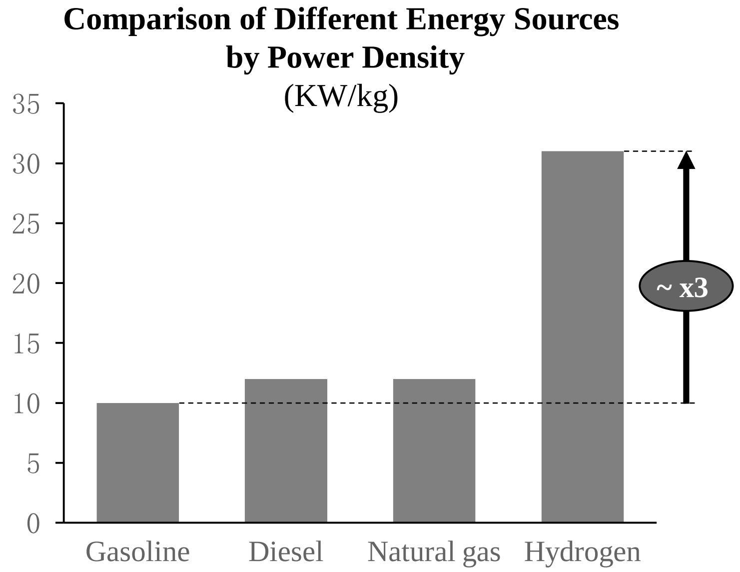
Hydrogen and fuel cell
- Challenge & Opportunities

