includes hydrogen production (electrolysis, industrial by-product hydrogen, etc.), hydrogen storage, transportation, and refueling. In the fuel cell sector, upstream components like bipolar plates, membrane electrodes, and sealing layers play a crucial role. The midstream involves fuel cell system integration, covering both the stack and auxiliary systems. Downstream applications mainly focus on various scenarios utilizing fuel cells. Moreover, hydrogen, aside from its use as an energy source, serves as a raw material in the chemical industry, widening the scope for downstream applications.
- Currently, many segments of the hydrogen energy value chain are in the early stages of development. Looking ahead, the market holds significant growth potential.

Release Date	Issuing Countries/Regions	Policies	Comments
Dec. 2023	Europe	National Hydrogen Strategy (France)	• By 2030, France plans to achieve 6.5 GW of low-carbon hydrogen capacity, reaching 10 GW by 2035. This target will be achieved through the country's low-carbon power mix, nuclear or renewable power, while following the principle of technological neutrality of hydrogen energy sources. • From January 2023, renewable hydrogen is eligible for this program. From January 2024, low-carbon hydrogen is also eligible, with a subsidy of up to 4.7 euros per kilogram.

Source: Frost & Sullivan

Overview of Hydrogen Industry

Favorable Policies/Regulations Regarding Global Hydrogen Industry

Release Date	Issuing Countries/Regions	Policies	Comments
Jul. 2023	Europe	The National Hydrogen Strategy (Germany)	• Germany has increased its 2030 capacity target for domestic hydrogen production from electrolyzed water from 5GW to 10GW, and expects hydrogen imports to account for 50-70% of the total hydrogen supply in 2030, and will further strengthen international cooperation and introduce a dedicated hydrogen import strategy. • In terms of hydrogen transportation, Germany will strengthen the expansion of hydrogen infrastructure networks such as pipelines and enhance international and domestic hydrogen transportation capacity. By 2027-2028, Germany will renovate more than 1,800 kilometers of hydrogen pipelines in the country and add about 4,500 kilometers of hydrogen pipelines in Europe, connecting all aspects of hydrogen production, storage, import and consumption by 2030.
Jul. 2023	Australia	Hydrogen Headstart	• On 9 May 2023, the Federal Government announced it will invest $2.0 billion in the new Hydrogen Headstart program (the Program) to accelerate the development of Australia's hydrogen industry, catalyze clean energy industries, and help Australia connect to new global hydrogen supply chains, to take advantage of hydrogen's immense jobs and investment potential.
Jun. 2023	Japan	Hydrogen Basic Strategy	• The government of Japan plans to contribute upfront investments worth 20trillion yen in order to attract the public and private sectors to Green Transformation initiatives-related investments and achieve combined investments of 150 trillion yen or moreover the next decade. • Japan plans to reduce hydrogen supply cost in Japan, to 30yen/Nm^3 by 2030 and to 20yen/Nm^3 by 2050; and expand the number of water electrolysis equipment with Japan-made parts in them, to approximately 15GW globally by 2030.

Overview of Hydrogen Industry

Favorable Policies/Regulations Regarding Global Hydrogen Industry

Release Date	Issuing Countries/Regions	Policies	Comments
Nov. 2023	Middle East	National Hydrogen Strategy (UAE)	• By 2031, the UAE hydrogen production capacity is targeted to reach 1.4 million tons/year, including 1.0 million tons of green and 400,000 tons of blue hydrogen capacity. • The UAE government plans to set up Hydrogen Oasis to promote the construction and development of the country's hydrogen industry chain in terms of policies, platforms and talents. (Two by 2031 and five by 2050).
Jun. 2023	North America	U.S. National Clean Hydrogen Strategy and Roadmap	• This policy explores opportunities for low-carbon hydrogen to contribute to national decarbonization goals across multiple sectors of the U.S. economy. It provides a snapshot of hydrogen production, transport, storage, and use in the U.S. • Pathways for clean hydrogen to decarbonize applications are informed by demand scenarios for 2030, 2040, and 2050 with strategic opportunities for 10 million metric tonnes (MMT) of clean hydrogen annually by 2030, 20 MMT annually by 2040, and 50 MMT annually by 2050.
Oct. 2022	Singapore	Singapore's National Hydrogen Strategy	• The Hydrogen Energy Strategy proposes the development of hydrogen energy as a key decarbonization pathway to support Singapore's international climate commitment to achieve net-zero emissions by 2050. • Singapore will take a phased approach to the adoption of low-carbon hydrogen. Singapore will closely monitor technological developments in different hydrogen carriers and applications at the endpoint and make major infrastructure investments accordingly to avoid stranded assets and land take.

Source: Frost & Sullivan

Overview of Hydrogen Industry

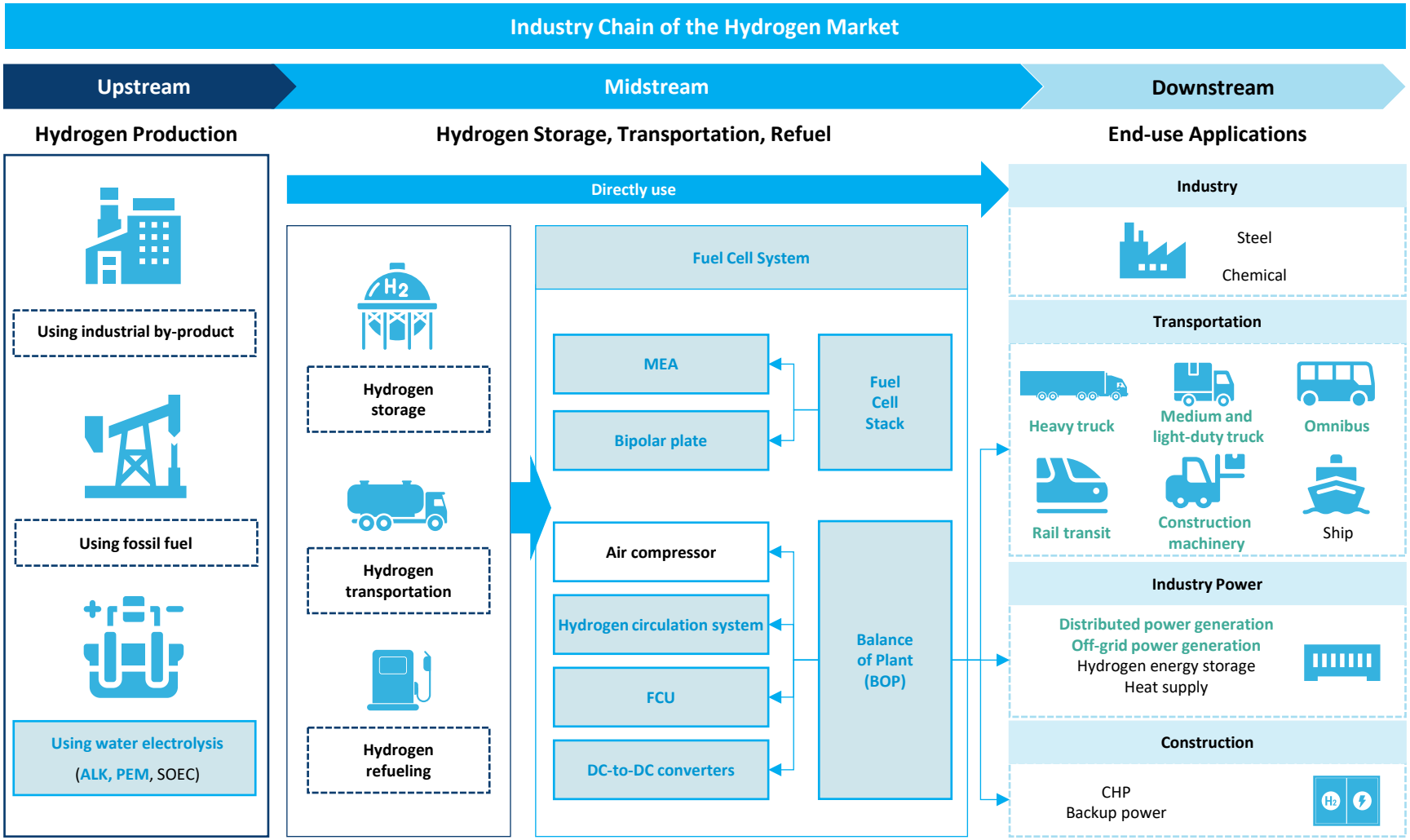
Favorable Policies/Regulations Regarding Global Hydrogen Industry

Release Date	Issuing Countries/Regions	Policies	Comments
Nov. 2021	Korea	Basic Plan for the Implementation of Hydrogen Economy	• "Basic Plan for the Implementation of Hydrogen Economy" is the first basic plan announced by the Ministry of Industry, Trade and Resources (MITR) since the implementation of the Korean Hydrogen Energy Act. • The government has set a goal of being able to produce 27.9 million tons of low-carbon hydrogen gas by 2050. Hydrogen is expected to be the largest source of energy in Korea in 2050, supplying 33% of energy consumption and 24% of electricity generation.
Dec. 2020	Canada	Hydrogen Strategy for Canada	• The focus of the next 5 years will be on laying the foundation for the hydrogen economy in Canada. This includes developing new hydrogen supply and distribution infrastructure to support early deployment HUBs in mature applications while supporting Canadian demonstrations in emerging applications. • By 2050, Canada could grow production by a factor of seven to meet domestic demand, producing >20 Mt of low-carbon hydrogen per year, with potential for significant expansion to meet global demand.
Jul. 2020	Europe	A hydrogen strategy for a climate neutral Europe	• From 2020 to 2024, we will support the installation of at least 6 gigawatts of renewable hydrogen electrolysers in the EU, and the production of up to one million tonnes of renewable hydrogen. • From 2025 to 2030, hydrogen needs to become an intrinsic part of our integrated energy system, with at least 40 gigawatts of renewable hydrogen electrolysers and the production of up to ten million tonnes of renewable hydrogen in the EU. • From 2030 to 2050, renewable hydrogen technologies should reach maturity and be deployed at large scale across all hard-to-decarbonise sectors.

Source: Frost & Sullivan

Overview of the Hydrogen Industry

Industry Chain of the Hydrogen Market



Note: 1. The blue-colored text represents items fall within our Group's business scope;
2. The downstream applications of the company's products are highlighted in green.

Overview of the Hydrogen Industry

Analysis of the Industrialization Progress _Hydrogen Production

Hydrogen Production Method	Fossil Fuel Hydrogen Production		Industrial By-Product Hydrogen Production		Hydrogen Production by Water Electrolysis		
	coal production	natural gas	Hydrogen production by COG	Hydrogen production by chlor-alkali	ALK	PEM	SOEC
Principal	coal gasification	steam reforming	PSA	deoxygenation, dechlorinate, and PSA	water decomposition by electrolysis		
Advantage	rich in coal reserves; mature technology; low cost	relatively low cost	Low cost	High purity of Hydrogen	relatively mature technology, relatively low cost	small size, suitable for renewable energy power generation	high energy conversion efficiency
Disadvantage	high carbon emission	high carbon emission	air pollution; geographic restrictions: Construction sites are limited by where raw materials are supplied	Construction sites are limited by where raw materials are supplied	the product should be dealkalilzed need a stable power supply	raw material includes Pt, a type of rare metal, which is of high cost. The supply of Pt mainly comes from foreign countries	Operate under high temperature

Source: Frost & Sullivan

Overview of the Hydrogen Industry

Analysis of the Industrialization Progress _Hydrogen Storage and Transportation

Hydrogen Storage and Transportation Method	Core technologies	Advantages	Disadvantages	Technology maturity
Gaseous state	High-pressure compression	• Low cost • Operate in normal temperature • Low energy consumption for hydrogen storage • Fast hydrogen charging and discharging	• Low hydrogen storage density • Large-scale container • Risks of leakage and explosion of container	Mature technology, the most widely used currently
Low-temperature Liquid state	low temperature insulation	• High energy density • High bulk density • Short refueling time	• Relatively high cost • High energy consumption of cooling • High requirement for insulation	Mature technology, mainly used in aviation fields
Organic liquid state	liquid organic hydrogen carriers	• High energy density • High stability • Safe • Convenient transportation • Carriers could be recycled many times	• Relatively high cost • High temperature for dehydrogenation • High energy consumption • Low hydrogen purity, chance of generating impurity gases	No major technical obstacles remain
Solid state	Physical or chemical Adsorption of hydrogen storage	• Safe • High density of hydrogen storage • High hydrogen purity for hydrogen purification • Convenient transportation • Fast hydrogen charging and discharging	• High cost • Hydrogen storage and release constraints, heat exchange is more difficult, hydrogen release needs to be done at higher temperatures	Still in the technology upgrading stage, and has been demonstrated in distributed power generation, wind power hydrogen production, and large-scale hydrogen storage.

Source: Frost & Sullivan

Overview of the Hydrogen Industry

Analysis of the Industrialization Progress _Hydrogen Refueling

The Procedure of the Hydrogen Refueling

Hydrogen Tube Trailer → Supply Cabinet → Compressor → Hydrogen Storage Tank → Hydrogen Dispenser → FCEV

Introduction of Key Device

	Compressor	Hydrogen Dispenser
Introduction & Localization Progress	• The compressor is the key device to refuel hydrogen into the gas storage system. The most important performance indicators of a compressor are the output pressure and gas containment. • There are three types of compressors, namely diaphragm compressors, liquid-driven compressors, and ion compressors. The diaphragm compressor is the most widely used, because of its strong hermetic sealing capacity and high output pressure. The second most widely used is the liquid-driven compressor, which has a simple structure but weak hermetic sealing. The ionic compressor is less widely used because of its complex manufacturing process and high cost. Although state-owned customers tend to choose foreign brands, domestic manufacturers master mature technology and have no technical bottlenecks in diaphragm compressors. As the domestic equipment has been proven safe and efficient, the localization is advanced.	• Hydrogen refueling machine is the core equipment for refueling station to refill hydrogen fuel. The refueling pressure is its main performance indicator. There are two common type of hydrogen dispensers, 35MPa or 70MPa. • The main structure and working principle of the hydrogen dispenser is similar to the natural gas refueling machine. The future development trend lies in the improvement in intelligence and safety of the refueling system.

Source: Frost & Sullivan

Overview of the Hydrogen Industry

Introduction to the Hydrogen Industry

Downstream Application of Hydrogen Energy

Transportation Industry	• Fuel cell vehicles are one of the important measures for the global road transportation industry to realize "carbon emission reduction" in the future. Benefiting by the technology innovation and breakthroughs, the cost of FCEV will reduce substantially in the future, and the penetration rate will be enhanced in certain scenarios. • In addition, with the advantages of lightweight and high calorific value of fuel, FCEV will be more focused on scenarios such as road freight, cold chain logistics, long-distance passenger transportation, and special operating vehicles, etc., which have higher requirements for the stability of recharge mileage.
Power Generation Industry	• To ensure zero carbon emissions and balance the power system, hydrogen fuel cell technology is crucial. In the future, stationary hydrogen fuel cell power generation solutions will be highly competitive in the stationary power sector. • Hydrogen fuel cells enable the conversion of electricity and hydrogen energy and can be used for long-term storage of large-scale renewable energy. Moreover, hydrogen production from electrolyzed water as a means of energy storage has the advantages of high energy conversion efficiency, low environmental pollution, and a small footprint.

Source: Frost & Sullivan

Overview of the Hydrogen Industry

Introduction to the Hydrogen Industry

Downstream Application of Hydrogen Energy	
Iron and Steel Industry	• The iron and steel industry is one of the largest carbon emitters, accounting for about 7.2% of global carbon emissions. Traditional steel production is characterized by high-temperature combustion and coke reduction reactions, resulting in high carbon emissions. The method of utilizing hydrogen instead of coke for the reduction reaction will be one of the most critical and promising solutions for the steel industry to reduce carbon emissions.
Chemical Industry	• Hydrogen is a widely used chemical raw material, especially in the fields of petroleum refining, ammonia synthesis, and methanol. Among them, petroleum refining, as the main process in the petrochemical industry, has a high demand for hydrogen. Almost all large refineries have on-site hydrogen production facilities and adopt natural gas reforming or coal gasification as the main hydrogen supply method.
Construction Industry	• The demand for hydrogen in the construction sector is mainly in the area of electrical energy consumption for heating. Hydrogen can be delivered as pure hydrogen or mixed with natural gas to large commercial buildings or district heating networks.

Source: Frost & Sullivan

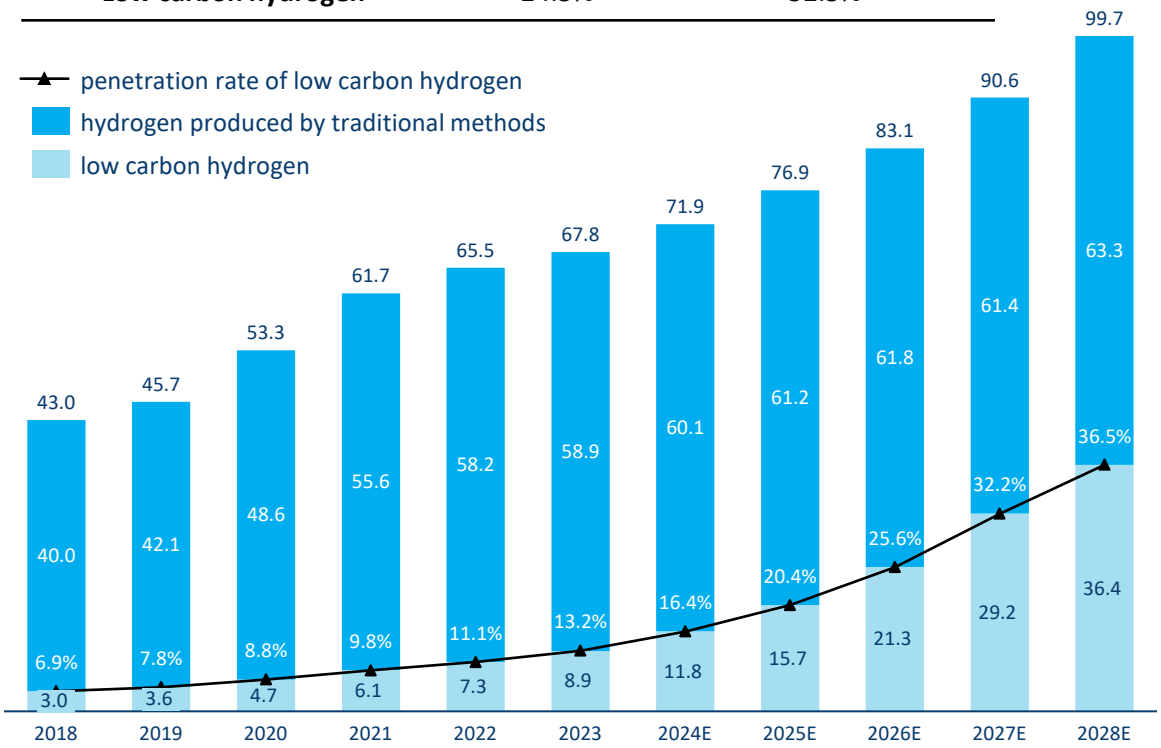
Overview of the Hydrogen Industry

Market Size of Global Hydrogen Consumption

Market Size of Global Hydrogen Consumption, by Volume

Million Tons, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	9.5%	8.0%
Low carbon hydrogen	24.3%	32.5%



Key Findings

- The market size of global hydrogen consumption is large, and increased from 43.0 million tons in 2018 to 67.8 million tons in 2023, with a CAGR of 9.5%. From the supply side, as technology advances, the cost of hydrogen production, storage, and transportation will reduce in the future. From the downstream demand side, the production, storage, and transportation costs for hydrogen are decreasing with technological advancements, stimulating the demand for hydrogen. Therefore, hydrogen will remain in strong demand in the future.
- In detail, low-carbon hydrogen will be the trend under the background of carbon reduction. The penetration of low-carbon hydrogen will experience a great increase and the low-carbon hydrogen consumption will increase from 8.9 million tons in 2023 to 36.4 million tons in 2028, with a CAGR of 32.5%.

Note: The low-carbon hydrogen refers to hydrogen produced from renewable energy sources and hydrogen processed by CCUS technology.

Source: IEA, Hydrogen Council, Frost & Sullivan

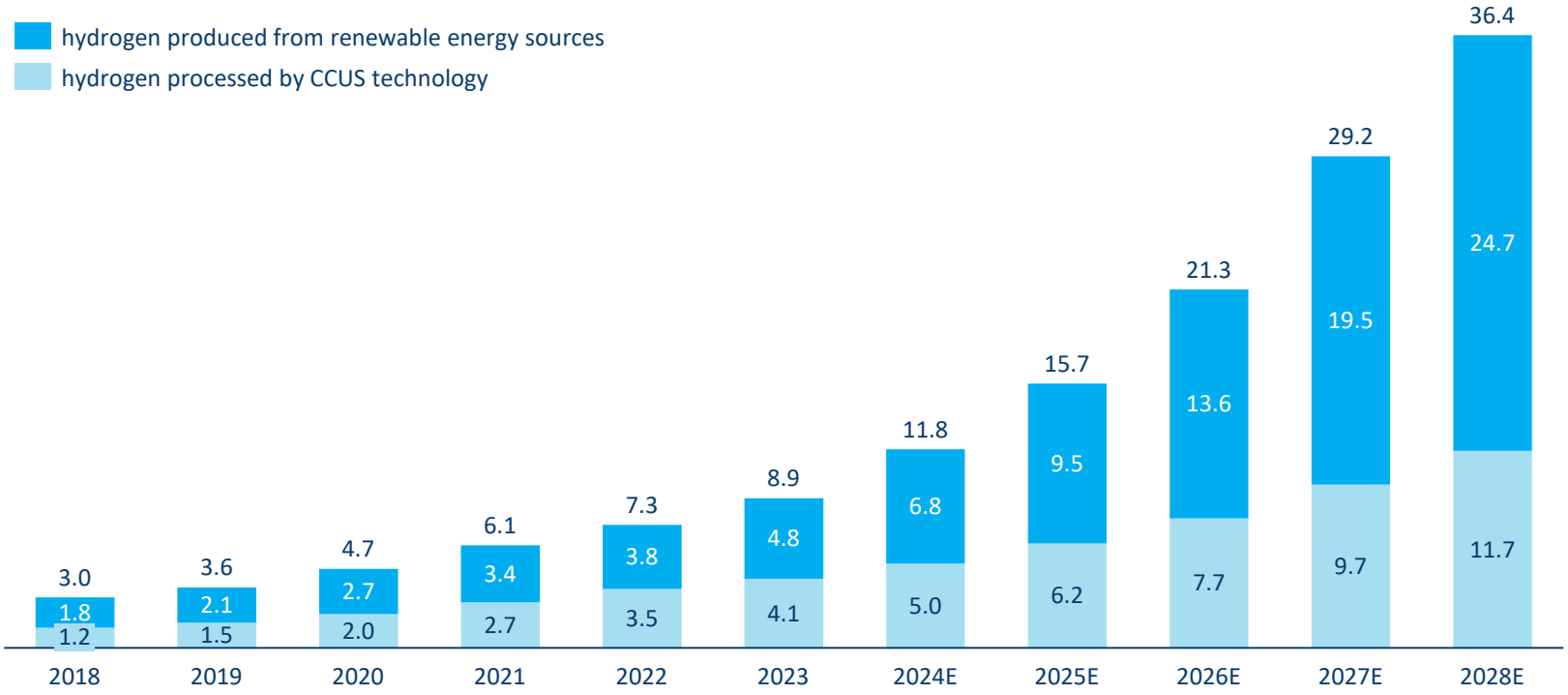
Overview of the Hydrogen Industry

Market Size of Global Hydrogen Consumption

Market Size of Global Low Carbon Hydrogen Consumption, by Volume

Million Tons, 2018-2028E

CAGR	2018-2023	2023-2028E
hydrogen produced from renewable energy sources	23.1%	38.8%
hydrogen processed by CCUS technology	27.9%	23.3%



Note: The low-carbon hydrogen refers to hydrogen produced from renewable energy sources and hydrogen processed by CCUS technology.

Source: IEA, Hydrogen Council, Frost & Sullivan

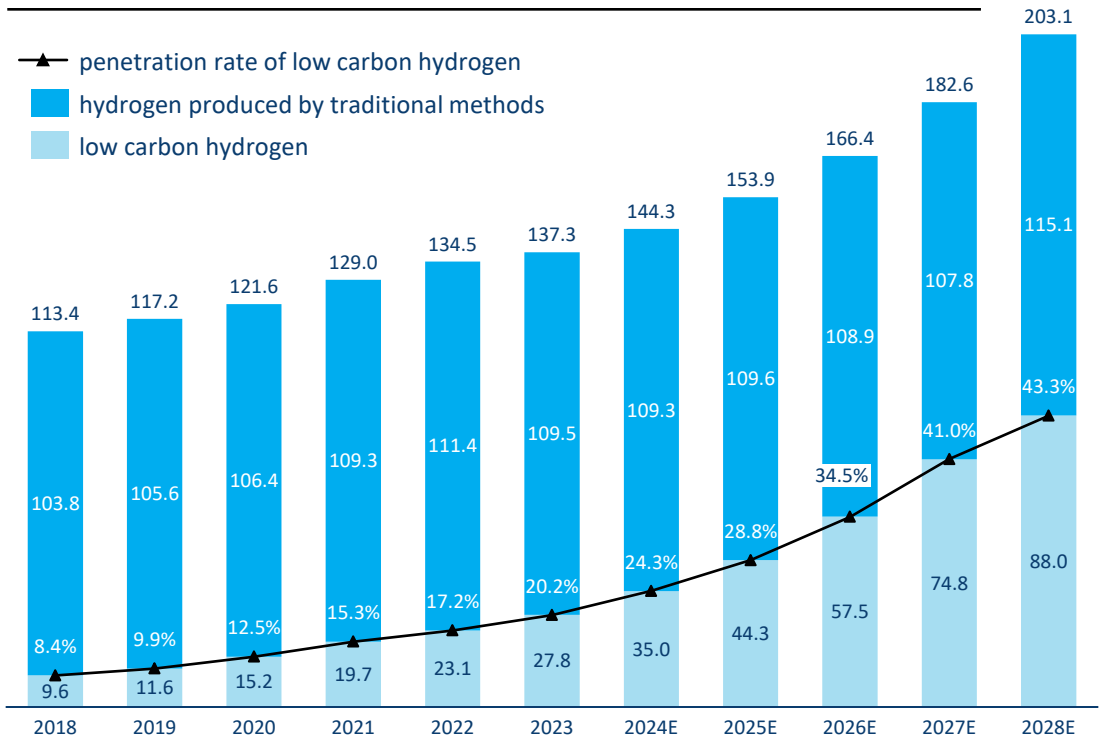
Overview of the Hydrogen Industry

Market Size of Global Hydrogen Consumption

Market Size of Global Hydrogen Consumption, by Value

Billion USD, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	3.9%	8.1%
Low carbon hydrogen	23.7%	25.9%



Key Findings

- The market size of the global and Chinese hydrogen consumption market refers to the corresponding output value in various fields of hydrogen consumption within the global and Chinese scope. Due to the close connection between the operation of the hydrogen industry and hydrogen consumption, this figure is one of the core indicators for measuring the development of the hydrogen energy sector.
- The market size of global hydrogen consumption value is great, and increased from USD 113.4 billion in 2018 to USD 137.3 billion in 2023, with a CAGR of 3.9%.
- In detail, low-carbon hydrogen will be the trend under the background of carbon reduction. The penetration of low-carbon hydrogen will experience a great increase and the low-carbon hydrogen consumption value will increase from USD 27.8 billion in 2023 to USD 88.0 billion in 2028, with a CAGR of 25.9%.

Note: The market size of global hydrogen consumption, by value, refers to the corresponding output value in various fields of global hydrogen consumption.

Source: IEA, Hydrogen Council, Frost & Sullivan

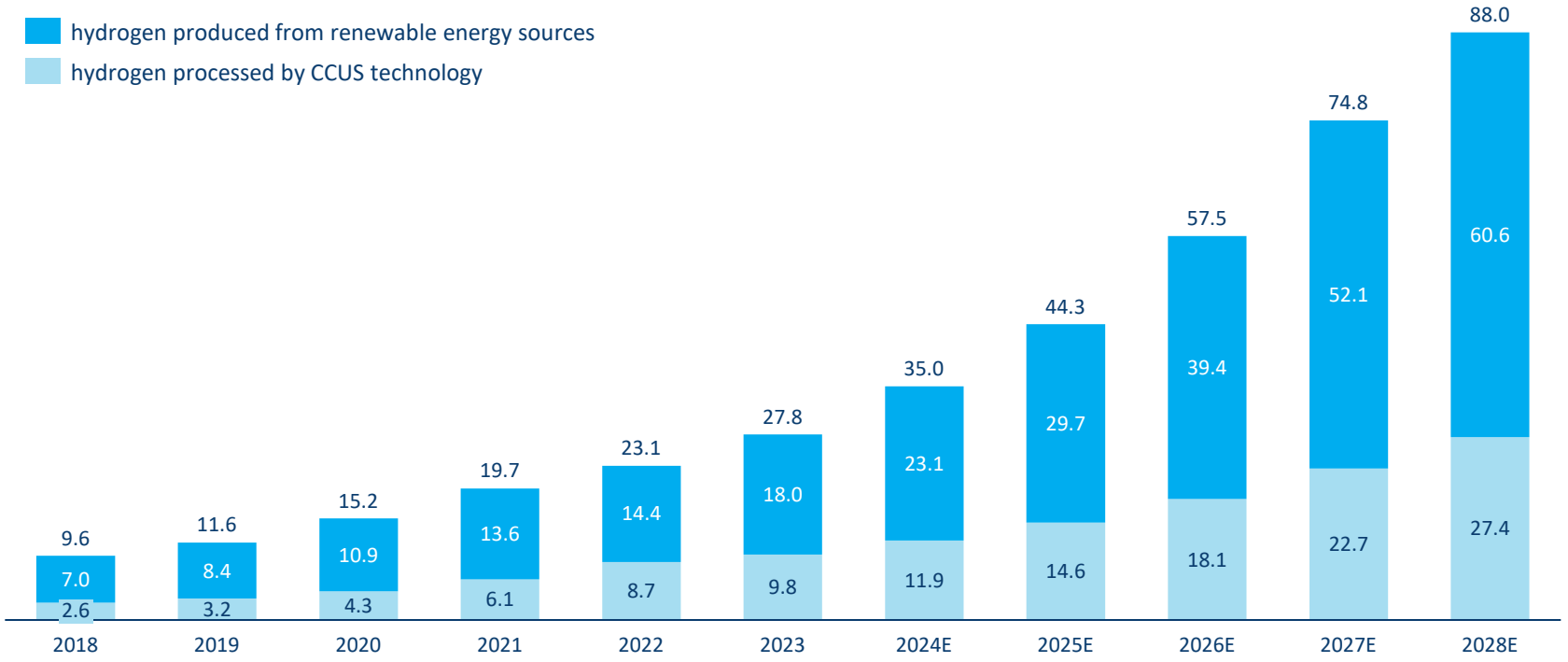
Overview of the Hydrogen Industry

Market Size of Global Hydrogen Consumption

Market Size of Global Low Carbon Hydrogen Consumption, by Value

Billion USD, 2018-2028E

CAGR	2018-2023	2023-2028E
hydrogen produced from renewable energy sources	20.8%	27.5%
hydrogen processed by CCUS technology	30.4%	22.8%



Source: IEA, Hydrogen Council, Frost & Sullivan

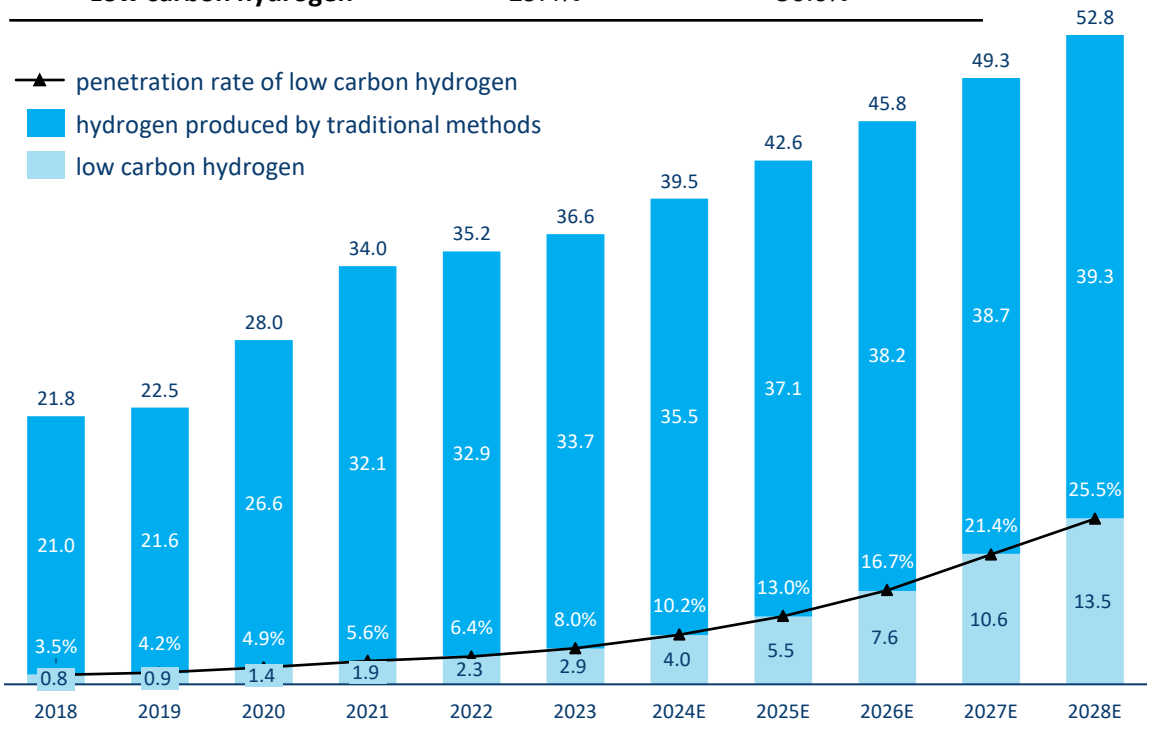
Overview of the Hydrogen Industry

Market Size of China's Hydrogen Consumption

Market Size of China's Hydrogen Consumption, by Volume

Million Tons, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	10.9%	7.6%
Low carbon hydrogen	29.4%	36.0%



Note: 1) The market size of China's hydrogen consumption, by volume, refers to the apparent consumption volume of hydrogen in China. (apparent consumption = current year imports - current year exports + current year production);
2) The low-carbon hydrogen refers to hydrogen produced from renewable energy sources and hydrogen processed by CCUS technology.

