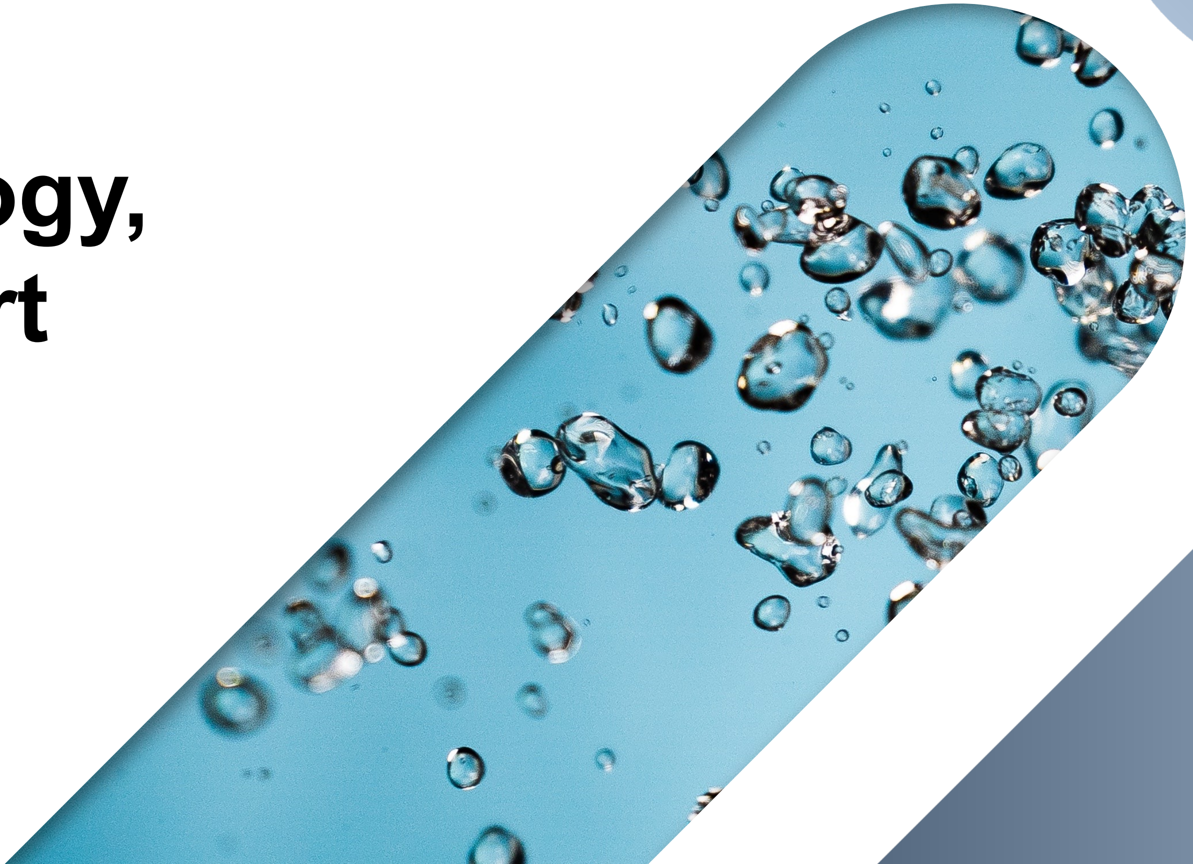
REPORT SAMPLE

Green Hydrogen Supply, Technology, and Policy Report



H1 2024

Green Hydrogen Supply, Technology, and Policy Report

The semi-annual Green Hydrogen Supply, Technology & Policy Report (STP) provides an in-depth look at the green hydrogen sector. It offers a comprehensive evaluation of electrolyzer production capacity expansion, detailed analysis of industry technology roadmaps, and an extensive evaluation of policy impacts on supply and demand.

The strategic value of the STP lies in its ability to enhance project profitability by leveraging industry incentives. It establishes security of supply through a thorough understanding of trade policy and aids stakeholders in understanding the project performance implications of new technology adoption.

Deliverables of the STP include a semi-annual report delivered in a PowerPoint format and full analyst support for any questions pertaining to its coverage. With the STP, stakeholders gain a detailed view of the supply landscape, technology trends, and policy impacts, empowering them to make informed decisions and optimize their strategies in the PV and energy storage sectors.