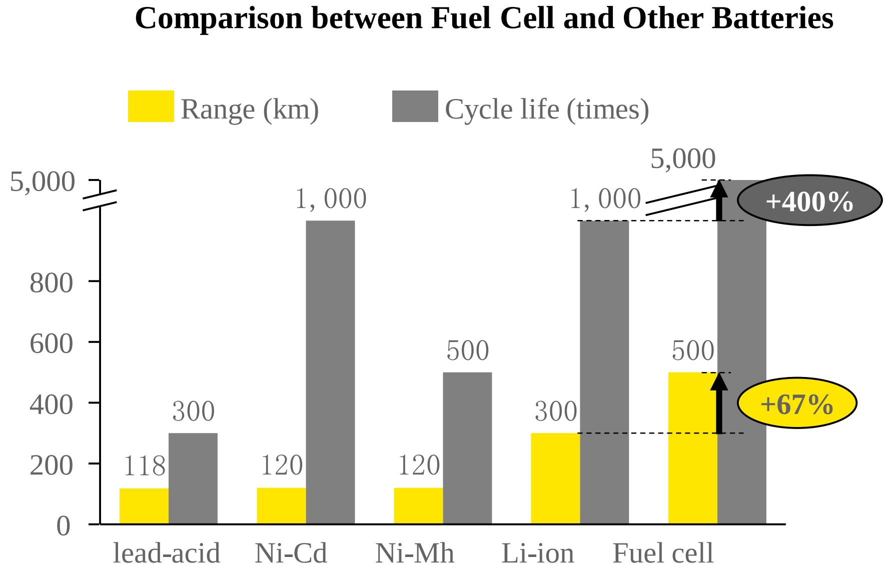
2018 CPCIC, Chengdu

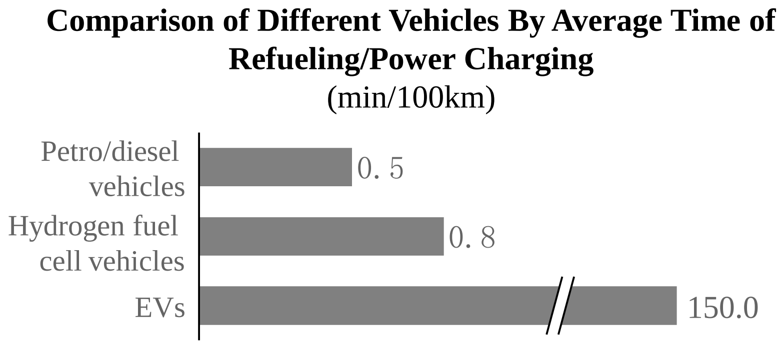
12 September 2018

Building a better working world

Hydrogen energy is an ideal energy source comparing with other sources







- **Hydrogen has better performance than other types of energy:** Hydrogen is superior to gasoline, diesel and natural gas in terms of energy density. According to the statistics of the US Department of Energy, the power density of hydrogen is more than 3 times that of fossil fuels
- **Fuel cells perform better than lithium batteries:** Lithium batteries, subject to the bottleneck of energy density, are impossible to be the ultimate power sources for new energy vehicles; fuel cells, however, are expected to become the next-generation of mainstream supporting applications due to high energy density (energy density of hydrogen fuel cells can be up to 300~500 wh/kg), longer cruising range and longer service life
- **The refueling time of fuel cell electric vehicles (FCEVs) is close to that of petrol /diesel vehicles,** far less than that of EVs

Sources: DOE, research report of Cinda Securities, research report of www.chyxx.com and analysis of Ernst & Young

Fuel cell is mainly used for transportation sector, where commercial vehicles account for the majority of market share

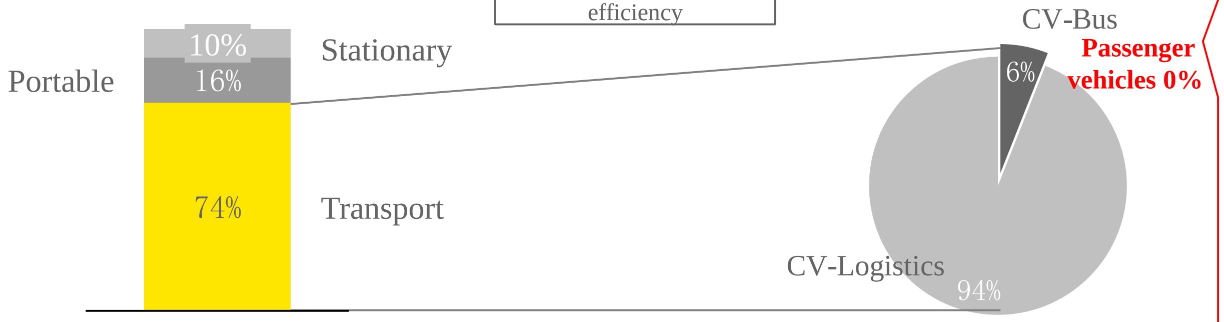
Hydrogen → **Fuel cell** / **Heat engine combustion** → **FCEV**

Gradually eliminated due to waste of heat and low energy utilization efficiency

Market Shares of Fuel Cell Applications in China (Packs/2017)

FCEV Market Structure of China （Vehicles/ 2017）

Portable devices have low market share due to small size and the inability of high-pressure oxygen storage. The global market share of portable fuel cells is **less than 1%** (in packs).



China's FCEV industry started late. Due to favorable policies and higher subsidies of the country for commercial vehicles policies and relatively easy implementation of the technologies, **passenger vehicles will not become mainstream in the market in the near future**

Transport

Hydrogen fuel cells are mainly used for passenger vehicles in Japan and South Korea and commercial vehicles in China and the US

Stationary

Stationary application scenarios mainly include domestic hydrogen fuel cells, uninterrupted power supplies or backup power supplies in the telecommunication industry, etc.

