Green Hydrogen
Green Electricity

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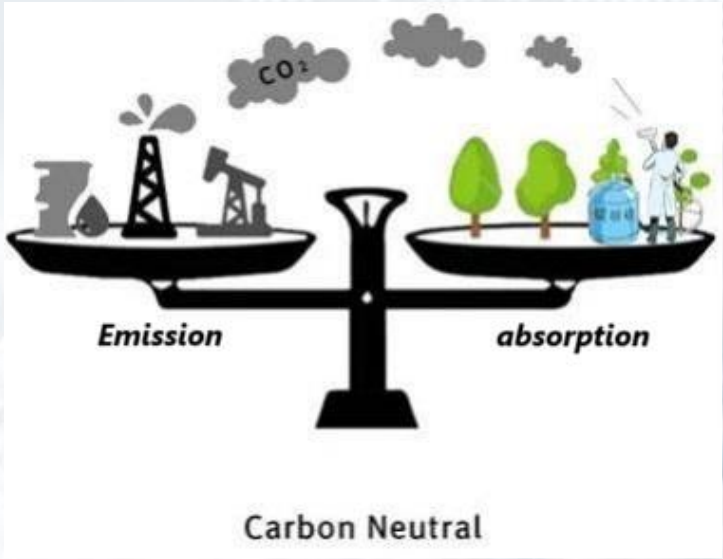
Strategic demands and necessities

strategic demands

New strategy for energy security: Four revolutions one cooperation

3060 carbon peak、carbon neutral



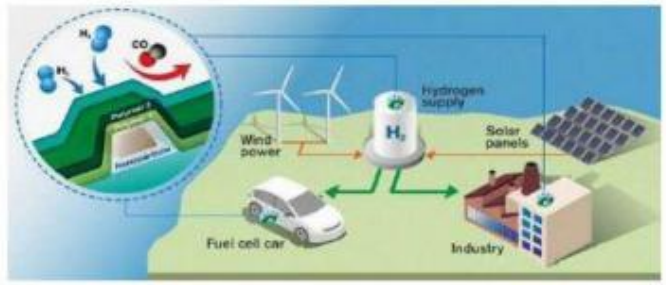
target task

Construct a new power system dominated by renewable energy bulid a clean,low-carbon,safe and efficient modern energy system

General Secretary Xi Jinping proposed at the 9th meeting of the Central Committee for Finance and Economics to build a clean, low-carbon, safe and efficient energy system, control the total amount of fossil energy, focus on improving utilization efficiency, and implement actions of renewable energy substitution, deepen the reform of the power system and construct a new power system dominated by renewable energy**.**

State Grid Corporation of China released its "Carbon Peak and Carbon Neutrality" action plan, becoming the first state-owned enterprise to publicly disclose a specific action plan for "Carbon Peak and Carbon Neutrality**". On the energy supply side,** build a diversified clean energy supply system.
This includes promoting the utilization of hydrogen energy, comprehensively advancing electrification and energy conservation and efficiency improvement **on the energy consumption side,** This includes accelerating the adoption of electric energy substitution, promote the application of electric hydrogen production technology,

The future of multi scenario applications of hydrogen energy



Electricity

Industry

Metallurgy

Chemical Industry

(Synthetic ammonia, methanol, etc.)

Refining, Food, Biology, Medicine

transportation

construction

City gas

Cogeneration of Heat and Power

Properties of Hydrogen Energy

Hydrogen has an extremely high energy density and is the most suitable choice for us as a clean, renewable, and new energy source.

Relatively high energy density

It is 100 times higher than diesel, 6.8 times higher than coal, 3.3 times higher than gasoline, and 3.4 times higher than natural gas.

High ignition point, rapid ignition

It can be used as a new energy source to promote the clean and low-carbon transformation of energy in the dual-carbon goal.

Good thermal conductivity

It is 10 times higher than the thermal conductivity of most gases and is a good heat transfer carrier.

Diverse forms of hydrides

It can adapt to the different requirements of storage and transportation and various application environments.

For the dual-carbon goal, hydrogen is undoubtedly the best element, with a wide range of sources, renewable, non-toxic, clean, high fuel value, high energy density, and high conversion efficiency.

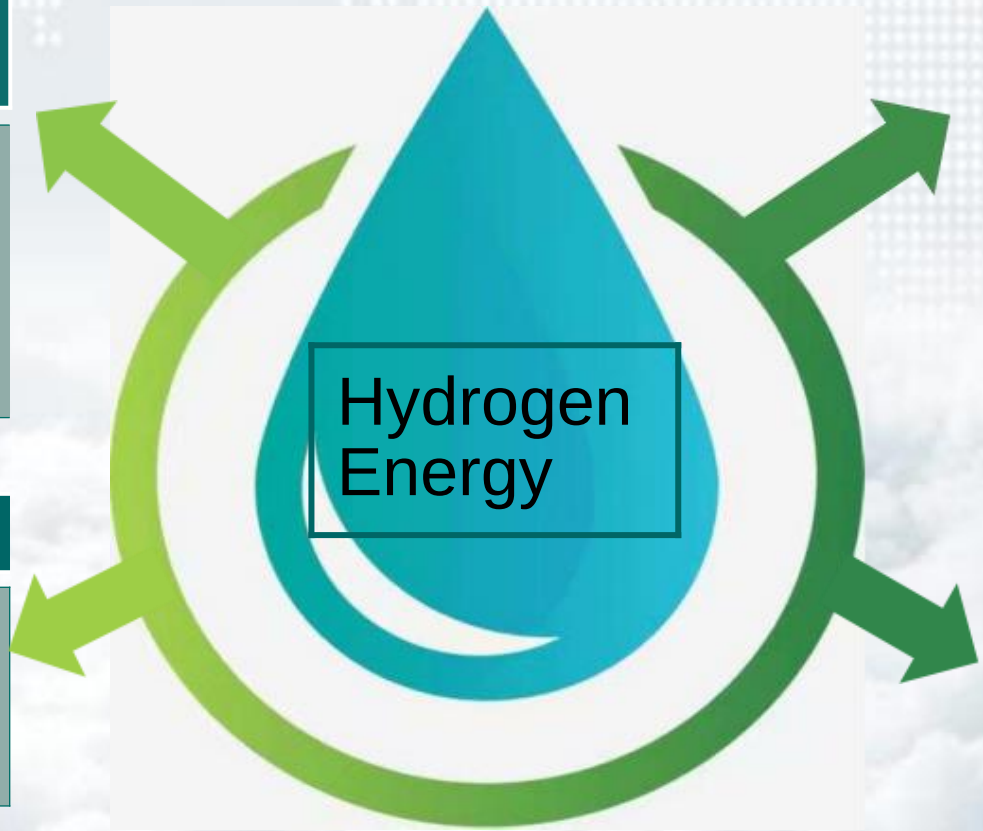
Characteristics of Hydrogen Energy

Wide range of sources .

1.Hydrogen production from renewable energy sources .
2.Production of hydrogen from industrial by-products .
3.Hydrogen from fossil fuels

Easy to store

Storage, scale, long-term energy storage competitiveness higher than lithium batteries.



Safe and efficient

Small volume density, strong escape.Flexible conversion.

Clean low carbon

The end product of hydrogen power generation is water, environmentally friendly.

Types of Hydrogen

- Sources

Source of raw materials

- Hydrogen production from fossil feedstock → It is necessary to combine regional resource conditions and adapt to local conditions. → Gray hydrogen
- Hydrogen production from industrial by-product → It can meet the demand for hydrogen sources during a certain period. → blue hydrogen
- Electrolysis of water to produce hydrogen → Environmentally friendly, is the future trend. → green hydrogen

CCS CCUS

The hydrogen production route is shifting from "blue hydrogen" and "grey hydrogen" to "green hydrogen," which means focusing on producing hydrogen through the electrolysis of water using renewable energy sources.

Renewable energy powered Green Hydrogen Production Technology

In the future, under the global carbon neutrality environment, hydrogen will mainly be obtained from renewable energy sources, and **green hydrogen will become a truly new energy resource for the new generation.**

The IEA report points out that given the current insufficient hydrogen production capacity, the rapid deployment of **electrolysis-based hydrogen production technology systems required** to achieve net-zero emissions by 2050 is a key challenge.