In this report you will find:

- Comprehensive evaluation of **production capacity expansion**
- Detailed analysis of **industry technology roadmaps**
- Extensive evaluation of **policy impacts to supply/demand**

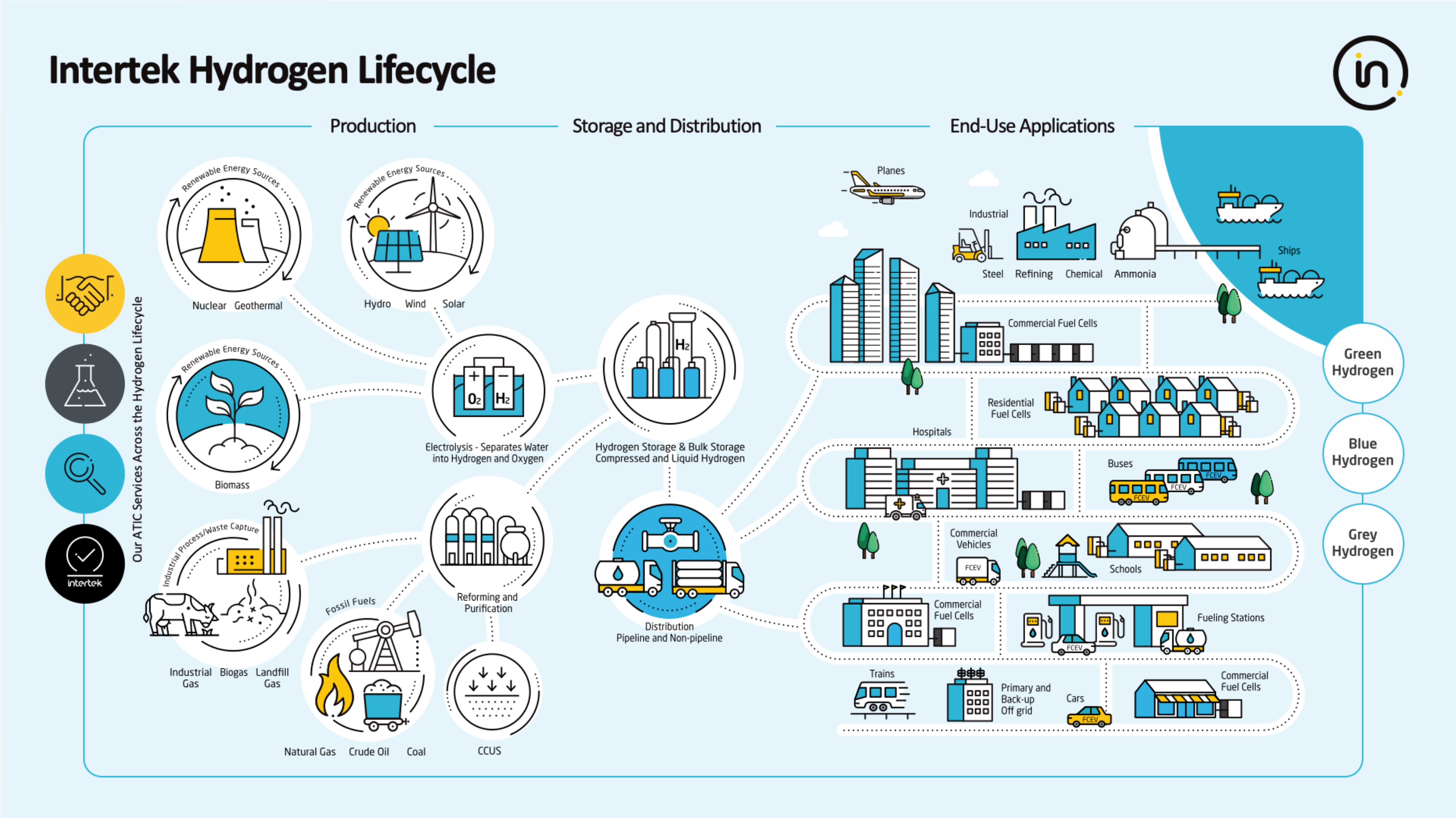
Green hydrogen will be the big enabler of net zero emissions

Production from water electrolysis using renewable energy such as solar or wind

- Hydrogen can be produced from variable pathways and a specific color name is used to differentiate the sources:

Brown	Produced from coal gasification with very high carbon emissions.
Grey	Produced from natural gas by steam reformation with high carbon emissions.
Blue	Produced from fossil fuels with carbon capture and storage, the carbon emissions are less than brown or grey hydrogen.
Pink	Produced from nuclear power, zero carbon emissions but radioactive waste produced during nuclear power operations.
Green	Produced from renewable sources, such as solar, wind through electrolyzer, green hydrogen can be zero carbon emissions.