Key Findings

- In 2023, China holds approximately a 54.0% share of the global hydrogen consumption market in terms of consumption volume.
- The market size of China's hydrogen consumption volume refers to the apparent consumption volume of the hydrogen.
- The market size of China's hydrogen consumption is great, and increased from 21.8 million tons in 2018 to 36.6 million tons in 2023, with a CAGR of 10.9%. Since 2018, China's hydrogen consumption has been driven by technological developments in the downstream petrochemical and metallurgical industries. And using hydrogen as the reducing agent in the metallurgical industry has gradually become more common.
- As the sales of FCEV soar in China, the demand for hydrogen will increase. It is expected that hydrogen consumption in China will reach 52.8 million tons in 2028, with a CAGR of 7.6%.
- In the future, low-carbon hydrogen will be the trend and experience fast growth, increasing from 2.9 million tons to 13.5 million tons with a CAGR of 36.0%.

FROST & SULLIVAN 沙利文

Source: China National Coal Association (CNCA), National Alliance of Hydrogen and Fuel Cell (CHA), Frost & Sullivan

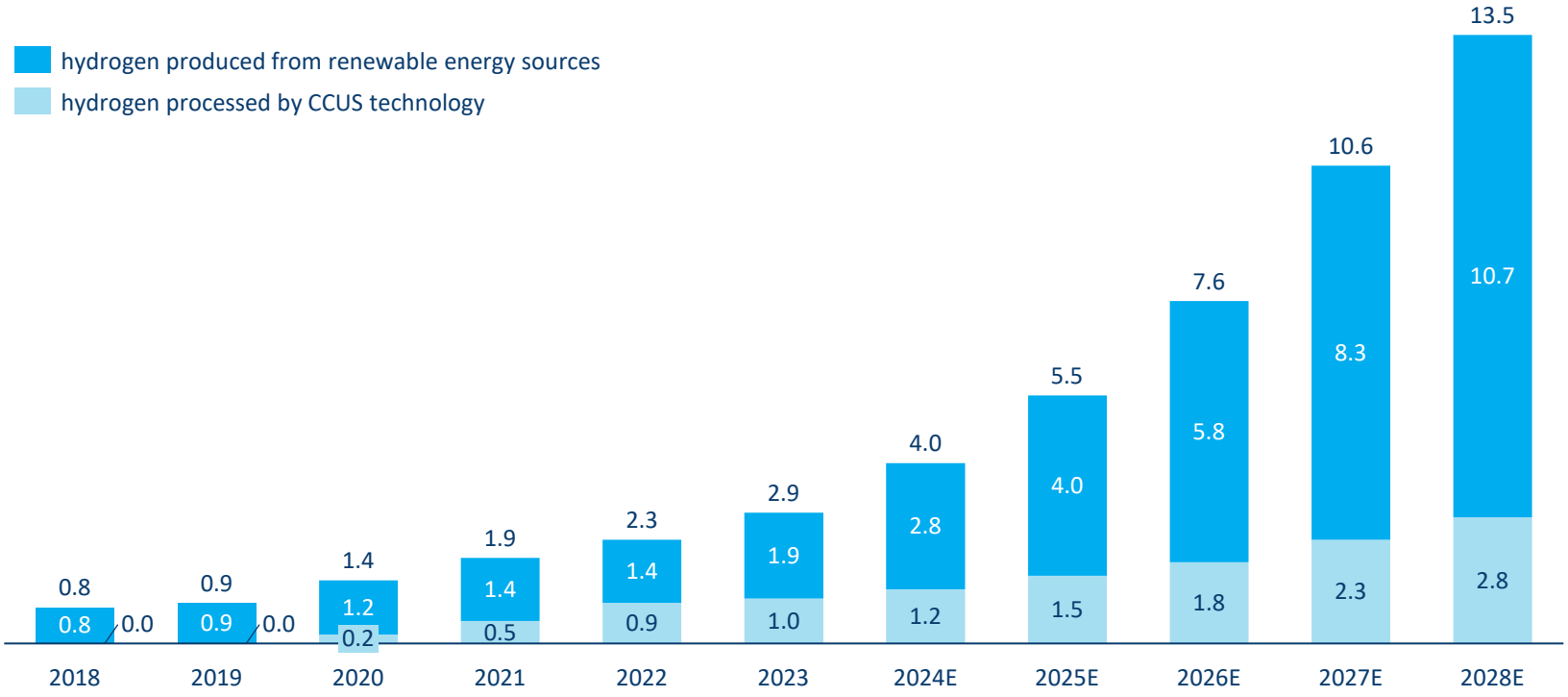
Overview of the Hydrogen Industry

Market Size of China's Hydrogen Consumption

Market Size of China Low Carbon Hydrogen Consumption, by Volume

Million Tons, 2018-2028E

CAGR	2018-2023	2023-2028E
hydrogen produced from renewable energy sources	18.9%	41.3%
hydrogen processed by CCUS technology	/	22.9%



Source: IEA, Hydrogen Council, Frost & Sullivan

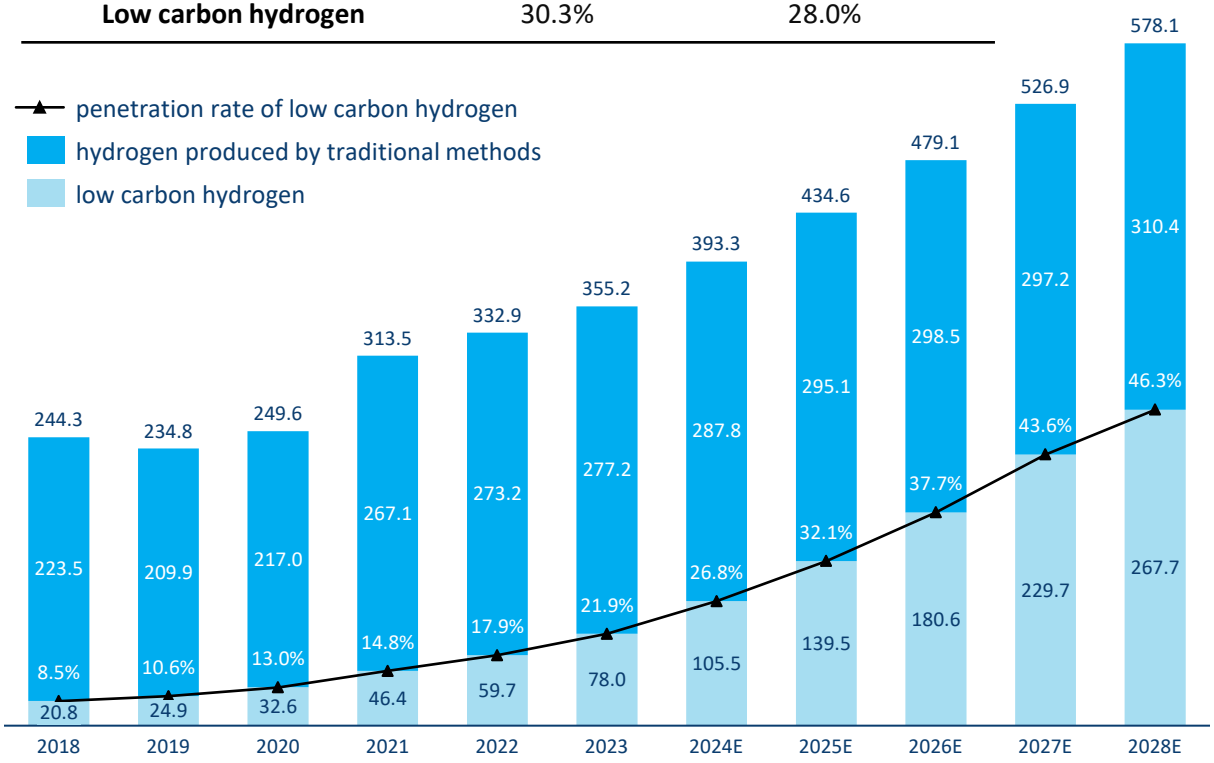
Overview of the Hydrogen Industry

Market Size of China's Hydrogen Consumption

Market Size of China's Hydrogen Consumption, by Value

Billion RMB, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	7.8%	10.2%
Low carbon hydrogen	30.3%	28.0%



Key Findings

- In 2023, China holds approximately a 36.9% share of the global hydrogen consumption market in terms of consumption value.
- The market size of China's hydrogen consumption value is great, and increased from RMB 244.3 billion in 2018 to RMB 355.2 billion in 2023, with a CAGR of 7.8%.
- As the sales of FCEV soar in China, the demand for hydrogen will increase. It is expected that hydrogen consumption value in China will reach RMB 578.1 billion in 2028, with a CAGR of 10.2%.
- In the future, low-carbon hydrogen will be the trend and experience fast growth, increasing from RMB 78.0 billion to RMB 267.7 billion with a CAGR of 28.0%.

Note: The market size of China's hydrogen consumption, by value, refers to the corresponding output value in various fields of hydrogen consumption in China.

Source: CNCA, CHA, Frost & Sullivan

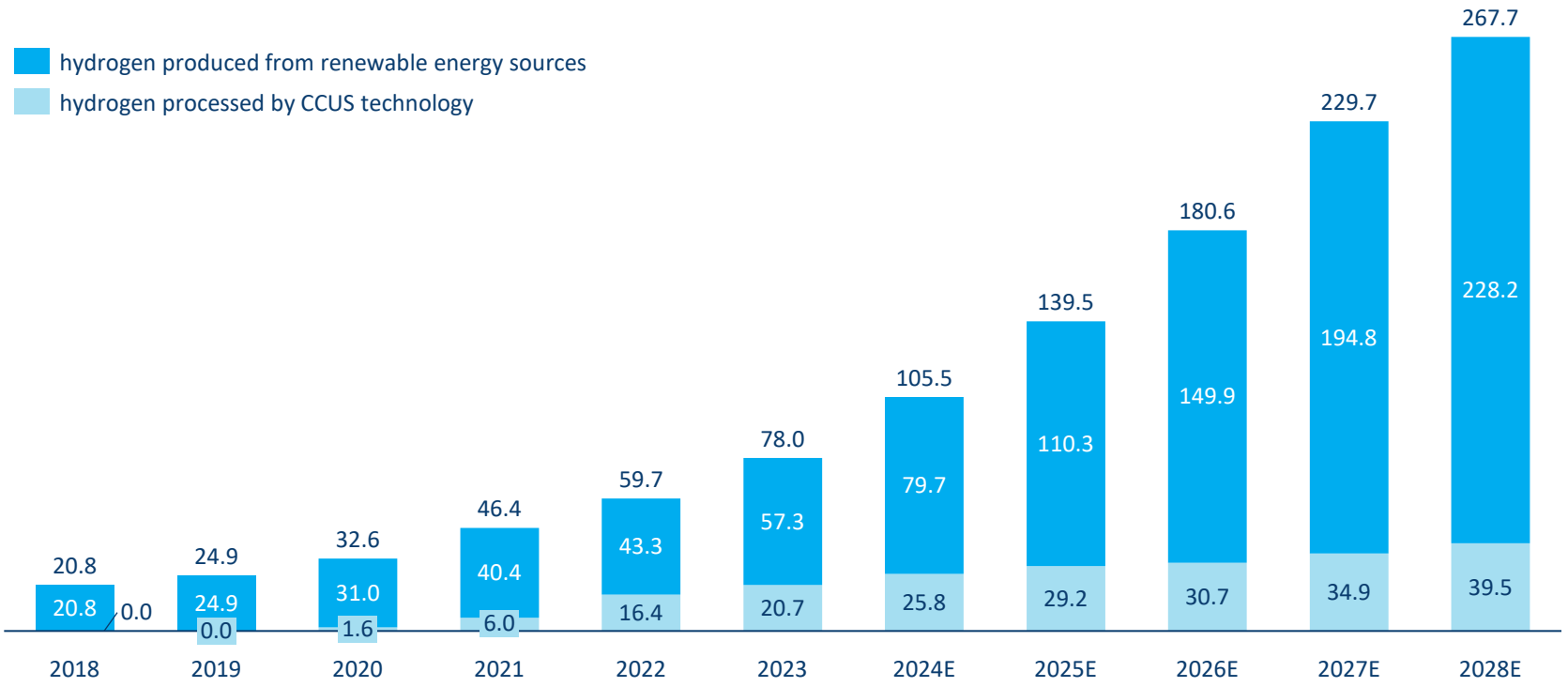
Overview of the Hydrogen Industry

Market Size of China's Hydrogen Consumption

Market Size of China Low Carbon Hydrogen Consumption, by Value

Billion RMB, 2018-2028E

CAGR	2018-2023	2023-2028E
hydrogen produced from renewable energy sources	22.5%	31.8%
hydrogen processed by CCUS technology	/	13.8%



Source: IEA, Hydrogen Council, Frost & Sullivan

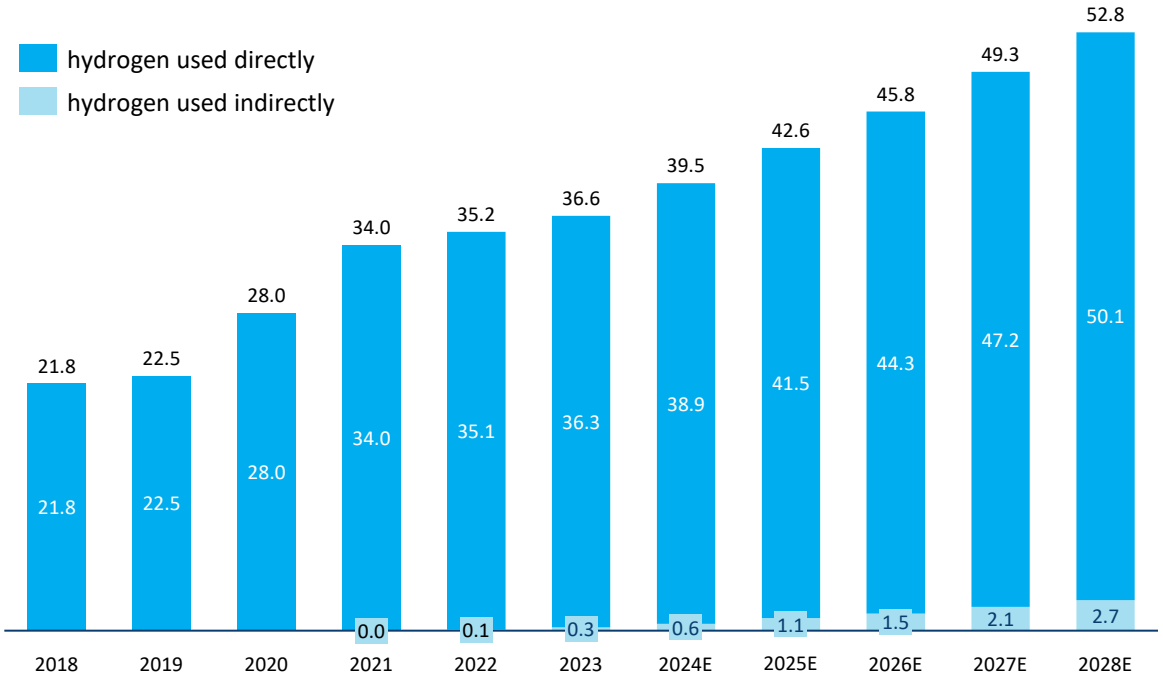
Overview of the Hydrogen Industry

Market Size of China's Hydrogen Consumption

Market Size of China's Hydrogen Consumption, by Volume

Million Tons, 2018-2028E

CAGR	2018-2023	2023-2028E
Hydrogen used directly	10.7%	6.6%
Hydrogen used indirectly	126.8%	59.9%



Note: Hydrogen could be directly used in the chemical industry, iron industry, and so on; hydrogen can be indirectly used in the transportation industry, electricity generation, construction industry, etc., through fuel cell systems.

Key Findings

- Currently, the chemical industry presents the most promising downstream application scenarios for direct hydrogen use. Hydrogenation closely follows, showing potential to emerge as the primary downstream application scene for direct hydrogen utilization in the future. Presently, industries like steel and chemicals demonstrate substantial demand for hydrogen absorption, leading to a greater proportion of directly applicable hydrogen usage. Looking forward, with the gradual proliferation of fuel cell technology in both passenger and commercial vehicle sectors, hydrogen will see growing application in transportation. Moreover, significant potential development opportunities exist for indirect hydrogen utilization in the medium to long term, especially in the construction and power generation sectors.

Source: China Hydrogen Alliance, Frost & Sullivan

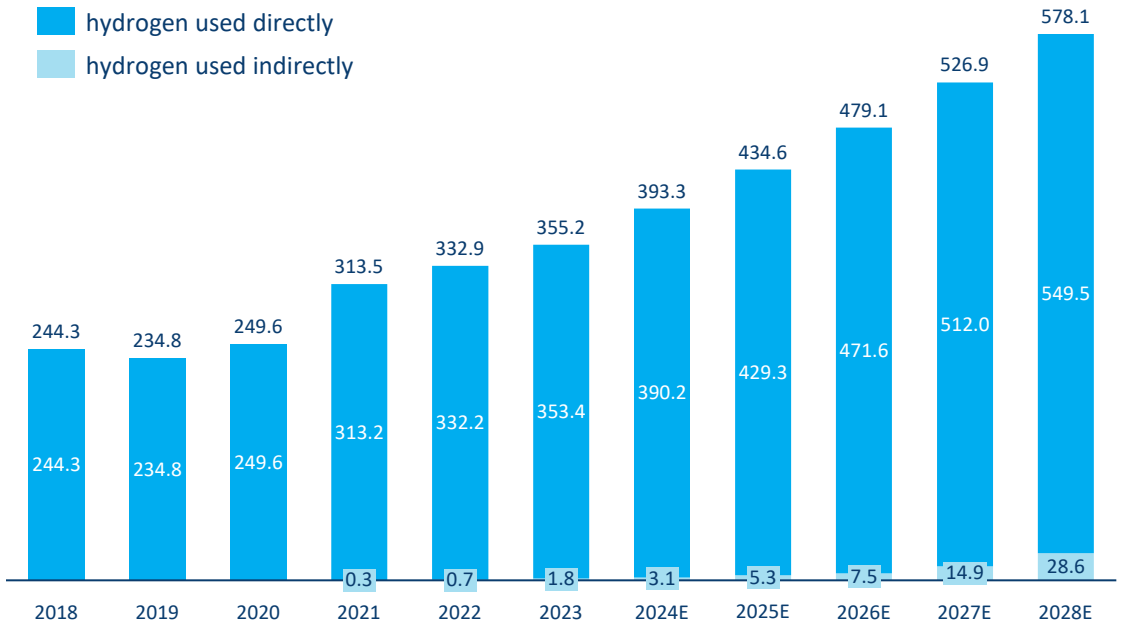
Overview of the Hydrogen Industry

Market Size of China's Hydrogen Consumption

Market Size of China's Hydrogen Consumption, by Value

Billion RMB, 2018-2028E

CAGR	2018-2023	2023-2028E
Hydrogen used directly	7.7%	9.2%
Hydrogen used indirectly	/	74.4%



Note: Hydrogen could be directly used in the chemical industry, iron industry, and so on; hydrogen can be indirectly used through fuel cell systems in the transportation industry, electricity generation, construction industry, etc

Source: China Hydrogen Alliance, Frost & Sullivan

Key Findings

- Currently, the chemical industry presents the most promising downstream application scenarios for direct hydrogen use. Hydrogenation closely follows, showing potential to emerge as the primary downstream application scene for direct hydrogen utilization in the future. Presently, industries like steel and chemicals demonstrate substantial demand for hydrogen absorption, leading to a greater proportion of directly applicable hydrogen usage. Looking forward, with the gradual proliferation of fuel cell technology in both passenger and commercial vehicle sectors, hydrogen will see growing application in transportation. Moreover, significant potential development opportunities exist for indirect hydrogen utilization in the medium to long term, especially in the construction and power generation sectors.

Market Analysis of Hydrogen Industry

Market Driver of China's Hydrogen Industry (1/2)

Market Driver	
The development of the hydrogen industry is a crucial pathway to ensure China's energy security	• Energy is vital to a nation's economy. From the perspective of energy structure, China has a high external dependence on energy sources such as crude oil and natural gas, making energy transition imperative. In addition, China is a high carbon emission country. In the context of China's commitment to achieving peaking carbon emissions by 2030 and achieving carbon neutrality by 2060, hydrogen energy, as a green energy source, holds strategic significance in China's development. Hydrogen can replace some traditional energy sources in industries, construction, transportation, and other sectors, promoting the overall development and transformation of high carbon-emitting industries towards low-carbon paths. Therefore, accelerating the development of the hydrogen industry is a crucial pathway to achieve carbon peaking and carbon neutrality goals, as well as to ensure China's energy security.
The sustainable development of renewable energy generation stimulates the demand for the hydrogen industry	• Driven by the combined forces of dual carbon targets and technological advancements, the costs associated with renewable energy generation are consistently decreasing, highlighting its economic viability. Consequently, in recent years, the installed capacity of renewable energy has been steadily increasing. Due to the fluctuating and intermittent nature of renewable energy sources such as wind and solar power, as well as factors like the distance between generation and consumption locations, power grids face a series of technical and economic challenges in accommodating these energy sources. The rapid development of renewable energy generation has stimulated the demand for grid integration. Hydrogen energy, being a relatively scarce form of long-duration energy storage, can assist in the large-scale integration of such renewable energy sources, enabling grid-scale peak shaving and cross-seasonal, cross-regional energy storage. For example, during periods of low electricity demand, abundant wind and solar power can be utilized for electrolysis to produce hydrogen, storing the energy in the form of hydrogen. During peak demand, the stored hydrogen can be used for power generation through hydrogen fuel cells, achieving peak load balancing through the "electricity-hydrogen-electricity" conversion. Therefore, with the continuous development of renewable energy generation, hydrogen energy, as an effective grid integration solution, is poised for rapid growth.

Source: Frost & Sullivan

Market Analysis of Hydrogen Industry

Market Driver of China's Hydrogen Industry (2/2)

Market Driver	
More favorable policies to support the growth of the industry	• Hydrogen energy is an abundant, green, low-carbon, and widely used secondary energy source, which is gradually becoming one of the important parts of the global energy revolution. In the face of the growing challenge of the climate crisis, China is pushing to achieve its goal of carbon neutrality, and hydrogen, as an important part of clean energy, is gaining more and more attention from the country. Hydrogen energy is a crucial part of the future national energy system, a strategic emerging industry, and an important instrument for China to achieve the goal of carbon neutrality. In recent years, a series of hydrogen industry support policies have been introduced at the national, provincial, and municipal levels, forming a relatively complete policy support system.
Hydrogen production, storage and transportation costs are decreasing with the development of technology	• A significant impediment to the development of a hydrogen industry was the high production and utilization cost of hydrogen produced from renewable energy sources. The cost of hydrogen production through water electrolysis remains high, attributable to factors such as high electricity prices and the demanding nature of the technology. However, as various technologies continue to advance in the future, corresponding costs are expected to decrease. As the costs of producing hydrogen from renewable energy sources decrease, the hydrogen industry will see efficient growth. • In addition, there is a geological mismatch between the supply and demand of hydrogen energy in China. While the demand of hydrogen resources is much higher in the eastern and southern area of China, the supply of China's hydrogen resources is mostly located in the western and northern region in China. Therefore, efficient and low-price hydrogen storage and transportation technology is the necessary guarantee for the development of the hydrogen industry. Currently, ambient temperature high pressure hydrogen gas storage is China's most mature hydrogen storage technology. In the future, low temperature liquid hydrogen storage, organic liquid hydrogen storage, and solid hydrogen storage will continue to develop, aiming to achieve low-cost and efficient hydrogen storage. In terms of transportation, the currently technically mature and economically feasible transportation method is primarily gaseous hydrogen transport. With the expansion of the hydrogen industry, the cost of hydrogen transport will keep reducing.

Source: Frost & Sullivan

Market Analysis of Hydrogen Industry

Future Trend of China's Hydrogen Industry

Future Trend	
Transition from policy-driven to market-driven	• The hydrogen industry in China is transitioning from being primarily influenced by policies to being more market-driven. In 2020, China introduced the support policy of "Awards in lieu of Subsidy", aiming to promote the domestic production of key components and the commercialization of hydrogen vehicles. Recent technological advancements along the industry chain have led to a gradual reduction in the cost of hydrogen production. The hydrogen industry's reliance on policies is expected to decrease as technological progress and market competition become the driving forces behind its development. On the production side, the decreasing cost of hydrogen production is influenced by the lower cost of industrial by-product hydrogen and the downward trend in wind and solar electricity prices. Breakthroughs in pipeline and liquid hydrogen transport have addressed large-scale transportation challenges, reducing the overall transportation cost of hydrogen. Additionally, the localization and scale production of core equipment are contributing to a decrease in refueling costs. As the different segments of the industry chain progress together, the economic viability of hydrogen is becoming increasingly apparent, marking a shift from policy-driven to market-driven development.
The integrated projects of "generating electricity through renewable energy sources – electrolysis – downstream consumption with hydrogen fuel cells" will be involved in the future trend	• The future trend is also expected to involve integrated projects that combine renewable energy generation, electrolysis for hydrogen production, and downstream consumption in fuel cells. Common hydrogen application areas include regions with abundant renewable energy resources and high local demand for hydrogen. In such areas, hydrogen is produced through electrolysis using renewable energy, and the produced hydrogen is used for fuel cells in vehicles, providing a solution for local hydrogen-powered transportation. Alternatively, in areas with significant demand for large-scale, long-term flexible grid adjustments, hydrogen can be produced through electrolysis using renewable energy. When electricity is needed, hydrogen fuel cells can be used for distributed power generation. Leveraging the conversion technology of power-hydrogen-power, the advantages of hydrogen as a long-term and large-capacity energy storage can be harnessed. In addition, in the case of excess electrical energy, the surplus portion can be converted into hydrogen, and hydrogen can be further processed into ammonia alcohol, providing expanded capacity for hydrogen consumption. In the future, the development of the "electricity-hydrogen-ammonia alcohol" is also expected to be involved in the future trend.

Source: Frost & Sullivan

Market Analysis of Hydrogen Industry

Future Trend of China's Hydrogen Industry

Future Trend

The cost of producing hydrogen from renewable energy sources is expected to decline while its penetration rate will increase

- The main costs of producing hydrogen from renewable energy sources are electricity and equipment depreciation. Therefore, reducing electricity prices and electrolysis equipment costs are the two key factors for achieving the industrialization and scalable production of such hydrogen. In recent years, the cost of renewable energy generation has further decreased, and the large-scale and modular development of electrolysis cells has lowered their prices, contributing to the overall reduction of costs of producing hydrogen from renewable hydrogen sources. Specifically, according to data from the National Energy Administration, from 2013 to 2023, the costs of electricity generation from wind power and photovoltaic (PV) power have decreased by approximately 60% and 80%, respectively. With the continuous improvement of related infrastructure construction, the installed capacity of wind power grew from over 76 million kilowatts to around 440 million kilowatts; the installed capacity of photovoltaic power increased from around 19 million kilowatts to around 600 million kilowatts. The economies of scale in installed capacity of such power sources will further drive down the cost of generating such renewable power, which in turn drive down cost of electricity generation from such power sources. The cost of hydrogen production equipment is also continuously decreasing. Currently, ALK and PEM are still the mainstream methods for water electrolysis hydrogen production, with ALK being the most commonly used method. The selling price of ALK equipment has shown a significant downward trend in recent years, dropping from about RMB1,998.5/kW in 2018 to about RMB1,194.3/kW in 2023, with a CAGR of -11.4%. It is expected that there is still room for further reduction in the future. With additional requirements for carbon reduction, the proportion of hydrogen produced from traditional methods is expected to decline continuously, and the penetration rate of green hydrogen will continue to increase.

Agenda

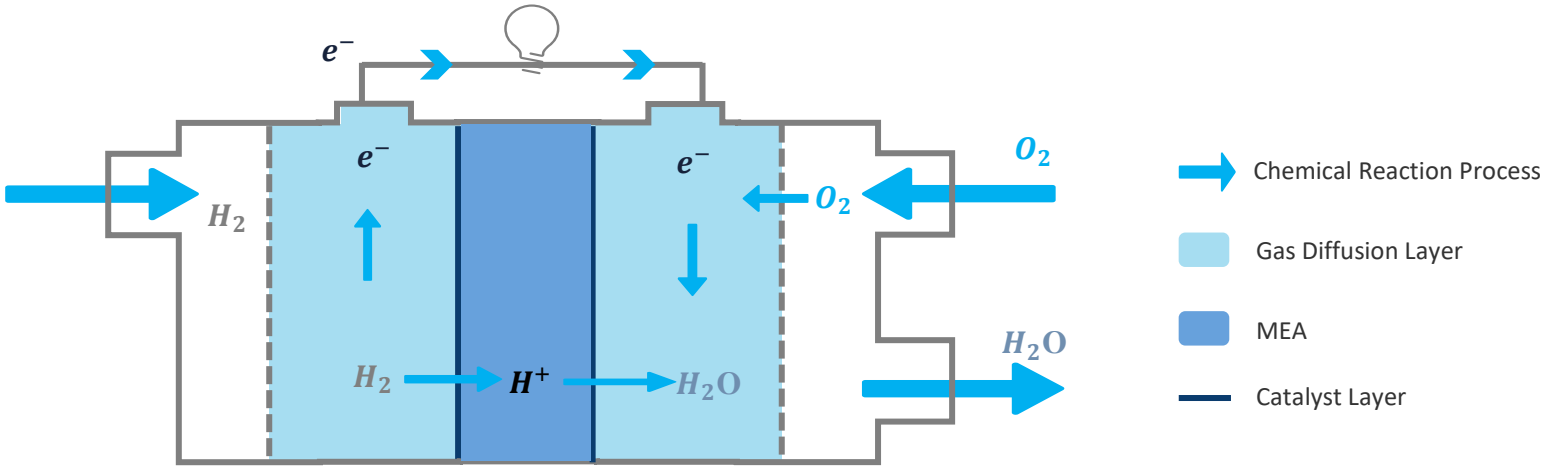
Overview of the Fuel Cell Industry

Introduction to the Fuel Cell

Definition and Working Principle

- A hydrogen fuel cell is a power generation device that directly converts its chemical energy into electrical energy through the reaction of hydrogen and oxygen. Because hydrogen energy has the advantages of high heating value and zero carbon emission, hydrogen fuel cells can be used as an ideal power generation device.

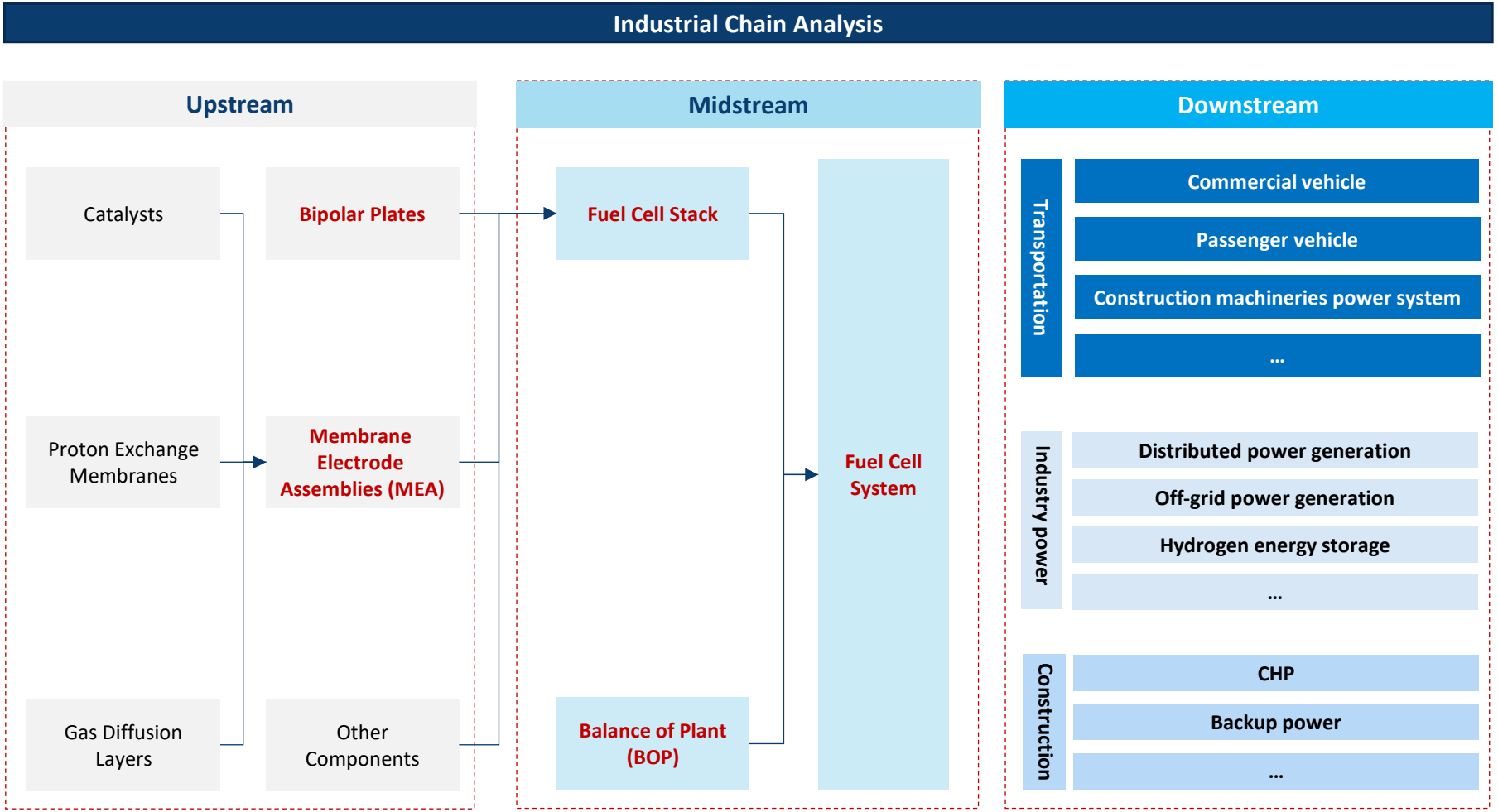
- The basic working principle of hydrogen fuel cell is the inverse reaction of electrolysis of water. Hydrogen and oxygen are supplied to the anode and cathode respectively, and hydrogen is oxidized to form hydrogen ions and electrons at the anode in the presence of the catalyst. Hydrogen ions pass through the electrolyte or the diaphragm and react together with the oxygen near the cathode and the electrons. The reduction-oxidation reaction occurs to generate water and heat. The electrons generated by the whole reaction generate electric current through the external circuit, which is the power generation process of the hydrogen fuel cell.



Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Industrial Chain Analysis



Note: products circled in red are those produced by REFIRE.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Upstream Analysis

Main Players of PEM

- Globally, the main players producing PEM are U.S. Gore, Chemours, Dow, 3M, Belgium Solvay, etc., of which Gore occupies a leading position in the industry's technology with its 8-micron thin membrane manufacturing capability. The gap between domestic and overseas PEM technology is not obvious, and the main obstacle to the commercialization of domestic membrane is reflected in the unstable quality brought about by the low scale of the industry.
- In fact, domestic chemical giants led by Dongyue have completed the development of domestically produced commercial PEM and have put them into production in small batches. In 2019-2022, Dongyue has become the largest domestic player with the largest share of the domestic market, with the total market share trailing only Gore and Chemours. Dongyue has a full industrial chain of raw materials, intermediates, monomers, and polymer membranes, and has built the nation's only production line for synthesizing perfluoroacid plasma membrane resins, which has been mass-produced and supplied in bulk.

Performance Indicator	China	World
Capacity（m^2/year）	~5000	1000000
Thickness Consistency（μm）	±2	±1
Swelling Rate	2%~5%	2%
Comprehensive Durability（h）	>6000	>6000
Pressure（MPa）	>30	>30
Equivalent mass of film-forming polymer（EW）	700~1100	700~1100

Overview of the Fuel Cell Industry

Upstream Analysis

Main Players of GDL

- The gap between China's GDL technology and foreign countries is not significant, but the commercialization gap is obvious. Domestic carbon paper-based materials laboratory technology can be benchmarked against some of the international level of advanced products, but there is no batch commercialization of products, the main R&D companies are Taiwan Carbon, General Hydrogen, Jiangsu Hydrogen Power, Qingneng Group, Shanghai Hesen Electric and so on.
- International companies are mainly Japan Toray, Mitsubishi, Canada Ballard Power Systems, Germany SGL Group and the U.S. E-TEK company. Toray Corporation in Japan in 1971 started to engage in the production of carbon fiber products. It is the world's largest supplier of carbon fiber products. Other companies are mainly based on the company's carbon products as the base material and have achieved large-scale production of gas diffusion layer. There are a variety of products to adapt to different scenarios for sale.

Performance Indicator	China	Global
Void ratio（%）	78.7	78
Air permeability【m^3 /（m^2·h'kPa）】	2,278	1,883
Graphitization Extent（%）	82.8	66.5
Resistivity（×103Ω m）	2.17	66.5
Tensile strength（N cm）	30.2	50

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Upstream Analysis

Main Players of Catalyst

- Now, China's platinum catalysts still relies on import, and the domestic industry is gradually maturing. Tanaka Precious Metals (Japan), Johnson Matthey (UK) and Unimicron (Belgium) are the world's largest suppliers of fuel cell catalysts, and possess the leading technology. These players are capable of realizing large-scale production (more than 10kg/batch) with stable performance and high reliability.
- Sino-Platinum Metal, Wuhan Himalaya, CSTC, Hydrogine Technology and WUT Hypower are the representative enterprises that carry out catalyst development in China. Among them, Sino-Platinum Metal is one of the five well-known international precious metal companies, with an early layout in the field of fuel cell catalysts, and is the only listed company in the industry. Sino-Platinum Metal has developed platinum-based catalysts in cooperation with SAIC. According to the official website of Hydrogine Technology, the platinum alloy catalyst developed by the company can reduce the platinum consumption of fuel cells by 7%, and it is the first platinum alloy catalytic product for fuel cells to realize mass production in China.

Performance Indicator of Catalyst of Hydrogine Technology	HPEC-151	HPEC-161
Component	Pt/C	Pt/C
ESCA(m^2/gpt)	60-70	50-60
A/mg Pt	0.2	0.18
Feature	Highly active	Balanced

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

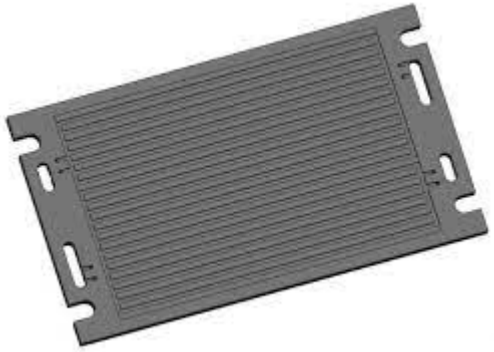
Upstream Analysis

Main Players of Bipolar Plate

- Bipolar plate can be divided into two types: graphite bipolar plate and metal bipolar plate. From the perspective of downstream application, graphite bipolar plates have strong durability, low density and large volume, which is suitable for long time work and large commercial vehicles, and is the ideal choice for fuel cells in large vehicles such as buses and medium and large freight vehicles.

- Due to the large scale of applications in commercial vehicles and relatively mature technology, graphite bipolar plates occupy more market share in China and basically achieve localization. Hyundai, Honda, Toyota and General Motors mainly use metal bipolar plate because their products are mainly passenger vehicles while American POCO, SHF, Japanese Fujikura Rubber and Canadian Ballard mainly develop graphite bipolar plates.
- Currently, the major domestic players in bipolar plate production are Refire, Sinosynergy, Sinosteel Tianyuan. Foreign players mainly producing metal plates include Dana, Grabener and treadstone, etc.
- Now domestic metal bipolar plates have gradually entered the testing stage. The composite plate is still in the laboratory research and development stage, the main R&D units are Wuhan University of Technology, Wuhan Himalaya, Sunrise Power.

Graphite Bipolar Plate



Metal Bipolar Plate

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Midstream Analysis

Companies that focus on fuel cell field	• Companies that originated from the fuel cell system business, such as Sinohytec, Refire, Dongfang Electric, have been focusing on system integration technology in the early stage of their business, purchasing key components from upstream suppliers and assembling them into fuel cell systems for sale to downstream OEMs. Driven by the rapid development of the market, midstream traditional integration players have begun to layout the hydrogen fuel cell as the core technology, penetrate the upstream manufacturing of key components, and downstream operation and service. Some of the top players, such as Refire, SinoHytec and Sino-synergy, have already possessed the ability to independently produce core modules, such as fuel cell stacks, by actively developing their own fuel cell stack technology. Among them, Refire not only possesses the stack technology but also has independent research and development capabilities for core components such as membrane electrodes, bipolar plates, and hydrogen circulation systems. • **Fuel cell systems have demanding requirements for performance attributes such as reliability, stability, and lifespan. This presents certain research and development barriers. In the industry, fuel cell stack manufacturers, lacking system integration capabilities, often seek collaboration with well-known system integrators.**
Cross-Industry Player	• Domestic vehicle enterprises have the ability to produce fuel cell passenger cars: SAIC Motor, GAC Motor, Dongfeng Motor and other domestic vehicle enterprises are actively researching and developing hydrogen fuel cell passenger cars, the fuel cell system engine and the whole hydrogen fuel cell car already could be localized.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Downstream Analysis

Application of Fuel Cell

- As a completely clean and non-polluting energy solution, hydrogen fuel cell has abundant downstream application scenarios in the context of carbon neutrality.
- Now the main application of hydrogen fuel cell in China is in the field of FCEV. FCEV is widely used in large commercial vehicles such as freight heavy trucks and buses, which is one of the important sources of carbon emissions in the current society. In addition, fuel cells are gradually being applied to other transportation sectors such as ships, rail vehicles, and aviation.
- Hydrogen fuel cell applications cover a wide range of transportation vehicles, providing a powerful carbon reduction and zero carbon solution for the world. In addition, given the excellent power storage performance of hydrogen fuel cells, stationary power supply, and portable power supply are also highly potential application scenarios in the future. The scenarios below are listed in accordance with the level of commercialization.

Commercial Vehicle

- The main application scenario of domestic fuel cell systems is commercial vehicles. FCEV boast powerful performance, with significantly longer operational time and mileage compared to electric cars, along with enhanced safety features. Currently, the main demonstration applications of hydrogen fuel cell commercial vehicles are concentrated in the fields of logistics, buses, etc. Under the incentives of industrial subsidies and national support policies, China's commercial vehicle applications of hydrogen fuel cells in buses and logistics vehicles have been ahead of other scenarios.

Stationary Power

- Stationary power includes all fuel cells operating in a fixed position as the main power source (power station), standby power source, or cogeneration, such as distributed power generation and waste heat supply, etc. They are mainly used for commercial, industrial, and residential power generation. Compared to traditional power generation systems, fuel cell power generation offers high efficiency, minimal transmission losses, and contributes to the reduction of carbon dioxide emissions. With tech development, stationary power demonstration projects based on fuel cell will be launched gradually.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Downstream Analysis

Construction Machinery

- Construction machineries, such as forklifts, cranes, mining trucks, and concrete mixers, also serve as important downstream applications for fuel cell systems. For example, hydrogen fuel cell forklifts is primarily utilized in efficiently handling materials over short distances in both indoor and outdoor fixed locations, typically within a 1-kilometer radius. Positioned within the framework of the “dual carbon” initiative, hydrogen fuel cell forklifts emerge as an attractive alternative to internal combustion forklifts. They offer compelling advantages, including zero pollution emissions, environmental sustainability, swift refueling, resilience in low temperatures, robust power, and consistent output. As technology matures and costs decline, such applications become a preferable choice, particularly in demanding operational scenarios involving heavy loads, low temperatures, and extended durations.

Passenger Vehicle

- Because passenger vehicles are better positioned to lead technological advancements and have a larger user base, they will inject sustained and robust momentum into the long-term development of fuel cell vehicles. The early demonstration and operation of commercial vehicles will generate a pioneering effect, driving collaborative progress across the entire fuel cell industry chain, resulting in favorable factors such as cost reduction. In recent years, with the combined effect of policy-driven and other favorable factors, China's fuel cell passenger car market has been initially formed, and SAIC EUNIQ 7, BAIC EU7 FC, and other models are ready for mass production or planned to be listed.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Downstream Analysis

Ships

- The application of hydrogen fuel cell technology in ships can achieve high energy efficiency, and zero emissions, and enhance the comfort of vessels, making it an ideal green propulsion system for ships.
- China‘s hydrogen fuel cell ships are still in the inspection stage. In May 2022, Wuhan Institute of Standard Research of China Classification Society completed the first batch of drawings of "Three Gorges Hydrogen Boat 1", marking China's first hydrogen fuel cell-powered ship formally entered into the stage of project classification and inspection. As of October 2023, China’s first hydrogen fuel cell-powered demonstration ship, the “Three Gorges Hydrogen Boat 1” completed its maiden voyage.

Rail Transit

- The hydrogen fuel cell power system allows rail to break free from the overhead line traction power system, reducing infrastructure investments. It also features low noise, minimal pollution, and a long lifespan.
- In 2013, Southwest Jiaotong University developed the "Blue Sky" using 150KW fuel cells as traction power, which is China's first hydrogen fuel cell electric locomotive.

Aviation

- Hydrogen, as a fuel, enhances the net thrust output of the engine and reduces fuel consumption rates. The application of a fuel radiator effectively improves engine performance. Hydrogen fuel cells have significant potential for application in the aviation sector.
- The application of fuel cells in aviation mainly focuses on drones and aviation vehicles. Among them, drones require lower output power of batteries, while aviation vehicles require higher output power of fuel cells. In 2017, the Dalian Institute of Chemical Physics made the first flight of China's first batch of fuel cell airplanes in Northeast China.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Downstream Analysis

Forklifts

- Compared to passenger cars, commercial vehicles and other applications, forklift trucks are expected to become the forefront of fuel cell applications by virtue of the smallest operating range, lighter body mass, lower technical requirements for fuel cell systems and other inherent characteristics.

Cement mixers

- Hydrogen fuel cell powered mixer trucks feature such hardcore advantages as zero-emission, high power, and long-range and meet the all-weather heavy-duty operation requirement. Pilot work on fuel cell cement vehicles is currently being carried out in an orderly manner, in the future, fuel cell-powered mixer trucks will be more widely used.

Emergency vehicles

- The Emergency Rescue Vehicle will increase resilience and clean energy for first responders performing emergency rescue and disaster management work. Emergency vehicles loaded with enough hydrogen to run cleanly and quietly and have microgrid set-up, heating, and water supply capabilities.

Heavy trucks

- Compared with traditional fuel trucks and emerging electric trucks, hydrogen heavy trucks can achieve zero carbon emissions while driving, as the powertrain module adopts a hydrogen fuel cell system or a hydrogen internal combustion engine, which converts the chemical energy generated by the hydrogen reaction into mechanical energy to propel the vehicle.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Policies for China Fuel Cell Industry (1/2)

Time	Policies	Main points
Aug. 2023	The Construction of the Hydrogen Energy Industry Standard System (2023 Edition)	The "Guidelines" system constructed the entire industry chain standard system for hydrogen energy production, storage transportation, and use, covering five subsystems: basic and safety, hydrogen production, hydrogen storage and transportation, hydrogen refueling, and hydrogen energy application.
Jun. 2023	The Blue Book on the Development of New Power Systems	Promotes the low-carbon development of energy used in various industries by 2030, the transfer of industries from the eastern to central and western regions, and the increase in the proportion of non-fossil energy consumption to 25%.
Jan. 2023	Guiding Opinions on Promoting the Development of the Energy Electronics Industry	The research and development and application of advanced technologies such as N-type high-efficiency cells, flexible thin-film cells, perovskite and laminated cells shall be promoted, and the capacity of large-scale production shall be improved.
Apr. 2022	14th Five-Year Plan for scientific and technological innovation in the energy sector	Carry out research on key technologies of high-performance and long-life proton exchange membrane fuel cell (PEMFC) stack heavy-duty integration, structural design and precision manufacturing.
Mar. 2022	Medium- and Long-term Plan for the Development of the Hydrogen Energy Industry (2021-35)	In 2025, the number of fuel cell vehicles will be about 50,000 and a number of hydrogen refueling stations will be deployed. The amount of renewable energy hydrogen production reaches 100,000-200,000 tons/year. By 2030, a more complete hydrogen energy industry technology innovation system, clean energy hydrogen production and supply system will be formed. By 2035, a hydrogen energy industry system will be formed, and a multi-dimensional hydrogen energy application ecology will be constructed to cover the fields of transportation, energy storage, industry and so on. The proportion of hydrogen production from renewable energy sources in end-use energy consumption will be significantly increased.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Policies for China Fuel Cell Industry (2/2)

Time	Policies	Main points
Dec. 2021	The 14th Five-Year Plan for Green Industrial Development	By 2025, the green and low-carbon transformation of industrial structure and production methods will have achieved significant results, green and low-carbon technologies and equipment will be widely used, the efficiency of energy and resource utilization will be significantly improved, the level of green manufacturing will be comprehensively upgraded.
Nov. 2021	Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy	It will steadily build a hydrogen industry system, improve the integrated layout of hydrogen energy production, storage, transmission and use, and actively deploy industrial chain demonstration projects in combination with typical energy-use scenarios in industry, transportation and other fields.
Oct. 2021	Peak Carbon Action Program by 2030	Hydrogen energy is used and penetrated in various fields such as steel, petrochemicals and transportation.
Jun. 2021	Standardization of Automotive Industry 2021	Focusing on the use of fuel cell electric vehicles, promoting the formulation and revision of standards for fuel cell electric vehicles in terms of energy consumption and driving range, low-temperature cold start, power performance, on-board hydrogen system, hydrogen refueling gun, etc.; emphasizing the use of fuel cells, and advancing the formulation of standards for fuel cells

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Policies Regarding "Award in lieu of Subsidy"

General policies regarding "awards in lieu of subsidy"

Time	Policies	Main points
Sept. 2020	**Notice on Launching Fuel Cell Vehicle Demonstration Projects**	Given the current situation of industrial development, the five departments will adjust the purchase subsidy policy for fuel cell vehicles to the fuel cell vehicle demonstration and application support policy, and give incentives to qualified city groups to carry out the industrialization of key core technologies of fuel cell vehicles and demonstration and application, so as to form a new mode of development of fuel cell vehicles with reasonable layout, different focuses and synergistic promotion. The demonstration period is tentatively set at four years. During the demonstration period, the five departments will adopt the "award in lieu of subsidy" approach to reward the city clusters shortlisted for the demonstration in accordance with the completion of their targets.
Apr. 2020	Notice of Improving the Policies on Government Subsidies for Promotion and Application of New Energy Vehicles	Extending the subsidy period and cutting subsidies at a steady intensity and pace: The policies on government subsidies for the promotion and application of new energy vehicles shall be extended to the end of 2022 based on the factors such as technological progress and economies of scale. The subsidies shall be cut at a steady intensity and pace. In principle, the subsidies for 2020-2022 shall be cut by 10%, 20% and 30%, respectively, from the previous year.

After identifying demonstration city clusters in 2021, for the implementation of the Policy, demonstration cities have introduced supportive policies and detailed implementation rules and measures, including local policies disclosed hereinafter in this section headed under "Involvement in Application Projects For 'Award in Lieu of Subsidy' ", as well as other policies in other demonstration cities. Such supportive policies and implementation rules and measures set out the application and evaluation criteria for "award in lieu of subsidy" for the period from 2021 to 2025 (i.e. the "Four-Year Demonstration Period").

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Policies Analysis Regarding "Award in lieu of Subsidy"

Analysis of "Notice on Launching Fuel Cell Vehicle Demonstration Projects"

Components being involved

- Fuel cell stack, MEA, bipolar plate, PEM, catalyst, carbon paper, air compressor, hydrogen circulation system

Demonstration objectives in Demonstration city-clusters

- The rated power of fuel cell system should be higher than 50kW, and the ratio of rated power between the fuel cell system and the drive motor shall not be less than 50%
- Starting temperature of fuel cell system should be lower than -30° C
- The Rated power density of fuel cell stack **used in passenger vehicles** should be higher than 3.0kW/L, and the rated power density of fuel cell system should be higher than 400W/kg. The rated power density of fuel cell stack **used in commercial vehicles** should be higher than 2.5kW/L, and the rated density of fuel cell system should be higher than 300W/kg

Incentive Points Criteria

- Key component products must undergo comprehensive testing by a third-party organization. Each product should have an application of no less than 500 units in the demonstration city cluster, undergo real vehicle operation verification of over 20,000 kilometers, and receive approval from an expert committee for its technical level and reliability, resulting in additional bonus points.
  - Fuel cell stacks and bipolar plates are awarded 0.20 points per vehicle
  - Membrane electrode assemblies, air compressors, and proton exchange membranes are awarded 0.25 points per vehicle
  - Catalysts, carbon paper, and hydrogen circulation systems are awarded 0.30 points per vehicle
- Each key component product can receive a maximum additional bonus of 1500 points. Nationally, a comprehensive evaluation is conducted based on factors such as the technology, quality, and safety levels of key component products. Up to 5 products in each category of key components can receive bonus points.
- In principle, 1 point is rewarded with approximately RMB100,000.

Overview of the Fuel Cell Industry

Policies Regarding "Award in lieu of Subsidy" in Demonstration City Clusters (1/3)

Demonstration city-clusters	Leading city	Cities involved	Policies and Launch time	Main points
Shanghai Demonstration City Cluster	Shanghai	• Jiangsu: Suzhou and Nantong • Zhejiang: Jiaxing • Shandong: Zibo • Ningxia: Ningdong Chemical Industry Base • Inner Mongolia: Ordos	Notice on Carrying out Fuel Cell Vehicle Demonstration Applications <Dec. 2021>	• The price of hydrogen energy for automobiles is expected to drop significantly, with the terminal selling price not exceeding RMB35/kg; • The scale of promotion of vehicles that meet the technical specifications should be more than 1,000 vehicles; • More than 15 hydrogen refueling stations is expected to be built and put into operation.
Beijing-Tianjin-Hebei Demonstration City Cluster	Beijing	• Tianjin: Binhai New Area • Hebei: Baoding and Tangshan • Shandong: Binzhou and Zibo	Notice on Conducting Applications for the Beijing Fuel Cell Vehicle Demonstration and Application Project 2021-2022 <Apr. 2022>	• The basic information, key components, and operational data of the entire vehicle must be unconditionally connected to the designated third-party platform. Hydrogen-powered vehicles need to achieve a mileage of over 7,500 kilometers in the first year and exceed 12,500 kilometers annually for the following three years. Additionally, the proportion of hydrogen-driven mileage within the demonstration city cluster should be above 80%.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Policies Regarding "Award in lieu of Subsidy" in Demonstration City Clusters (2/3)

Demonstration city-clusters	Leading city	Cities involved	Policies	Main points
Guangdong Demonstration City Cluster	Foshan	• Guangdong: Guangzhou, Shenzhen, Zhuhai, Dongguan, Zhongshan, Yangjiang, Yunfu • Fujian: Fuzhou • Anhui: Lu'an • Shandong: Zibo • Inner Mongolia: Baotou	Action Plan for Accelerating the Construction of Fuel Cell Vehicle Demonstration City Clusters (2022-2025) <Aug. 2022>	• Support production of main components such as fuel cell stack, MEA, bipolar plates, PEM, catalyst, carbon paper, air compressor, and hydrogen circulation system. At the end of the demonstration period, the eight main components should be ranked in top five in China. • Realize the goal of promoting over 10,000 fuel cell vehicles, with an annual hydrogen supply capacity exceeding 100,000 tons. Establish more than 200 hydrogen refueling stations, and reduce the retail price of automotive hydrogen to below 30 RMB/kg.
Henan Demonstration City Cluster	Zhengzhou	• Henan: Xinxiang, Kaifeng, Anyang, Luoyang, Jiaozuo • Shanghai: Jiading District, Fengxian District, Lingang section of Shanghai Pilot Free Trade Zone • Hebei: Zhangjiakou, Baoding, Xinji • Shandong: Yantai, Zibo, Weifang • Guangdong: Foshan • Ningxia: Ningdong town	Medium- and Long-Term Plan for the Development of Hydrogen Industry in Henan Province (2022-2035) <Aug. 2022>	• The application fields of hydrogen energy are expected to expand. By 2025, more than 5,000 FCEVs of various types are expected to be promoted, the supply capacity of automotive hydrogen is expected to reach 30,000 tons/year, the terminal selling price of hydrogen is expected to be reduced to less than 30 yuan/kg, the proportion of green and low-carbon is increasing, and 3-5 green hydrogen demonstration projects have been built.

Overview of the Fuel Cell Industry

Policies Regarding "Award in lieu of Subsidy" in Demonstration City Clusters (3/3)

Demonstration city-clusters	Leading city	Cities involved	Policies	Main points
Hebei Demonstration City Cluster	Zhangjiakou	• Hebei: Tangshan, Baoding, Handan, Qinhuangdao, Dingzhou, Xinji, Xiong'an New Area • Hubei: Wuhai • Shanghai: Fengxian District • Henan: Zhengzhou • Shandong: Zibo, Liaocheng • Fujian: Xiamen	Several Measures of Zhangjiakou to Support the Construction of Fuel Cell Vehicle Demonstration City <Jul. 2022>	• Support production of main components such as fuel cell stack, MEA, bipolar plates, PEM, catalyst, carbon paper, air compressor, and hydrogen circulation system. • Supporting enterprises engaging in transportation services with fuel cell vehicles, incentives will be provided for vehicles meeting the average hydrogen mileage condition per vehicle (≥7,500 kilometers per year, exceeding 30,000 kilometers in 4 years). For hydrogen fuel cell-powered small and large passenger vehicles, light and medium-duty trucks, and heavy-duty trucks, each vehicle will be eligible for an annual incentive of 20,000 RMB, 30,000 RMB, 30,000 RMB, and 50,000 RMB, respectively. A municipal financial allocation of 10 million RMB will be coordinated to establish a comprehensive supervision platform for fuel cell vehicles in urban clusters.

In addition to the above policies implemented in the demonstration application city clusters, many other provinces and cities have implemented incentive policies for hydrogen fuel cell industry in China. In 2023, nearly a hundred relevant policies were introduced in non-demonstration cities in China.

Source: Frost & Sullivan

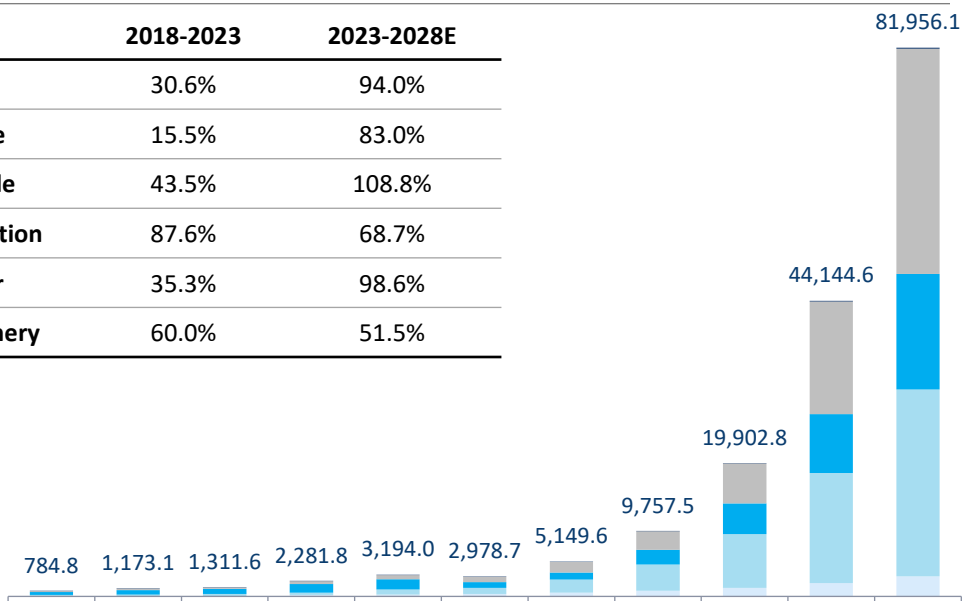
Overview of the Fuel Cell Industry

Market Size of Global Fuel Cell Industry

Market Size of Global Fuel Cell Industry, by Sales Power Output, by Type

MW, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	30.6%	94.0%
Passenger vehicle	15.5%	83.0%
Commercial vehicle	43.5%	108.8%
Others in transportation	87.6%	68.7%
Stationary power	35.3%	98.6%
Construction machinery	60.0%	51.5%



	2018	2019	2020	2021	2022	2023	2024E	2025E	2026E	2027E	2028E
Total	784.8	1,173.1	1,311.6	2,281.8	3,194.0	2,978.7	5,149.6	9,757.5	19,902.8	44,144.6	81,956.1
Others in transporation	0.4	0.1	0.4	0.5	3.8	9.3	13.5	22.5	40.8	73.0	127.1
Commercial vehicle	139.2	213.5	201.3	444.8	613.9	847.5	1,573.2	2,788.3	5,976.1	16,836.3	33,646.0
Passenger vehicle	410.3	673.7	765.9	1,285.8	1,542.1	841.8	1,067.8	2,178.0	4,576.7	8,810.4	17,261.6
Stationary power	198.9	247.5	292.5	313.2	778.5	903.2	1,933.0	3,920.1	8,012.8	16,420.5	27,914.8
Construction Machinery	36.0	38.3	51.5	237.6	255.7	376.9	562.1	848.6	1,296.4	2,004.4	3,006.6

Note: 1) Stationary power refers to distributed generation, combined heat and power(CHP), and other stationary power; others in transportation involves fuel cell-powered aircraft, hydrogen-powered ship, fuel cell train, and etc.
2) Sales power output refers the aggregate of the power supplied by the fuel cell system manufacturers.

Key Findings

- Globally, the hydrogen fuel cell sales power output has increased from 784.8MW in 2018 to 2,978.7 MW in 2023, with a CAGR of 30.6%. Specifically, the transportation field is the largest application scenario with 1689.3 MW in 2023, accounting for 56.7% of the total market.
- In the future, as the technology advances, the stationary power will be used more than before. It is expected that in 2028, the sales power output of the fuel cell system will reach 81,956.1 MW, growing at a CAGR of 94.0%.

Source: E4tech, Frost & Sullivan

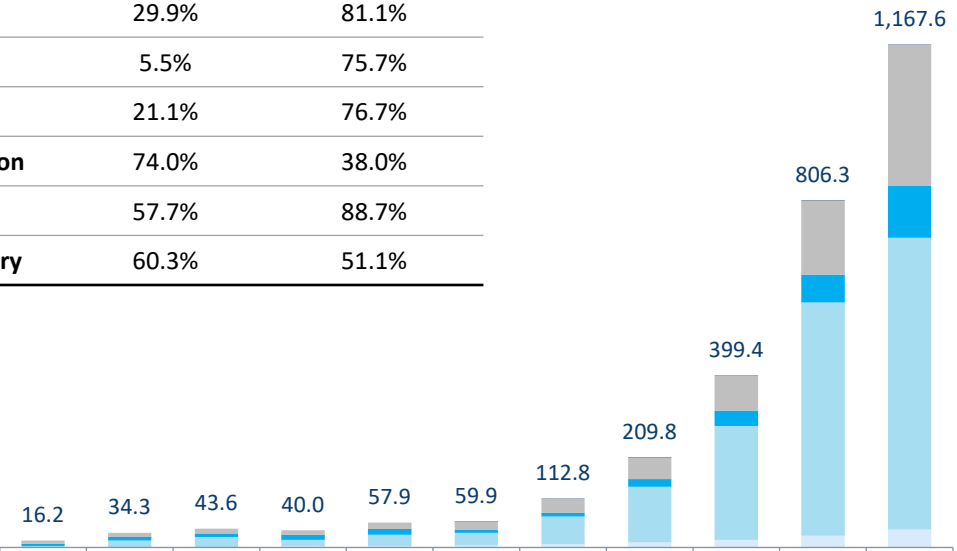
Overview of the Fuel Cell Industry

Market Size of Global Fuel Cell Industry

Market Size of Global Fuel Cell Industry, by Sales Value, by Type

100 Million USD, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	29.9%	81.1%
Passenger vehicle	5.5%	75.7%
Commercial vehicle	21.1%	76.7%
Others in transportation	74.0%	38.0%
Stationary power	57.7%	88.7%
Construction machinery	60.3%	51.1%



	2018	2019	2020	2021	2022	2023	2024E	2025E	2026E	2027E	2028E
Total	16.2	34.3	43.6	40.0	57.9	59.9	112.8	209.8	399.4	806.3	1,167.6
Others in transporation	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.5
Commercial vehicle	7.3	10.0	11.4	10.1	15.3	19.0	31.8	50.8	81.6	172.4	327.3
Passenger vehicle	5.5	8.1	8.2	12.3	13.2	7.2	9.2	17.7	35.4	64.7	120.5
Stationary power	2.9	15.6	23.2	14.1	25.7	28.3	63.8	129.3	264.3	541.6	677.6
Construction Machinery	0.5	0.6	0.8	3.4	3.7	5.3	7.9	11.8	17.8	27.2	41.7

Note: 1) Stationary power refers to distributed generation, combined heat and power(CHP), and other stationary power; others in transportation involves fuel cell-powered aircraft, hydrogen-powered ship, fuel cell train, and etc.
2) Sales value refers to the total value of products delivered by fuel cell system manufacturers.

Key Findings

- From the perspective of sales value, the global hydrogen fuel cell market size has reached USD 5.99 billion in 2023, growing at a CAGR of 29.9% since 2018. Now transportation and stationary power are the two largest segments in the downstream application scenario of hydrogen fuel cells globally, accounting for 43.7% and 47.2% respectively in 2023.
- FCEV is the main driver, but as the hydrogen fuel cell market continues to develop, stationary power and other transportation sectors will gradually commercialized. According to forecasts, the global hydrogen fuel cell market will reach USD 116.8 billion by 2028, with a CAGR of 81.1% from 2023 to 2028.