The Main Types of Electrolytic Hydrogen Production

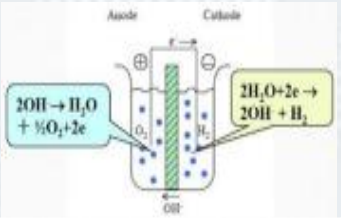
Green Hydrogen

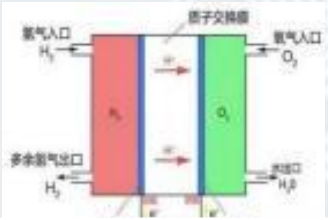
Electrolysis of Water for Hydrogen Production

- Alkaline Water Electrolysis → Alkaline water electrolysis technology is currently the most mature in the market and has the lowest cost for hydrogen production.
- Proton Exchange Eembrane Water Electrolysis → Proton exchange membrane water electrolysis for hydrogen production is a relatively mature technology that can adapt to the fluctuation of renewable energy.
- Solid Oxide Electrolysis → Solid oxide electrolysis of water for hydrogen production has the lowest energy consumption and the highest energy conversion efficiency.

$$2H_2O = 2H_2\uparrow + O_2\uparrow$$

- Green hydrogen production
  (Water electrolysis for hydrogen production is the main method for green hydrogen manufacturing).



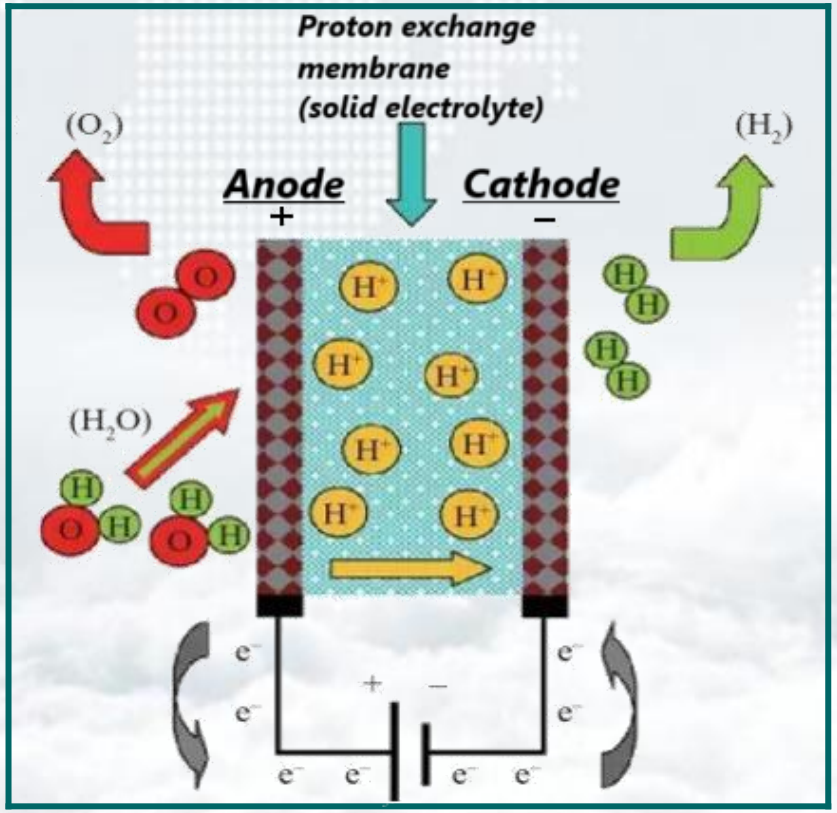


	Alkaline Electrolysis Cell(AEC)	Proton Exchange Membrane Electrolysis Cell(PEMEC)	Solid Oxide Electrolysis Cell(SOEC)
Technology Maturity Level	Fully Matured	On the Verge of Maturity	Undergoing Research
Operating Temperature(℃)	≤ 90(0-45)	≤ 80(0-45)	700~1000
Current Density(Acm^{-2})	0.2~0.4	1~3	1~10
Adaptability To Fluctuating Power Sources	Ramp-rate: 15~100% Load St/Sp: 1min for thermal start while 10min for cold start	Ramp-rate: 0~160% Load St/Sp: 1sec for thermal start while 5min for cold start	Insufficient Data Available
Energy Efficiency(%)	62~82	70~90	80~95
Advantages	Purity ≥ 99.8%	Purity ≥ 99.99% Volume 1/3	Insufficient Data Available
Disadvantages	Excessive equipment volume	Excessively high manufacturing costs	Insufficient Data Available

Comparison of Electrolytic Hydrogen Production Technologies

Characteristic	A E C	P E M E C	S O E C
Energy Consumption	4.5-5.5	3.8-5.0	2.6-3.6
Start / Stop Speed	Ralatively rapid	Rapid	Slow
Dynamic Responsiveness	Ralatively strong	Strong	Insufficient Data Available
Power Quality Requirements	Stable	Stable or fluctuating	Stable
Electrolyte	20-30% KOH	PEM(Nafion is frequently used)	Y_2O_3 / ZrO_2
System Operation and Maintenance	Contains corrosive liquids, complex maintenance in later stages, and high costs	Contains no corrosive liquids, simple operation and maintenance, and low costs	Currently focused on technical research, with no operational experience
Electrolyzer Lifespan	12000 h	10000h reached(domestic)	Insufficient Data Available
Electrolyzer Cost (USD/kw)	400-600	Around 2000	1000-1500
Degree of Environmental Friendliness	Ralatively poor	Ralatively	Insufficient Data Available

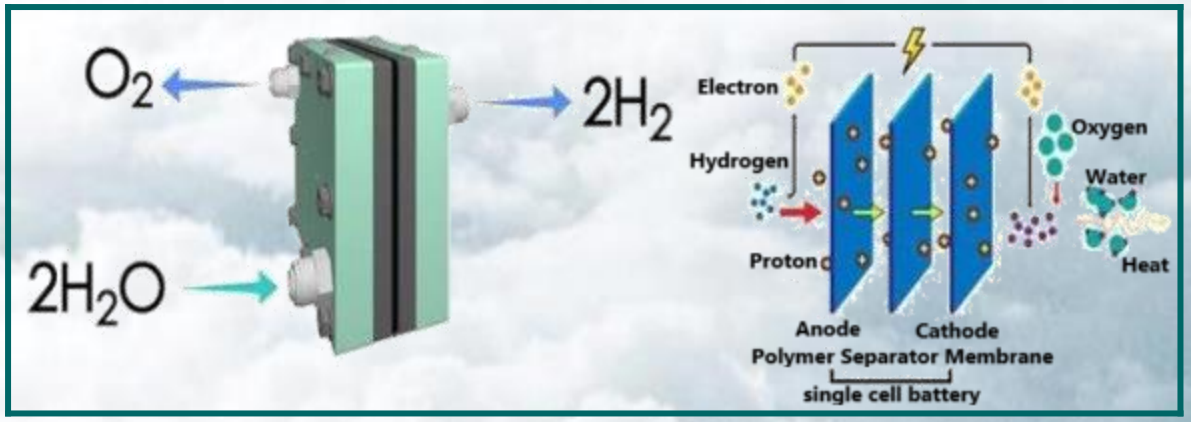
Principle of PEM Electrolysis for Hydrogen Production



Anode: $H_2O \rightarrow 1/2O_2 + 2H^+ + 2e^-$

Cathode: $2H^+ + 2e^- \rightarrow H_2$

Overall Reaction: $H_2O \rightarrow 1/2\ O_2 + H_2$



Currently, the research efforts in **PEM water electrolysis technology** are chiefly directed at optimizing electrolyzer cell design, advancing key materials (like catalysts, proton exchange membranes and bipolar plates), as well as refining the fabrication techniques for the electrodes.

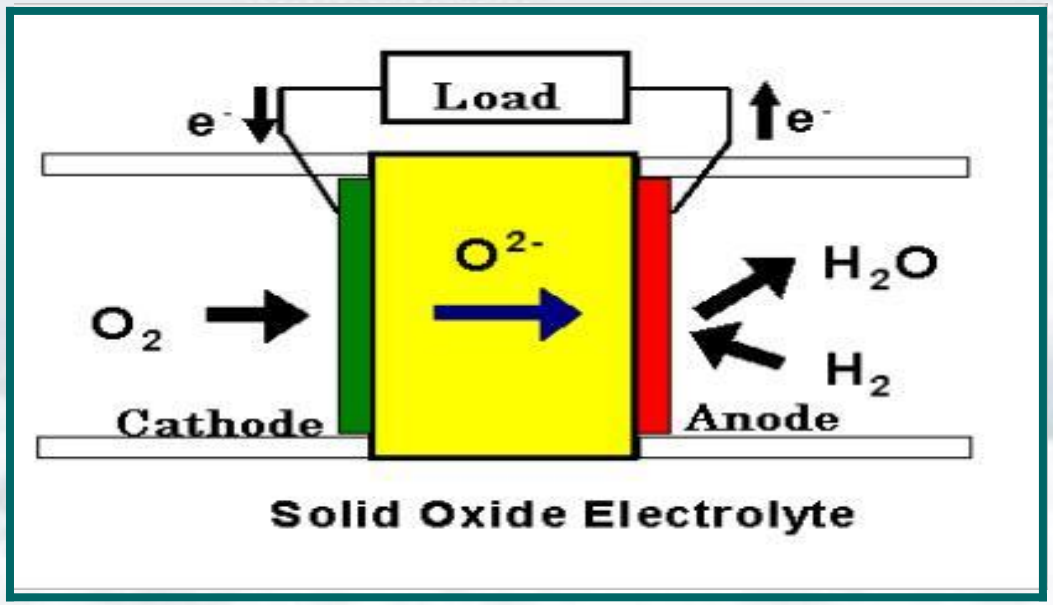
PEM Water Electrolysis for Hydrogen Production