Hydrogen production processes and applications

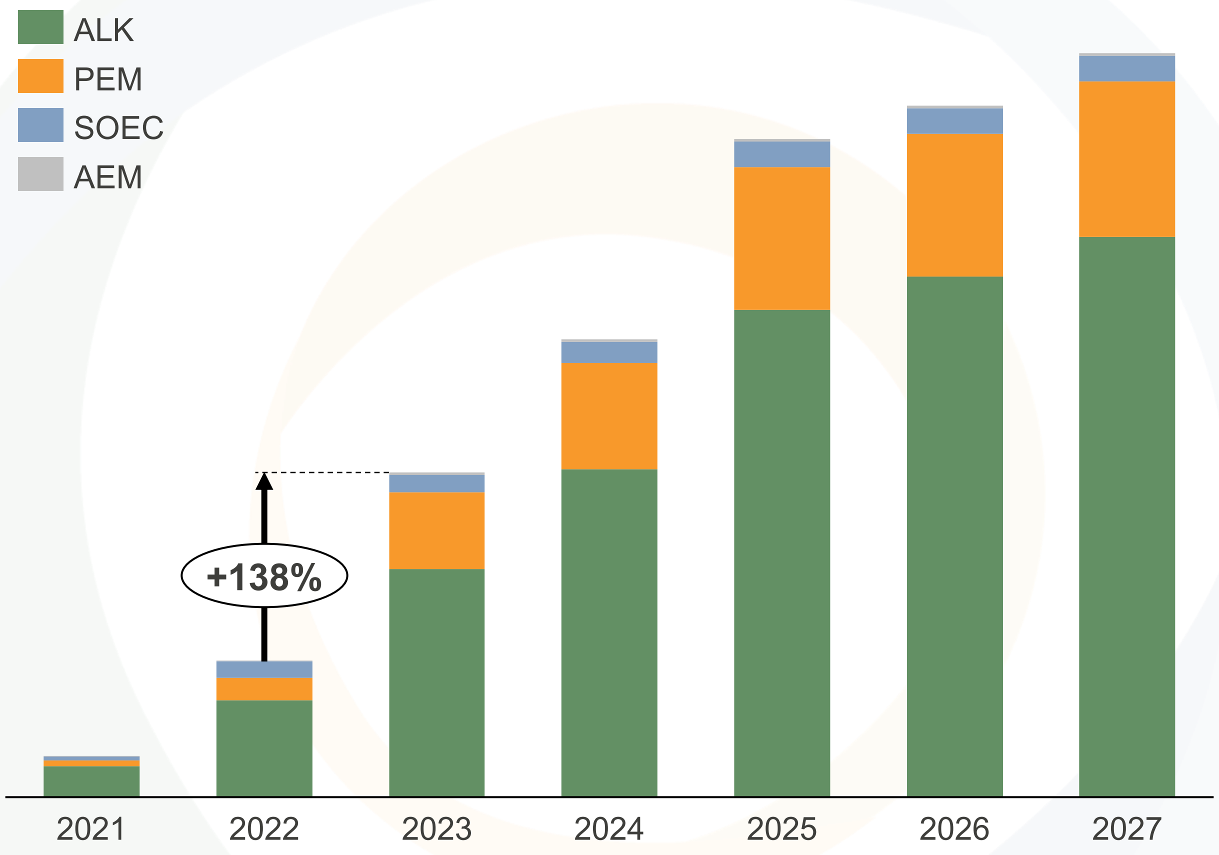


Notes | Picture source from Intertek.

Only the most mature technologies have credible expansion plans

Alkaline electrolyzer lead in capacity volume due to the low cost

Nameplate electrolyzer annual capacity by technology (GW)