Source: E4tech, Frost & Sullivan

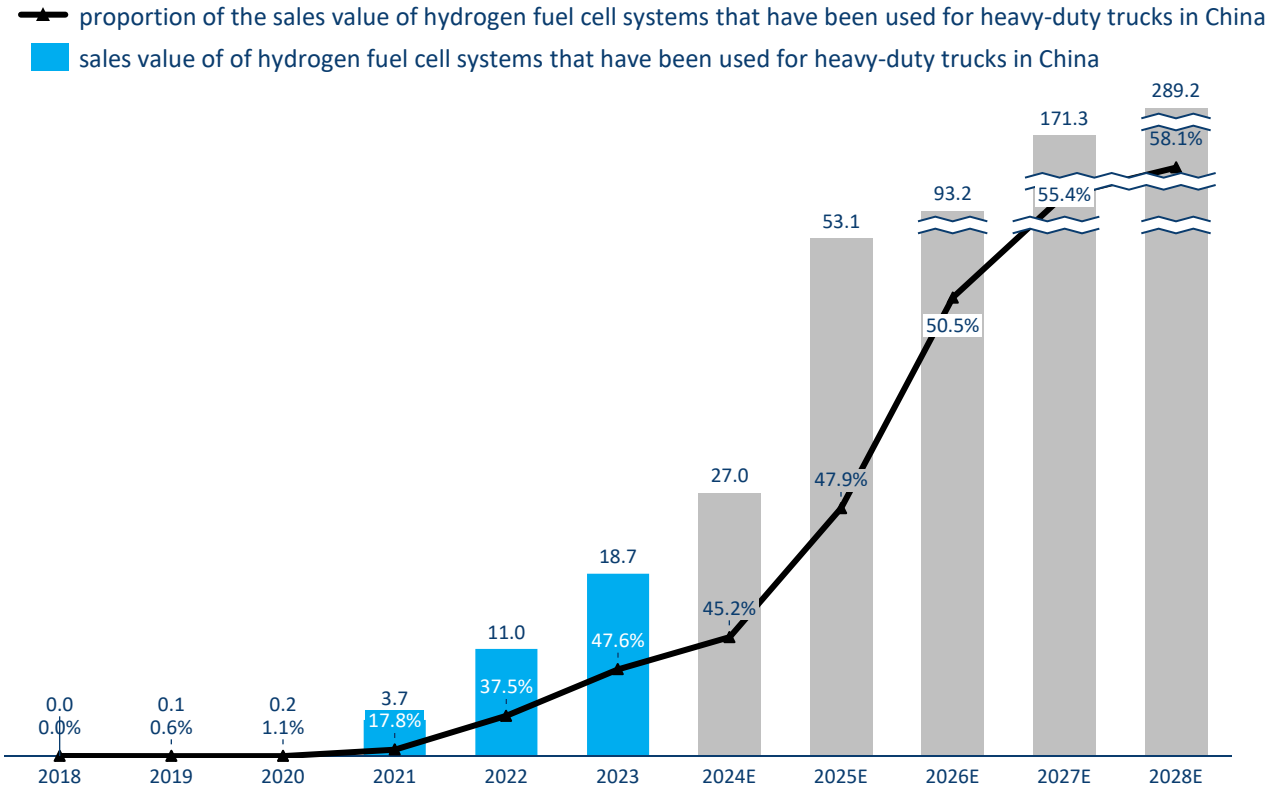
Overview of the Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Heavy Truck Industry

Market Size of China's Sales Value of fuel cell systems that have been used for heavy-duty trucks

100 Million RMB, 2018-2028E

CAGR	2018-2023	2023-2028E
Heavy truck	/	72.9%



Key Findings

- The fuel cell system market for heavy trucks is RMB1.87 billion in 2023, accounting for 47.6% of the overall fuel cell system market in China, making it the top sales scenario for fuel cells. The share of non-heavy truck commercial vehicles is 45.3%. The market for fuel cell systems for heavy trucks is expected to continue to grow to RMB28.92 billion by 2028, with a CAGR of 72.9% from 2023 to 2028.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Analysis of Market Size of Global Fuel Cell Industry

Passenger vehicle

- The market for fuel cell passenger vehicles, primarily dominated by South Korea, China, Japan, the United States, and some European countries, is undergoing continuous development. Additionally, the models and versions of fuel-cell passenger vehicles are gradually becoming more diverse. The Japanese auto giant has partnered with General Motors to bring a new FCEV — a fuel-cell version of its CR-V hybrid SUV — to market in 2024. The future of fuel cell systems in passenger vehicles seems to be promising, for example, Honda has projected sales of the FCEV would reach 2,000 units a year by 2025, before reaching 60,000 by 2030.

Commercial vehicle

- The usage of fuel cells in commercial vehicles including trucks, omnibuses, and so on. Prominent international enterprises are diversifying into these sectors, including fuel cell trucks. For instance, the Japanese automaker TOKYO is actively expanding its footprint in the fuel cell heavy-duty truck market. Governments worldwide are also actively fostering the growth of fuel-cell commercial vehicles. For instance, the Japanese government aims to have a cumulative fleet of 5,000 heavy fuel cell trucks operational by 2030. In addition, the advancement of hydrogen trucking technology has been swift, with certain original equipment manufacturers (OEMs) such as Hyundai already deploying hydrogen heavy-duty trucks in fleet operations, notably in Switzerland and Germany. Other than trucks, other commercial vehicles such as buses will also enter the hydrogen stage in the future which could drive the growth of fuel cells in commercial vehicles.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Analysis of Market Size of Global Fuel Cell Industry

Construction machinery

- The scene for fuel cell construction machinery is gradually expanding, with examples such as fuel cell forklifts, cranes, mining trucks, and concrete mixers. From the perspective of commercial fuel cell vehicles, forklifts stand out as the primary application area. Presently, fuel cell forklifts have gained widespread acceptance and represent the predominant use case in commercial vehicle applications. This is primarily attributed to their quiet operation in contrast to traditional energy-powered forklifts, along with their exceptional efficiency and minimal emissions. They are extensively employed in indoor warehouse logistics, dock handling, and similar settings. In terms of sales performance, the global leader in fuel cell forklifts, Plug Power, achieved sales of around 73,400 units in 2022, capturing a market share of over 90% in this sector. Looking ahead, we anticipate sustained growth in the fuel cell forklift market, alongside further expansion of fuel cell applications in other engineering machinery contexts. This market is positioned for continuous and rapid expansion.

Stationary power

- Some countries and regions have issued policies and plans related to using fuel cells for stationary power generation, providing a relatively clear growth path for the application of fuel cells in the field of stationary power generation.
    - In early 2023, Korea presented its 10th Basic Energy Plan for Electricity Supply and Demand, which provides revised targets27 for 2030 of 13 TWh of electricity generation from co-firing of hydrogen and ammonia at existing gas and coal power plants, and 16 TWh stationary fuel cells using natural gas or hydrogen.
    - Japan has set a concrete target, with 5.3 million micro-CHP fuel cells to be installed by 2030.
    - A strategy for the power sector is being prepared by the German government, including the requirement that new gas power plants have to be H2-ready. In addition, the government plans three tenders for hydrogen power plants and convertible or H2-ready power plants.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Analysis of Market Size of Global Fuel Cell Industry

Others in transportation	**Hydrogen flights**	• **Hydrogen flights:** During 2023, companies established hydrogen flight program. For example, a 19-seat Dornier 228 soared over Cotswold Airport (GBA) in Gloucestershire. It became the largest aircraft to be powered by a hydrogen-electric engine, according to hydrogen-electric aircraft manufacturer ZeroAvia. In addition, Universal Hydrogen's 40-passenger hydrogen electric plane completes maiden flight. ZeroAvia's 2-5 MW powertrain program, already underway, will scale the clean engine technology for up to 90-seat aircraft, with further expansion into narrowbody aircraft demonstrators over the next decade. Airbus is meeting several technology and testing milestones as it moves towards its ambition of bringing to market a hydrogen-powered commercial aircraft by 2035. Thus, different companies' plans provide a promising market for hydrogen flights in the future.
	Hydrogen trains	• **Hydrogen trains:** Shifting from diesel-powered trains to hydrogen fuel cell electric trains shows great promise in reducing carbon emissions within rail transportation. Presently, numerous pilot projects involving hydrogen fuel cell electric trains are underway worldwide, particularly in developed nations. Notably, Germany has implemented a commercialized and permanent route as part of these initiatives. In the future, pilot projects will launched as commercialized projects which increase sales of hydrogen trains in the future.
	Hydrogen ships	• **Hydrogen ships:** The potential could be seen since companies around the world are announcing the serving of hydrogen-powered ships. Japan's first Hydrogen and Bio Fuel Hybrid Passenger Ship Named 'HANARIA' start servicing from April 2024. Dutch shipowner Future Proof Shipping (FPS), the EU-funded Flagships project and the Interreg-funded ZEM Ports NS project have launched H2 Barge 2, a hydrogen-powered vessel that, according to the parties, will ship goods completely emission-free on the Rhine between Rotterdam, the Netherlands, and Duisburg, Germany.

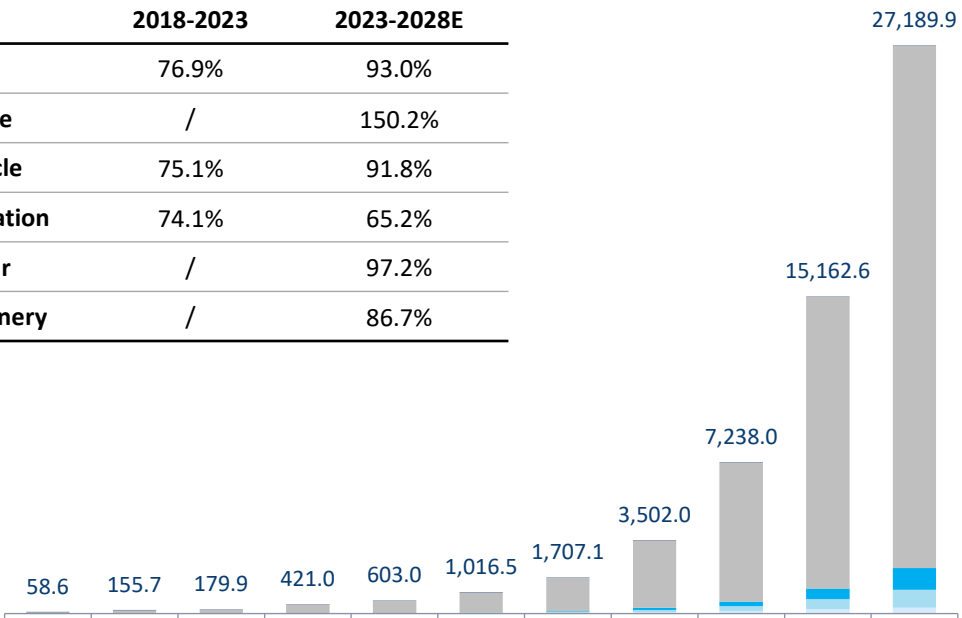
Overview of the Fuel Cell Industry

Market Size of China Fuel Cell Industry

Market Size of China Fuel Cell Industry, by Sales Power Output, by Type

MW, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	76.9%	93.0%
Passenger vehicle	/	150.2%
Commercial vehicle	75.1%	91.8%
Others in transportation	74.1%	65.2%
Stationary power	/	97.2%
Construction machinery	/	86.7%



	2018	2019	2020	2021	2022	2023	2024E	2025E	2026E	2027E	2028E
Total	58.6	155.7	179.9	421.0	603.0	1,016.5	1,707.1	3,502.0	7,238.0	15,162.6	27,189.9
Others in transporation	0.1	0.1	0.3	0.4	0.8	1.6	2.6	4.4	7.5	12.7	19.7
Commercial vehicle	58.5	155.6	179.6	412.4	585.3	963.0	1,590.2	3,222.1	6,654.6	13,948.9	24,988.8
Passenger vehicle	0.0	0.0	0.0	1.1	2.7	10.6	30.2	95.6	218.6	499.8	1,039.9
Stationary power	0.0	0.0	0.0	0.0	8.2	28.8	53.9	107.4	227.6	496.0	858.0
Construction Machinery	0.0	0.0	0.0	7.1	6.0	12.5	30.2	72.5	129.7	205.2	283.5

Key Findings

- In 2023, China holds approximately a 34.1% share of the global fuel cell system market in terms of sales power output.
- In 2023, the sales power output of China fuel cell system has reached 1,016.5 MW, with a CAGR of 76.9% from 2018 to 2023.
- As China's strategic approach to decarbonization is gradually landing, investment in the hydrogen industry is increasing, and the hydrogen industry is moving towards commercialization. With the technology development and the scale effect, the cost of fuel cell systems will reduce in the future, stimulating downstream demand. It is expected that the sales volume of the China fuel cell system will reach 27,189.9 MW in 2028.

Note: 1) Stationary power refers to distributed generation, combined heat and power(CHP), and other stationary power; others in transportation involves fuel cell-powered aircraft, hydrogen-powered ship, fuel cell train, and etc.
2) Sales power output refers the aggregate of the power supplied by the fuel cell system manufacturers.

Source: GGII, E4tech, Ministry of Industry and Information Technology of the People's Republic of China (MIIT), Frost & Sullivan

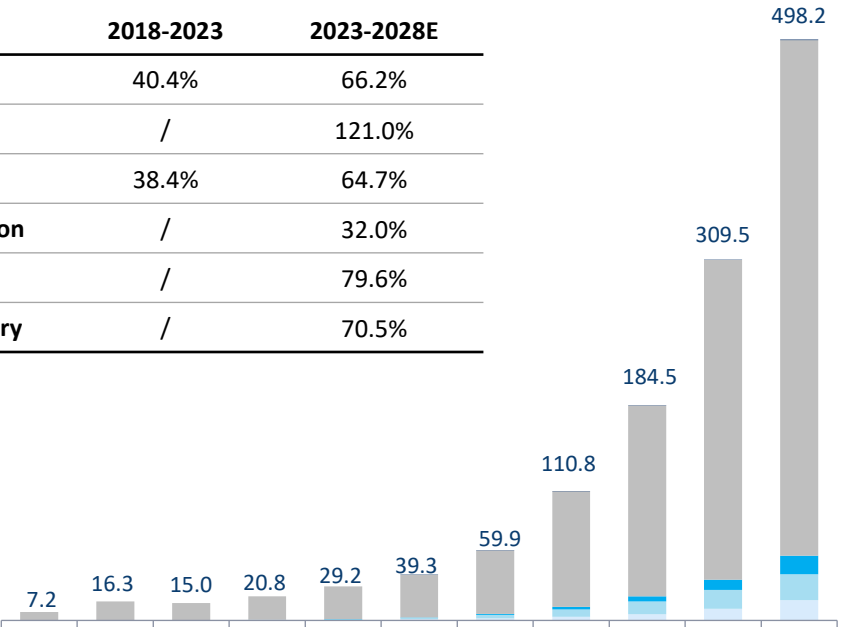
Overview of the Fuel Cell Industry

Market Size of China Fuel Cell Industry

Market Size of China Fuel Cell Industry, by Sales Value, by Type

100 Million RMB, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	40.4%	66.2%
Passenger vehicle	/	121.0%
Commercial vehicle	38.4%	64.7%
Others in transportation	/	32.0%
Stationary power	/	79.6%
Construction machinery	/	70.5%



	2018	2019	2020	2021	2022	2023	2024E	2025E	2026E	2027E	2028E
Others in transporation	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.4
Commercial vehicle	7.2	16.3	15.0	20.1	28.1	36.5	54.3	99.0	163.6	274.3	442.3
Passenger vehicle	0.0	0.0	0.0	0.0	0.1	0.3	0.8	2.2	4.4	8.7	15.8
Stationary power	0.0	0.0	0.0	0.7	0.6	1.2	2.9	6.5	10.9	16.2	22.4
Construction Machinery	0.0	0.0	0.0	0.0	0.4	1.2	1.8	3.0	5.4	10.0	17.3
Total	7.2	16.3	15.0	20.8	29.2	39.3	59.9	110.8	184.5	309.5	498.2

Key Findings

- In 2023, China holds approximately a 9.1% share of the global fuel cell system market in terms of sales value.
- As fuel cell electric vehicles entered the commercialized stage after 2015, the market size of China's hydrogen fuel cell started to grow. The market size of China's hydrogen fuel cell grew from 0.7 billion RMB in 2018 to 3.9 billion RMB in 2023, with a CAGR of 40.4%. Since the "13th Five-Year Plan", China has significantly emphasized the hydrogen energy sector.
- As of December 31, 2023, there are 57 fuel cell system companies in the China's hydrogen fuel cell system market, excluding their holding subsidiaries. The number of fuel cell manufacturers increased in 2023, indicating potential expansion of players within the hydrogen energy industry chain entering the fuel cell market.
- With wider usage of hydrogen fuel cells and decreasing cost of production, the market size of China's hydrogen fuel cell is expected to increase to 49.8 billion RMB in 2028.

Note: 1) Stationary power refers to distributed generation, combined heat and power(CHP), and other stationary power; others in transportation involves fuel cell-powered aircraft, hydrogen-powered ship, fuel cell train, and etc.
2) Sales value refers to the total value of products delivered by fuel cell system manufacturers.

Source: GGII, E4tech, MIIT, Frost & Sullivan

Overview of the Fuel Cell Industry

Market Size of China Fuel Cell Industry

Robust Analysis of Market Size of China Fuel Cell Industry

There are multiple factors contributing to the significant anticipated growth trajectory of the China's hydrogen fuel cell industry. Firstly, government support for the hydrogen fuel cell industry in China has been and will continue to be significant. According to the Medium and Long-Term Plan for Hydrogen Industry (2021-2035) issued by China, by 2025, companies in China are expected to master core technologies and manufacturing processes, and the total fleet of fuel cell vehicles is projected to reach approximately 50,000 units. Additionally, significant efforts are being made to deploy a network of hydrogen refueling stations and increase the production of hydrogen from renewable sources to 100,000 to 200,000 tons per year. Moreover, various provinces and cities in China have issued supportive policies to promote the development of the hydrogen fuel cell industry. For example, Shandong Province and Sichuan Province have implemented a policy exempting hydrogen-powered vehicles from toll fees on highways equipped with ETC devices. This policy, aims to promote the adoption of hydrogen-powered vehicles and drive demand growth in the hydrogen fuel cell industry. Furthermore, Shanghai aims to achieve the deployment of over 10,000 fuel cell vehicles by 2025, while Foshan plans to promote the adoption of at least 3,000 fuel cell vehicles and establish 60 hydrogen refueling stations by the same year. These policy initiatives provide a strong basis for the anticipated growth of the hydrogen fuel cell industry.

In addition, the significant cost reductions and the resulting decrease in the total cost of ownership (TCO) for fuel cell electric vehicles (FCEVs) will also drive the future growth of the hydrogen fuel cell system market. Technological advancements, particularly in fuel-cell technology, are continuously driving down the purchase price of FCEVs and lowering the terminal price of hydrogen. One significant factor is the continuous reduction in the cost of hydrogen fuel cell systems themselves. Advancements in technology, such as the optimization of system design and the localization of critical components, have contributed to substantial reductions in the production costs of fuel cell systems. Additionally, economies of scale in production have further mitigated costs, making hydrogen fuel cell systems more economically viable. The decreasing TCO of FCEVs, in comparison to traditional energy vehicles, underscores their growing competitiveness in the market. For instance, heavy-duty trucks, which constitute a substantial market segment within the hydrogen fuel cell industry, exhibit significant growth potential. Sales of heavy-duty fuel cell electric trucks are projected to increase rapidly, with a compound annual growth rate (CAGR) of 86.6% from 2022 to 2027, reaching 41,336 units by 2027.

Furthermore, the competitive advantages of FCEVs, particularly heavy-duty trucks, over traditional diesel combustion engine vehicles and electric heavy trucks in terms of range, overall vehicle load capacity, and performance in long-distance heavy-load scenarios, position them favorably in the market. As the TCO of hydrogen fuel cell heavy trucks continues to decrease due to advancements in technology and economies of scale, they are expected to surpass both traditional energy heavy trucks and electric heavy trucks in terms of cost effectiveness. Ultimately, the combination of government support, cost reduction efforts, technological innovation, and market expansion initiatives will drive the rapid growth of the hydrogen fuel cell system market in the foreseeable future.

Source: Frost & Sullivan

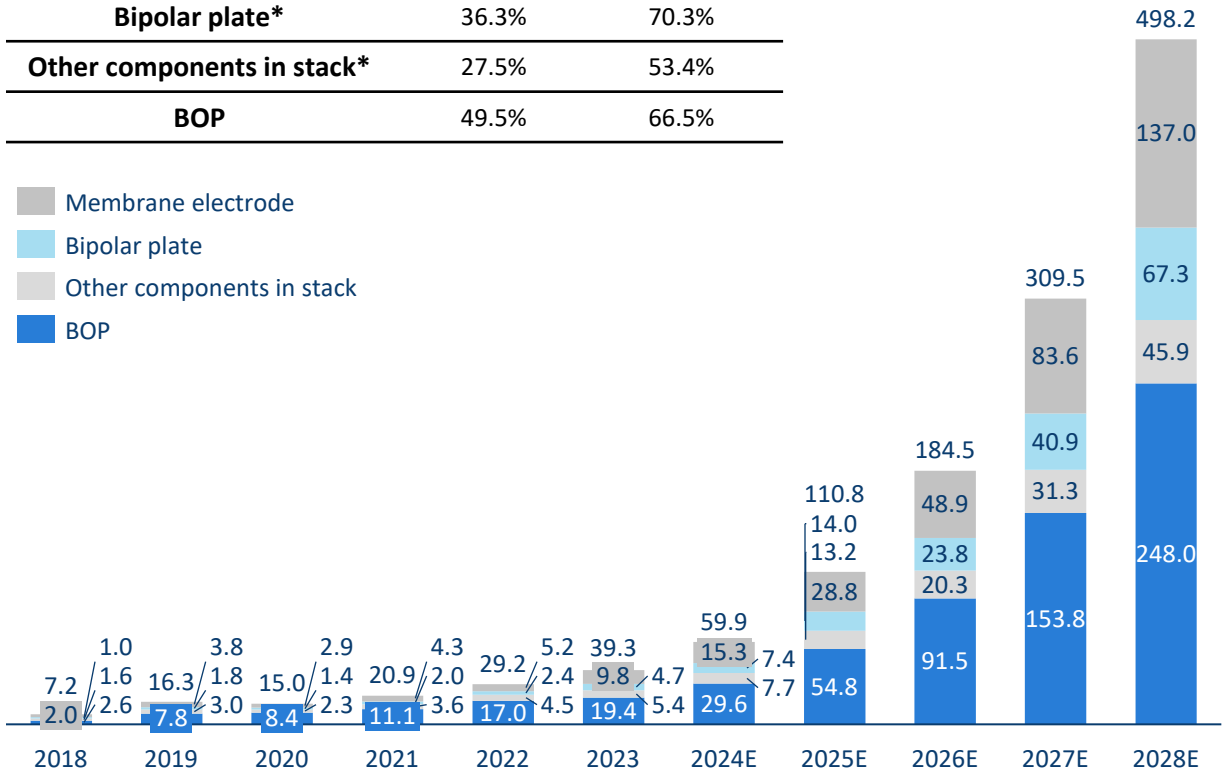
Overview of the Fuel Cell Industry

Market Size of China Fuel Cell Industry

Market Size of China Fuel Cell Industry, by Sales Value, by Components

100 Million RMB, 2018-2028E

CAGR	2018-2023	2023-2028E
Membrane electrode*	37.4%	69.5%
Bipolar plate*	36.3%	70.3%
Other components in stack*	27.5%	53.4%
BOP	49.5%	66.5%



Key Findings

- Currently, within fuel cell systems, the stack remains the most crucial component, with membrane electrodes and bipolar plates accounting for significant sales amounts. In 2023, system sales amounted to 3.9 billion RMB, with membrane electrodes and bipolar plate sales reaching approximately 1.0 billion RMB and 0.5 billion RMB, respectively.
- As the domestication of components deepens, sales value for various components will continue to rise. By 2028, fuel cell sales are estimated to reach 4.98 billion RMB, with a compound annual growth rate of 65.9%.

*Note: *The sales value of fuel cell stack comprises the sales value of membrane electrodes, bipolar plates and other components in stacks.*

Source: GGII, E4tech, MIIT, Frost & Sullivan

Market Driver of the Fuel Cell Industry

Analysis of Fuel Cell Cost Reduction Paths

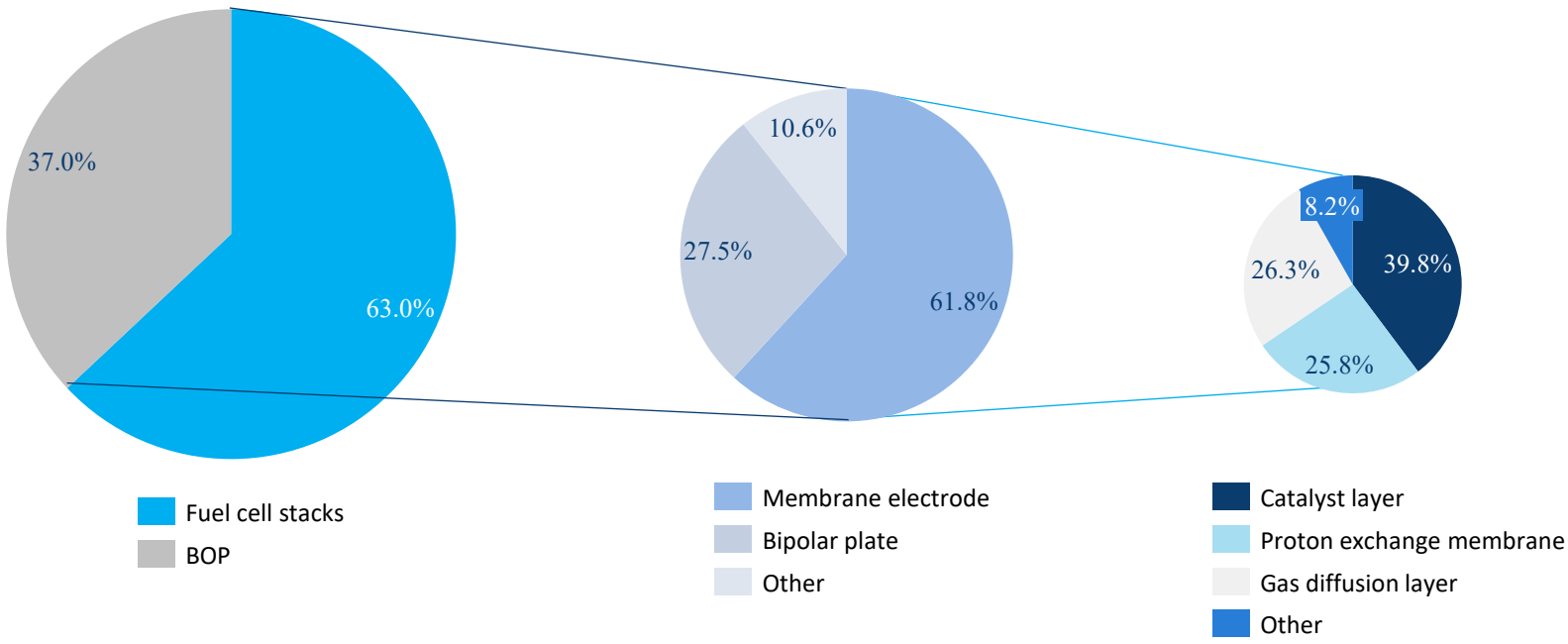
Technological Progress	• Two main streams could be developed to achieve cost reduction. On the one hand, companies could optimize system design to explore cost reduction opportunities, which is to simplify the system and reactor structure by exploring the reduction of components such as diffusion layers. On the other hand, companies can lower costs by enhancing technical capabilities in critical materials and components. This includes advancing the localization of proton exchange membranes, reducing platinum loading in catalysts, and designing new catalyst structures to improve catalytic activity. The combined efforts in these two directions can effectively reduce the overall costs of fuel cell systems.
Localization	• With the formulation of China‘s policy on independent research and development of all fuel cell components, China’s fuel cell market has gradually achieved full localization of key components, such as membrane electrodes and bipolar plates. At the present stage the proton exchange membrane, gas diffusion layer and catalyst layer have achieved preliminary commercialization attempts. Localization will further help to reduce the overall cost of production.
Scale Effect	• Scale production of different parts composed of hydrogen fuel cells will help deduct cost. Previously, as companies were only in the developing stage, production cost was relatively high. Those companies developed during these years, as they enlarged their production volume with commercialized products, cost of production will be lower. Scale production effect shows significantly in main components such as membrane, bipolar plate, catalyst and so on.

Source: Frost & Sullivan

Market Driver of the Fuel Cell Industry

Analysis of Fuel Cell Cost Reduction Paths

Cost Structure of Fuel Cell System's Core Components



- Taking the single stack assembly of a single hydrogen fuel cell system as an example, the fuel cell stack occupies about 63.0% of the cost of the fuel cell system and is the core component of the fuel cell system. Within the fuel cell stack, the bipolar plate accounts for about 27.5% of cost of the fuel cell stack; the membrane electrode accounts for about 61.8% of cost of the fuel cell stack; in the membrane electrode structure, the catalyst is the largest cost item, accounting for about 39.8% of the overall membrane electrode cost, followed by the gas diffusion layer, which accounts for about 26.3% of the overall membrane electrode cost, and the proton exchange membrane cost accounts for about 25.8% of the overall membrane electrode cost.

Source: Frost & Sullivan

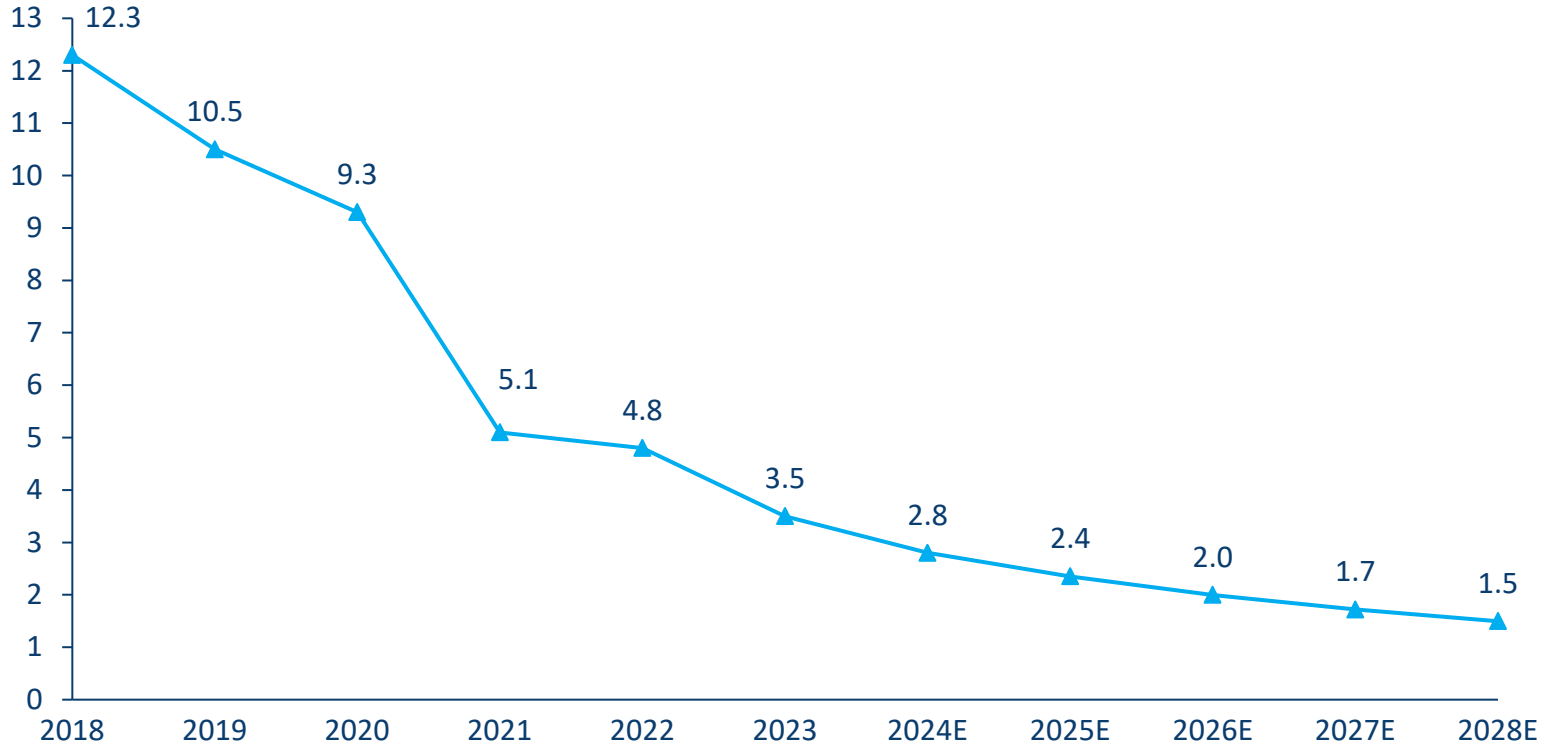
Overview of the Fuel Cell Industry

Market Size of China Fuel Cell Industry

Average Price of Hydrogen Fuel Cell Systems in China

Thousand RMB/KW, 2018-2028E

CAGR	2018-2023	2023-2028E
Market	-22.2%	-15.6%



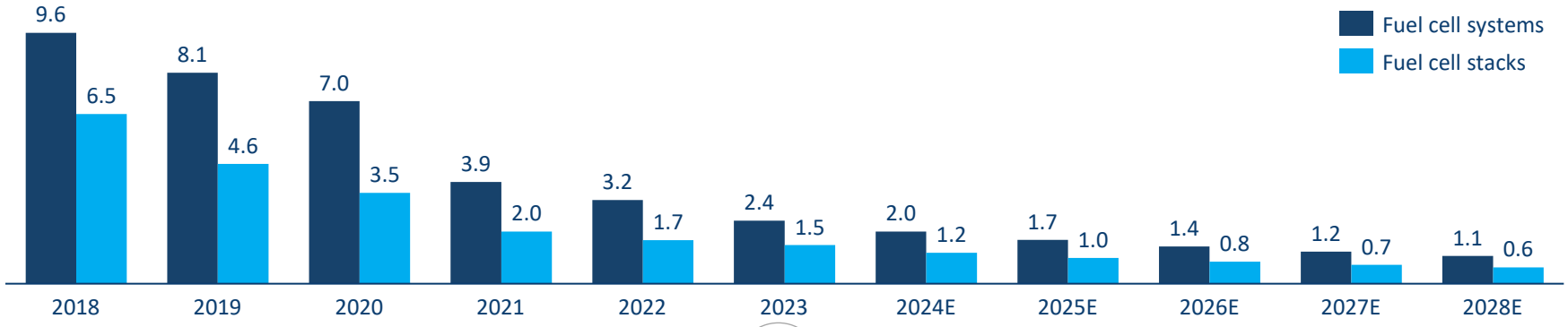
Source: China Society of Automotive Engineers (China-SAE), Frost & Sullivan

Market Driver of the Fuel Cell Industry

Analysis of Fuel Cell Cost Reduction Paths

Cost Analysis of Fuel Cell System and Stacks in China

Thousand RMB/KW, 2018-2028E



- The cost of fuel cell system has decreased from RMB 9,600/KW to RMB 2,400/KW from 2018 to 2023. It is expected that the cost of the fuel cell system will decrease to RMB 1,100/KW by 2028. The cost reduction of fuel cell systems primarily stems from technological advancement, economies of scale, and the localization of core components.