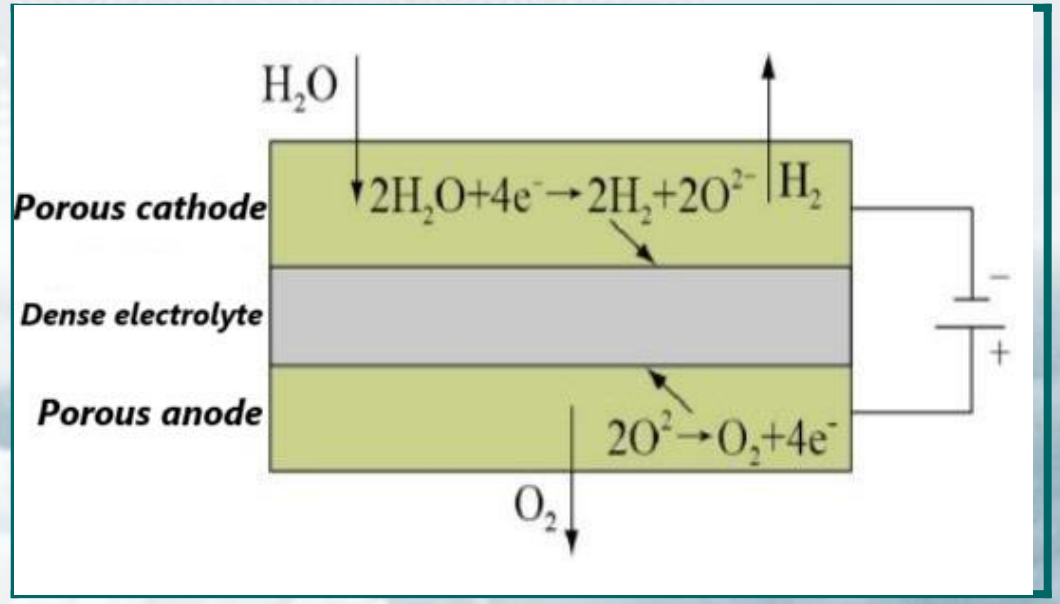
Characteristics of PEM water electrolysis for hydroge production

- The membrane is relatively thin, and the anode and cathode are integrated with the membrane, resulting in a lower internal resistance.
- The gas produced is relatively pure, no purification device is needed; it can withstand high pressure, providing high-pressure hydrogen without a compressor.
- It can operate at a higher current density of beyond 2000 mA/cm^2 , which is conducive to reducing costs.
- Responds quickly to changes in input power, suitable for the fluctuation of renewable energy, with a wide load range operation.
- Using pure water electrolysis, the corrosiveness is relatively low, and the performance is relatively stable.

The principle of SOEC electric hydrogen production

The high-temperature solid oxide electrolytic cell (SOEC) uses the heat and electricity provided by various renewable energy sources as well as advanced nuclear energy to efficiently electrolysis water vapor into hydrogen and oxygen at high temperatures, which can achieve a hot hydrogen conversion efficiency of up to 50%. In the middle of SOEC, dense electrolyte layer separates oxygen and fuel gas and conducts oxygen ions at the same time; Porous hydrogen and oxygen electrodes are used on both sides to facilitate the diffusion and transmission of gas.



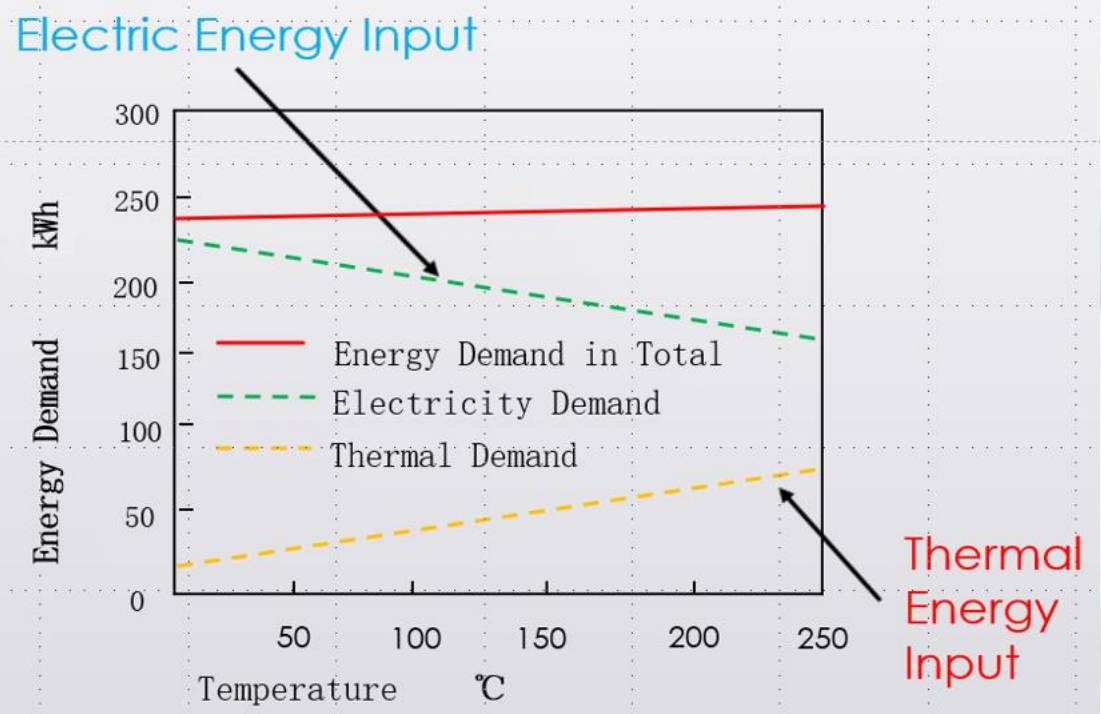


• Advantages: The existing solid oxide fuel cell technology can be used to use non-precious metals as electrode materials; And **low power consumption.**

• Challenge: The technology is still in the research and development stage, **which needs to solve the high temperature** and stable operation of solid oxide electrolytic cell pile, and lacks systematic experience and verification

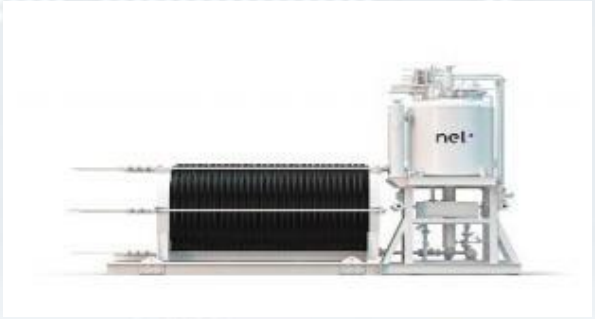
SOEC electric green hydrogen production

The following figure shows the relationship between the energy demand of water electrolysis and the change of temperature. With the increase of temperature, the demand for heat of electrolytic water increases significantly, while the demand for electric energy decreases significantly, but the total energy demand does not increase greatly.



In 2020, the world's first commercial green SOEC hydrogen production equipment will be put into use in the Netherlands. Using waste heat as a source of heat, the project can produce six times as much hydrogen per kilowatt-hour of electricity as an ordinary unheated electrolyzer. After completion, the project can produce 60kg of hydrogen per hour, and is expected to produce 960t of green hydrogen energy by the end of 2024.

Comparison of Electric Green Hydrogen Production Technology



Lye hydrogen production equipment

Proton membrane hydrogen production equipment

Solid oxide hydrogen production equipment

IEA:At 322 million tonnes of green and electrolytic hydrogen in 2050, 3,585 gigawatts of global electrolytic cell capacity (currently about 300 megawatts) would be required to generate about 14,500 TWH of electricity - about 20% of the world's electricity supply.

By 2025, China's annual demand for hydrogen will be about 35 million tons, renewable hydrogen will be about 2 million tons (500,000 tons in 2020), and the total installed capacity of electrolysis tank will be about 20GW. Under the carbon peak scenario in 2030, China's annual demand for hydrogen will reach 37.15 million tons, accounting for about 5% of the terminal energy consumption, the amount of renewable hydrogen is about 5.5 million tons, and the total installed capacity of electrolytic cells is about 80GW. In the carbon neutral scenario in 2060, China's annual demand for hydrogen will increase to about 130 million tons, accounting for about 20% of the final energy consumption.