Portable

Portable devices of hydrogen fuel cells are mainly backup power sources. Due to such advantages of high power storage and light weight, hydrogen fuel cells can be used on outdoor and military power devices

- **Market structure:** At present, the domestic market share of fuel cell passenger vehicles is zero, main players of commercial vehicles are bus manufacturers, and as for the market shares of various types of fuel cells for logistic commercial vehicles take up 94% and buses take up 6%
- **Causes:**
  - **Subsidy:** domestic subsidies for commercial vehicles are higher
  - **Price sensitivity:** commercial vehicles are less price-sensitive
  - **Technical ability:** commercial vehicles (bus particularly), due to large size, can increase cruising range simply by increasing the capacity of the hydrogen tank and have low requirements for hydrogen storage technology
- **In the medium and long term, the commercial vehicle market will first see explosive growth**

Source: libattery.ofweek.com, research report of Cinda Securities, research report of www.chyxx.com and analysis of Ernst & Young

We have observed the raise of hydrogen energy players along the value chain in China

Fuel cell material suppliers

AEET	> With leading technology in gas diffusion layers of hydrogen fuel cells > With technologies of solid-state hydrogen storage materials
DY	> Fuel cell membrane R&D reaching leading level in the world, large-scale trial production already in progress
SINOMA	> Having quickly entered the field of hydrogen energy storage tanks with its advantageous technologies in special fiber composite materials
Sino-platinum	> Producing platinum catalytic materials with its own resources in precious metal researches > China's only listed manufactures of hydrogen fuel cell catalysts
Snow-key	> Mainly producing air supply systems for hydrogen fuel cells > Invested in Hydrogenics, a Canadian company engaged in hydrogen fuel cell technology in 2017

- All key enterprises of core technologies along hydrogen energy industry chain rely on their original technical advantages

Fuel cell stack integrators

Vision Group	> Having its own hydrogen fuel testing platform and cooperating with multiple universities > Cooperating with the People's Government of Datong, Shanxi Province in 2018 to launch the Vision Hydrogen Energy Industrial Park Project in Datong.
Sunrise Power	> Undertaking major special projects of the Ministry of Science and Technology, with some key technologies reaching international top level > Having a number of patented technologies with independent intellectual property rights > 34.2% equity held by SAIC
Sino-Hytec	> Relying on the Tsinghua university and New Energy Automobile Engineering Center, > Listed on NEEQ in 2016

- Main midstream stack manufactures have strong technical backgrounds
- Some are dominated by automobile companies, such as SAIC's participation in equity of Sunrise Power

FCEV OEMS

Yutong	> The fourth generation of products to be released in 2018, achieving major technological breakthroughs by 2018, reducing costs and trying business expansion > Large-scale promotion campaigns to be launched in 2019-2020
KLM	> Developing four models of hybrid cells, extenders and fuel cell packs
Feichi	> Authorizing 100FCEV to SinoHytec in 2016 > Continuing to develop 6-12m city buses and logistics vehicles
FAW	> Reaching strategic agreement with Sunrise Power to develop J6F light commercial vehicles and produce 100 vehicles in 2017
Youngman	> Developing 8m MD buses and 8-ton MD trucks > Planning to produce passenger vehicles as from 2020

- Most FCEV OEMS are dedicated to technological development
- And due to subsidy policies and governmental initiatives, priority is given to city buses

Sources: Desk Research, analysis of Ernst & Young

Since 2009, China has launched series of favorable policies for FCEVs, driving the growth of fuel cell technologies

2009

- The ***Interim Measures for the Administration of Financial Assistance Funds for the Demonstration and Promotion of Energy Saving and New Energy Vehicles*** was launched, and the Central Treasure started to provide one-off fixed-amount subsidies for pilot cities

2010

- Pursuant to the ***Vehicle and Vessel Tax Law of the People's Republic of China***: Battery electric vehicles, FCEVs and plug-in hybrid electric vehicles **are exempted from vehicle and vessel tax**

2014

- The ***Announcement on the Exemption of Vehicle Purchase Tax on New Energy Vehicles*** was issued, stipulating that new energy vehicles purchased during September 1, 2014-December 31, 2017 were **exempted from vehicle and vessel tax**
- The Ministry of Finance issued the ***Notice on Rewards for the Construction of New Energy Vehicle Charging Facilities***, pursuant to which the **reward of RMB 4 million** will be granted to each new **hydrogen refueling station** for FCEVs compliant with the standards