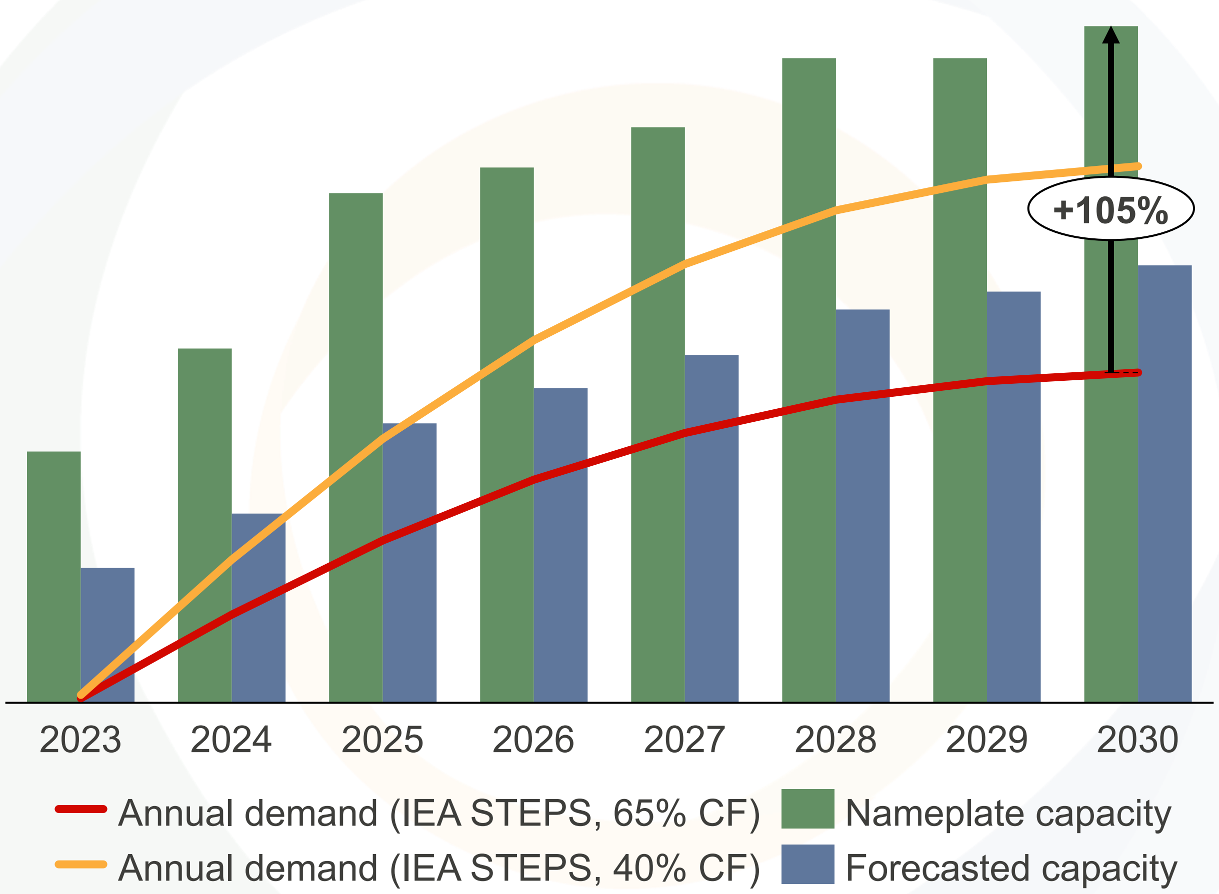
- The most mature technology level, the cost advantage, and potential room for efficiency improvement make the alkaline (ALK) technology domain the electrolyzer market.
- The barrier for PEM development is the use of rare metals in PEM electrodes. Those metals are found in extremely low concentrations in the earth's crust and lead to high price for stack.
- AEM is a much less mature technology compared with ALK and PEM. The bottleneck is unstable and short lifetime of the anion exchange membrane, which leads to high cost for LCOH.
- SOEC is in the demonstration stage, and the current SOEC project size is limited. The high-temperature operating scenario and short lifetime hinder the development of SOEC technology.
- Alkaline electrolyzers will remain the most produced technology in the next ten years due to their cost advantage and potential efficiency improvement. Alkaline electrolyzer manufacturers are primarily located in China and Europe, whereas PEM electrolyzer manufacturers are more spread out globally.

Notes | Source: CEA database

Electrolyzer manufacturing capacity up to ~2x of demand in 2030

The actual capacity is discounted at ~60% of the nameplate due to market uncertainty

Global electrolyzer demand and supply (GW)



- As manufacturing capacity grows at a fast pace, the actual usable capacity is expected to be less than the nameplate capacity. In CEA's analysis, a discount factor is applied for each supplier according to the assessment of its manufacturing maturity, ability to scale up, and investment decisions based on market factors.
- The forecasted electrolyzer demand is highly uncertain, as it can be affected by policy implementation, downstream industry developments, low-cost renewable energy availability and operation of existing projects.
- CEA applies CFs of 40% and 65% to the IEA STEP green hydrogen demand scenario to calculate the annual electrolyzer demand trend from 2023 to 2030. In both CF scenarios, there is a gap between nameplate capacity and the annual demand, which indicates a potential overcapacity in electrolyzer manufacturing. However, with great uncertainty for both actual manufacturing capacity and the capacity factor of projects globally, there could be a long way for the supply and demand of electrolyzer systems to reach balance.