For China, renewable energy to produce green hydrogen is the key to hydrogen as a zero-carbon new energy source. It is estimated that in 2030/2060, the proportion of renewable energy electricity green hydrogen production in China is expected to be 15%/80%.

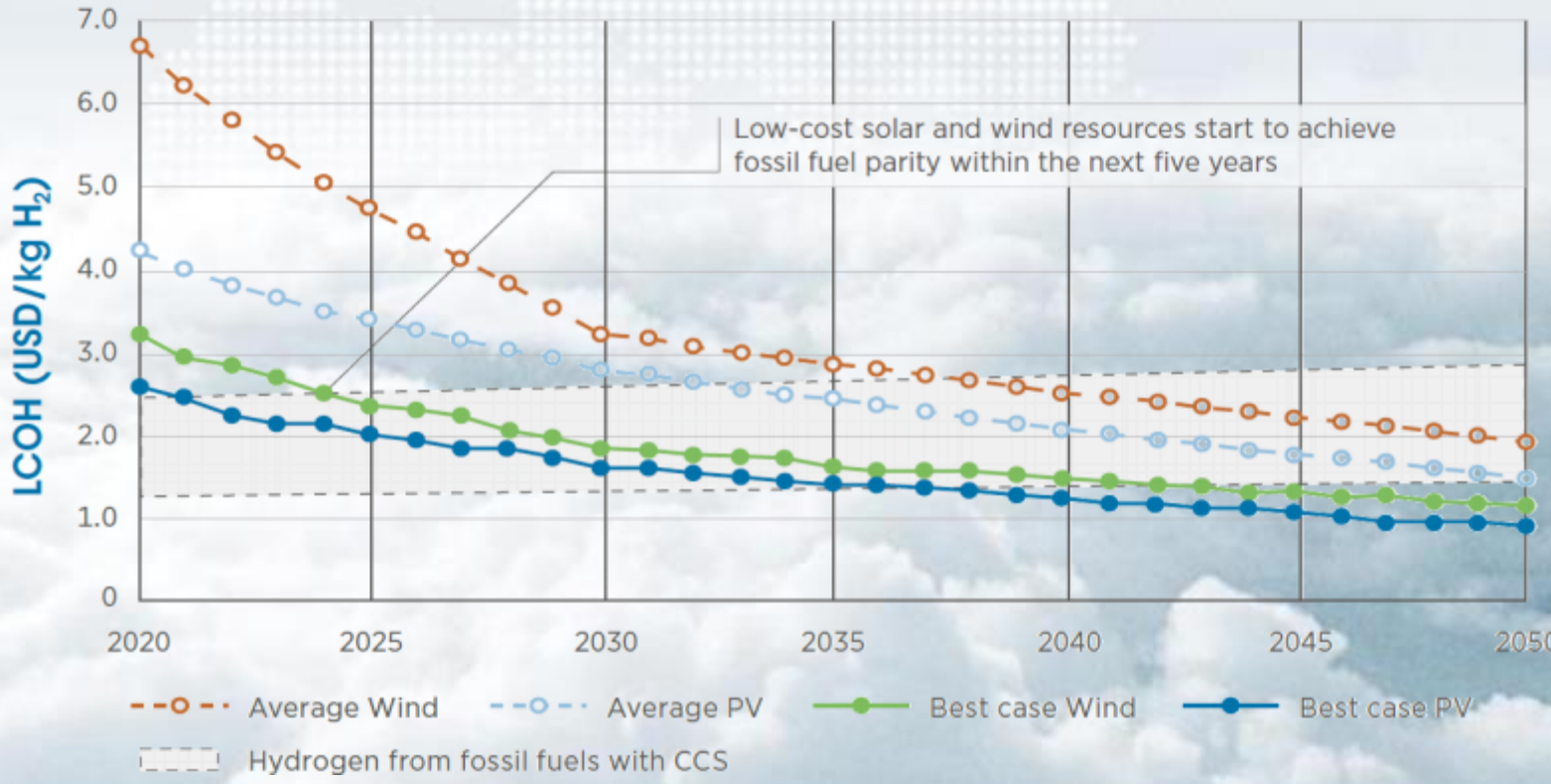
The Economy of Green Hydrogen Through Electricity

The production of green hydrogen through wind and solar power became competitive in some regions around 2020 expected to reach parity by 2030, and by 2035, it will be overall cheaper than blue hydrogen.

Hydrogen Production Cost

When the electricity price is 0.2 yuan/kWh and the cost of the electrolysis hydrogen production system is reduced to about 3000 yuan/kW, the cost of hydrogen production reaches 1.2 yuan/Nm^3H_2, which is comparable to the cost of hydrogen production from coal gasification with carbon capture.

When the electricity price is 0.15 yuan/kWh and the cost of the electrolysis hydrogen production system is reduced to about 2200 yuan/kW, the cost of hydrogen production reaches 0.8 yuan/Nm^3H_2, which is equivalent to the cost of hydrogen production from coal gasification without carbon capture



Source: International Renewable Energy Agency, 2019a
Note: LOCE (levelised cost of electricity)

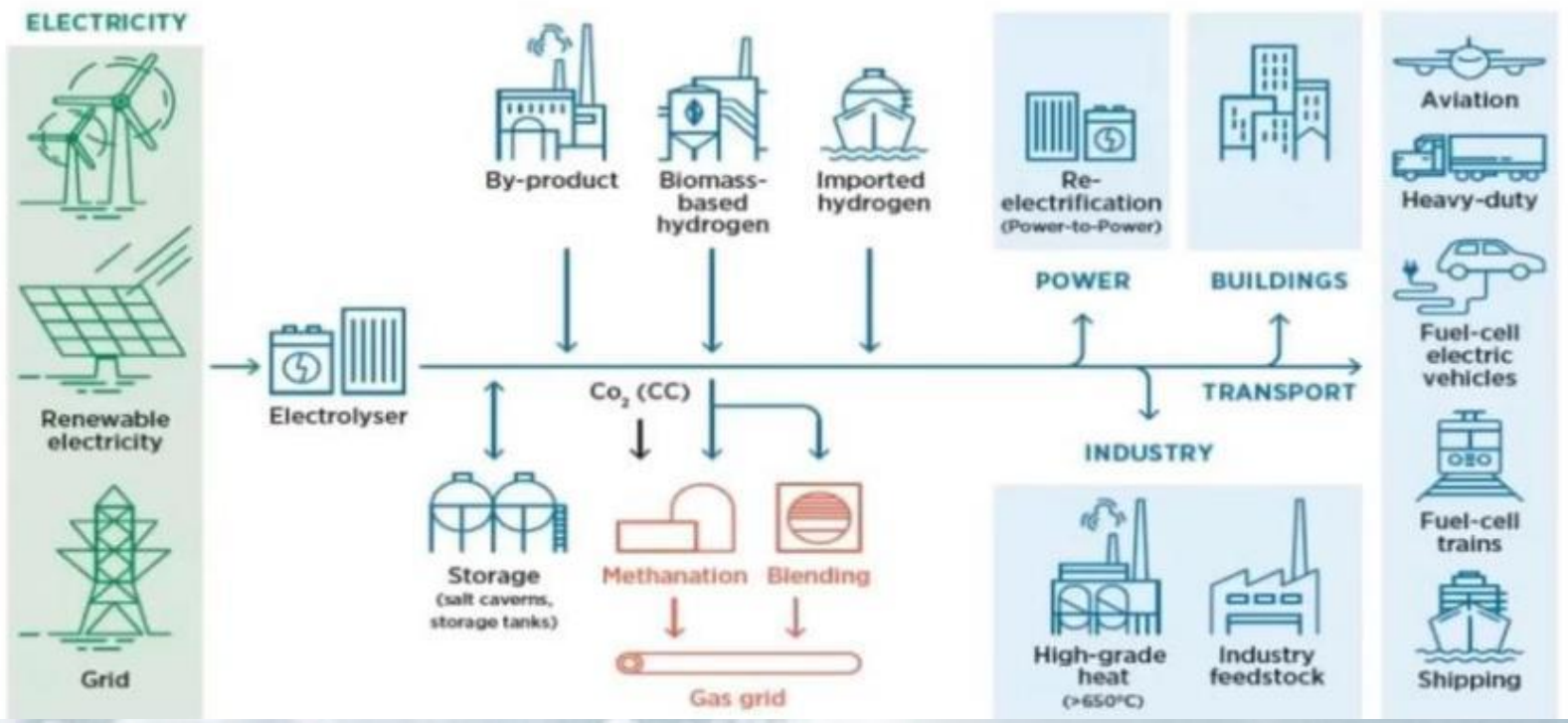
Foreign Electric Green Hydorgen Project

➢ European Hydrogen Organization's Green Hydrogen Action Plan":

The widespread use of hydrogen energy is based on the reduction of renewable energy generation costs.