- The cost of the fuel cell stack has decreased from RMB 6,500/KW to RMB 1,500/KW from 2018 to 2023. It is expected that the cost of the fuel cell stack will decrease to RMB 600/KW by 2028. The cost reduction stems from technological advancements, process innovations, and the domestication of critical components, such as MEA and bipolar plates. With the cost reduction of fuel cell system and fuel cell stack, the cost of hydrogen vehicles is expected to significantly decrease, thereby enhancing the commercialization rate of downstream applications for hydrogen energy.

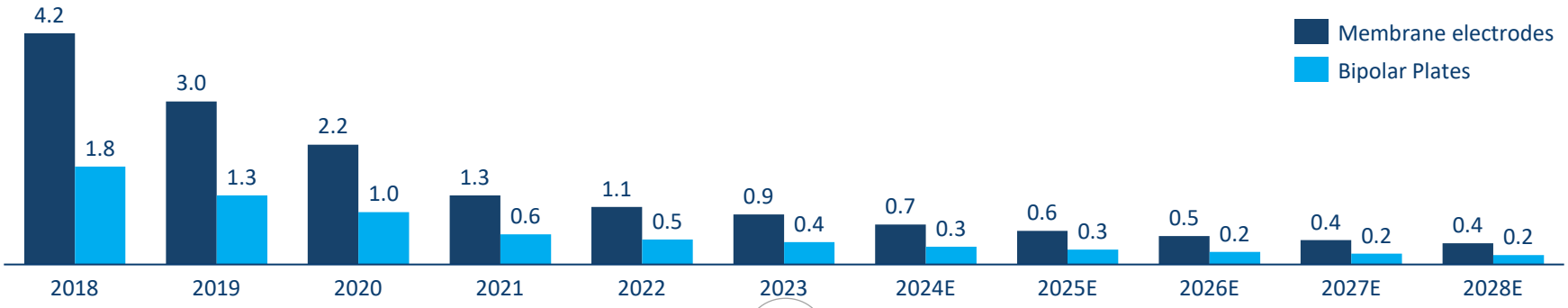
Source: China-SAE, Frost & Sullivan

Market Driver of the Fuel Cell Industry

Cost Analysis of Membrane Electrodes and Bipolar Plates in China

Cost Analysis of Membrane Electrodes and Bipolar Plates in China

Thousand RMB/KW, 2018-2028E



- The cost of membrane electrodes has decreased from RMB 4,200/KW to RMB 900/KW from 2018 to 2023. It is expected that the cost of membrane electrodes will decrease to RMB 400/KW by 2028. The membrane electrode consists of PEM, catalyst, gas diffusion layer, and other important components. 1) PEM: The domestic chemical giant DongYue Group has begun to try to scale up the promotion of domestically produced proton exchange membrane products, breaking the long-standing monopoly of foreign technology. The process of localization will significantly reduce the cost of fluoride membrane application. 2) Catalyst: In the long run, reducing the amount of platinum loaded is the future to reduce the overall cost of fuel cell membrane electrodes and stack. As the platinum load per unit of power of the international leading enterprises has been optimized from 0.8~1.1g/kW to 0.1~0.4g/kW, the overall cost reduction is obvious. 3) GDL: Scale production of the gaseous diffusion layer will lead to significant cost reduction. It is predicted that, when the overall production scale of the market increases from 1,000 to 500,000 sets, the cost of a single unit will be reduced from $2,661/set to $102/set, which is 3% of the original cost.
- The cost of bipolar plate has decreased from RMB 1,800/KW to RMB 400/KW from 2018 to 2023. It is expected that the cost of bipolar plates will decrease to RMB 200/KW by 2028. At present, domestic bipolar plate enterprises are expanding their production in graphite bipolar plate, and the cost reduction brought by the scale effect will directly drive down the overall cost.

Source: China-SAE, Frost & Sullivan

Overview of the Fuel Cell Industry

Market Drivers of Fuel Cell Industry

Significant Government Support

- According to the Medium and Long-Term Plan for Hydrogen Industry (2021-2035) issued by China, by 2025, companies in China are expected to master core technologies and manufacturing processes, and the total fleet of fuel cell vehicles is projected to reach approximately 50,000 units. Furthermore, significant efforts are being made to deploy a network of hydrogen refueling stations and increase the production of hydrogen from renewable sources to 100,000 to 200,000 tons per year. These policy initiatives are expected to continue to drive the growth of the hydrogen fuel cell industry.

Continuous growth in downstream application markets

- The future growth of the Chinese fuel cell vehicle market will drive an increase in demand for hydrogen fuel cells. The market size of fuel cell vehicles in China was RMB45.7 billion in 2022, and is expected to reach a total market size of RMB54.85 billion by 2027, with a compound annual growth rate of up to 64.4%. Benefiting from the rapid development of fuel cell vehicles in major downstream scenarios, global demand for hydrogen fuel cells will continue to increase. On the other hand, the emergence of the "abandonment of wind and light" problem brought about by the grid connection of new energy generation provides opportunities for the development of the hydrogen storage market. As China continues to attach importance to environmental governance and energy crises caused by other geopolitical crises, new energy generation is gradually becoming one of the focuses of attention. At present, new energy generation such as photovoltaics and wind energy generation suffer from many pain points such as poor regulation flexibility, intermittency, and strong volatility. Hydrogen storage, as an emerging energy storage technology, will effectively solve these pain points. Future grid connection of new energy generation will drive the development of the hydrogen fuel cell market on the demand side.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Market Drivers of Fuel Cell Industry

Continued Improvement of Infrastructure

- As the hydrogen fuel cell industry advances, there is a growing emphasis on infrastructure development. This includes the expansion of hydrogen refueling stations, hydrogen supply centers, and hydrogen pipelines, among other components. The ongoing enhancement of infrastructure is crucial for supporting the growth of the hydrogen fuel cell industry. It ensures adequate accessibility to refueling stations and hydrogen supply points, facilitating the widespread adoption of fuel cell vehicles and other hydrogen-based applications. Moreover, a well-established infrastructure network contributes to the overall efficiency and reliability of hydrogen fuel cell systems, thereby boosting confidence among industry stakeholders and consumers. Therefore, the sustained improvement of infrastructure serves as a significant driver for the growth and development of the hydrogen fuel cell industry.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Future Trend of Fuel Cell Industry

Fuel cell will develop in the direction of high-power, high reliability, long life, low cost	• As heavy trucks are becoming the future trend of FCEV commercialization, high-power fuel cells are becoming the main focus of fuel cell development. From the year 2022, fuel cell companies successively introduced fuel cells above 200kW. With technological advancements, process innovations, and the domestication of critical components, fuel cells are on the way to cost reduction. Besides, with the usage of advanced materials and better production methods, fuel cells are expected to achieve longer life and higher reliability.
The application of hydrogen fuel cell systems in the stationary power generation will experience rapid growth	• In the future, transportation and stationary power generation will continue to be the two main applications for hydrogen fuel cell systems. as transportation undergoes widespread promotion, the technological maturity of hydrogen fuel cells is expected to experience significant advancement. Concurrently, hydrogen fuel cell stationary power generation is anticipated to find application in various scenarios based on distinct needs. Fields such as off-grid power generation, combined heat and power (CHP), backup power, and others are experiencing rapid growth.
Optimized costs drive the growth in demand	• With the advancement of material technology, manufacturing process, localization of key components, and scale effect, the cost of fuel cell systems will continue to show a downward trend in the future, and the procurement cost of fuel cell commercial vehicle manufacturers will be significantly reduced. Lower costs will accelerate the overall life cycle cost parity of downstream applications. Profit-driven hydrogen fuel vehicle operators will have a stronger willingness to purchase, and the demand side of hydrogen fuel cells will continue to grow.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Future Trend of Fuel Cell Industry

- Initially, the top-level planning of hydrogen fuel cells was led by the State Council, the National Energy Administration & the Ministry of Industry and Information Technology, and other central organizations. Since then, the State has successively introduced the purchase subsidy policy for fuel cell vehicles and the new support policy of **"Awards in lieu of Subsidy"**, with the focus of subsidies shifting from the downstream OEMs to the upstream core components and main material enterprises, and with the implementation power decentralized from the central to the local level.

Continued focus on the upstream of the industry chain and infrastructure development	• In the future, the policy will continue to focus on the upstream of the industrial chain, help domestic key components and materials enterprises to achieve technological and commercial breakthroughs, to achieve full coverage of localization and lead the healthy and controllable development of the domestic hydrogen fuel cell market.
Interpenetration of industry chain players	• With the gradual improvement of the industry chain, more upstream, midstream, and downstream players will penetrate into each other. Domestic midstream head players such as REFIRE have laid out the core fuel reactor plate and already have the reactor production capacity. In the future, with market expansion and technological progress, the industry chain midstream head players will continue to increase their investment in the core components plate and commercialization applications.
Cost optimization drives demand growth	• With the advancement of material technology, manufacturing process, localization of core components, and scale effect, the cost of fuel cell systems will continue to show a downward trend in the future, and the procurement cost of fuel cell vehicle manufacturers will be significantly reduced. With lower costs, profit-driven hydrogen fuel vehicle operators will have a stronger willingness to purchase, and the demand side of hydrogen fuel cells will continue to grow.

Source: Frost & Sullivan

Overview of the Fuel Cell Industry

Entry Barriers and Challenges of Fuel Cell Industry

Difficulty in R&D of Core Components	• Fuel cell systems comprise various components, including stacks, hydrogen supply systems, and air supply systems. Among these, the development of core components, such as proton exchange membranes and electrode materials, presents significant challenges. The intricate nature of electrochemical materials and membrane electrodes, crucial for efficient fuel cell operation, amplifies the complexity of research and development efforts. These components are predominantly led by overseas companies, heightening the barriers to entry for new market players.
Rapid Iteration Speed of Fuel Cell Systems	• With the acceleration of the deployment of fuel cell commercial vehicles and other downstream applications, there is an increasing demand for enhanced performance, cost-effectiveness, and durability of fuel cells. Leading manufacturers are actively engaged in research and development to meet these evolving market demands. This rapid iteration of fuel cell technology aims to transition from meeting policy requirements to addressing market-driven needs for improved performance, cost-efficiency, and durability. However, the swift pace of iteration also presents challenges and serves as a barrier for new entrants, who must contend with the complexities of meeting these dynamic market demands while navigating the competitive landscape.

Challenges of China's Hydrogen Fuel Cell Industry

Gradual reduction of future government subsidies. Currently, the government's subsidies for the application of fuel cells in the transportation sector are relatively large, aimed at promoting the increase of fuel cell applications. However, government subsidies will gradually decrease in the future, and this impact will also be transmitted to fuel cell manufacturers. Automotive companies will squeeze the cost of fuel cells, so reducing the cost of fuel cells is a major challenge in the future.

Source: Frost & Sullivan

Agenda

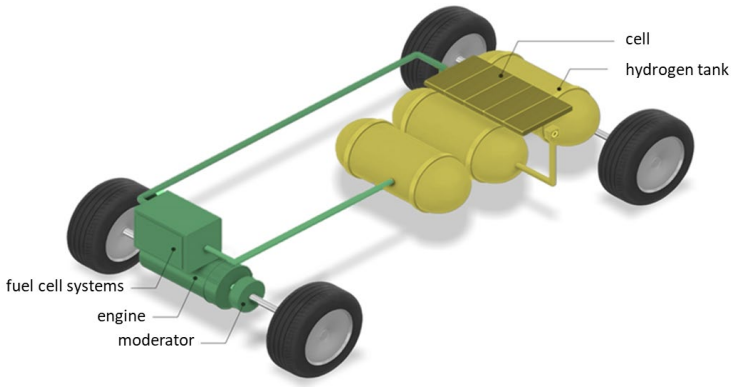
Overview of the Fuel Cell Electric Vehicle Industry

Definition and Importance of Fuel Cell Electric Vehicle

Definition

- Fuel cell electric vehicle (FCEV) is a non-polluting vehicle that generates electric power through the reaction between high-pressure hydrogen stored in onboard hydrogen tanks and oxygen extracted from ambient air in a fuel cell system. Since the electric power required for FCEVs comes from the electrochemical reaction between hydrogen and oxygen, the by-product of the energy generation process is only pure distilled water, and ultra-fine dust can be removed from the environment during operation, FCEVs are attracting much attention as an ecologically friendly means of transportation in the future.

Overview of the internal structure of a hydrogen fuel cell vehicle



- **The crucial core technologies for hydrogen fuel cell vehicles are clustered in the fuel cell system and the storage hydrogen tanks.** According to the U.S. Department of Energy, the fuel cell stack accounts for more than 50% of the cost of the power system. Depending on the fuel type or material, hydrogen fuel cell vehicles can utilize different types of fuel cell systems, each with different efficiency, cost, and maintenance characteristics. Fuel cell system components typically include the fuel cell stack, hydrogen supply system air supply system, and thermal cooling system.

- **Global standard impacting usage of FCEV:** Global Technical Regulations (GTR) are also regularly revised to ensure the safety of FCEV on an international scale, and each market adopting FCEV has, or is in the process of developing, localized regulations and laws on electrical safety and hydrogen safety by international standards.

Source: Frost & Sullivan

Overview of the Fuel Cell Electric Vehicle Industry

Analysis of the Advantages of Fuel Cell Electric Vehicle

Metric	Fuel cell electric vehicle	Electric vehicle	Fuel-driven vehicle
Mechanical system	Fuel cell systems	Lithium battery	Internal combustion engine
Filling material	Hydrogen	Electricity	Gasoline or diesel
Safety	Risks arise mainly from hydrogen storage and hydrogenation processes	Risks mainly come from the battery system, where it is difficult to balance high quality power density with safety	Not applicable
Low-temperature performance	-30° C low ambient temperature self-activation -40° C low-temperature storage	Conventional lithium batteries cannot be recharged in low ambient temperatures below -20° C and can lose up to approximately 30% of their range	Below -18° C require high-performance engine lubricants, inlet cryogenic preheaters, and high-energy auxiliary machinery
Environmental protection	Reduce or zero carbon emissions	Pollution partially transferred upstream	Emissions of greenhouse gases such as CO_2, CO, SO_2, etc.
Mileage	Relatively long, 400-800 kilometers	Limited, 200-400 kilometers	Relatively long, approximately 500 km
Energy conversion rate	40-60%	Not applicable	30-40%
Infrastructure for refilling/charging services	Hydrogen station, filling time: 3-15min	Charging port, filling time: 30 min to 8 hours on average	Gas station, filling time: 5-10min
Field of application	Medium and long distance, heavy transportation	Short- and medium-distance transportation	Universally applicable
Fuel energy density	~12kWh/kg	~0.2Wh/kg	Not applicable
Load capacity	Lightweight, small battery to vehicle weight, high cargo capacity per unit	Heavy, batteries account for a large portion of the vehicle's weight, low cargo capacity per unit	Not applicable
Noise generation	Generate noise, but less than conventional fuel-driven vehicles	Generate noise, but less than conventional fuel-driven vehicles	Loud noise

Both fuel cell heavy trucks and electric heavy trucks are alternatives to diesel combustion engine heavy truck. However, electric heavy trucks encounter difficulties competing with traditional diesel combustion engine heavy truck and fuel cell heavy trucks in areas such as range, overall vehicle load capacity, and cargo space, particularly in long-distance heavy-load scenarios. Moreover, their performance is significantly affected in low-temperature conditions, rendering them unsuitable for long-distance heavy-load freight transport. As a result, when comparing the TCO for heavy trucks, we focus solely on diesel combustion heavy trucks and fuel cell heavy trucks. If fuel cell heavy trucks demonstrate a favorable TCO, it becomes feasible to replace diesel combustion engine-heavy trucks on a scalable basis with fuel cell heavy trucks.

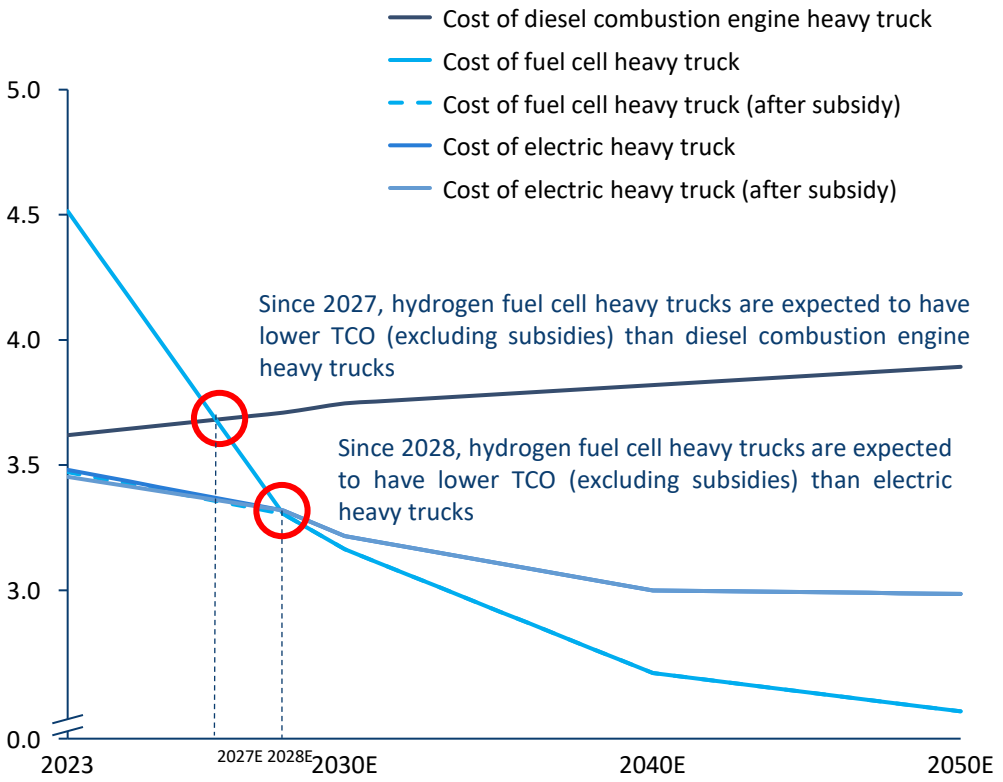
Source: Frost & Sullivan

Overview of the Fuel Cell Electric Vehicle Industry

Cost Analysis of China Heavy Truck

Total Cost of Ownership of China Heavy Truck, by Value, by Type

Million RMB, 2023, 2027E, 2030E, 2040E, 2050E



Key Findings

- Both fuel cell heavy trucks and electric heavy trucks are alternatives to diesel combustion engine heavy truck. However, when compared, electric heavy trucks face distinct challenges, particularly in crucial areas such as payload capacity and cargo volume. As heavy-duty vehicles used for transporting goods, payload capacity and cargo volume are essential metrics, influencing their value as productive assets. Electric heavy trucks often lag behind in these aspects, despite potentially comparable Total Cost of Ownership (TCO). This disparity can be likened to renting a property with shared amenities, where the actual utility value diminishes due to increased shared usage. This inherent limitation significantly impacts the ability of electric heavy trucks to create value, particularly in scenarios requiring long-distance heavy-load freight transport. Therefore, it is imperative to underscore this point when contrasting electric heavy trucks with other alternatives. In 2050, the cost of ownership of hydrogen fuel cell heavy trucks will decrease significantly due to the scale effect and the enhancement of the technology of hydrogen fuel cell system, and the cost of the life cycle will be reduced to RMB2.52million ,which is lower than that of electric heavy truck.

Source: Frost & Sullivan

Supply Chain Analysis of the Fuel Cell Electric Vehicle Industry

Industry Chain of Fuel Cell Electric Vehicle Industry

Upstream

Hydrogen Production

Hydrogen Storage and Transportation

Hydrogen Refuel

Midstream

Components R&D/Production

System R&D /Production

MEA

Bipolar plate

Fuel Cell Stack

Air compressor

DC/DC

FCU

Hydrogen circulation system

BOP

Fuel Cell System

High-pressure hydrogen tank

Pipeline

Valve

Pressure reducer

On-board Hydrogen Supply System

Downstream

FCEV Production

FCEV Sales

FCEV Operation

FROST & SULLIVAN 沙利文

Source: Frost & Sullivan

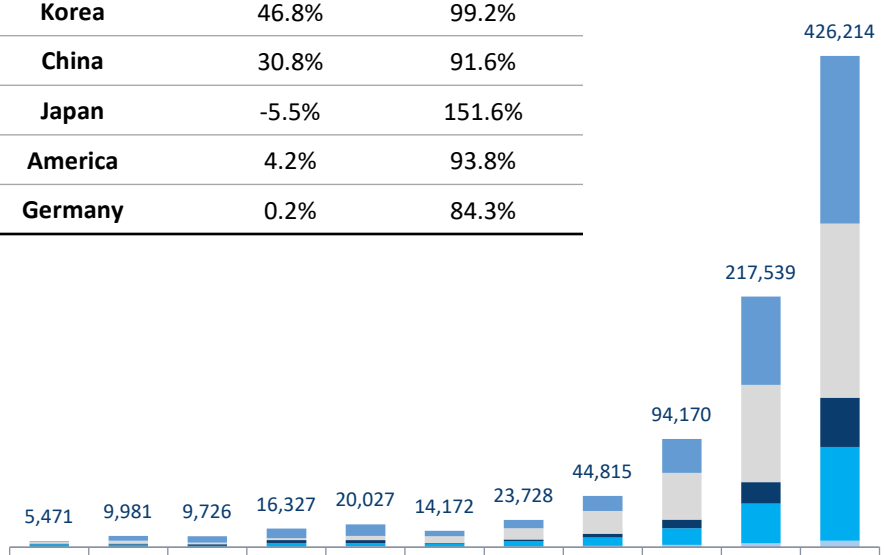
Overview of the Fuel Cell Electric Vehicle Industry

Market Size of Global Fuel Cell Electric Vehicle Industry

Market Size of Global Fuel Cell Electric Vehicle Industry, by Sales Volume, by Country

Unit, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	21.0%	97.5%
Korea	46.8%	99.2%
China	30.8%	91.6%
Japan	-5.5%	151.6%
America	4.2%	93.8%
Germany	0.2%	84.3%



	2018	2019	2020	2021	2022	2023	2024E	2025E	2026E	2027E	2028E
Total	5,471	9,981	9,726	16,327	20,027	14,172	23,728	44,815	94,170	217,539	426,214
Korea	680	4,174	5,793	8,412	10,164	4,635	7,184	13,111	29,336	76,531	145,410
China	1,527	2,737	1,177	1,586	3,397	5,843	9,678	19,742	40,534	84,425	150,889
Japan	560	634	1,445	2,464	2,784	422	1,477	3,249	7,539	18,485	42,515
America	2,429	2,083	937	3,341	2,707	2,978	4,467	7,371	14,557	34,427	81,420
Germany	260	303	304	424	835	263	736	1,119	1,936	3,350	5,594

Key Findings

- Global fuel cell vehicle sales reached 14,172 units in 2023. From 5,471 units in 2018 to the scale in 2023, the industry as a whole has grown rapidly, with a CAGR of 21.0%.
- In 2023, global sales of fuel cell electric vehicles experienced a significant decline, primarily due to a more than 50% drop in the sales of fuel cell vehicles in South Korea. The main reason for the decrease in South Korea was the government's 43% cut in subsidies related to hydrogen fuel cell vehicles. Additionally, the high cost of constructing hydrogen refueling stations and its reduced subsidies has led to a shortage of refueling stations. Furthermore, the price of hydrogen fuel in South Korea increased by over one-third in 2023, with the country's largest hydrogen station operator, Hydrogen Energy Network, announcing a 34% price hike for hydrogen.
- Given the high dependency of the development of fuel cell vehicle on policy support, fluctuations in South Korea's hydrogen policies significantly impacted fuel cell vehicle sales.
- However, starting from May 2024, South Korea has introduced new policies: from May 1, 2024, to 2025, the government will provide 8.2 billion KRW in subsidies for 152 hydrogen refueling station operators. Additionally, the government will subsidize the 2024 Hyundai NEXO, reducing its retail price by 32.5 million KRW. In 2024, South Korea will also offer subsidies of 300 million KRW per vehicle for 1,720 hydrogen-powered buses. Given the positive shift in South Korean government's policies in the first quarter of 2024, we still anticipate an increase in fuel cell vehicle sales in South Korea for 2024, which will, in turn, drive the recovery of the sales of global fuel cell vehicles.
- In addition, with the further increase in investment in the hydrogen fuel vehicle industry in various countries, the overall global fuel cell vehicle market size is expected to reach 426,214 units by 2028, with a CAGR of 97.5%, forming a trend of gradually replacing fossil fuel vehicles.

Source: IEA, The Orange Group, Frost & Sullivan

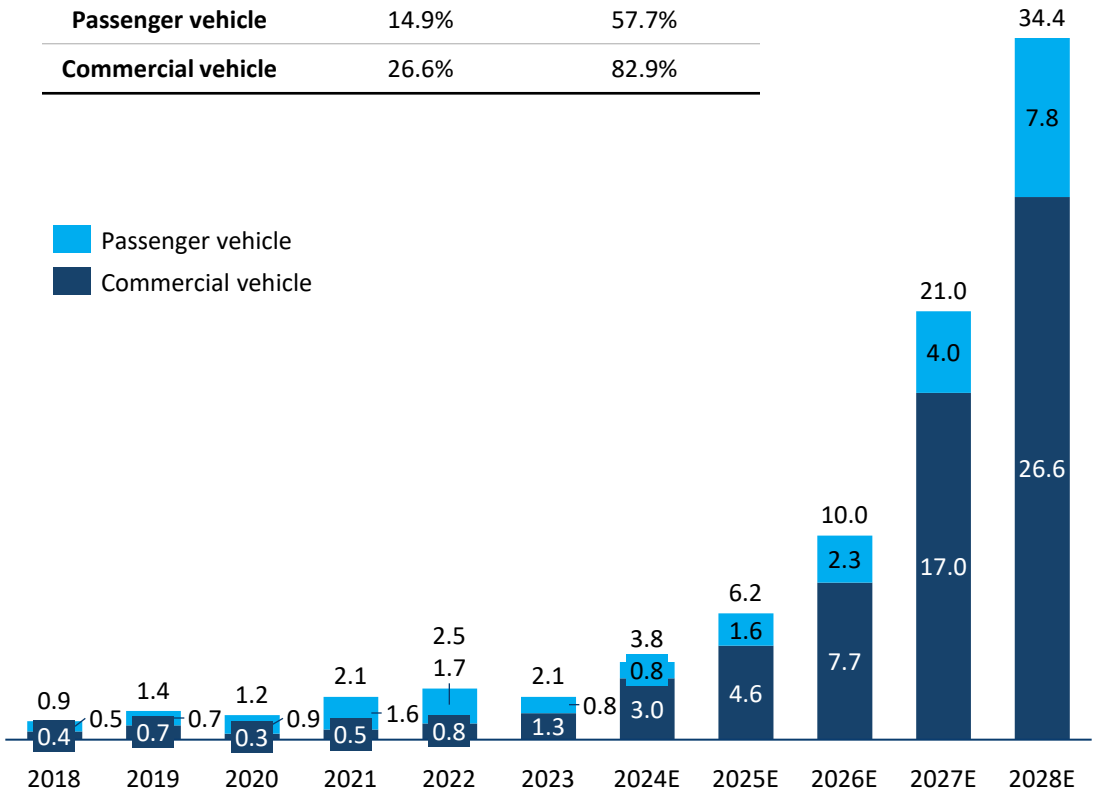
Overview of the Fuel Cell Electric Vehicle Industry

Market Size of Global Fuel Cell Electric Vehicle Industry

Market Size of Global Fuel Cell Electric Vehicle Industry, by Sales Value, by Type

Billion USD, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	21.3%	74.9%
Passenger vehicle	14.9%	57.7%
Commercial vehicle	26.6%	82.9%



Key Findings

- The global fuel cell vehicle market size reached 2.5 billion USD in 2023, and the global hydrogen fuel cell vehicle market has grown at a CAGR of 21.3% since its development of 0.9 billion USD in 2018. Sales of global commercial vehicles fluctuated in 2020. China is the main country to sell commercial vehicles.
- In 2023, it is expected that the sales of passenger vehicles will decrease mainly because the sales in South Korea decline. The underdeveloped infrastructure for hydrogen vehicles in South Korea, resulting in inconvenience during usage, stands as a primary factor contributing to the decline in hydrogen vehicle sales. However, South Korea has launched policies aiming to establish corresponding infrastructure. The Clean Hydrogen Energy Ecosystem Development Plan includes the construction of a world-class facility capable of producing 40,000 tons of high-quality liquefied hydrogen annually, alongside the expansion of liquefied hydrogen refueling stations. This initiative is set to cultivate a robust hydrogen industry ecosystem. Since South Korea show strong determination to develop hydrogen industry, it is expected that the sales of passenger vehicles will keep growing in the future.
- With the active deployment of countries for the clean energy vehicle market, the hydrogen fuel cell vehicle market is expected to reach a size of 34.4 billion USD by 2028, with an overall CAGR of up to 74.9%.

Source: IEA, The Orange Group, Frost & Sullivan

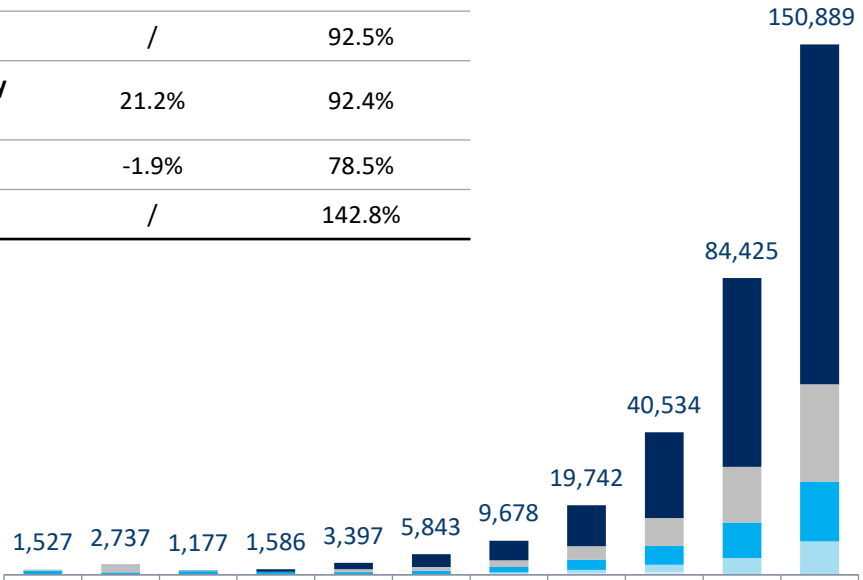
Overview of the Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Electric Vehicle Industry, by Sales Volume, by Type

Unit, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	30.8%	91.6%
Heavy trucks	/	92.5%
Medium and Light-duty trucks	21.2%	92.4%
Omnibus	-1.9%	78.5%
Passenger vehicle	/	142.8%



	2018	2019	2020	2021	2022	2023	2024E	2025E	2026E	2027E	2028E
Total	1,527	2,737	1,177	1,586	3,397	5,843	9,678	19,742	40,534	84,425	150,889
Heavy trucks	0	10	20	690	1,829	3,653	5,589	11,625	24,413	53,709	96,676
Medium and Light-duty trucks	402	2,015	128	51	762	1,052	1,914	3,828	7,925	15,849	27,736
Omnibus	1,031	638	947	723	737	935	1,543	2,854	5,365	10,086	16,945
Passenger vehicle	0	0	0	12	29	111	306	941	2,088	4,636	9,365
Others	94	74	82	110	40	92	326	494	743	145	167

Key Findings

- In 2023, China holds approximately a 41.2% share of the global FCEV market in terms of sales volume.
- From 2018 to 2023, the overall fuel cell vehicle market in China grew from 1,527 units in 2018 to 5,843 units in 2023, representing a CAGR of 30.8%. The government has vigorously promoted establishing hydrogen energy demonstration zones and cities since 2021. Therefore, driven by strong policy support, continuous breakthroughs in core tech, improved infrastructure, and a further reduction in production costs. With further acceleration of market development and the gradual popularization of passenger cars, the production of fuel cell vehicles will gradually form a scale effect. It is expected that China's fuel cell vehicle sales will increase to 150,889 units in 2028.