2015

- ***Made in China 2025*** clearly proposed the development plan for FCEVs

2016

- The National Development and Reform Commission and the National Energy Administration issued a document within the system, proposing **15 key innovation tasks**, including technological innovation of hydrogen energy and fuel cells

2018

- The four ministries and commissions jointly promulgated the ***Notice on Adjusting and Improving the Fiscal Subsidy Policies for the Application and Promotion of New Energy Vehicles***, with the subsidy policies for fuel cells basically unchanged and the **intensity not reduced**

- The domestic subsidy policy first appeared in 2009, mainly in the forms of exemption from purchase tax and one-off subsidies at different amounts, **which were leading in the world**
- There were no subsidy policies on the **manufacturing** of hydrogen FCEVs

In 2014, hydrogen refueling stations were included in the scope of subsidy

The national subsidy standard for li-ion battery vehicles declined slightly while that for FCEVs did not decline

Sources: Desk Research, analysis of Ernst & Young

Japan / US and EU all have competitive edges in hydrogen energy and fuel cell technologies, China is more focused on end-market applications

Leading fields of different countries

	Technical level	Construction of hydrogen refueling stations	Fuel cell electrical vehicle	FCEV applications
China	As a late mover, China is temporarily behind in terms of technology and is introducing overseas leaders to accelerate the development.	The number of hydrogen refueling stations is planned to reach 100 in 2020 and 1,000 in 2030; The hydrogen refueling station network is planned to be completed by 2050	Mainly distributed in the field of commercial vehicles, where hydrogen FCEVs have been mass-produced; passenger vehicles are still in the stage of demonstration operation	**Largest subsidy in the world: RMB 200,000 per passenger vehicle** **RMB300,000 per light bus/truck** **RMB500,000 per medium/large bus/medium/heavy truck**
Japan and South Korea	The Japanese government's efforts on promoting hydrogen energy and fuel cells, including stationary applications, is leading in the world; **Japan's shipments/installed capacity of fuel cells account for more than 60% of the world's total**	**World leader in the construction of hydrogen refueling stations**, expected to complete the construction of 160 hydrogen refueling stations by 2020 The South Korean government has invested a lot in the construction of 310 new hydrogen refueling stations	**Toyota is currently the most successful company of the world in the commercialization of FCEVs. In 2020, the annual output of Mirai will reach about 30,000** **Hyundai is the world first FCV to achieve mass production**	FCEV buyer subsidy in Tokyo: 1 million yen (about RMB55,000) by Tokyo government + 2 million yen (about RMB110,000) by the central government FCEV buyer subsidy in Seoul: 27.5 million won (about RMB170,000) by the state and various preferential policies on tax exemption
US	**Mastering the world's most advanced technologies and gathering many leading companies of the world; having absolute advantages in terms of production scale and price of liquid hydrogen**	Toyota and Shell plan to construct 100 hydrogen refueling stations in California, which has the highest industry concentration, by 2024	Vehicle parc of fuel cell passenger vehicles and forklifts in the US is leading in the world	In 2015, the US Congress raised the tax credit of FCEVs to USD8,000, which is decreased to USD4,000 in 2017
Europe	**Germany is leading in Europe and in the world in terms of hydrogen energy technology and its application; six leading companies in the hydrogen energy industry have formed the H2Mobility Alliance to support the development of Germany's hydrogen industry**	**139 hydrogen stations were operating in Europe in 2017** **The number of hydrogen refueling stations in Germany is expected to increase to 100 by 2019**	The companies pay high attention to the development of FCEVs Mercedes-Benz has launched hydrogen fuel cell and plug-in hybrid versions of GLG Audi has announced cooperation with Hyundai to develop hydrogen fuel cell technology	**Germany has set up awards for vehicle model development** The purchase subsidy for FCEV in the UK is 4,500 pounds (about RMB45,000)