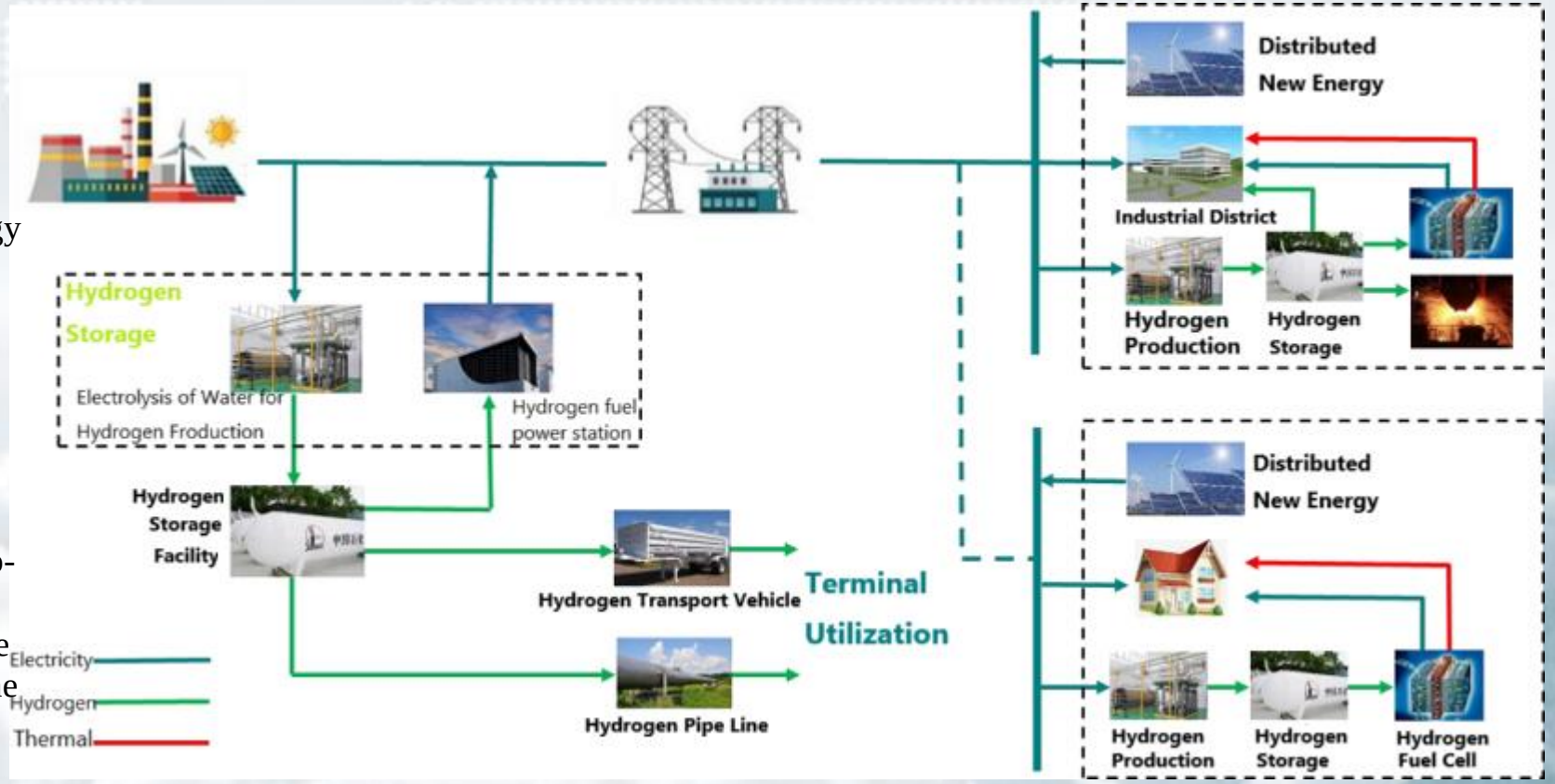
Green hydrogen cost
1.5-2.0 euros/kg by 2025,low carbon hydrogen
1.0-1.5 euros/kg by 2030,grey hydrogen

In the future, as the cost of renewable energy generation continues to decline, **cheap electricity will bring cheap hydrogen**, providing a foundation for the rapid penetration of hydrogen energy



Electric and hydrogen fusion to build a new energy system

Hydrogen energy, like electricity, is a secondary energy source. It can easily couple with various forms of energy such as electricity, heat, and fuel, and together with electricity, it can establish a modern energy system of "industrial interconnection." The integration and conversion of hydrogen energy with electricity, the organic fusion of hydrogen networks with power grids, the complementary support of hydrogen energy storage and electricity, and the interconnectivity of various energies within the comprehensive terminal energy system will be able to realize the peak-valley regulation of the power system and the spatio-temporal regulation of energy. This will promote the absorption of new energy and the deep decarbonization replacement, support the construction of the energy internet, and help achieve the dual carbon goals.

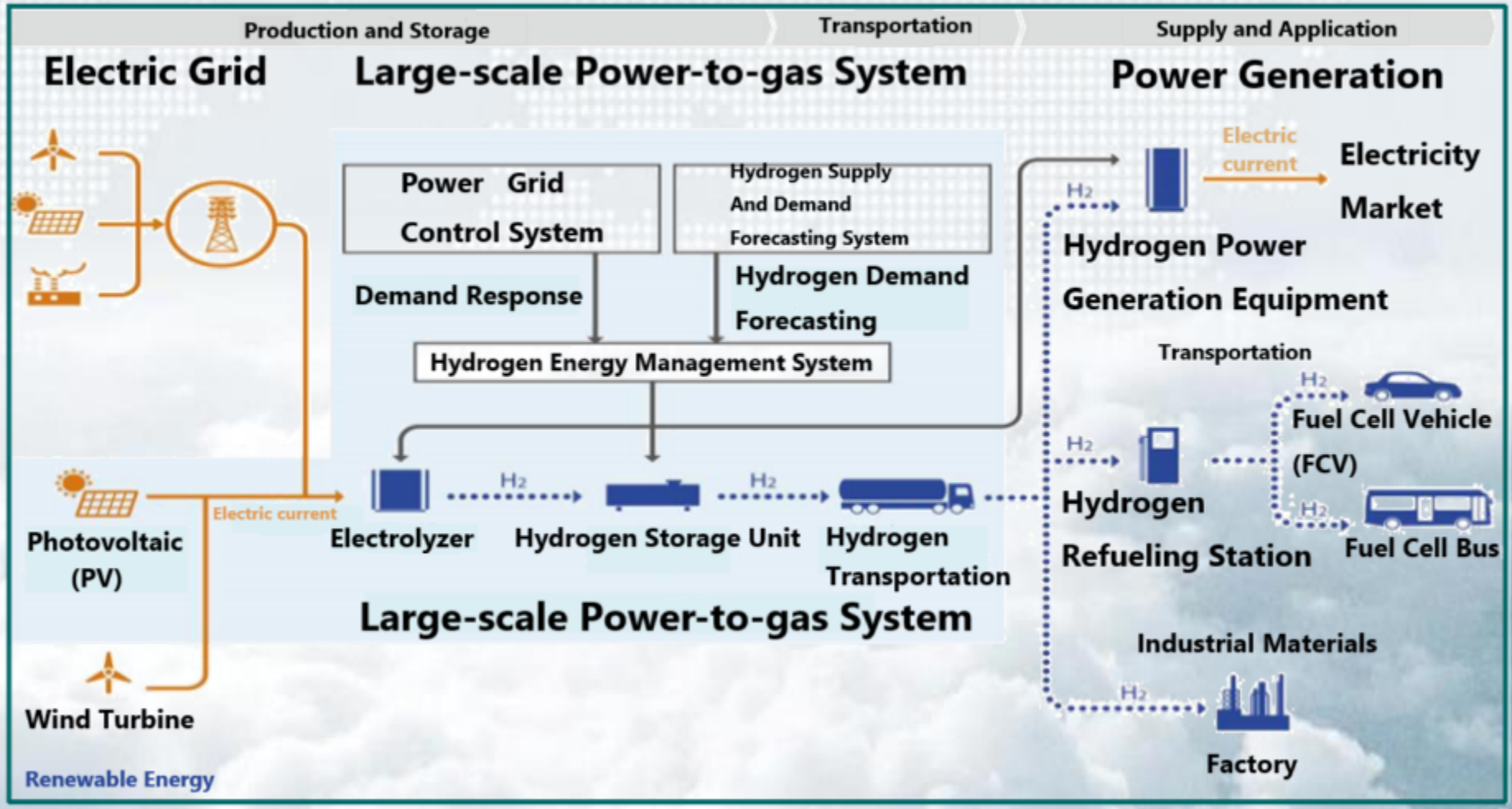


Based on technologies such as green hydrogen production for ammonia and methanol from renewable electricity, issues related to carbon-free fuel substitution, electricity substitution, and zero-carbon processes in industries like metallurgy and chemical engineering will be resolved. By utilizing comprehensive energy technologies such as Power-to-Gas (P2G) and Power-to-X (PTX) to transform fossil energy power generation and power systems, the interoperability of the energy system can be enhanced, making it possible to establish a broad, new low-carbon and zero-carbon green energy system.