Source: GGII, China Association of Automobile Manufacturers, CPCA, Frost & Sullivan

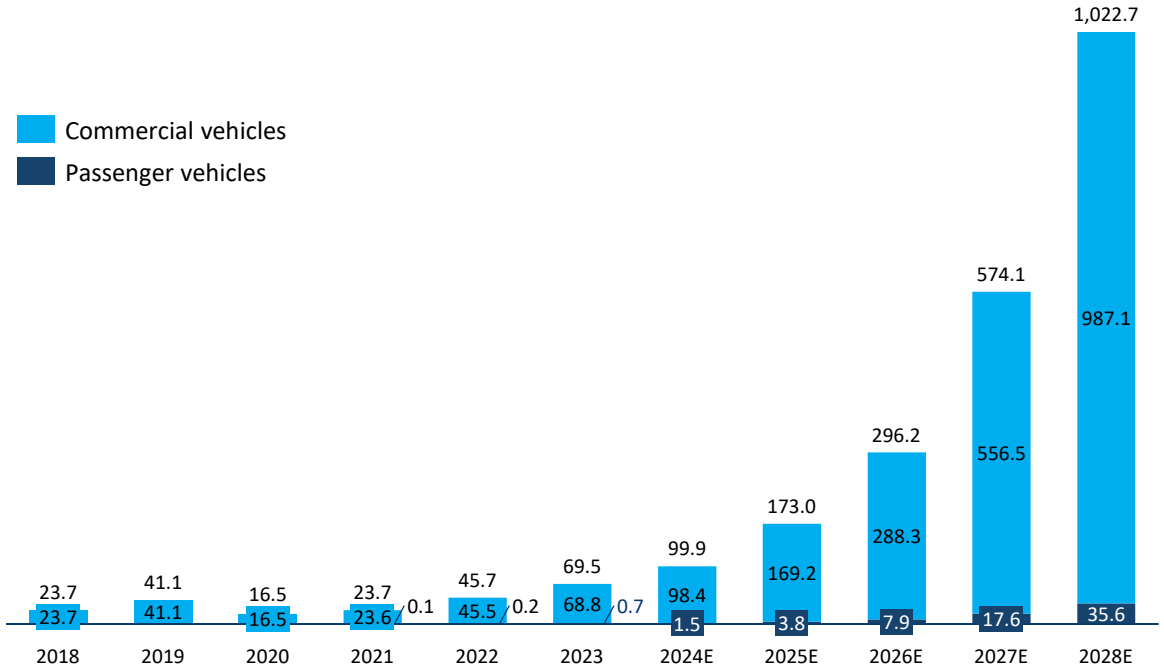
Overview of the Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Electric Vehicle Industry, by Sales Value, by Type

100 Million RMB, 2018-2028E

CAGR	2018-2023	2023-2028E
Total	24.0%	71.2%
Commercial vehicle	23.8%	70.4%
Passenger vehicle	/	119.4%



Key Findings

- In 2023, China holds approximately a 47.3% share of the global FCEV market in terms of sales value.
- China's fuel cell vehicle market size grew from RMB2.37 billion in 2018 to RMB6.95 billion in 2023, with a CAGR of 24.0%. Driven by strong policy support, continuous breakthroughs in core technologies, improved infrastructure such as hydrogen refueling stations, and a further reduction in production costs, China's hydrogen fuel cell vehicle sales will usher in a high-speed growth phase similar to that of electric vehicles. The fuel cell vehicle market is expected to reach a size of RMB102.3 billion by 2028, with a CAGR of 71.2%.

Source: GGII, China Association of Automobile Manufacturers, CPCA, Frost & Sullivan

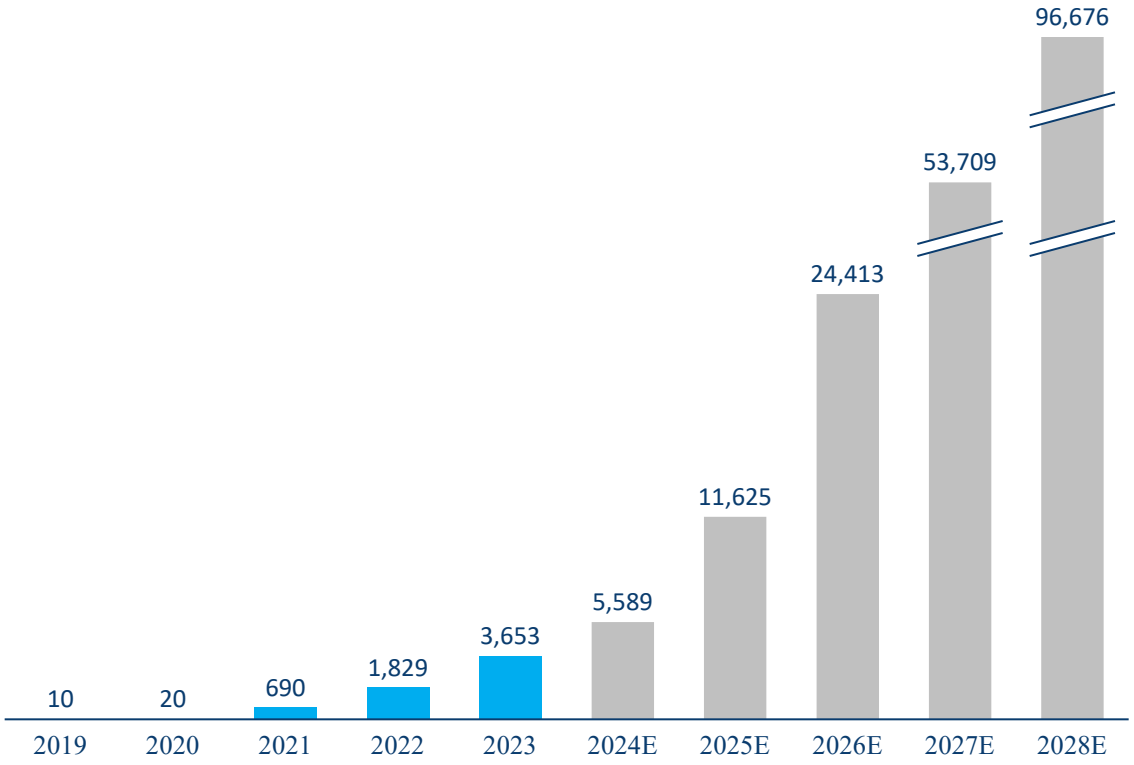
Overview of the Fuel Cell Electric Vehicle Industry

Market Size of China Fuel Cell Heavy Truck Industry

Market Size of China Fuel Cell Heavy Truck Industry, by Sales Volume

Unit, 2019-2028E

CAGR	2019-2023	2023-2028E
Heavy truck	337.2%	92.5%



Key Findings

- China's fuel cell heavy truck sales volume is 3,653 units in 2023 and is expected to be 96,676 units in 2028, with a CAGR as high as 92.5%. Combined with its rising penetration rate in the overall domestic automobile market, the fuel cell heavy truck market is growing rapidly, and the development strategy of fuel cells mainly applied to heavy trucks is promising in the future, with good prospects.

Source: Frost & Sullivan

Market Analysis of the Fuel Cell Electric Vehicle Industry

Future Trend of China Fuel Cell Electric Vehicle Industry

Future Trend	
Fuel cell heavy trucks will become an important commercialized application area	• Firstly, under the "dual-carbon" target, carbon reduction requirements for both the supply side and demand side of the heavy truck industry were put forward, which will accelerate the substitution of hydrogen-energy heavy trucks for fuel-heavy trucks. • Secondly, compared with heavy trucks using lithium batteries, fuel cell heavy trucks have four major advantages: high load efficiency, ease of long-distance transportation, ease of low-temperature start-up, and fast replenishment. • In the future, policy support and cost reduction will further drive the TCO of heavy trucks to decrease. Thus, the commercialization process of heavy trucks will be accelerated which means heavy trucks are heading towards one of the main commercialization areas in the FCEV industry.
Northwest region will be a crucial area for FCEV development	• The price of electricity for large industries in China's Northwest region is generally below the national average, which is more favorable for the development of hydrogen production from water electrolysers to save energy consumption. With the lower cost of using hydrogen, the Northwest region in China will be a crucial area for FCEV development.
Fields of application will continue to diversify	• After commercialization application in omnibuses and logistics, future application of FCEV is expected to expand to more fields. Along with the technological development and cost reduction of hydrogen energy and fuel cell systems, it will expand towards rail transportation and passenger vehicles on specific routes, intercity logistics, intercity passenger transportation, and other fields. Considering the differences in the energy structure of different regions, FCEV and electric vehicles will enter a long-term coexistence and complement each other's market applications.

Source: Frost & Sullivan

Market Analysis of the Fuel Cell Electric Vehicle Industry

Future Trend of China Fuel Cell Electric Vehicle Industry

Future Trend	
The Promotion of Fuel Cell Electric Vehicle is Transitioning from Policy-driven to Market-driven	• In the short term, incentive policies play a crucial role in propelling the development of the fuel cell electric vehicle industry. However, in the medium to long term, the widespread adoption of fuel cell electric vehicles will gradually shift away from dependence on policy subsidies and expand from demonstration city clusters to non-demonstration cities. The extensive adoption of fuel cell electric vehicles depends largely on the Total Cost of Ownership (TCO). When the TCO of fuel cell electric vehicles becomes lower than that of traditional fuel vehicles, they become a viable alternative. • The TCO of fuel cell electric vehicles is primarily composed of purchase costs and energy usage costs. Advancements in fuel cell technology are continuously reducing the purchase price of fuel cell electric vehicles. In addition, progress in upstream production, storage, transportation, and technology is lowering the terminal price of hydrogen, consequently reducing the energy usage costs of these vehicles. Given these cost reduction factors, the current industry trend is to promote fuel cell electric vehicles in regions abundant in low-price hydrogen resources, with a primary focus on areas with rich industrial by-product hydrogen resources. Taking into account the current status of technological development, industrial by-product hydrogen represents a low-cost method of hydrogen production. Promoting fuel cell electric vehicles in these regions translates to lower energy consumption costs and a reduced TCO, making them more economically competitive compared to traditional fuel vehicles. For instance, in Shanxi province, where chemical enterprises such as coke plants, steel mills, and chlor-alkali plants are concentrated, there exists a robust industrial foundation for industrial by-product hydrogen. From the supply side, fuel cell electric vehicles in these regions provide businesses with lower transportation costs, and from the demand side, industries in low-price hydrogen regions, particularly chemical enterprises, exhibit a demand for long-distance transportation, precisely the downstream application area where fuel cell electric vehicles targeted to. In China, as of 2022, there are over one million heavy trucks utilized in bulk cargo transportation scenarios. Consequently, the future market for fuel cell electric vehicles will gradually expand into regions with low-price hydrogen, eventually replacing traditional fuel vehicles. Even in scenarios where future policy subsidies diminish, fuel cell electric vehicles continue to possess extensive application scenarios and can maintain a high growth rate.

Source: Frost & Sullivan

Agenda

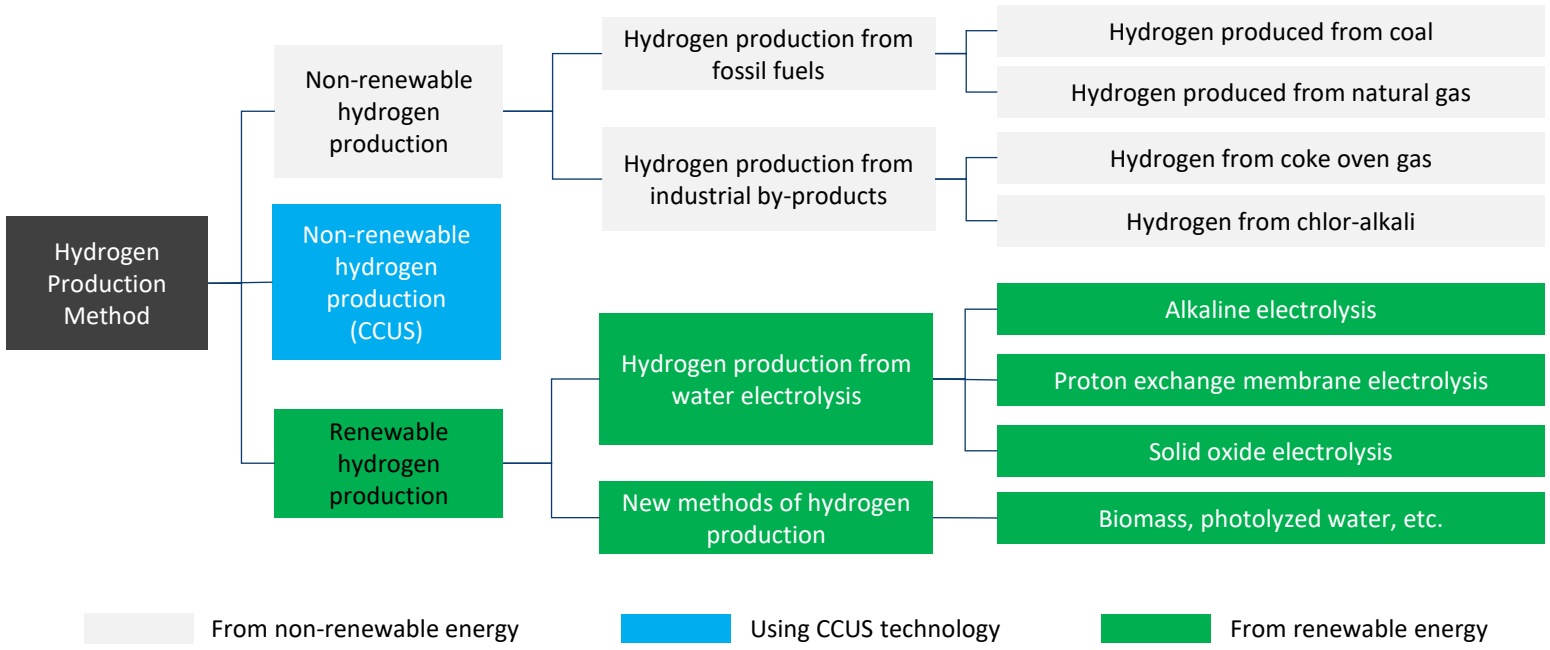
Overview of the Hydrogen Production Industry

Definition and Methods of Hydrogen Production

Definition

- Hydrogen differs from most traditional fossil energy sources as it is produced through man-made chemical processes. Different raw materials can be used to prepare hydrogen. Hydrogen production methods can be divided into two categories: non-renewable hydrogen production and renewable hydrogen production.
- Based on preparation methods, hydrogen can be categorized as: (i) hydrogen produced from traditional sources (such as natural gas or coal), (ii) hydrogen produced by combining traditional sources with CCUS (Carbon Capture, Utilization, and Storage) technology, and (iii) hydrogen produced from renewable energy sources, such as wind power, solar power, photovoltaic, etc.

Methods of Hydrogen Production



Overview of the Hydrogen Production Industry

Comparison of Different Hydrogen Production Technologies

Hydrogen production process		Principles of reaction	Advantages	Disadvantages
Hydrogen production from fossil fuel	Coal	Coal coking and coal gasification	China has rich coal reserves, abundant production, lower costs and mature technology	Greenhouse gas emission
	Natural gas	Steam reforming mainly, some oxidation and catalytic cracking	Lower cost and abundant production	Greenhouse gas emission
Hydrogen production from industry by-products	Coke oven gas	Direct separation and purification of hydrogen by pressure change adsorption	Industrial by-products, low cost	Air pollution, construction sites limited by raw material supply
	Chlor-alkali	• Sodium chlorate tail gas: deoxygenation and dichlorination, PSA separation and purification • PVC tail gas: pressure change adsorption purification, pressure change adsorption PSA hydrogen extraction	High product purity and abundant raw materials	Construction sites are limited by the availability of raw materials
Future trend				
Hydrogen production from water electrolysis	**Alkaline electrolysis (ALK)**	Direct current decomposition of water	More mature technology, lower cost	Gas production requires dealkaline and stable power supply
	Proton exchange membrane electrolysis (PEM)		Flexible operation, small equipment size, high output pressure, volatility for renewable power generation	Requires the use of rare metals such as platinum, and iridium, which have high cost and limited supply chain
	Solid Oxide Electrolysis (SOEC)		High conversion efficiency	Operate under high temperature
New methods of hydrogen production	Biomass, photolyzed water, etc.	Hydrogen release from sunlight-catalyzed water, hydrogen production from microbial-catalyzed water decomposition	Eco-friendly	Immature technology, low hydrogen purity

Source: Frost & Sullivan

Overview of the Hydrogen Production Industry

Comparison of Different Hydrogen Production Technologies

- The main principle of hydrogen production by water electrolysis is that water molecules are dissociated under the action of direct current to produce oxygen and hydrogen, which are precipitated from the anode and cathode of the electrolyze respectively. Depending on the diaphragm material of the electrolyze, it can be categorized into ALK, PEM, SOEC and anion exchange membranes (AEM). **Based on the degree of commercialization, ALK and PEM are mainstream methods.**
- Other technologies, such as SOEC and AEM, face higher technical complexities and are in the early stages of commercialization.
- In the future, as technology advances, SOEC and AEM may gain a larger market share in the hydrogen production industry.

	ALK	PEM	SOEC
Electrolytes	**20-30% KOH**	**PEM (Nafion, etc.)**	**Y_2O_3/ZrO_2**
Working temperature	70-90 °C	70-80 °C	700-1,000 °C
Electric density	0.25 A/cm^2	1-3 A/cm^2	1-10 A/cm^2
Energy consumption	4.5-5.5 kWh/Nm^3	3.8-5.0 kWh/Nm^3	3.0-3.6 kWh/Nm^3
Dynamic responsiveness	Faster start/stop	Fast start/stop	Inconvenient start/stop
Electric mass requirements	Relatively strong	Strong	/
System operation and maintenance	Corrosive liquid, complicated operation and maintenance in the later stage, high-cost	No corrosive liquids, simple operation and maintenance, low-cost	Currently focused on technical research, no operational maintenance needs yet
Stack life	Up to 120,000h	Up to 100,000h	/
Maturity of technologies	Commercialized	Commercialized aboard	R&D in lab
Pollution	Lye contamination	Pollution free	Pollution free
Advantages	The most mature water electrolysis tech; Could generate hydrogen on a large scale; The most economical tech in China; Equipment localization performance close to the international level	Requires relatively small area; Higher adaptability to renewable energy sources since it could adapt to intermittent power supply;	Consume less electricity; Suitable for concentrated solar power; generation with high-temperature and high-pressure steam
Disadvantages	High electricity consumption; Requires power supply with high stability	Main components still rely on import	Operate under high temperature

Source: Frost & Sullivan

Overview of the Hydrogen Production Industry

Industry Chain of the Hydrogen Production from Water Electrolysis

Industry Chain of the Water Electrolysis Industry

Upstream

Equipment Manufacturer

Resources and raw materials

Platinum

Perfluorosulfonic acid membrane

Polyphenylene sulfide-based membranes

Iridium

Nickel

Component suppliers

ALK

Membrane
Electrode
Polar plate
...

PEM

MEA
Bipolar plate
...

Power supply

Cooling system

Hydrogen processing

...

Midstream

Electrolytic Tank Manufacturer

Equipment suppliers

Electrolytic stack assembly

BOP

System integration

Electrolyzed water system

Downstream

Clients

Hydrogen Production Company

Industrial clients

Ammonia production

Methanol synthesis

Oil refining

Steelmaking

Owners and developers of electricity generation from renewable energy projects

Hydrogen refueling station operators

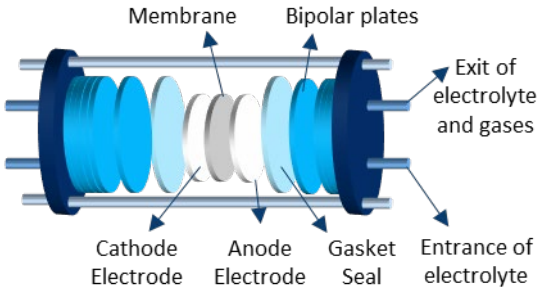
Source: Frost & Sullivan

Overview of the Hydrogen Production Industry

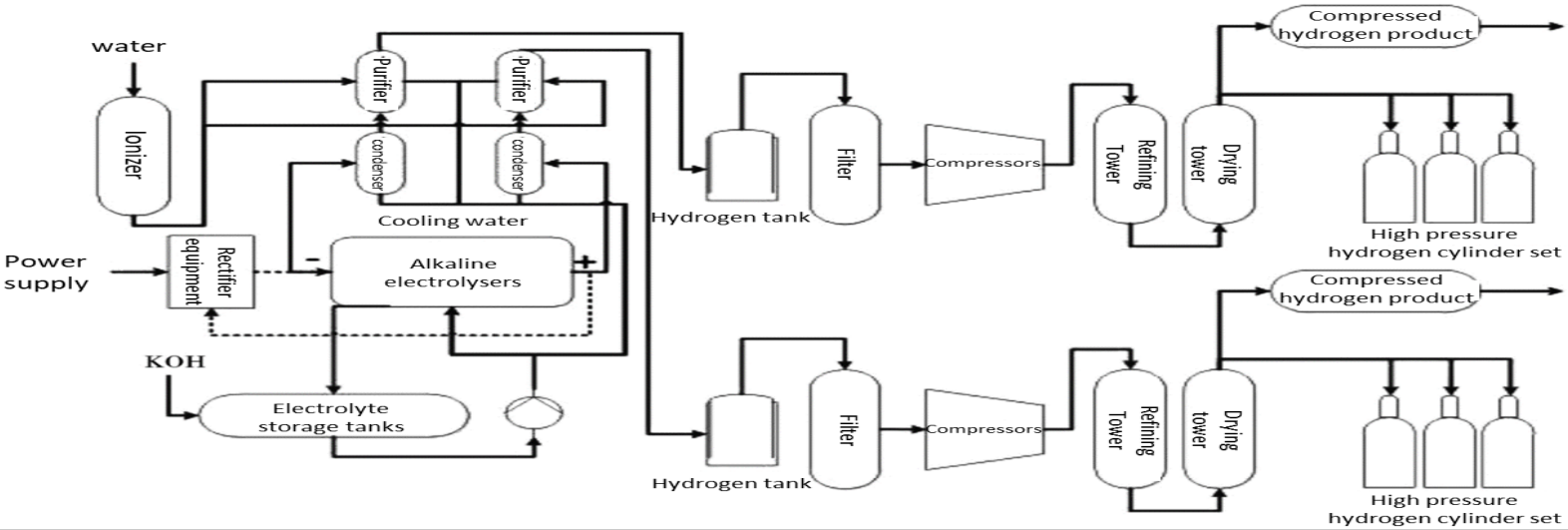
Principle of ALK

- **ALK is the most mature water electrolysis technology.**
- The basic principle: KoH and other alkaline aqueous solution as the electrolyte, the use of non-woven fabrics (fluorine-containing or fluorine-chlorine polymers) as a diaphragm, under the action of direct current, the water electrolysis to generate hydrogen and oxygen, and precipitation in the cathode and anode of the electrolytic cell. The system of ALK equipment is relatively complex, mainly including an electrolysis tank, pressure regulating valve, lye filter, lye circulating pump, lye preparation and storage device, hydrogen purification device, gas detection device, and other modules. ALK hydrogen production technology is mature, with low investment and operating costs, but problems such as lye loss, corrosion, high energy consumption, taking more floor space, and so on exist.

Structure of ALK Electrolyser



Operating Principle of ALK



Source: Frost & Sullivan

Overview of the Hydrogen Production Industry

Main Components of ALK electrolyser (1/2)

- **Among fuel cell players, only a few have the ability to develop main components for ALK electrolyser, including but not limited to REFIRE and CEMT.**
- Electrodes and membrane act as the most important parts in ALK electrolyser, since **it decides the capability of hydrogen production.** The better material used to produce membrane and electrodes, the higher electric density, thus, leading to higher hydrogen production capacity.

	Electrodes	Membrane	Gasket seal	Polar plates and stage frames
Main purposes	Where the electrochemical reaction takes place is crucial for hydrogen production	Prevent a mix of hydrogen and oxygen	Realization of insulation between pole pieces	Support electrodes and diaphragms and conductive
Materiality	**Determines current density**	Stability determines life of the electrolyser		
Performance requirement	• Alkali-resistant • High-temperature resistant • Large surface area	• Ensure that hydrogen and oxygen molecules can not pass through the diaphragm, but allow electrolyte ions to pass through; • Resistance to corrode in high concentrations of lye; • Good mechanical strength; • High diaphragm porosity; • Maintain chemical stability in the electrolysis temperature and lye conditions; • Raw materials are readily available, non-toxic, non-polluting	Its performance affects the gas yield and stability, as well as the service life of the plates and diaphragms.	Not easily corroded in lye
Material/ component equipment	Porous metal frame structures (e.g. steel or nickel-plated alloy steel materials) and surface-coated catalyst layers are currently available in the form of nickel mesh-coated Raney nickel, nickel foam, and other forms of electrodes.	• **The earliest:** Asbestos diaphragm; • **Current mainstream in China**: polyphenylene sulfide PPS • **Future R & D focus**: polytetrafluoroethylene resin-modified asbestos diaphragm, polyether ether ketone fiber diaphragm, polysorbate fiber diaphragm	Mostly use composite PTFE material	Cast iron plate, nickel plate, or stainless steel plate

Source: Frost & Sullivan

Overview of the Hydrogen Production Industry

Main Components of ALK electrolyser (2/2)

Systems	Appliances	Functions
Power supply system	• Rectifier • Transformers	The hydrogen generation power supply in the hydrogen generation module changes the voltage level of the input electrical energy. Then the electric energy is transferred to the subsequent electrolyser to produce hydrogen. **It is required to ensure the stable operation of the electrolyser.** Therefore, the stable operation of the hydrogen production power supply is the key factor to ensuring the high purity and high efficiency of hydrogen produced.
Control system	• Hydrogen production • PLC control cabinet	Monitoring of temperature, pressure, flow rate, gas purity, etc., in the measuring device
Gas-liquid separation system	• Gas-liquid separation tank • Gas coolers	Separation of hydrogen and oxygen with lye respectively
Purification system	• Purification equipment	Purification of gases
Lye system	• Lye tank • Lye filter • Lye circulation pumps	Ensure the stable and consistent supply of lye
Water supply system	• Charge pump • Radiator	Ensure the consistent and stable supply of water
Cooling and drying system	• Heat exchanger • Coolers	Lower temperature or cooling regeneration gas from drier
Affiliate system	• Nitrogen purge system • Affiliate framework • Bellow valve	Control valves, hydrogen/oxygen purity testers, level meters, pressure gauges, flow meters, etc.

Source: Frost & Sullivan

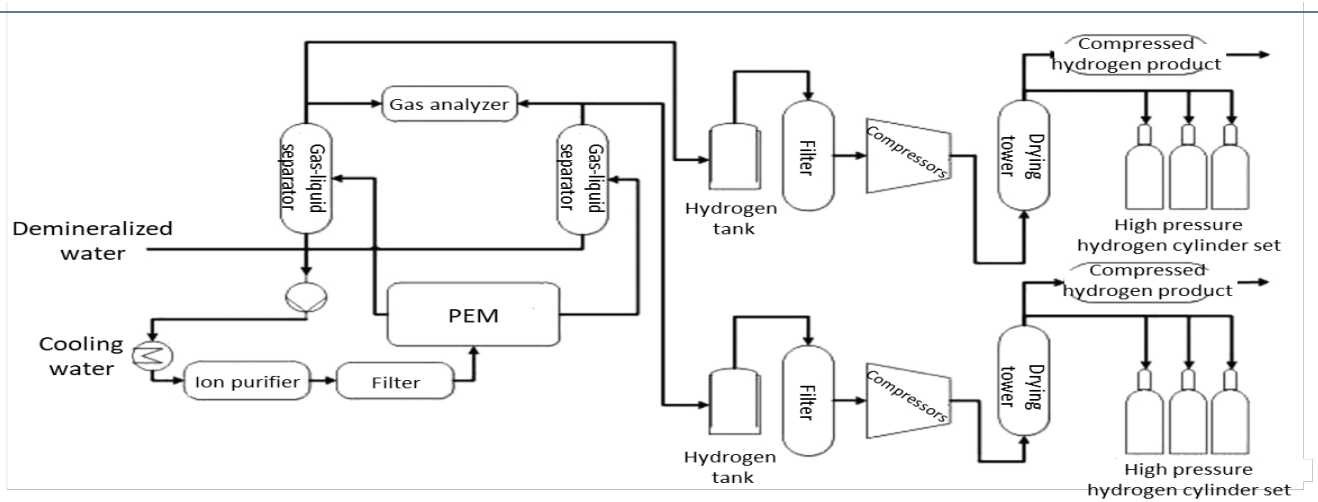
Overview of the Hydrogen Production Industry

Principle of PEM

- PEM is currently in the early stages of marketization. Unlike ALK, PEM electrolysis uses a proton exchange membrane as the solid electrolyte instead of the diaphragm and alkaline electrolyte, and uses pure water as the feedstock for hydrogen production, avoiding potential alkali contamination and corrosion issues. **Fuel cell companies that expand their business scope to PEM electrolysers have certain advantages, because PEM electrolyser and fuel cell have similar structure, their main components such as membrane and catalyst have similar perspectives.**

- **Operating principle of PEM:** Water is catalytically decomposed at the anode into oxygen and H^+, which passes through the electrolyte membrane to the cathode, where it gains electrons to form hydrogen, which is collected and transported through the cathode and anode bipolar plates. The PEM system is much simpler than the alkaline system. Typically, on the anode (oxygen) side, a circulation pump heat exchanger, pressure control, and monitor are required. On the cathode side, a gas separator, deaerator (usually without differential pressure), gas dryer, and terminal compressor are required.

Operating Principle of PEM



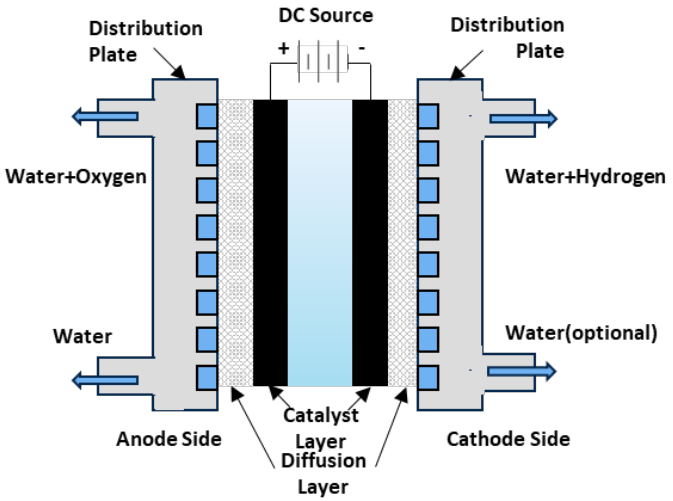
Source: Frost & Sullivan

Overview of the Hydrogen Production Industry

Main components of PEM electrolyser

Structure of a PEM electrolyser

- **Main components of PEM electrolyser include membrane electrode assembly, bipolar plate, end plate, and power supplier.** End plate stations components, guides electricity transformation and distributes water and air. Power suppliers convert AC power to a stable DC power source.



- **Membrane Electrode Assembly:** A membrane electrode assembly (MEA) is an assembled stack of proton-exchange membranes (PEM) or alkali anion exchange membrane (AAEM), catalyst, and flat plate electrode used in fuel cells and electrolysers.
  - **Diffusion layer**: facilitate gas-liquid transfer;
  - **Catalyst layer:** the three-phase interface between the catalyst, the electron-conducting medium, and the proton-conducting medium is the core of the electrochemical reaction;
  - **Proton-exchange membrane:** as a solid electrolyte, perfluorosulfonic acid (PFSA) membranes are generally used to isolate the cathode and anode gases, prevent the transfer of electrons, and transfer protons. It is crucial to electrolyser since it could enhance current density.

- **Bipolar plates:** a key component of proton exchange membrane with multifunction character. It acts as a crucial part in supporting membrane electrode assembly and gas diffusion layer, while it uniformly distributes fuel gas and air and conducts electrical current from cell to cell. Bipolar plates from the anode and cathode side confluence hydrogen and oxygen generated and output both gases;
- Bipolar plates need to have high mechanical stability, chemical stability, low hydrogen permeability, and high conductivity.

Source: Frost & Sullivan

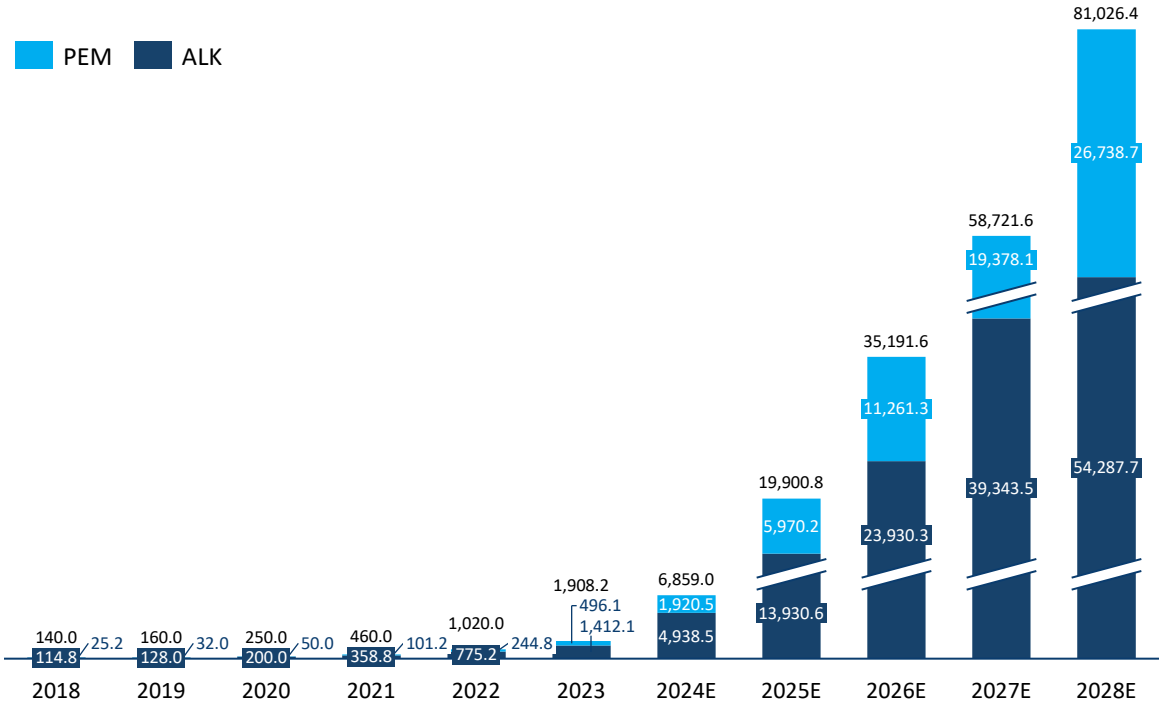
Overview of the Hydrogen Production Industry

Market Size of Global electrolyser Industry

Market Size of Global electrolyser Industry, by Shipment Volume, by Type

MW, 2018-2028E

CAGR	2018-2023	2023-2028E
PEM	81.5%	122.0%
ALK	65.2%	107.5%
Total	68.6%	111.6%



Key Findings

- PEM and ALK are two major hydrogen production methods. Each method has its own advantages. In 2023, ALK shipment volume reaches 1,412.1 MW while PEM shipment volume reaches 496.1 MW. Due to the technology complexity and the high cost, PEM shipment volume is lower than ALK. However, considering that PEM has the advantages of over current density and hydrogen purity, the market share of PEM will increase in the future. Meanwhile, PEM responds swiftly with a wide adjustment range, making it compatible with the passive characteristics of renewable energy electricity. It is expected that the shipment volume of PEM will increase from 496.1 MW to 26.7 GW at a CAGR of 122.0%. The shipment of ALK will increase from 1,412.1 MW to 54.3 GW at a CAGR of 107.5%.