Sources: Desk Research, analysis of Ernst & Young

FCEV industry is concentrated in East Coast, with focus mainly on end-market applications

Regional distribution

		Time	City-Projects	Representative companies
Pilot Project	Beijing	2006	> Hydrogen energy demonstration project for Beijing 2008 Olympics Games	> SinoHytec, Foton
	Shanghai	2011	> Hydrogen energy demonstration project for Expo 2010 Shanghai	> SAIC
North China Region	Hebei	2016	> Zhangjiakou - ICH	> Yutong, Foton
	Shandong	2017	> Jinan - Hydrogen Valley of China	> DY, Broad-Ocean Motor, Zhong Tong Bus
Yangtze River Delta	Jiangsu	2017	> Rugao - Hydrogen Energy Industrial Park	> Nanjing University, Shenhua Group
	Anhui	2017	> Liu'an - Mingtian Hydrogen Energy Industrial Park	> Mingtian Hydrogen Energy
	Wuhan	2017	> Wuhan - Hydrogen Fuel Cell Park, Wuhan Development Zone	> Vision Group, Troowin
Greater Bay Area	Guangdong	2017	> Foshan (Yunfu) Industrial Transfer Park	> Broad-Ocean Motor, Feichi, Sinopec

Shanghai:
FCEV Development Plan of Shanghai

Suzhou:
Guiding Opinions of Suzhou on the Development of the Hydrogen Energy Industry (Trial)

Beijing:
Guiding Opinions of Beijing on Accelerating Science and Technology Innovation to Cultivate the New Energy Intelligent Automobile Industry

Foshan:
Development Plan for the New Energy Automobile Industry of Nanhai District, Foshan (2015-2025),
Measures of Nanhai District, Foshan on Promoting the Construction and Operation of Hydrogen Refueling Stations and Supporting the Operation of Hydrogen-fueled Vehicles

Sources: Desk Research, analysis of Ernst & Young

EY 安永

Storage, fuel cell components and stack design & assembly are the key areas along the value chain

Focused fields

Hydrogen

	Hydrogen production	1 Hydrogen storage	Hydrogen transport & refueling stations
Core technology	▸ **Hydrogen production from chemical materials**: using raw materials like methanol, ethanol and liquid ammonia for reaction with water vapor ▸ **Hydrogen production from petrochemical materials**: using resources like petroleum, water gas and natural gas for reaction with water vapor ▸ **Hydrogen production by electrolyzing water**: electrolyzing water into hydrogen and oxygen, solar and wind power can be used to reduce costs	▸ **High pressure gaseous hydrogen storage**: pressurized hydrogen to reduce its volume for storage in containers ▸ **Liquid hydrogen storage**: cooling hydrogen to liquefy it for storage in specific containers ▸ **Solid hydrogen storage**: adsorbing hydrogen atoms by lattice gaps of metal alloys (hydrogen storage alloys)	▸ **Gaseous hydrogen transportation**: transportation with high pressure hydrogen cylinders and tube trailers, generally <200 km ▸ **Liquid hydrogen transportation**: transportation with liquefied hydrogen tanks, suitable for long distance transportation ▸ **Pipeline transportation**: short-distance pipe transportation, the cheapest way
Major company	Sinopec, 中国石油, NOWOGEN	氢阳能源 Hynertech, Sinoma 中国中材	中国神华 CHINA SHENHUA, Bolken, 明天集团 TOMORROW GROUP, HQHP