Electric and hydrogen fusion to build a new energy system

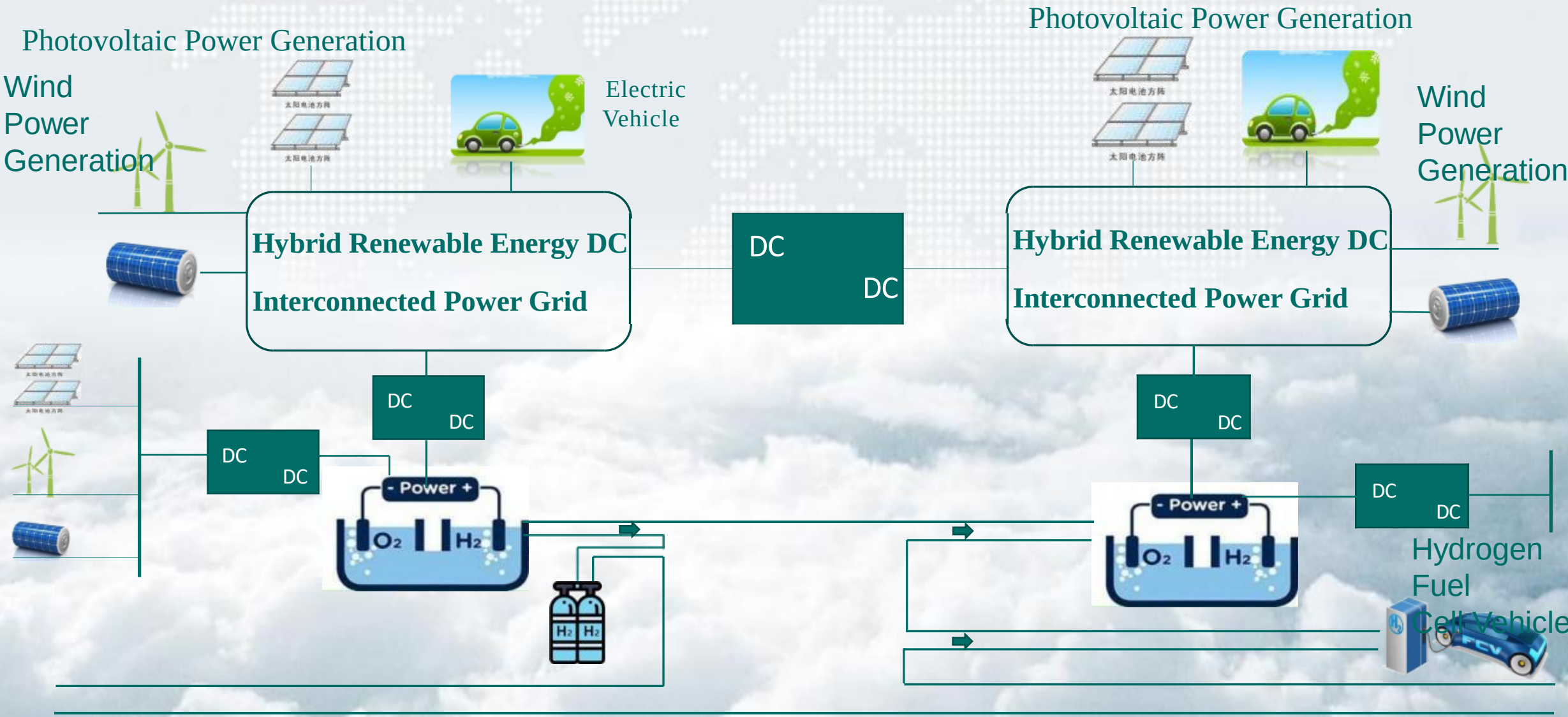
➢Through wind power, photovoltaic and other renewable energy to produce hydrogen, to obtain true clean "green hydrogen".

➢It can convert intermittent and unstable large-scale renewable energy into chemical energy and promote the absorption of new energy power.



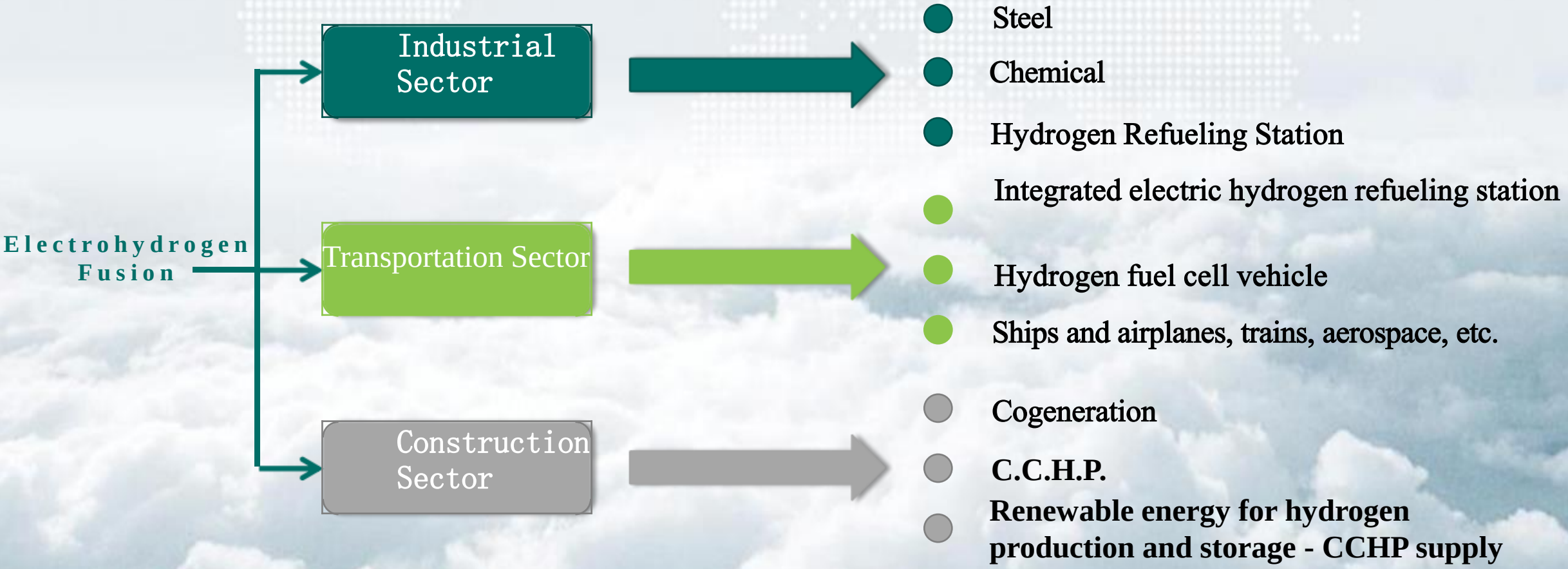
➢Through large-scale hydrogen energy storage and on-site or terminal power generation, it can meet the needs of energy storage and transformation at multiple space-time scales.

Electric-Hydrogen Integration for New Energy Systems



Building a green energy system by integrating hydrogen electricity and electric hydrogen

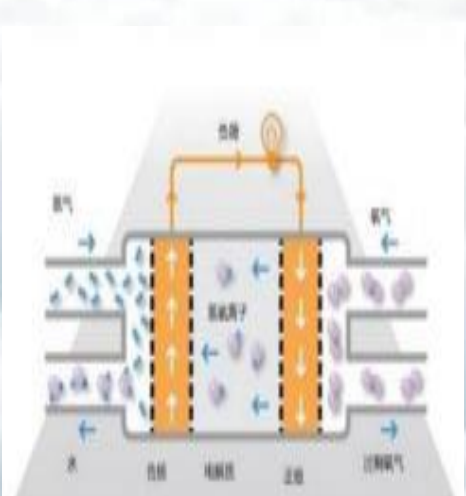
Accelerate the promotion of deep electric energy substitution and zero carbon substitution based on hydrogen energy utilization