Source: IEA, Policies by different governments, Frost & Sullivan

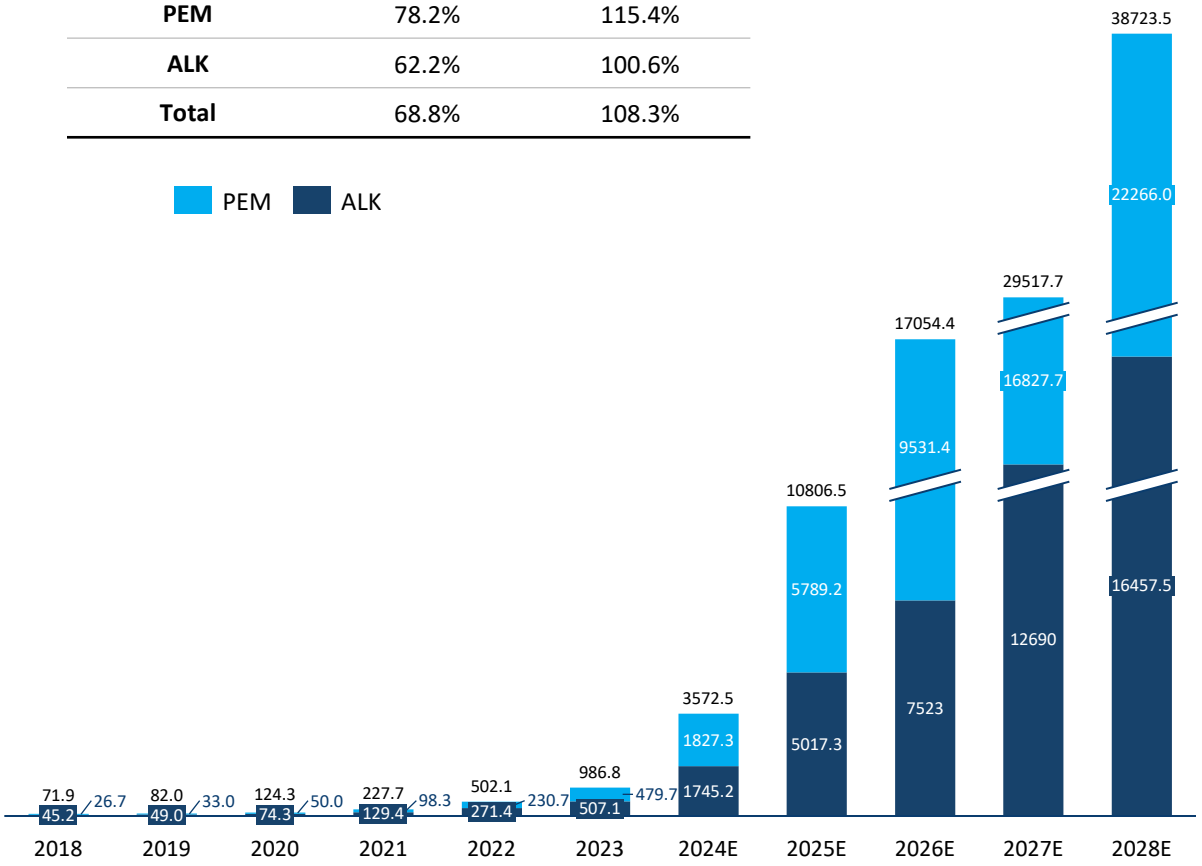
Overview of the Hydrogen Production Industry

Market Size of Global electrolyser Industry

Market Size of Global electrolyser Industry, by Shipment Value, by Type

Million USD, 2018-2028E

CAGR	2018-2023	2023-2028E
PEM	78.2%	115.4%
ALK	62.2%	100.6%
Total	68.8%	108.3%



Key Findings

- Due to the scarcity of the raw material, PEM electrolyser is more expensive than ALK electrolyser. This is primarily attributed to PEM's dependence on precious metals such as iridium, platinum, titanium, etc., for electrodes and catalysts. The market size of PEM has increased from USD 26.7 million in 2018 to USD 479.7 million in 2023 with a CAGR of 81.5%. The market size of ALK has increased from USD 45.2 million to USD 507.1 million with a CAGR of 62.2%. Given that PEM has competitive advantages over ALK, the penetration rate of PEM will increase in the future. It is expected that the value of PEM will increase from USD 479.7 million to 22.3 billion USD at a CAGR of 115.4%. The shipment value of ALK will increase from USD 507.1 million to USD 16.5 billion at a CAGR of 100.6%.

Source: IEA, Policies by different governments, Frost & Sullivan

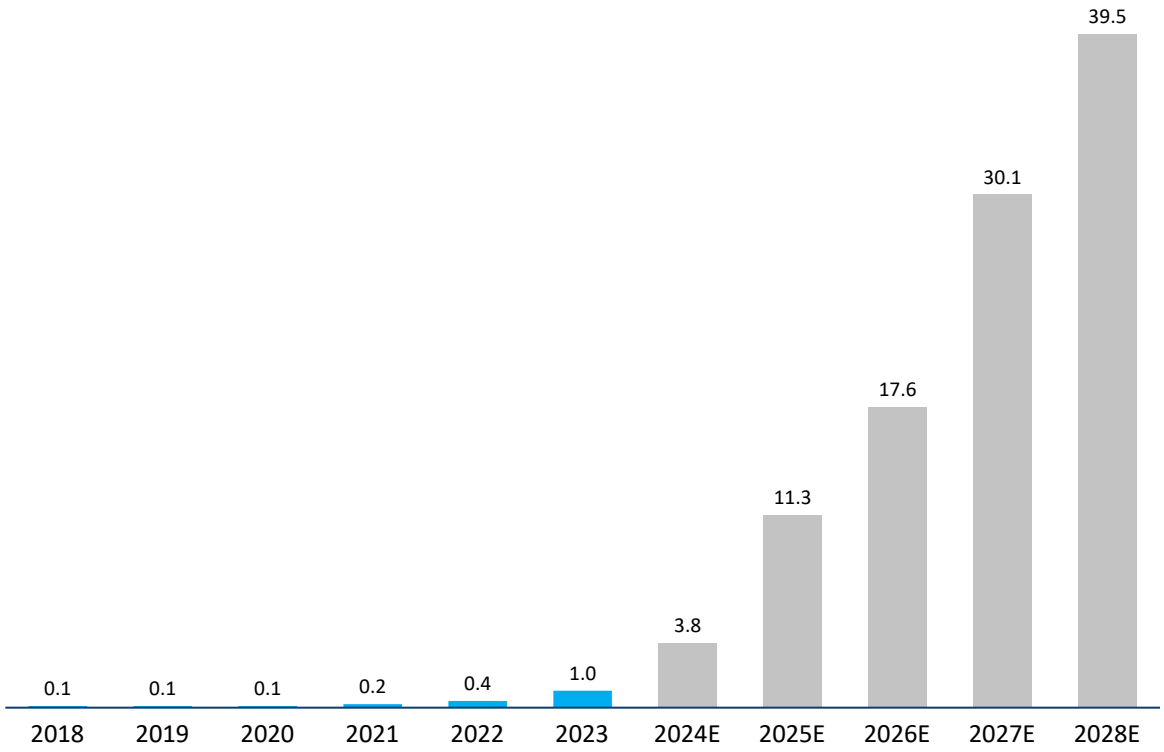
Overview of the Hydrogen Production Industry

Market Size of Global electrolyser Industry

Market Size of Global electrolyser Industry, by Sales Revenue

Billion USD, 2018-2028E

CAGR	2018-2023	2023-2028E
Market	70.2%	108.6%



Key Findings

- Driven by the rising demand for hydrogen and advancements in related water electrolysis technology, the market size of the global water electrolysis hydrogen production equipment industry in terms of revenue kept a steady increase and is expected to continue the growing trend in the coming years. The market size of sales revenue of global electrolyser has increased from USD 0.1 billion to USD 1.0 billion from 2018 to 2023 with a CAGR of 70.2%.
- According to the green hydrogen strategy announced by different governments, the investments into electrolyser is expected to rise in the future which will contribute to the growth of the global electrolyser market in the future.

Source: IEA, Frost & Sullivan

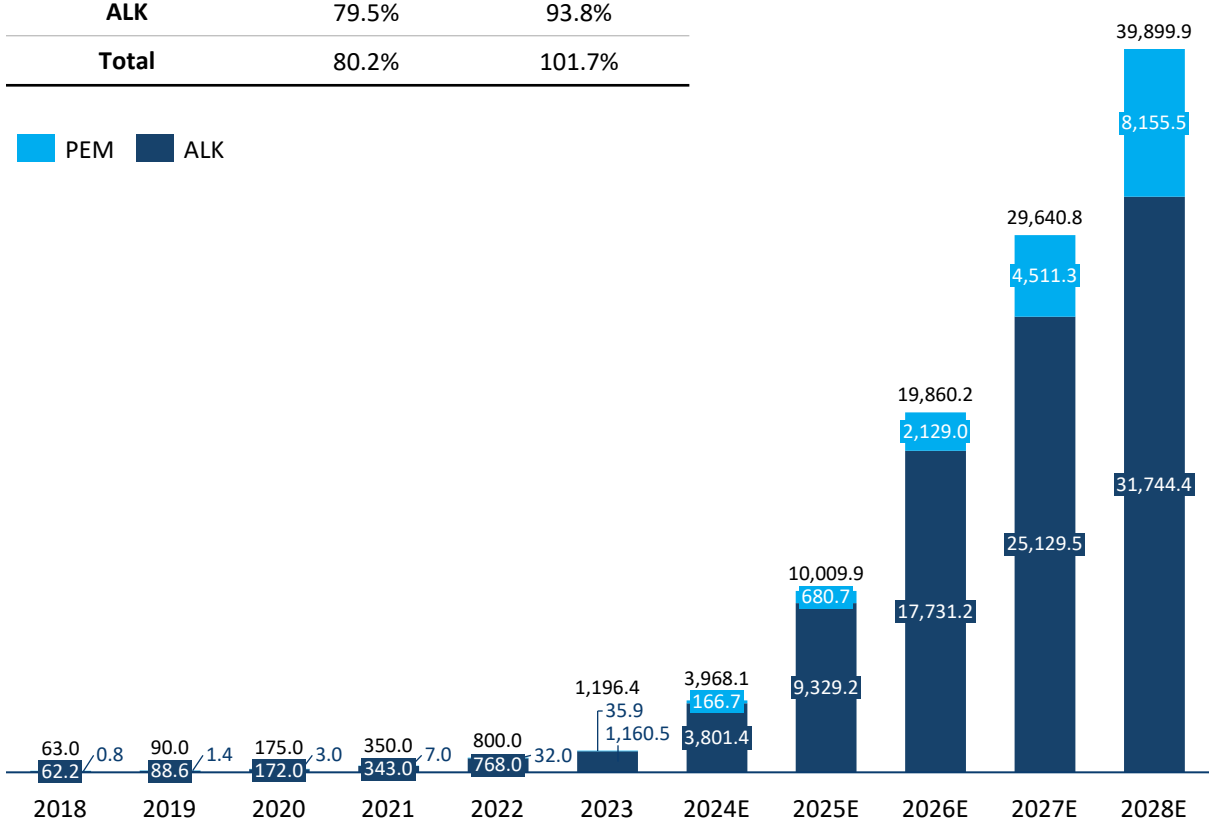
Overview of the Hydrogen Production Industry

Market Size of China electrolyser Industry

Market Size of China electrolyser Industry, by Shipment Volume, by Type

MW, 2018-2028E

CAGR	2018-2023	2023-2028E
PEM	114.0%	196.0%
ALK	79.5%	93.8%
Total	80.2%	101.7%



Key Findings

- In 2023, China holds approximately a 62.7% share of the global electrolyser market in terms of shipment volume.
- In China, ALK is far more popular than PEM, because the technology of ALK is more mature than PEM. there are quite a few players in China dedicated to the ALK industry. In 2023, ALK shipment volume reaches 1,160.5 MW while PEM shipment volume reaches 35.9 MW. It is expected that in the future, domestic PEM technology will break through the technical bottleneck and thus, the shipment volume will experience an increase. Based on the forecast, the shipment volume of PEM will increase from 35.9 MW to 8.2 GW at a CAGR of 196.0% from 2023 to 2028. The shipment volume of ALK will increase from 1,160.5 MW to 31.7 GW at a CAGR of 93.8%.

Source: GGII, Frost & Sullivan

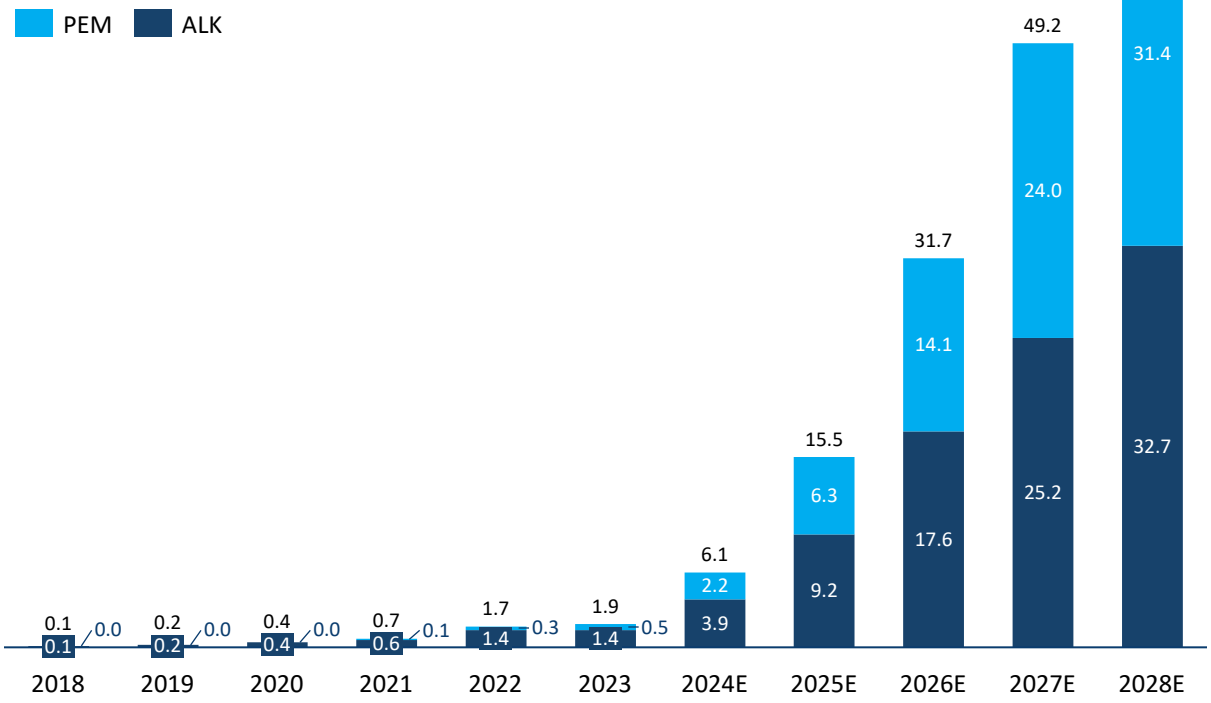
Overview of the Hydrogen Production Industry

Market Size of China electrolyser Industry

Market Size of China electrolyser Industry, by Shipment Value, by Type

Billion RMB, 2018-2028E

CAGR	2018-2023	2023-2028E
PEM	122.5%	128.9%
ALK	69.5%	87.8%
Total	77.1%	102.1%



Key Findings

- In 2023, China holds approximately a 27.5% share of the global electrolyser market in terms of shipment value.
- Due to the immaturity of the technology and the scarcity of raw material, such as ridium, platinum, titanium. PEM electrolyser made in China is more expensive than in foreign countries. The shipment value of PEM has increased from RMB 10 million to RMB 0.5 billion. The shipment value of ALK has increased from RMB 0.1 billion to RMB 1.4 billion with a CAGR of 87.8%.
- It is expected that the shipment value of PEM will increase from RMB 0.5 billion to RMB 31.4 billion at a CAGR of 128.9%. The shipment value of ALK will increase from RMB 1.4 billion to RMB 32.6 billion at a CAGR of 87.8%.

Source: GGII, Frost & Sullivan

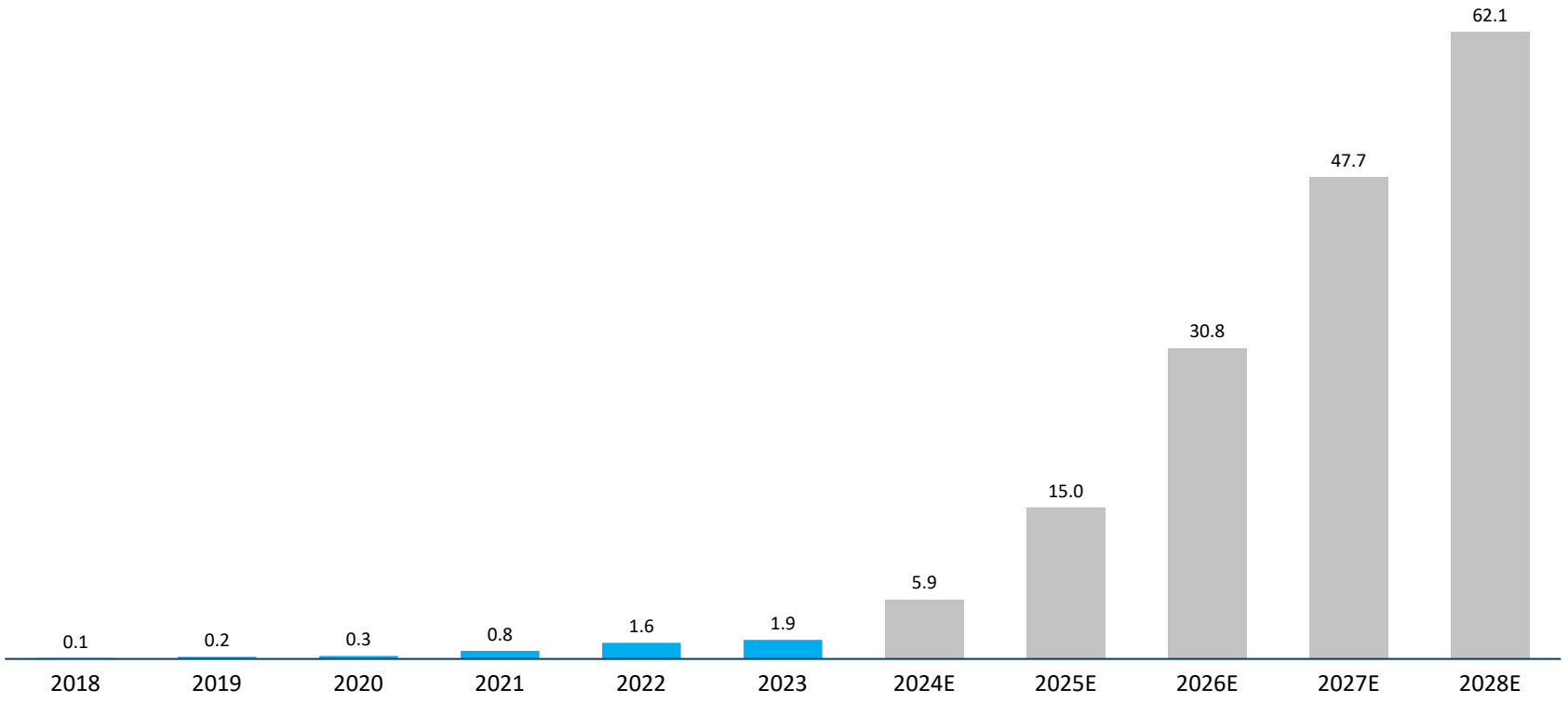
Overview of the Hydrogen Production Industry

Market Size of China electrolyser Industry

Market Size of China electrolyser Industry, by Sales Revenue

Billion RMB, 2018-2028E

CAGR	2018-2023	2023-2028E
Market	80.2%	100.8%



Source: IEA, Frost & Sullivan

Overview of the Hydrogen Production Industry

Market Driver of Hydrogen Production Industry

Market Driver	
Cost Reduction will drive commercialization of hydrogen production	• With technological advancements, the energy conversion efficiency of electrolytic cells has been improved, which could reduce energy consumption. Rational utilization of waste electricity generated by wind and photovoltaic power generation can also lower electricity prices. • From the perspective of equipment investment, the expansion of installed capacity will lead to a significant reduction in equipment costs. With technological advancements, the amount of precious metal catalyst used will decrease, bipolar plates will be replaced with cheaper materials for their precious metal coating, and proton exchange membranes will be replaced with domestically produced alternatives, all of which will lead to a reduction in equipment prices. The reduction in equipment prices will contribute to the increased commercialization of the hydrogen production industry.
Support from favorable policies	• Policy measures are strengthened to clarify the development direction of the hydrogen industry. Since hydrogen energy was first included in the government work report in 2019, the government has implemented a series of policies to support the development of the hydrogen industry. In November 2020, the "Development Plan for New Energy Vehicle Industry (2021-2035)" proposed adapting renewable energy production of hydrogen technology according to local conditions; in June 2022, the 14th Five Year Plan" Renewable Energy Development Plan" promotes the large-scale production and application of hydrogen from renewable energy. According to the Medium- and Long-term Plan for the Development of the Hydrogen Energy Industry (2021-35) published in March 2022, in 2025, the number of fuel cell vehicles will be about 50,000 and a number of hydrogen refueling stations will be deployed. The amount of renewable energy hydrogen production reaches 100,000-200,000 tons/year. By 2030, a more complete hydrogen energy industry technology innovation system, clean energy hydrogen production and supply system will be formed. By 2035, a hydrogen energy industry system will be formed, and a multi-dimensional hydrogen energy application ecology will be constructed to cover the fields of transportation, energy storage, industry and so on. The proportion of hydrogen production from renewable energy sources in end-use energy consumption will be significantly increased. With policy support, the hydrogen production industry will develop further.

Source: Frost & Sullivan

Overview of the Hydrogen Production Industry

Future Trend of Hydrogen Production Industry

Future Trend	
Emergence of Water Electrolysis Technology as the Long-Term Mainstream	• Water electrolysis hydrogen production technology has unparalleled superiority for several reasons. Firstly, it refrains from using fossil fuels and avoids the production of harmful gases. Secondly, the purity of the product gas is consistently high, typically exceeding 99.7%. Additionally, the technology has reached a mature stage, and both the process and equipment involved are simple. Moreover, there is a high level of automation, adopting micro-computer control to ensure stable and reliable operations. With the maturation of water electrolysis technology and its economic feasibility, it is expected to develop into the mainstream of hydrogen production technology in the long term. Furthermore, the utilization of small-size hydrogen production machines is emerging as a new trend in hydrogen production industry.
Development of Hydrogen Produced from Renewable Energy Sources	• Hydrogen produced from renewable energy sources represents the most favorable form of hydrogen production, especially considering its low-carbon footprint. However, it currently faces constraints posed by technological barriers and relatively high costs, and the realization of large-scale applications will require time. While the production of hydrogen from renewable energy sources demands relatively higher water resources, it's essential to note that hydrogen production from traditional methods also relies on water supplies. Technological advancements are expected to enhance the cost efficiency and resource conservation of such production, thereby making such hydrogen's advantages more apparent. The future of hydrogen production through renewable energy sources is anticipated to be one of the most effective approaches to increase the proportion of renewable energy applications and construct a clean, low-carbon, secure, and efficient energy system.

Source: Frost & Sullivan

Overview of the Hydrogen Production Industry

Future Trend of Hydrogen Production Industry

Future Trend	
Addressing Curtailment in Hydro, Wind, and PV Power Generation through Hydrogen Production using Renewable Energy	• China's hydropower, wind power, and photovoltaic power generation have characteristics such as randomness, volatility, and intermittency. Due to the difficulty in accurately predicting power generation, it can lead to a certain degree of energy waste. Hydrogen storage can enable the smooth operation of the power system through the mutual conversion between hydrogen energy and electrical energy. When there is surplus electricity, excess energy can be stored through hydrogen production using water electrolysis technology. When electricity output is insufficient, the stored hydrogen can be utilized in fuel cells to generate power and feed back into the grid system. This effectively addresses the challenges of renewable energy integration and grid stability, enhancing the efficiency of the transmission network and energy utilization.

Overview of the Hydrogen Production Industry

Entry Barriers and Challenge of Hydrogen Production Industry

Entry Barriers

Iteration risks of technological development	• Since low-carbon hydrogen produced in the future almost does not generate carbon emissions during production, it is expected to become the mainstream of the market in the future. However, this type of technology currently has a low maturity and high cost, and the technology needs to be promoted, posing challenges to the R&D direction of new entrants.
Differences in location of renewable energy resources	• Different regions in China have different capabilities for supplying renewable energy. Currently, photovoltaic, solar thermal, wind power and other renewable energy are concentrated in the northwest and northeast regions, forming natural barriers to entry for players in the industry. Additionally, entry into the hydrogen production industry requires expertise in the development of core components and know-how for hydrogen production equipment, and strong market development and scenario development capabilities are essential, particularly for integrated projects combining hydrogen production with renewable energy sources in the northwest. These projects demand not only hydrogen production capabilities but also the ability to address downstream green hydrogen consumption, a combination that is rare among market players. As a result, barriers to entry remain significant in this sector.

Challenge

Relatively high cost of electrolytic water hydrogen production technology	• Although electrolytic water hydrogen production has less environmental pollution compared to traditional hydrogen production methods, it is still limited by the level of electricity prices and initial investment costs. At the present stage, the cost of electrolytic water hydrogen production is still relatively high. In the future, large-scale use of hydrogen means that the price of hydrogen will be more sensitive, so suppressing costs will become a challenge for the development of electrolytic water hydrogen production.

Source: Frost & Sullivan

Agenda

Competitive Landscape

Leading Players

REFIRE		Company Base	Shanghai
		Company Website	https://www.refire.com/
Year of Establishment	2015	**2023 Total Revenue**	895.3 Million RMB
Introduction and competitive advantage	• The company specializes in the research and development of fuel cell technology, the research and development, production, and sales of fuel cell system-related products, and fuel cell engineering application development services. The company's fuel cell system-related products are mainly used in the fuel cell automobile industry and have established in-depth cooperation with FAW Jiefang, Dongfeng Motor, Yutong Bus, Zhongtong Bus, Mitsubishi Fuso and other domestic and foreign well-known automobile enterprises, providing fuel cell systems and developing a number of fuel cell automobile models in combination with the actual application scenarios of the products. • The company ranked the first in the hydrogen fuel cell system market in China, in terms of the sales power output of hydrogen fuel cell systems in 2023, with a market share of 23.8%. The company ranked the first in the hydrogen fuel cell system market in China, in terms of the total sales power output of hydrogen fuel cell systems that have been used for heavy-duty trucks in 2023, with a market share of 42.4%. The company ranked the first in the hydrogen fuel cell system market in China, in terms of the total sales value of hydrogen fuel cell systems that have been used for heavy-duty trucks in 2023, with a market share of 29.4%. The company is the first company in hydrogen fuel cell industry in China that has independently developed and realized mass-production of hydrogen fuel cell systems, fuel cell stacks, MEAs, and bipolar plates. The company has both PEM and ALK electrolysis products. In addition, the company became the first enterprise in hydrogen fuel cell industry in China that realized commercialization of its proprietary hydrogen fuel cell systems abroad.		

Source: Frost & Sullivan

Competitive Landscape

Leading Players

SinoHytec		Company Base	Beijing
亿华通 SinoHytec		Company Website	https://www.sinohytec.com/
Year of Establishment	2012	2023 Total Revenue	800.7 Million RMB
Introduction and competitive advantage	• The company is a high-tech enterprise focusing on the research, development, and industrialization of hydrogen fuel cell engine systems. It is committed to becoming a leading international hydrogen fuel cell engine supplier. The company has independent core intellectual property rights, and has taken the lead in realizing the batch localization of engine systems and fuel cell stacks, focusing on the development of fuel cell demonstration city clusters and potential cities, and has established in-depth cooperative relationships with domestic mainstream commercial vehicle enterprises, such as Yutong Bus, Beiqi Foton, Zongtong Bus, and Geely Commercial Vehicles, etc. Fuel cell vehicles equipped with the products of the company have been put into operation in many cities, such as Beijing, Zhangjiakou, Shanghai, Chengdu, Zhengzhou, Zibo. The company's product application scene to further expand to the cold chain transportation, sanitation and heavy trucks and other scenarios.		

Source: Frost & Sullivan

Competitive Landscape

Leading Players

SHPT		Company Base	Shanghai
捷氢科技 SHPT		Company Website	https://www.shpt.com/
Year of Establishment	2018	**2023 Total Revenue**	480.9 Million RMB
Introduction and competitive advantage	• The company is a high-tech enterprise specializing in the research and development, design, manufacture, sales, and engineering services of fuel cell stacks, systems, and core components. The company has core technology advantages in the design, control, integration, process development, manufacturing, and vehicle adaptation of fuel cell stacks and systems, and has made breakthroughs in the independent R&D and manufacturing of membrane electrodes, which are the key core components of fuel cell stacks and achieved localization and industrialization. At present, the company's fuel cell technology and products have made good breakthroughs in the commercial application of buses, city official vehicles, group buses, heavy trucks, logistics, light trucks, and other scenarios.		

Source: Frost & Sullivan

Competitive Landscape

Leading Players

SINO-SYNERGY		Company Base	Jiaxing, Zhejiang Province
国鸿氢能 SINOSYNERGY		Company Website	https://www.sinosynergypower.com/
Year of Establishment	2015	**2023 Total Revenue**	700.6 Million RMB
Introduction and competitive advantage	• The company is a high-tech enterprise with hydrogen fuel cells as its core products, with the core technology mastered in the field of hydrogen fuel cells, the company has laid out a rich product line, the products mainly include fuel cell stacks, fuel cell system modules, stationary power generation systems, fuel cell air filters and other core technology products in the field of hydrogen fuel cells; • In 2016, Ballard authorized SINOSYNERGY to produce Its FCvelocity®-9SSL fuel cell set and provide the corresponding technology and equipment, SINOSYNERGY, Ballard and REFIRE respectively set up a joint venture company to produce electric stacks and system modules.		

Source: Frost & Sullivan

Competitive Landscape
Leading Players

Weichai Group		Company Base	Weifang, Shandong Province
		Company Website	https://www.weichai.com/
Year of Establishment	2002	**2023 Total Revenue**	214.0 Billion RMB
Introduction and competitive advantage	• The company is one of the automobile and equipment manufacturing groups with the strongest comprehensive strength in China. The company has successfully constructed a new pattern of synergistic development of powertrain, vehicle and machine, intelligent logistics, and other industrial segments, with vehicle and machine as the leader and powertrain as the core technology support.		

Source: Frost & Sullivan

Competitive Landscape

Leading Players

SFCC	Company Base	Shenzhen
	Company Website	https://www.sino-sfcc.com/
	Year of Establishment	2016
Introduction and competitive advantage	• State Fuel Cell Technology Corporation, an enterprise founded in 2016 in Shenzhen. Its main business includes fuel cell power system solutions related to leading fuel cell power system and core components R&D and manufacturing, and fuel cell application development; and fuel cell industry ecological closed-loop solutions related to hydrogen refuelling station energy foundation R&D, production, design, construction and operation of core equipment of the facility, operation and management of new energy vehicles	

Source: Frost & Sullivan

Competitive Analysis of Fuel Cell

Competitive Landscape

Ranking of top five fuel cell system providers in terms of total sales volume of fuel cell systems sold in China

MW, 2023

Ranking	Company	Sales Volume	Market Share
1	Our Group	242.3	23.8%
2	SinoHytec	189.4	18.6%
3	Sino-synergy	148.6	14.6%
4	SHPT	~100	~9.8%
5	SFCC	~40	~3.9%

Source: Frost & Sullivan

Competitive Analysis of Fuel Cell

Competitive Landscape

Ranking of Fuel Cell System Providers in terms of Sales Value of Fuel Cell Systems sold in China

100 Million RMB, 2023

Ranking	Company	Sales Value	Market Share
1	SinoHytec	7.2	18.2%
2	Sino-synergy	6.8	17.3%
3	Our Group	6.4	16.2%
4	SHPT	~4.0	~10.2%
5	SFCC	~2.4	~6.4%

Source: Frost & Sullivan

Competitive Analysis of Fuel Cell

Competitive Landscape

Ranking of China's Fuel Cell System in terms of Total Power Output of Sold Hydrogen Fuel Cell Systems that Have Been Used for Heavy-duty Trucks

MW, 2023

Ranking	Company	Power Output	Market Share
1	Our Group	209.2	42.4%
2	SinoHytec	99.8	20.2%
3	Sino-synergy	86.7	17.6%
4	SHPT	23.1	4.7%
5	Weichai Group	14.3	2.9%

Source: Frost & Sullivan

Competitive Analysis of Fuel Cell

Competitive Landscape

Ranking of China's Fuel Cell System in terms of Total Sales Value of Sold Hydrogen Fuel Cell Systems that Have Been Used for Heavy-duty Trucks

100 Million RMB, 2023

Ranking	Company	Sales Value	Market Share
1	Our Group	5.5	29.4%
2	Sino-synergy	3.2	17.2%
3	SinoHytec	3.0	16.0%
4	SHPT	0.9	4.8%
5	Weichai Group	0.6	3.2%

Source: Frost & Sullivan

Competitive Analysis of Electrolyser

Competitive Landscape

The Product Layout of the Electrolyser among Fuel Cell System Players

	PEM	ALK
Our Group	✓	✓
Company A	✓	
Company B		
Company C		
Company G		✓
Company H	✓	

- The company is the first fuel cell system player to lay out PEM and ALK simultaneously.