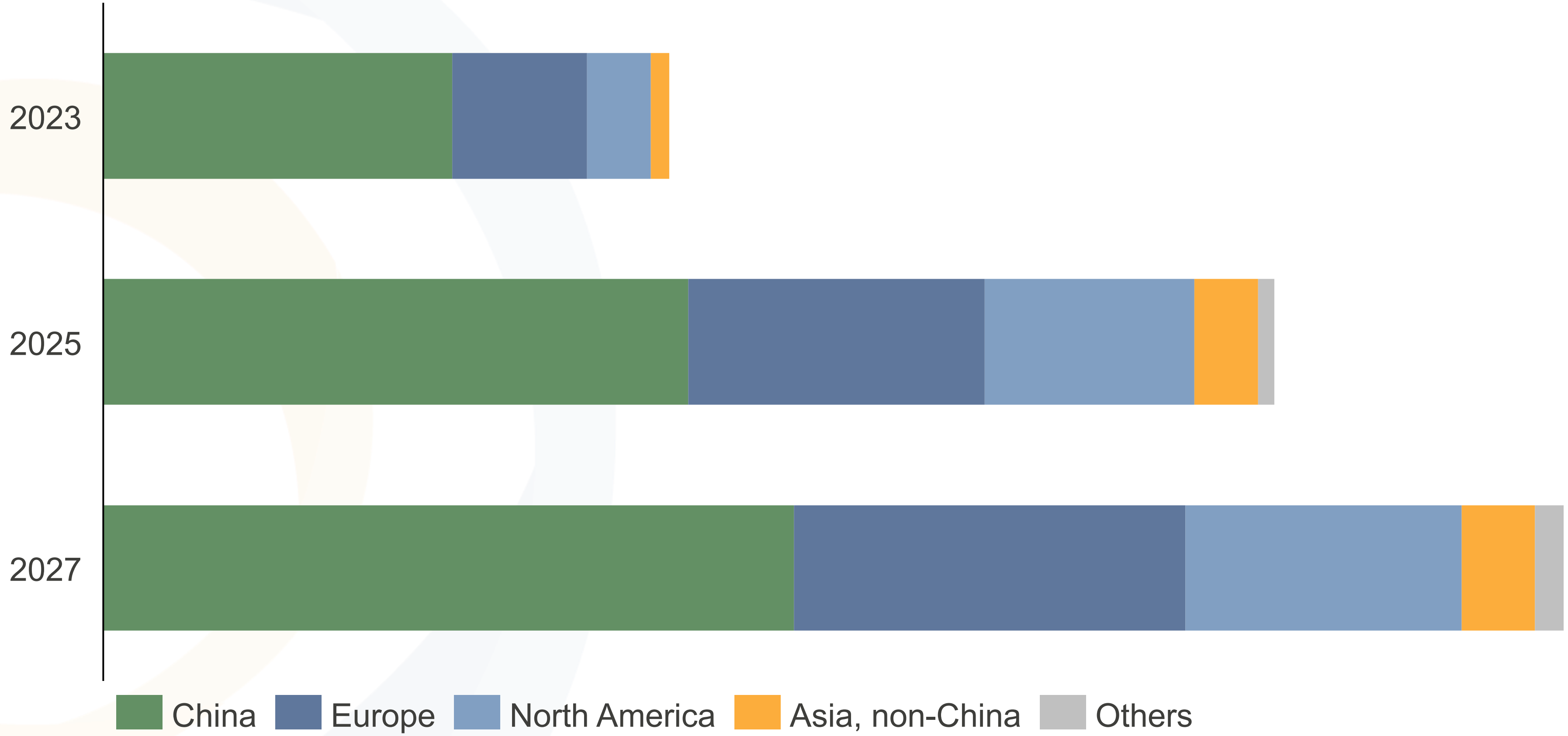
Notes | Information and data aggregated from CEA data, and International Energy Agency (IEA).

Global forecasted manufacturing capacity to reach 54 GW by 2027

China will continue to account for almost half of the global capacity by 2027

- China, North America, and Europe together will take 93% of the global market share of electrolyzer capacity by 2027.
- Due to the complete supply chain and low costs, China currently holds around 61% of global manufacturing capacity and will continue to account for about half of the total capacities by 2025 and 2027.
- With the strong support from the U.S. Inflation Reduction Act, North America's capacity will start to grow rapidly from 2023.