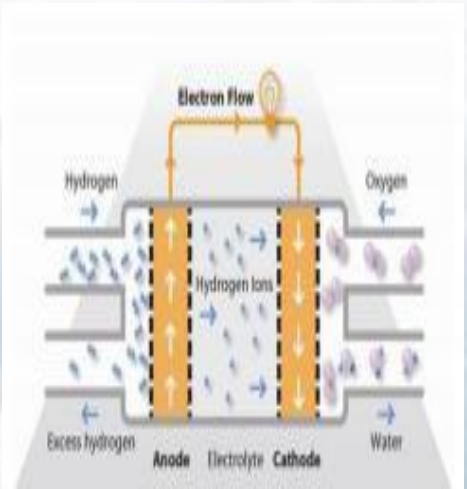


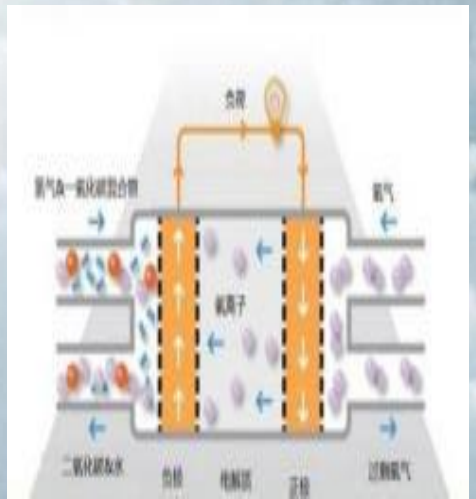
Green energy substitution is the key to achieving carbon peak and carbon neutrality

Fuel cell (PEMFC is the main market)

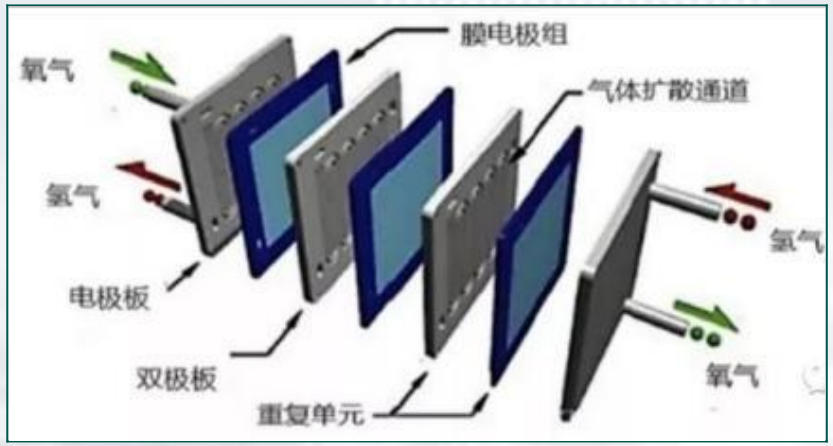
	alkaline fuel cell (AFC)	pem fuel cell (PEMFC)	solid oxide fuel cell (SOFC)
Operating temperature(℃)	≤ 100	≤ 100	~800
Specific power (W/kg)	10-30	300-1000	15-20
Power generation efficiency(%)	45-60	50-75	50-60







Efficient use of hydrogen energy - fuel cell technology



Hydrogen fuel cells are one of the few technologies that can link different energy sources and end users together, and play a new carrier technology between electricity, heat and fuel in the energy architecture of the future”

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The power application of hydrogen energy can be done in two ways: direct combustion (hydrogen gas turbine, hydrogen internal combustion engine), and the adoption of fuel cell technology.

Form of Power Generation	Energy Efficiency
Internal combustion engine and external combustion engine	10-50%
turbine motor	Maximum accessible 44%
Gas turbine engine plus steam turbine (combined cycle)	Maximum accessible65%
hydraulic motor	Maximum accessible90%
Wind engine	Maximum accessible59% (The theoretical upper limit)
solar cell	6%-40% (It is related to the use of technology, the general efficiency is about15-20%, The theoretical upper limit is85%-90%)
Hydrogen gas turbine (combined cycle) fuel cell combined heat and power	~ 85% ~95%

Hydrogen can be used efficiently and flexibly - hydrogen gas turbine

Electric hydrogen production can give full play to the role of hydrogen in large-scale renewable energy grid-connected slip and energy storage peak regulation. Hydrogen gas turbine can provide rotational inertia and maintain the key for the high specific coagulation electric current step electron mothering The need for network flexibility thus supports the proposed construction of a new electrical system with renewable energy as the main body

➢By transforming gas turbine into hydrogen gas turbine, it helps to adjust the flexibility of power grid

Finland Aurelia Turbine A400 high-efficiency hydrogen gas turbine, power generation efficiency can reach 40%, far higher than the general efficiency of about 20% of the micro gas turbine, will break the status quo of end-user CCHP, more importantly, with another hydrogen solution to break through the efficiency of Carnot cycle and expand the value of hydrogen itself. The transformation of traditional gas turbine has a new hope.

✓GE and Australia 10MW 100% hydrogen gas turbine unit;

✓Mitsubishi, Hitachi Electric and Intermountain Power 100% renewable hydrogen fuel,

✓ **440MW M701 conversion in the Netherlands;**

✓Mitsubishi Electric, $3 billion world's first green hydrogen integrated standard package

✓ **Hy**daptiveTM and HystoreTM, 100% green hydrogen fuel.

✓ **SIEMEN** announces that all gas turbine products will be hydrogen fuel by 2030

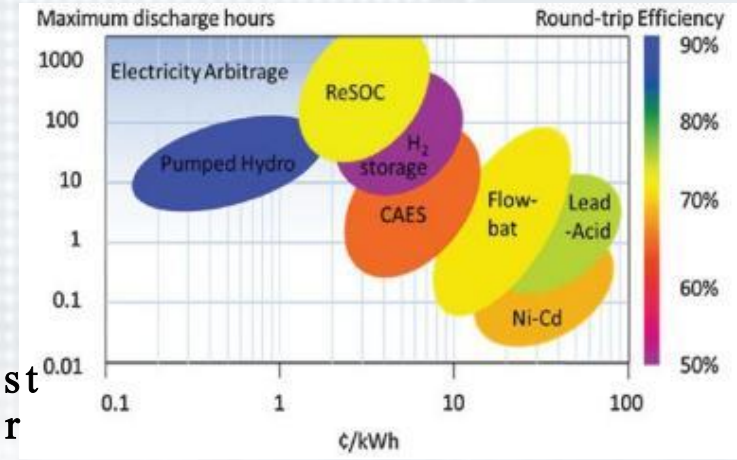
✓ The STG-600 test achieves 100% hydrogen fuel at full load

Hydrogen gas turbine will become one of the keys to the flexibility regulation of the new power system based on new energy

Hydrogen storage:
large-scale cross-space and time energy storage & hydrogen generation

■ High-power storage: energy storage batteries can be used. But the depreciation cost of single charge and discharge cycle equipment is too high;

■ Large-scale storage: can only rely on hydrogen production, the cost is energy storage battery



	Generation component price ($/kW)	Partial storage price ($/kW)	overall efficiency(%)	Number of charge and discharge cycles	Depreciation cost of equipment for a single charge and discharge cycle($/kWh)
Lithium-ion battery energy storage	400	300	80	2000	0.280
compressed-air energy storage	700	5	70	25000	0.020
pumped storage power station	1200	75	85	25000	0.043
Hydrogen production energy storage	1000	150	40	15000	0.030

➢ Hydrogen storage and transportation methods will include hydrogen pipeline, compressed hydrogen (CH2), liquefied hydrogen gas (LH2), liquid organic hydrogen carrier (LOHC), metal alloy hydrogen storage, etc., to meet the needs of large-scale energy transfer.

Hydrogen Home

Hydrogen storage facilities

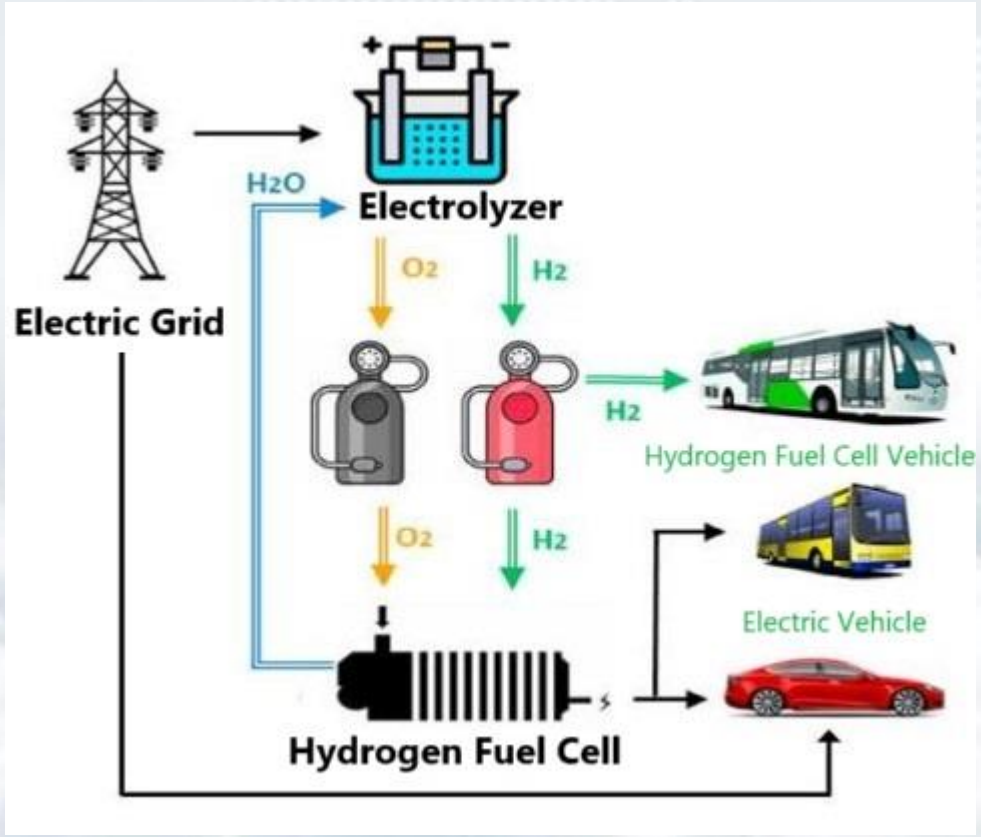
A household hydrogen storage device that can store excess energy in the form of hydrogen, enough for an average household to use for two days.