Fuel cell system

	2 Raw materials	2 Stack design & assembly	Fuel cell management system	Transport / Stationary applications / Portable applications
Concept	▸ **Membrane electrodes** ▸ **Proton Exchange Membrane** ▸ **Catalysts** ▸ **Gas diffusion layers** ▸ **Bipolar plates**	▸ A stack, consisting of multiple cells stacked in series, is the place where chemical reactions happen and the core part of a fuel cell	▸ The management system adjusts the quantization factor and the scale factor in a timely manner to improve the system's static and dynamic characters and reduce fuel consumption	▸ **Transport**: FCEVs ▸ **Stationary applications**: household co-generation, household fuel cells, backup power supplies for telecommunication base stations and UPS, etc. ▸ **Portable applications:** auxiliary charging devices, etc.
Major company	DY DONGYUE FEDERATION, 贵研铂业, 3M, AT&M 安泰科技, POCO GRAPHITE	SUNRISE POWER 新源动力, REFIRE, 亿华通 SinoHytec, 神力科技, 雄韬股份 VISION GROUP, 国鸿氢能 SINOSYNERGY	Pdc, 亿华通 SinoHytec, plug power	FOTON, 宇通客车, 金龙客车 KING LONG, 上汽集团 SAIC MOTOR, TOYOTA

Sources: Desk Research, analysis of Ernst & Young

1 Gaseous storage is the mainstream of storage technology, solid state hydrogen storage is expected to lead in future

Low High

Hydrogen storage mode	Gaseous hydrogen storage	Liquid hydrogen storage	Solid state hydrogen storage
Key parts	Heavy pressure container	Must be equipped with cooling devices and excellent thermal insulation layer	Metal hydride hydrogen storage device made of hydrogen storage materials such as rare earth
Key technologies	Hydrogen compression technology	Cooling technology, thermal insulation measures	Ability to reversibly absorb, store and release hydrogen in a large amount at a certain temperature and hydrogen pressure
Application sceneries	All FCEVs introduced by major companies adopt high-pressure gaseous hydrogen storage, which, in comparison, is more suitable for passenger vehicles.	Due to the large size of the subsidiary system, it is more suitable for medium and large/heavy vehicles/commercial buses.	The hydrogen release process is a chemical reaction process, which requires a certain temperature and pressure, and is thus inconvenient.
Representative companies	SinoHytec, Sinoma S&T, Jingcheng Mac	Hydrogenious, Furui Special Equipment	ECD Ovonic, Whole Win (Beijing)
Hydrogen storage capacity			
Hydrogen storage safety			
Technical achievability			
Economy			
Evaluation	**Low cost and easy to use The most mainstream mode of hydrogen storage**	**High hydrogen storage density, but with high requirements More rational hydrogen storage in the short term**	**High hydrogen storage density and high safety Expected to become the mainstream hydrogen storage mode in the future**

Sources: Desk Research, analysis of Ernst & Young

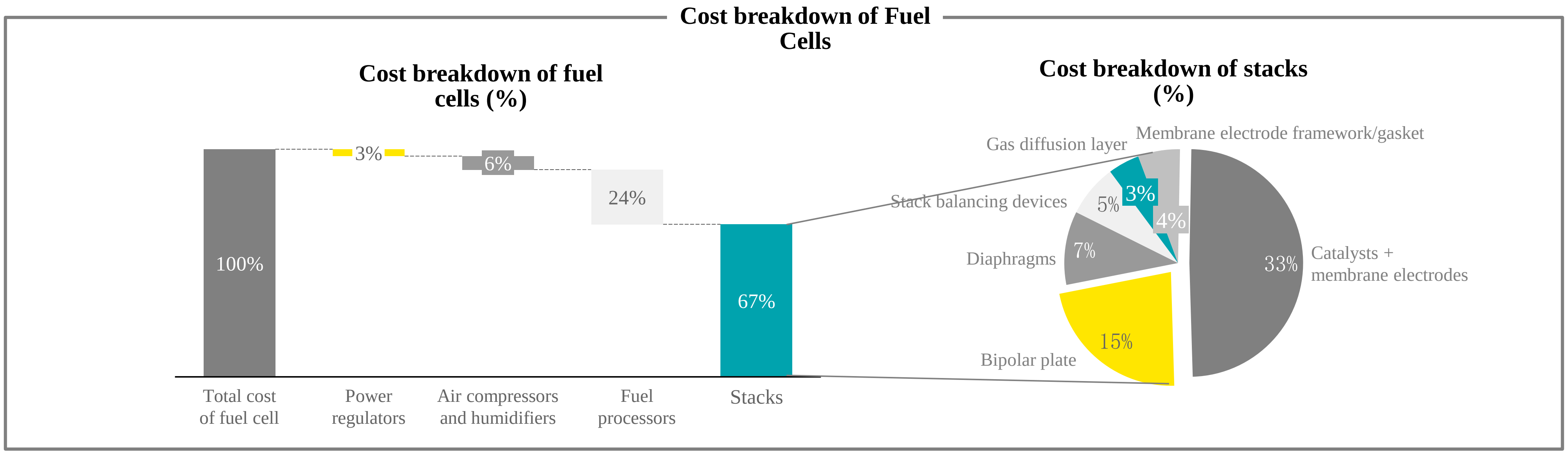
❷ From application perspective, PEMFC is leading the market and expected to grow faster due to its efficiency and working condition requirement