CEA forecasted global capacity by factory region (GW)



Notes | Sources from CEA database

Four electrolyzer technologies, each with advantages and drawbacks

ALK and PEM are the most used due to maturity and long-term industrial application

- Water electrolysis is the electrochemical process that produces hydrogen from electricity and water or water-based solutions.
- Electrolyzer technology, including alkaline (ALK), proton exchange membrane (PEM), anion exchange membrane (AEM), and solid oxide electrolyzer cells (SOEC).
- There is no clear winner across all applications, which leaves the door open for competition and innovation to drive costs down.
  - ALK: Mature, cheap but low efficiency
  - PEM: Mature, expensive but high efficiency
  - AEM: Not mature enough, unstable but combine the advance of ALK and PEM.
  - SOEC: Not mature enough, but with the highest efficiency, need high value heat to operate

Mainstream electrolyzer technologies comparison

	ALK	PEM	AEM	SOEC
Electrode material	Raney Nickel, Ni alloy, Pt/Ru/Ir based precious metals	Pt/C, IrO2	Non-rare metal	Ni-YSZ
Electrolyte material	30% Potassium-hydroxide	Proton exchange membrane	Polymer membrane	Oxide ceramic
Operating temperature	80-95°C	50-60°C	40-60°C	600-900°C
Current density (A/m^2)	2,500-8,000	10,000-20,000	5,000-10,000	10,000
DC energy consumption (kWh/Nm^3)	4.3-4.8	4.2-4.8	4.2-4.8	3.5-4.0
Efficiency	~65%	~68%	N/A	~85%
Purity	99.5%-99.9998%	99.9%-99.9999%	99.40%	N/A
Internal pressure	<3 MPa	3 - 4 MPa	<3.5 MPa	~0.1 MPa
System Cost (5 MW)	$242/kW	$950/kW	-	> $2,000/kW
Lifetime (hour)	60,000-90,000	50,000-80,000	>5,000	5,000-10,000
Advantages	Low cost	Small footprint High H_2 quality Faster response time than ALK	Theoretically lower cost compared to PEM and higher current density to ALK	Low electrolysis energy consumption
Disadvantages	Low current density	High cost Low life span	Unstable polymer membrane	Durability and sealing problems
Maturity level	Commercialized	Commercialized	R&D transitioning to commercialization	R&D transitioning to commercialization

Notes | Information aggregated by CEA.

PEM leads in current density, load range, and working pressure

ALK has advantages in design life, system cost, and stack size

Current Density
The current density of PEM electrolyzers can be up to 3-5 times that of alkaline electrolyzers, which means higher efficiency.

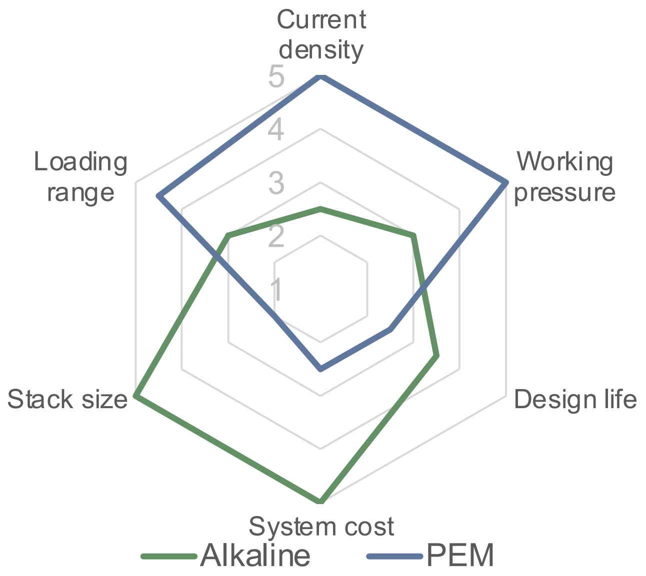
Loading Range
Compared to alkaline electrolyzers, PEM electrolyzers are more suitable for working at low loads, so there is a wider load range for PEM.

Working Pressure
The maximum output pressure of alkaline electrolyzers is 3.0 MPa, but large standard products are generally 1.6 MPa, while PEM can reach 3.0 - 4.0 MPa.