The hydrogen battery is like a household single door refrigerator, connected to the photovoltaic system through an inverter and to tap water through a purifier.

The system can convert excess energy from electrolyzing water into hydrogen gas， Stored in 4 red jars. When needed, the stored hydrogen is generated through an internal fuel cell power generation,

The system is connected in parallel with a 5kWh lithium battery buffer to increase the system's instantaneous response. Mobile phones can monitor and control the system through WiFi, and can increase storage and power generation through parallel connection.

Hydrogen Vehicle



The characteristics of hydrogen fuel cells are as follows:

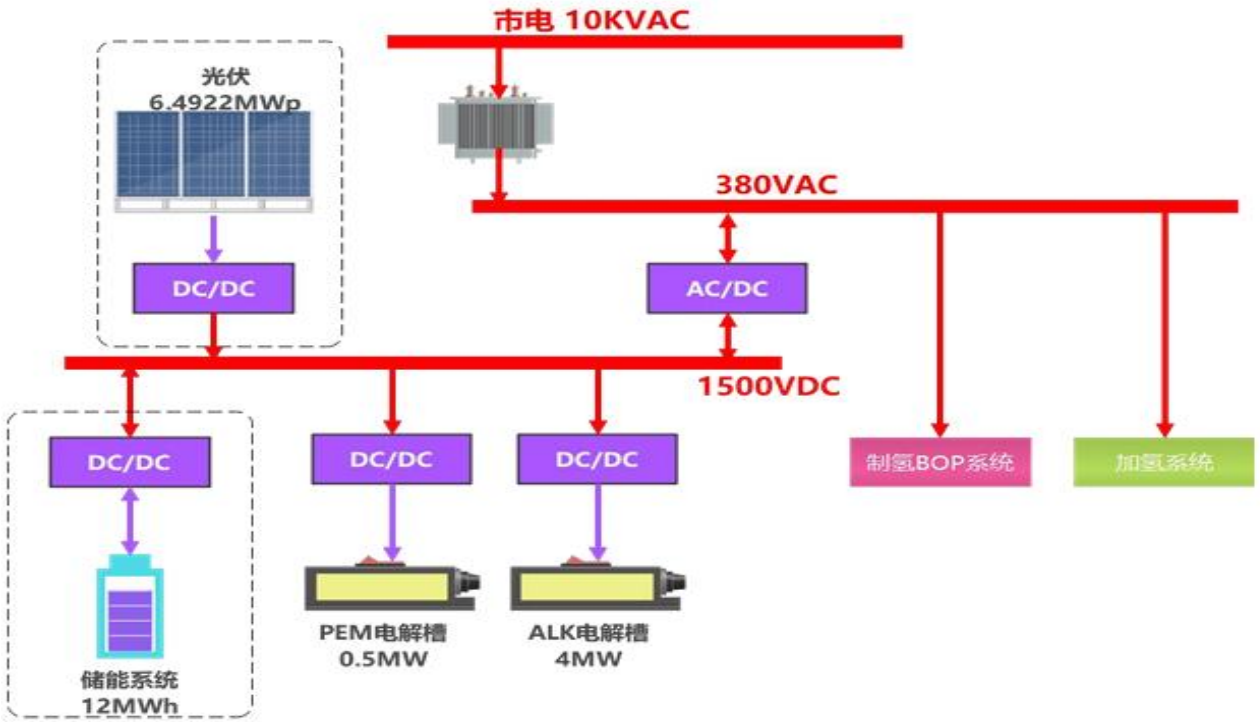
1. High energy conversion efficiency, reaching up to 60%~80%, which is 2 to 3 times that of internal combustion engines;

2. Pollution-free, the fuel for fuel cells is hydrogen and oxygen, and the byproduct is clean water.

3. Filling time is measured in minutes, with minimal environmental impact.

The Project

Zhengzhou is a important development city in central China, which has good policies and practical demand in fuel cell vehicles and green electricity hydrogen production.



It is **planned to build a hydrogen production station with a daily hydrogen production capacity of 1.0 tons, electricity from the 6.0MW photovoltaic, 12MWh energy storage, power grid, hydrogen production equipment using ALK and PEM, with a total capacity of 900Nm³/h.** The hydrogen is pressurized by the compressor and stored in the tank, then the hydrogen fuel cell is filled, and the hydrogen is capable of external transport.

The Simulation

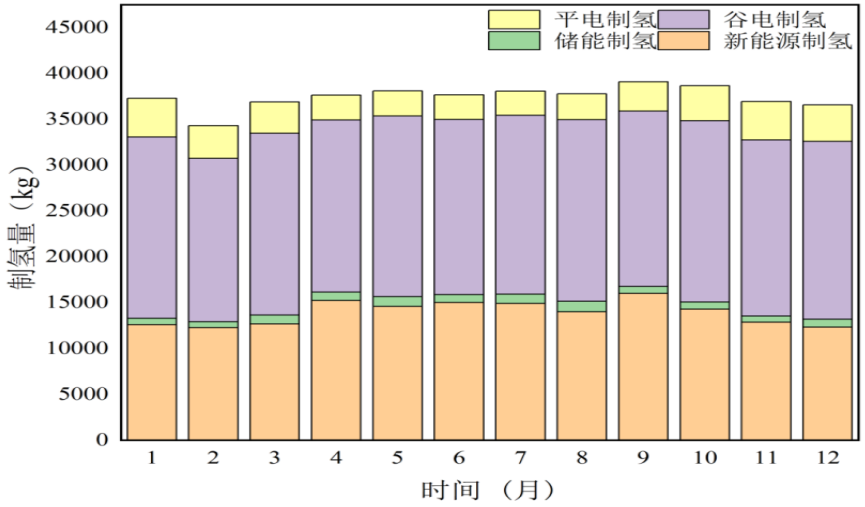
In order to predict hydrogen production system data accurately, the green hydrogen planning and design optimization software developed was used to conduct hourly production simulation throughout the year.

Last: set the simulation time to 365 days and the sampling frequency to 3600 seconds.

The data analysis

Compared with the initial design, the simulation results are as follows:

item	The hydrogen produciton(t)	Electricity purchase	Electricity purchase cost	The proportion of new energy	Carbon emission	Equivalent operating time of
the initial design	408	1854	694	28%	11309	5048
The simulation	428	1483	583	35%	9046	5295
Change ratio	4.9%	-20%	-16%	7%	-20%	4.9%



Monthly hydrogen production

The suggestions

According to the simulation results, **in order to improve the economy of the system,** the following optimization can be carried out:

1. Give priority to the use of new energy power generation equipment for power supply to reduce the cost of hydrogen production, followed by the adjustment of the hydrogen production load during the valley power period, which can reduce the cost of hydrogen production.

2. Develop new EMS strategies to make full use of the charge and discharge capacity of energy storage to improve the economy of the system.

3. Combined with machine learning technology, forecast hydrogenation load and new energy power generation, optimize EMS strategies and improve system economy.

Key Technology

- **Stability mechanism analysis method of multi-element coupled DC interconnection system supported by hydrogen energy**

  Wide-range efficient proton exchange membrane hydrogen production system

  Fast response and high conversion rate multi-port hydrogen production/fuel cell DC converter

  Real-time Simulation and Test System for DC Interconnection System Coupled with Electricity and Hydrogen

Conclusion

Toward carbon neutrality, implementing **the renewable energy power substitution action,** the production **of green hydrogen using electricity** holds great promise.

Accelerating the construction of a new type of power and energy system based on **the integration of electricity and hydrogen,** and building a new ecosystem of zero-emission energy internet is an inevitable trend.