	Alkaline fuel cell （AFC）	Phosphoric acid fuel cell (PAFC)	Molten carbonate fuel cell (MCFC)	Solid oxide fuel cell (SOFC)	Proton exchange membrane fuel cell (PEMFC)
Description	The first to be successfully developed, adopting alkaline electrolyte as an electrolyte to make the oxygen reduction faster than in acidic media	The first generation of fuel cell technology, which, using phosphoric acid as the electrolyte, is not volatile and requires a corrosion-resistant material to make the casing.	The second generation of fuel cell technology, which adopts molten lithium potassium carbonate or lithium sodium carbonate as electrolyte	The third generation of fuel cell technology, which adopts ceramic materials as solid electrolytes to effectively prevent the electrolytes from corroding the stacks.	Proton exchange membranes are used as electrolytes and pure hydrogen must be used as fuel
Specific power (W/kg)	35-105	100-200	30-40	15-20	300-750
Power density (W/cm^2)	0.5	0.1	0.2	0.3	1-2
Fuel type	H_2	H_2, natural gas	H_2, natural gas, biogas	H_2, natural gas, biogas	H_2
Catalysts	Mainly nickel	Platinum	Non-precious metal	Non-precious metal	Platinum
Generating efficiency (%)	45-60	35-50	50-60	50-70	50-60
Starting time	~5min	2-4h	>10h	>10h	~5min
Reaction temperature (℃)	80-120	180-220	600-700	750-1000	25-105
Applications	Aerospace	Large power stations	Large co-generation power stations	Distributed power stations	FCEV

PEMFC, with the operating temperature **below 120℃, short start-up time** and **simple structure,** has the **most promising** prospect of application and will be **the fastest growing** fuel cell technology in the future

Sources: Desk Research, analysis of Ernst & Young

As key to fuel cells, stacks take up 67% of production cost, the optimization of stacks to lower cost will be the key focus for fuel cell development



- **Stacks take up the most share in the cost of fuel cells (67%), and improving stack technology has become the key to reducing costs**
- **The cost of catalysts + membrane electrodes takes up the highest share in the stack cost, and the membrane electrode is the heart of a fuel cell, so these two materials have become the key to the development of the fuel cell technology**
  - The main raw materials for catalysts and membrane electrodes are precious metals such as platinum, which account for 33% of the total cost of the battery system and 49% of the cost of the stack, and is the largest source for the costs of fuel cells
  - The costs of components other than catalysts and membrane electrodes, such as bipolar plates and membranes have decreased significantly with the increase of production. Therefore, reducing the dosage of platinum catalysts and improving the cost performance of proton exchange membranes is the most direct way to break through the bottleneck of fuel cell costs
- **In the future, the dosage of platinum is expected to keep declining, and platinum catalysts will achieve 99% recycling, thus ensuring effective control of the costs. However, due to the high production difficulty and high costs of proton exchange membranes, there's still a long way to go for exploring ways of cost reduction**