Stack Size
It can be understood as power for single electrolyzer. Larger stack size means a relatively lower unit cost. The largest stack size of alkaline electrolyzer (LONGi) has reached 15 MW, mainstream products 2.5 - 10 MW, PEM electrolyzer stack size (Cummins) 2.5 MW, mainstream products 0.5 - 2.5 MW

Design Life
On CAPEX ($/kWh), PEM systems are typically 2-3 times more expensive than the alkaline system. Alkaline electrolyzers have a claimed design life of 80,000 hours (close to 10 years), and the current lifetime of PEM is also striving to achieve this goal.

Specification comparisons of ALK and PEM



Specifications	ALK	PEM
Current Density	2,500 - 8,000 A/m^2	> 10,000 A/m^2
Loading Range	Finite lower bound	From 0% - 100%
Working Pressure	1.6 MPa - 3.0 MPa	3.0 MPa - 4.0 MPa
Stack Size	Up to 3,000 Nm^3	Up to 500 Nm^3
Design Life	80,000 h	50,000 h

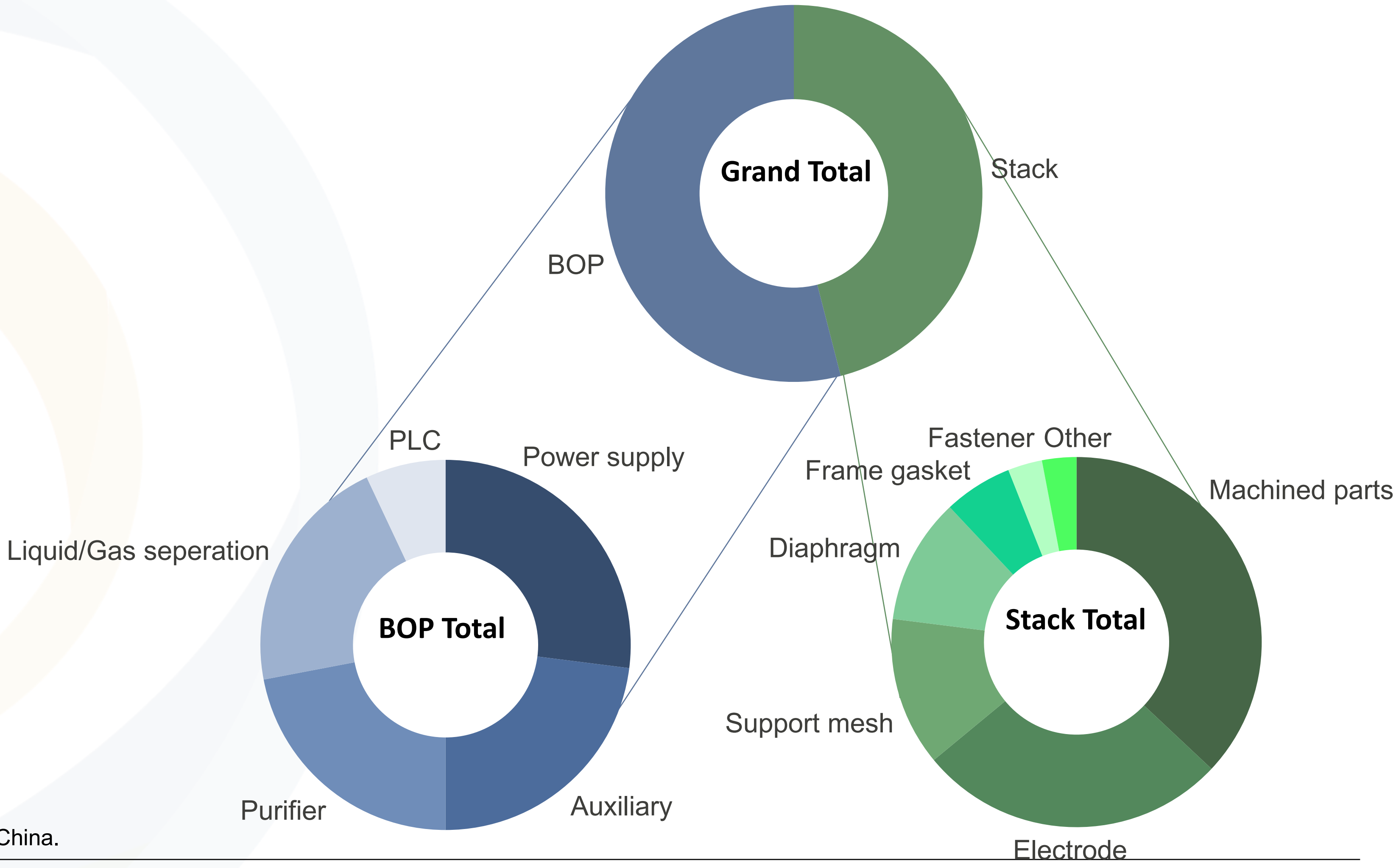
Notes | Information and data aggregated by CEA.