Note: Product Layout here refers that the company has finished products available for sale.

Company G was founded in 2016 and is based in Jiashan, Zhejiang Province. It focuses on developing hydrogen energy equipment in China with its own independent research and development team. Its products include but not limited to fuel cells.
Company H was founded in 2017 and is based in Shanghai. It focuses on the research and development, production, sales and overall solutions of fuel cell stacks.

Source: Frost & Sullivan

Competitive Analysis of Electrolyser

Competitive Landscape

The Self-Developed Product Layout of the PEM Electrolyser among Fuel Cell System Players

	MEA	Power Supply System
Our Group	✓	✓
Company A		
Company B		
Company C		
Company G		
Company H	✓	

- The company is the first fuel cell system player to realize the self-development of MEA and power supply systems simultaneously.

Source: Frost & Sullivan

Competitive Analysis of Electrolyser

Competitive Landscape

Currently, ALK and PEM are the primary methods for producing hydrogen through water electrolysis. In China, ALK is far more popular than PEM, because the technology of ALK is more mature than PEM. In 2023, ALK shipment volume reaches 1,160.5 MW while PEM shipment volume reaches 35.9 MW in China. In 2023, there are more than 30 major participants in China's ALK water electrolysis hydrogen production equipment industry. In 2023, the top five ALK water electrolysis equipment suppliers accounted for over 50% of the market share by revenue. Additionally, more than 15 well-known companies are engaged in PEM water electrolysis technology. However, the PEM market in China is in the early stages of commercialization, and each company's business scale is quite small. Therefore, reliable market share data for PEM companies is currently unavailable.

Source: Frost & Sullivan

Competitive Analysis of Fuel Cell Systems

Competitive Landscape

	The Group	SinoHytec	Sino-synergy
Proprietary core components	Fuel cell stacks, MEAs, bipolar plates, hydrogen circulation system	Fuel cell stacks, bipolar plates	Fuel cell stacks, bipolar plates
Application scenarios	Vehicle scenarios: commercial vehicles; Non-vehicle scenarios: power generation applications, construction machinery, rail transit	Vehicle scenarios: commercial vehicles; Non-vehicle scenarios: power generation applications	Vehicle scenarios: commercial vehicles; Non-vehicle scenarios: power generation applications, construction machinery, rail transit
Range of rated power	63kW-220kW	80.5kW-240kW	65kW-240kW
Range of power density	400W/kg-815W/kg	494W/kg-820W/kg	402W/kg-906W/kg
Life-span	30,000 hours for majority of the products	5,000 hours and 20,000 hours for majority of the products	20,000 hours for majority of the products, only one model reaches 30,000 hours
Freeze-start temperature	-30˚C without auxiliary heat nor damage to system	-35˚C /-30˚C	-30˚C
High-temperature operating capability	95˚C	95˚C	95˚C
Hydrogen consumption	9.0kg/100km-10.0kg/100km	10.0kg/100km-12.0kg/100km	~10.0kg/100km
Average selling prices	~3,720 RMB/kW	~4,238 RMB/kW	~4,079 RMB/kW
Synergies with in-house developed hydrogen production products	Yes	N/A	N/A

Notes:(1) The average selling price of fuel cell systems listed here refers to price in 2022; the average selling price of the Company's fuel cell systems refer to price of those incorporating its own fuel cell stacks.(2) Hydrogen consumption listed above refers to related figures for hydrogen fuel cell systems empowering 49T heavy-duty trucks.

Notes: Hydrogen consumption is an indicator influenced by multiple factors, for instance, vehicle types, vehicle weight, power output of the hydrogen fuel cell systems, etc. To assess the performance of hydrogen fuel cell systems, it is reasonable and meaningful to compare hydrogen consumption of the same vehicle type and weight incorporating hydrogen fuel cell systems provided by different companies, than to compare hydrogen consumption of different vehicle types and weight.
As confirmed by Frost & Sullivan, heavy-duty truck is the largest application segment of hydrogen fuel cell systems in 2023. Among heavy-duty trucks in different weights, 49T heavy-duty truck is the most commonly used type, accounted for approximately 40% of all heavy-duty trucks as of the end of 2023.

Competitive Analysis of Fuel Cell Systems

Comparative Analysis of Key Features of Fuel Cell Systems and Fuel Cell Stacks Among Competitors

Comparative Analysis

The table above demonstrates that the Group is the only one out of the three that is capable of developing and producing MEAs independently. MEA is a crucial component of the fuel cell system and fuel cell stack, that plays a dominant role in determining the overall performance of the fuel cell system and fuel cell stack, including factors such as, reliability, lifespan, cost-effectiveness, etc. In terms of cost structure, MEAs accounts for approximately 40.0% of the total cost of a fuel cell system. Therefore, since the Group can independently develop and produce MEAs, it has more flexibility and autonomy in controlling the overall performance and cost of the hydrogen fuel cell system, enabling better cost reduction and efficiency improvement. In contrast, the other two shall rely on third-party developed MEAs, therefore are harder to control costs, and are also constrained by the development strategy and development progress of the third parties.

In terms of application scenarios, rated power and power density, the Group's products exhibit a wider or comparable range of application scenarios, extending beyond various commercial vehicle types; and also exhibit similar ranges of rated power and power density. While the Group may not have a distinct advantage over the competitors listed above in terms of application scenarios, power and power density, it is crucial to look into the lifespan of the fuel cell systems and their adaptability to different temperature conditions, when evaluating the durability and cost-effectiveness of the FCEVs in specific application contexts, which holds greater value for end-users of FCEVs.

Specifically, in terms of product lifespan, the majority of the Group's products can reach lifespan of 30,000 hours. In contrast, for Company A, the lifespan ranges between 5,000 hours and 20,000 hours for majority of its products. For Company B, majority of its products can only reach lifespan over 20,000 hours, only one model can reach lifespan of 30,000 hours.

Moreover, the Group's products exhibit enhanced adaptability to extreme temperature conditions. While freeze-start generally requires auxiliary heat assistance or otherwise may cause material fatigue, degradation or failure of the fuel cell system, the Group's fuel cell system can initiate a freeze-start without requiring auxiliary heat (thereby reducing energy consumption) and without causing any damage to the fuel cell system (thereby extending lifespan). Moreover, these products have high-temperature operation capability to withstand high reaction temperature in the fuel cell stacks, thereby reducing the amount of heat dissipated into the environment. Such increased resilience renders the Group's products more reliable and capable of performing optimally in diverse environments over an extended period.

Competitive Analysis of Fuel Cell Systems

Comparative Analysis of Key Features of Fuel Cell Systems and Fuel Cell Stacks Among Competitors

Comparative Analysis

The hydrogen consumption is a crucial metric for evaluating the commercial viability of hydrogen fuel cell systems. It indicates how efficiently the system utilizes hydrogen to generate power. Similar to how fuel efficiency is important for conventional diesel-powered vehicles, hydrogen consumption plays a vital role in the overall cost-effectiveness and practicality of FCEVs. In the case of 49T heavy-duty trucks, the Group's hydrogen fuel cell systems have demonstrated an advantage in achieving lower hydrogen consumption as compared to those of the two competitors as listed above. This means that while offering similar load-carrying capacity and transportation capabilities, the Group's hydrogen fuel cell systems can effectively help end-users reduce their daily operational costs associated with using FCEVs in the long term, which contributes to the market-driven transformation, and widespread adoption of hydrogen fuel cell systems without subsidies going forward.

Furthermore, despite possessing key features that are equally good or superior to those of its main competitors, the Group's products have lower average selling prices (measured in RMB/kW). This cost efficiency makes the Group's products more appealing to customers in terms of affordability while maintaining their superior qualities as described above. With the Group's continuous development, it not only focuses on hydrogen fuel cell systems but also gradually expands into hydrogen production systems. Such expansion is not only built upon the Group's mature network in the hydrogen industry and solid collaborations with other relevant stakeholders in hydrogen market, but more importantly, built upon the Group's existing technologies and know-hows in MEAs. PEM fuel cell systems and PEM water electrolysis hydrogen production systems have a reciprocal relationship in terms of chemical reactions. As the Group has core technologies in developing and producing MEAs, its research and development capabilities and technological foundation provide a solid basis for the development of hydrogen production systems, which provide robust support for development of hydrogen production systems. Conversely, without the core technologies of MEAs, it would be difficult to develop PEM water electrolysis hydrogen production products. Unlike Company A and Company B, the Group can provide comprehensive hydrogen energy solutions that encompass both hydrogen fuel cell systems and hydrogen production systems, which enables the Group to better meet customer needs and offer integrated solutions, further driving the development of the hydrogen industry.

Agenda

Appendix
Research Methodology & Basic Assumptions

Research Methodology

Primary research involved discussing the status of the industry with certain leading industry participants across the industry value chain and conducting interviews with relevant parties to obtain objective, factual data and prospective predictions. Secondary research involved information integration of data and publication from publicly available sources, including official data and announcements from government agencies, company reports, independent research reports and data based on Frost & Sullivan's own data base.

Basis and assumptions

All statistics are based on the information available as at the date of the Frost & Sullivan Report, with the potential impact of the COVID-19 pandemic taken into account.

Hydrogen Production

Currently, China has the world's highest hydrogen production, with more than 35 million tons of hydrogen production in 2023, representing 38% of the global hydrogen production volume in the same year. However, hydrogen preparation is still dominated by non-renewable hydrogen production methods from raw materials such as coal. Hydrogen produced from renewable energy sources presents numerous advantages, particularly in terms of low carbon emissions and its capacity for large-scale, long-term storage. In the future, as China's hydrogen production technology advances, the cost of producing hydrogen through renewable energy sources will continue to decrease, and the price of hydrogen energy is expected to be further optimized, accelerating the consumer penetration of hydrogen energy and improving China's energy structure. Hydrogen produced from renewable energy sources is primarily produced through the method of water electrolysis. As per the Hydrogen Energy Alliance's forecast, hydrogen produced from renewable sources will take about 15% of total hydrogen produced in China by the year 2030.

Appendix
Pricing Range

Hydrogen Supply System

The higher the tonnage of the vehicle being loaded, the higher the required scale of hydrogen storage, and therefore the higher the pricing of the hydrogen supply system. During 2021 to 2023, the market price range for the hydrogen supply system was between RMB 30,000 per set and RMB 230,000 per set.

Bipolar Plates

During 2021 to 2023, the price range of bipolar plates is between RMB 50/set to RMB 200/set.

Membrane Electrode

During 2021 to 2023, the price range of membrane electrode is between RMB 250/unit to RMB 500/unit.

Fuel Cell Stack

The differences in power output of the electrolyzer are greatly affected by the rated power, with market prices of fuel cell stack ranging from 1500 RMB/KW to 2500 RMB/KW during 2021 to 2023.

Appendix

Industry Chain of the Hydrogen Market

Upstream: hydrogen production

Hydrogen produced through traditional methods currently constitutes the predominant form of hydrogen globally, accounting for approximately 86.9% of the total. Nonetheless, hydrogen produced from renewable energy sources presents numerous advantages, particularly in terms of low carbon emissions and its capacity for large-scale, long-term storage and environmental sustainability. As technology progresses, the production costs of hydrogen produced from renewable energy sources are expected to decrease in the future, making it a promising growth area for the hydrogen market.

Midstream: hydrogen storage, transportation and refuel

Currently, high-pressure compression is the predominant gas storage method, offering advantages such as rapid filling and discharging, straightforward container structure, and cost-effectiveness.

Solid hydrogen storage is in the early stages of commercialization, while liquid hydrogen storage has not gained widespread usage in China.

Transportation:... Currently, the primary methods of long-distance distribution for gas hydrogen involves using long-haul trailers or pipelines. However, pipeline transportation demands significant upfront investment for construction. Liquid hydrogen can be conveyed using specialized tanks installed in trucks or ships. This method enhances transport efficiency and augments the supply capacity of hydrogen refueling stations. Solid-state hydrogen storage involves using materials to physically and chemically absorb hydrogen, storing it within solid substances. An example is magnesium-based solid-state storage, where hydrogen is stored in the form of magnesium alloy MgH2 (magnesium hydride).

Refueling: Among the emerging downstream applications of hydrogen, fuel cell vehicles represent the largest segment with the great growth potential. Therefore, hydrogen refueling stations have become crucial infrastructural facilities for promoting the development of the hydrogen industry.

Downstream: end-use applications

In particular, with application of hydrogen-powered fuel cell systems to undertake end-use applications, which emits only water (H2O) and warm air, without any of harmful substances emitted from gasoline and diesel vehicles, relevant industries may effectively reduce their carbon emission footprint associated therein.

Appendix

Preferential Policies and Regulations

- In June 2022, China issued the 14th Five-Year Plan for the Development of Renewable Energy, promoting hydrogen production from renewable energy and promotes large-scale utilization of hydrogen produced from renewable sources.
- In 2023, more than 30 provinces, autonomous regions and municipalities in China issued over 200 local policies related to hydrogen energy.

Release Date	Issuing Authority	Policies	Comments
Jan. 2022	National Development and Reform Commission, National Energy Administration	The 14th Five-Year Plan for Modern Energy System	• Throughout the 14th Five-Year Plan period, there is a specific focus on achieving an annual average growth in R&D funding for energy of over 7%. It is anticipated that there will be approximately 50 breakthroughs in key technology areas, aligning with the overarching objective of reaching a non-fossil energy consumption share of 25% by 2030.
Mar. 2022	**National Development and Reform Commission**	**The Medium and Long-term Plan for Hydrogen Industry (2021-2035)**	• **The plan analyzes the current development situation of China's hydrogen industry and clarifies the strategic positioning, overall requirements, and development goals of the industry. The importance of hydrogen is increased.** • From a domestic perspective, China is the world's largest hydrogen producer, with an annual hydrogen production of approximately 33 million tons, of which around 12 million tons meet industrial hydrogen quality standards. China leads globally in renewable energy installed capacity, positioning itself with significant potential in providing clean and low-carbon hydrogen.

The fuel cell vehicle industry experiences seasonality which is mainly influenced by the periodical issuance or updates of related governmental policies in the hydrogen fuel cell industry and the kick-off of related government award projects, which generally occurs in the second half of the year. Fuel cell vehicle manufacturers generally determine and place orders accordingly only after assessment of such newly issued or updated award policies.

China's fuel cell vehicle industry is still in the early stages of development and is highly affected by government subsidy policies. Hydrogen fuel cell commercial vehicle manufacturers typically sell and charge prices to customers after deducting applicable subsidies at the time of sale before receiving government subsidies. Commercial vehicle manufacturers can collect the relevant subsidies from the government, but this usually takes a lengthy period of time. The period between when hydrogen fuel cell commercial vehicles manufacturers sell their vehicles and when they can collect the full amount of qualified subsidies is typically more than two years. Commercial vehicle manufacturers may face working capital constraints affected by such time fact that hydrogen fuel cell commercial vehicle manufacturers have strong bargaining power given the industry is still in the early stages of development.

Except for certain FCEV manufacturers, a majority of the market players, along the hydrogen value chain in China, whose main businesses are related to hydrogen industry, are still loss-making, mainly because the industry is still in a relatively early stage, requiring substantial investment in research and development as well as sales and marketing, which in turn demand significant financial resources, and the industry is still primarily policy-driven, with market players more or less rely on government subsidies, while production costs of related products are relatively high.

However, there are also a few disadvantages of hydrogen, including but not limited to (i) producing hydrogen through electrolysis using renewable electricity can be costly and energy-intensive; (ii) hydrogen is a highly reactive and low-density gas, which presents challenges for distribution. Current infrastructure for hydrogen storage and transportation is limited, requiring significant investments in infrastructure development; and (iii) most energy systems were designed for fossil fuels, and while renewable energy like solar and wind energy can be integrated with existing infrastructure, hydrogen energy requires special fuel cells for storage, which could be challenging.

Source: Frost & Sullivan

Appendix
Additional Information

Regarding market size of global hydrogen fuel cell industry, by sales power output: The historical data for total sales power output is derived by multiplying the sales volume of each type of downstream applications globally (such as commercial vehicles, passenger vehicles, others in transportation, stationary power, construction machinery) by the average power output per unit of each type of downstream applications, and then adding up the power outputs of all such types of downstream applications. The underlying assumptions for the expected future growth rate mainly include two aspects: (1) as the cost of producing hydrogen fuel cell systems is driving down. Taking two major markets globally as examples, in China, the cost of producing hydrogen fuel cell systems had decreased significantly from RMB9,600/kW in 2018 to RMB2,400/kW in 2023, and is expected to further decrease to RMB1,100/kW in 2028. In Japan, the cost of producing hydrogen fuel cell systems is expected to decrease from JPY20,000/kW in 2019 to JPY5,000/kW in 2025; and (2) the infrastructure of the hydrogen industry has reached a relatively advanced level, and will be continuously improved. Specifically, the number of hydrogen refueling stations globally increased from 597 in 2019 to 1,362 in 2023, and is expected to increase significantly to 4,761 in 2028. The market's acceptance of hydrogen fuel cell systems will gradually increase, thereby promoting a rapid growth trend in downstream applications. In addition, in the future, as the production, storage, transportation, refueling, and utilization of hydrogen are streamlined, hydrogen fuel cell systems will also be promoted on a larger scale. And (3) as the cost of producing hydrogen globally continues to decrease, the hydrogen price will therefore continue to decrease, the demand for FCEVs will correspondingly increase, thereby further expanding the market size of fuel cell systems. The traditional sources are major sources for hydrogen production globally. Hydrogen produced from traditional sources accounts for more than 85% of the total hydrogen consumption, while hydrogen produced from renewable energy sources accounts for about 7%. The production cost of hydrogen produced from traditional sources globally is expected to decrease from the range of USD1.0/kg to USD2.0/kg in 2021 to the range of USD0.9/kg to USD1.8/kg in 2030. The production cost of hydrogen produced from renewable energy sources globally is expected to decrease from the range of USD2.5/kg to USD8.0/kg in 2021 to the range of USD1.3/kg to USD5.0/kg in 2030. FCEV users pay attention to hydrogen retail prices, regardless of the hydrogen production sources. The retail price of hydrogen is influenced by hydrogen production costs, storage costs and refueling costs. Regardless of whether hydrogen is derived from traditional or renewable energy sources, production costs are on a downward trend. While shifts in the mix of production sources can marginally impact retail prices, it is primarily technological advancements that are reducing hydrogen production costs, not the proportion of production sources. Taking two major markets globally as examples, in China, the hydrogen retail price is expected to decrease from the range of RMB50/kg to RMB60/kg in 2023 to the range of RMB30/kg to RMB40/kg in 2030. In Japan, the hydrogen retail price is expected to decrease from around JPY100/Nm3 in 2017 to around JPY30/Nm3 in 2030.

Source: Hydrogen and Fuel Cell Strategy Council of Japan, Frost & Sullivan

Appendix
Additional Information

As for China market, The underlying assumptions for the expected future growth rate mainly include two aspects: (1) as the cost of producing hydrogen fuel cell systems is driving down. Specifically, the cost of producing hydrogen fuel cell systems in China had decreased significantly from RMB9,600/kW in 2018 to RMB2,400/kW in 2023, and is expected to further decrease to RMB1,100/kW in 2028, help making the hydrogen fuel cell systems cost efficient in downstream applications; and (2) the infrastructure of the hydrogen industry has reached a relatively advanced level, and will be continuously improved. Specifically, the number of hydrogen refueling stations in China increased significantly from 56 in 2019 to 428 in 2023, and is expected to increase significantly to 2,766 in 2028. The market's acceptance of hydrogen fuel cell systems will gradually increase, thereby promoting a rapid growth trend in downstream applications. In addition, in the future, as the production, storage, transportation, refueling, and utilization of hydrogen are streamlined, hydrogen fuel cell systems will also be promoted on a larger scale; and (3) as the cost of producing hydrogen in China continues to decrease, the hydrogen price will therefore continue to decrease, the demand for FCEVs will correspondingly increase, thereby further expanding the market size of fuel cell systems in China. The traditional sources are major sources for hydrogen production in China. Hydrogen produced from traditional sources accounts for more than 90% of the total hydrogen consumption, while hydrogen produced from renewable energy sources accounts for about 5%. The production cost of hydrogen produced from traditional sources in China is expected to decrease from the range of RMB6.0/kg to RMB10.0/kg in 2023 to the range of RMB5.0/kg to RMB9.0/kg in 2030. The production cost of hydrogen produced from renewable energy sources in China is expected to decrease from the range of RMB15.0/kg to RMB45.0/kg in 2023 to the range of RMB5.0/kg to RMB15.0/kg in 2030. FCEV users pay attention to hydrogen retail prices, regardless of the hydrogen production sources. The retail price of hydrogen is influenced by hydrogen production costs, storage costs and refueling costs. Regardless of whether hydrogen is derived from traditional or renewable energy sources, production costs are on a downward trend. While shifts in the mix of production sources can marginally impact retail prices, it is primarily technological advancements that are reducing hydrogen production costs, not the proportion of production sources. The hydrogen retail price in China is expected to decrease from the range of RMB50/kg to RMB60/kg in 2023 to the range of RMB30/kg to RMB40/kg in 2030.

Source: Hydrogen and Fuel Cell Strategy Council of Japan, Frost & Sullivan

Appendix
Additional Information

Regarding market size of hydrogen fuel cell industry, by sales value: The historical data for total sales value is derived by multiplying the total sales output of each type of downstream applications globally by the average selling price per kW of each type of downstream applications, and then adding up the sales value of all such types of downstream applications.

For the year ended December 31, 2023, the annual production volume of hydrogen from renewable energies was approximately 80,000 tons. As of September 30, 2024, there were around 22,500 units of FCEVs. As of October 31, 2024, there were 435 units of hydrogen refueling stations.

As of the Latest Practicable Date, the company has successfully distinguished itself from other industry peers by its strong track record of achieving sustainable growth in non-demonstration cities in China.

To be specific, high-purity hydrogen in regions with rich and low-cost by-product hydrogen resources, such as Shanxi province, is around RMB25 per kilogram to RMB40 per kilogram at local hydrogen refueling stations, while high-purity hydrogen in other regions, such as Shanghai, is around RMB50 per kilogram to RMB70 per kilogram at local hydrogen refueling stations.

The operating cost of a hydrogen fuel cell heavy-duty truck for one hundred kilometers is generally around 35% lower than the corresponding operating cost of a diesel-fueled heavy-duty truck for one hundred kilometers.

Hydrogen fuel cell companies usually can only reach 90℃ or lower during stable operation.

Other market players may need to rely on external heat sources, or the lifespan of the hydrogen fuel cell system is greatly compromised to achieve freeze-start with external heat sources, thus are not suitable for heavy-duty trucks.

The transaction of the company and Beijing Nowogen which the fuel cell stacks sourcing from other place , such transactions is generally consistent with industry practice.

Source: Hydrogen and Fuel Cell Strategy Council of Japan, Frost & Sullivan

Assuming that the fuel cell heavy-duty trucks with ETC kit transport within the areas with such exemption of highway tolls, such policies are expected to reduce total cost of ownership of the fuel cell heavy-duty trucks by around 10% to 15%. In response to such policies, the number of hydrogen refuelling stations and related infrastructure are expected to witness a huge growth, which in turn will drive the adoption of fuel cell heavy-duty trucks and hydrogen fuel cell systems. Furthermore, in 2023, the first domestically developed hydrogen-powered urban rail train in China successfully completed a full-load running test in Changchun. This milestone signifies a new breakthrough in the application of hydrogen fuel cell system in rail transportation and demonstrating China's goal of promoting diversified application of hydrogen fuel cell systems, especially in heavy-duty logistics. The favourable policies will further drive growth in hydrogen industry.

Markets like Qingdao, Ningbo, Chongqing, Wuhan, Jiyuan, Linfen, Jinan, and Hohhot possess unique geographic, industrial, and/or market characteristics that promote the utilization of hydrogen energy. These characteristics include but not limited to, strong hydrogen supply with competitive prices, abundant industrial materials that require heavy-duty logistics, and supportive local policies encouraging the adoption of FCEVs to reduce carbon emissions in public transportation.

We think that local governments in China will continue to release and implement new favorable policies related to the hydrogen industry in the future.

Source: Frost & Sullivan

Appendix
Glossary of Technical Terms

Terms	Definitions
“alkaline electrolysis cells”	a device for the production of electrolytic hydrogen, by which water is decomposed into hydrogen and oxygen in an electrolytic cell
“anode”	an electrode through which the conventional current enters a polarized electrical device, which contrasts with a cathode
“bipolar plates”	a key component of a single hydrogen fuel cell system, which connects and separates the individual hydrogen fuel cells in series to form a hydrogen fuel cell stack with required voltage, aids uniform distribution of fuel gas and air over the reaction area of the membrane electrode assemblies
“by-product hydrogen”	hydrogen gas produced as a result of a process or processes dedicated to producing other products
“CAGR”	compound annual growth rate
“carbon neutrality”	the state where emissions of carbon dioxide and other greenhouse gases due to human activities and removals of these gases are in balance over a given period
“carbon peaking”	a point in time when carbon dioxide and other greenhouse gases emissions stop growing and peak, and then gradually fall back
“cathode”	through which the conventional current enters a polarized electrical device, which contrasts with an anode
“CHP”	cogeneration or combined heat and power, the use of a heat engine or power station to generate electricity and useful heat at the same time
“CCM”	

Appendix
Glossary of Technical Terms

Terms	Definitions
“current density”	the amount of charge per unit time that flows through a unit area of a chosen cross section
“DC-to-DC boost converters”	an electronic circuit or electromechanical device that converts a source of direct current from one voltage level to another
“decarbonization”	the process of reducing “carbon intensity”, lowering the amount of greenhouse gas emissions
“demonstration city clusters” or “fuel cell vehicle demonstration city clusters”	the five fuel cell vehicle demonstration city clusters, including Beijing-Tianjin-Hebei city cluster, Shanghai city cluster, Guangdong City Cluster, Hebei city cluster and Henan city cluster
“distributed power generation system”	the installation and operation of small modular power-generating units at or near the end user, which is used to reduce transmission and distribution losses and to improve reliability by combining energy management and storage systems
“dual-carbon” or “dual carbon” goal	a goal of reaching peak carbon emissions by 2030 and carbon neutrality by 2060, which were officially set by President Xi Jinping at the United Nations General Assembly in September 2020
“electric vehicle”	a type of vehicle that is powered by electricity, typically stored in rechargeable batteries
“electrochemical reaction”	reactions that occur at the interface of electronic conductors and ionic conductors. These reactions involve electron transfer and mass transport, influencing the transformation of reactants or products. Characteristics include spatially separated oxidation and reduction reactions, unique heterogeneous catalysis, and stoichiometric electron exchange
“electrolysis”	the process of passing an electric current through an electrolyte solution or molten electrolyte, inducing oxidation-reduction reactions at the cathode and anode. Electrolytic processes occur when an electrochemical cell is subjected to an applied direct current voltage

Appendix
Glossary of Technical Terms

Terms	Definitions
“electromagnetic compatibility” or “EMC”	the ability of electronic or electrical devices and systems to operate in their intended electromagnetic environment without experiencing performance degradation, loss of function, or damage due to surrounding electromagnetic influences. It also involves not emitting excessive electromagnetic energy that could disrupt the normal operation of nearby devices
“FCU”	fuel cell controller unit
“freeze-start”	the starting of a system or device at a temperature below the freezing point
“fuel cell controller”	a key component of fuel-cell electric vehicle drivetrain subsystems and is responsible for the overall process control of the entire fuel-cell system
“fuel cell electric vehicle” or “FCEV”	vehicles that use propulsion systems similar to that of electric vehicles, where energy stored as different forms hydrogen is converted to electricity by fuel cells
“fuel cell stack ”	a collection of single fuel cells, arranged in series or parallel to achieve the required power and voltage output
“fuel cell”	a power generator that converts the chemical energy stored in fuel and oxidizer into electricity through redox reactions
“gas diffusion layer” or “GDL”	a component that plays a critical role in fuel cells by providing support to the catalytic layer, collecting current, facilitating gas conduction, and expelling reaction product water
“graphite bipolar plate”	a component made through composite and forming processes using carbon-based conductive materials and polymer materials that serves for material and energy transfer in fuel cells
“GW”	gigawatt, a unit equals to one billion watts

Appendix
Glossary of Technical Terms

Terms	Definitions
“hydrogen circulation system”	a key component of the hydrogen supply system of the fuel cell engine that can circulate the unreacted hydrogen to the stack inlet. The cycle process can humidify the gas at the anode outlet, streamlining the fuel cell system
“hydrogen fuel cell system” or “fuel cell system”	a power system that converts the chemical energy of hydrogen and an oxidizing agent (often oxygen) into electricity through electrochemical reactions. In a fuel cell, hydrogen and oxygen are combined to generate electricity, heat, and water
“hydrogen production system”	a system for the production of hydrogen by various means
“hydrogen storage”	methods for storing hydrogen that include mechanical approaches such as using high pressures and low temperatures, or chemical methods such as metal oxides and organic compounds
“hydrogen”	a colorless, odorless gaseous chemical substance that can be produced from a variety of resources and has versatile application areas such as in transportation, whereas hydrogen is used as a clean fuel to power fuel cell vehicles. Depending on production methods, hydrogen can be classified into hydrogen produced from fossil fuels without capturing the greenhouse gases emitted, hydrogen generated from fossil fuels while the carbon dioxide is captured and then stored or reused, and hydrogen produced from renewable energy resources with no carbon dioxide emission
“hydrogenation”	the reaction process of hydrogen interacting with other compounds typically occurs in the presence of a catalyst
“hydrogeneration”	a technology that generates power by using a dam or diversion structure to alter the natural flow of a river or other body of water
“hydrogen-rich tail gas”	industrial exhaust gas containing abundant hydrogen
“hydrothermal management”	the collective term for all internal transfer processes in a fuel cell, encompassing the management of three fluid paths within a fuel cell stack or system (hydrogen, air, and cooling paths) and the associated engine cooling system

Appendix
Glossary of Technical Terms

Terms	Definitions
“kilowatts” or “kW”	a unit equals to one thousand watts
“LOHC”	A method of hydrogen storage utilizing a catalytic device to store hydrogen in organic liquid compounds such asbenzene, toluene, and methylcyclohexane. Hydrogen can be safely stored and transported in these organic liquid compounds
“low-carbon hydrogen”	hydrogen produced from renewable energy sources and hydrogen processed by CCUS (Carbon Capture,Utilization, and Storage) technology
“membrane-electrode assemblies” or “MEAs”	an assembled stack of proton-exchange membranes, a crucial site for electrochemical reactions in proton exchange membrane fuel cells that primarily consists of a proton exchange membrane, catalyst layers, and gas diffusion layers. MEA serves as the core component of a fuel cell stack
“MEFA”	membrane electrode framed assembly. A membrane assembly comprises a frame, and the frame is formed by bonding two opposing polymeric thin-film layers that encompasses the edge of a MEA
“MJ”	megajoules, a unit of calorific value equals to one million joules
“Mpa”	megapascal pressure per unit, a unit of pressure equals to 1,000,000 pascals
“MW”	megawatt, a unit of power equals to one million watts
“peak cut”	measure to adjust electrical loads. It involves strategically organizing and planning the electricity usage of various users according to their consumption patterns, aiming to reduce peak loads and fill in load valleys. It helps to minimize the disparity between peak and off-peak loads, achieving a balance between electricity generation and consumption
“PEN”	polyethylene naphthalate. A type of frame material bonded to the edge of MEA, which is capable of handling high stresses and temperatures and offers stability in the corrosive environment
“perfluorinated sulfonic acid” or “PFSA”	a fully fluorinated high-molecular-weight copolymer containing sulfonic acid groups. It exhibits excellent heat resistance and high chemical stability, making it suitable for hydrogen ion exchange and catalyst binding in fuel cells

Appendix
Glossary of Technical Terms

Terms	Definitions
"power density"	it is a measurement of power output per unit mass/volume; and for a fuel cell system it refers to its rated power divided by mass and is usually presented in kW/kg, and for a fuel cell stack it refers to its rated power divided by volume and is usually presented in kW/L
"proton-exchange membrane" or "PEM"	proton-exchange membrane, a component of membrane electrode assembly, serving as a thin film that conducts protons, prevents the transfer of electrons between internal cathode and anode, and separates the gases involved in the cathodic and anodic reactions in fuel cells
"R&D"	research and development
"rated power"	the continuous electrical power level that a fuel cell stack or system can deliver under the manufacturer's specified standard operating conditions. The unit of measurement for rated power is kW
"RDW"	Netherlands Vehicle Authority. The authority provides information about the rules and regulations concerning motor
"renewable energies"	energy sources that naturally regenerate over time and do not run out
"stationary power generation"	applications for fuel cells that are either connected to the electric grid (distributed generation) to provide supplemental power and as emergency power system for critical areas, or installed as a grid-independent generator for on-site service
"voltage"	a representation of the electric potential energy per unit charge

Thanks !

FROST & SULLIVAN