Sources: Desk Research, analysis of Ernst & Young

The challenges and risks of hydrogen fuel cell systems and downstream applications

Stack material suppliers	▶ Challenge ▶ Domestic companies need certain scientific research capabilities or cooperation with some fuel cell research institutes to successfully enter the field of membrane electrodes ▶ There are high technical barriers for catalysts, and the mainstream suppliers are still foreign companies. With no domestic companies that can produce catalysts, this field is a blue ocean ▶ Risk ▶ Some key materials such as electrocatalysts, proton exchange membranes and carbon paper for fuel cells are still experimental products, which feature volatile consistency and reliability ▶ **The development and production of proton exchange membranes is very difficult. Even mainstream foreign proton exchange membrane suppliers have not yet solved the problem of high manufacturing cost. Only a few domestic companies are capable of mass production, and there is a risk of incapability to make technical breakthrough**
Stack and fuel cell integrator	▶ Challenge ▶ There are three modes to enter the field of midstream fuel cell stack integration, independent R&D, Sino-foreign joint venture, technology introduction/investment. Companies capable of independent R&D are actively improving technical barriers and have dominated the domestic market of fuel cells with strong technical background and the advantage as first-movers ▶ Stacks have poor durability. In case of long-term use, such as use on a bus, it is possible to replace the stack in 2-3 years
Fuel cell commercial vehicle OEMs	▶ Challenge ▶ The industrial chain is still weak with insufficient engineering capacity. At present, the vehicle manufacturers have not yet formed stable parts supply systems and are subject to weak supply chain and insufficient engineering capability, which have resulted in low process quality of parts and nonconforming consistency, reliability and durability of products ▶ Risk ▶ Hydrogen is easy to leak, so the sealing requirements are extremely strict, furthermore, factors like difficult maintenance and the need of warming up before startup also affect the production of fuel cell vehicles ▶ **The high costs of fuel cell systems and on-board hydrogen systems cannot be overcome in a short period of time, and there is a high risk in the commercialization of hydrogen fuel cell vehicles**

Sources: Desk Research, analysis of Ernst & Young

The opportunities of hydrogen fuel cell systems and downstream applications

Stack material suppliers	▶ Gas diffusion layers, with the most mature technical conditions, are the best products for commercialization. However, the main technical patents and raw materials are currently in the hands of international manufacturers, and companies with carbon-related experience are suitable to enter this field ▶ **At present, the technical barriers of graphite bipolar plates are relatively low. In the context of China vigorous development of fuel cell commercial vehicles, domestic companies with graphite processing capabilities are suitable to invest in this field**
Stack and fuel cell integrator	▶ **In 2020, the market demand for fuel cell materials in China is expected to reach RMB160 million, and that of the global market is expected to reach RMB1.1 billion. The initial investment scale is about RMB500 million to 1 billion** ▶ In 2018, the durability of fuel cell stacks independently developed in China exceeded 5,000 hours, symbolizing continuous improvement of China's production technologies of hydrogen energy fuel cells and stacks ▶ With the localization of key materials and the increase in the volumetric power of stacks, the costs of stacks can be greatly reduced
Fuel cell commercial vehicle OEMs	▶ **Due to policy support and the cost reduction in the future due to technological advancement, the industrialization of fuel cell vehicles will become an inevitable trend. By 2020, the total output value of China's fuel cell vehicle industry will reach RMB300 billion, with the potential of growth by 10 times in 2018-2020** ▶ Due to high policy subsidies, low technical requirements and low cost sensitivity, commercial buses will usher in explosive growth and will take up over 50% of the market share in the fuel cell vehicle industry by 2050

Sources: Desk Research, analysis of Ernst & Young

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