Stack accounts for almost half of the total alkaline electrolyzer cost

Redesigning of the electrode and diaphragm is needed to reduce the stack cost

- ALK electrolyzer cost reduction routes:
    - Scaling up production for electrolyzer key components and increased automation of metal part processing.
    - Increase current density by developing electrode, diaphragm and bipolar plate to improve hydrogen production efficiency.
    - Reduce stack cell number and stack volume to reduce the use of raw materials.
    - Analyze the key degradation mechanism to extend the equipment life.
- R&D more advanced catalyst and diaphragm to widen the work loading and extend the stack life.
- The cost reduction room for the gas-liquid separation system, hydrogen purification system, and auxiliary system is small. Solving the application of large-scale power supply system is important for cost reduction.

5 MW ALK electrolyzer cost breakdown



Notes | Information and data aggregated by CEA. All costs are based on China.

LCOH depends on capacity factor, LCOE and CAPEX

Designing for minimized LCOH is restricted due to physical and commercial limitations

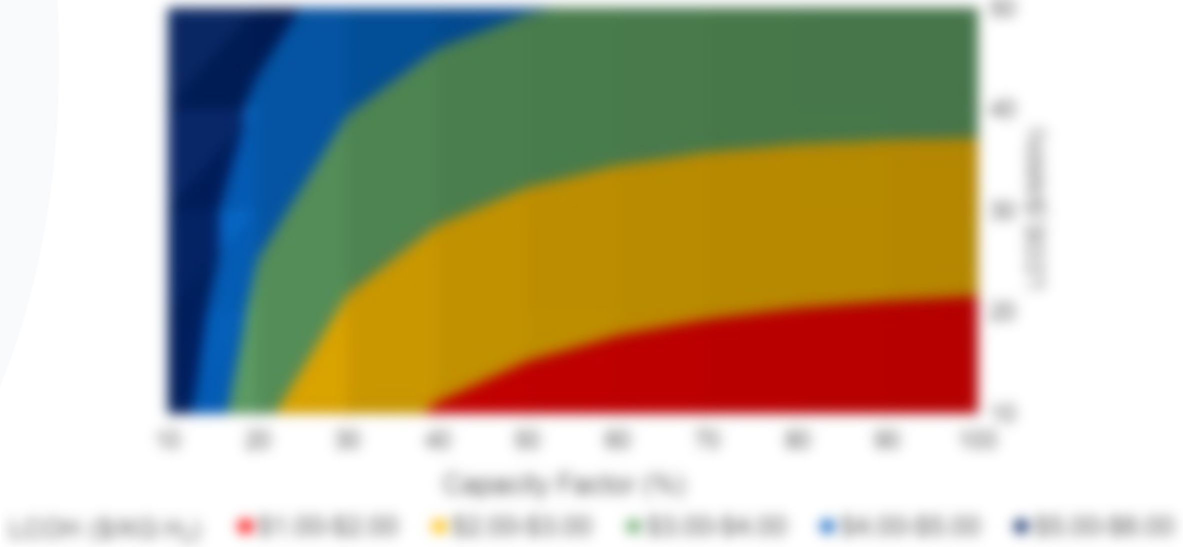
- Capacity factor (percentage of full load hours) is determined by the power supply conditions and directly impacts the operating time of the electrolyzer system.
- LCOE plays a dominant role in deciding LCOH at higher capacity factors.
- Alkaline electrolyzer with lower CAPEX shows better economies than PEM in a wide range for utilization rate and LCOE.

Limitations to developing low LCOH system:

- Physical limitations: water and power supply constraints.
- Commercial limitations: electricity PPAs and hydrogen offtake agreements.

5 MW Alkaline system LCOE vs capacity factor

5 MW PEM system LCOE vs capacity factor



Notes | Information and data aggregated by CEA. All costs based in China.

US vs EU hydrogen policy

EU green hydrogen threshold is much higher, but does not offer incentives

U.S. Section 45V vs. European initiatives

Initiative/Jurisdiction	"Clean" Hydrogen Threshold (Approximate % GHG Reductions Below Today's Incumbent Fossil Hydrogen)	Lifecycle greenhouse gas emissions rate kg(CO_2e)/kg(H_2)
US Section 45V	60%	3.7
(EU) Delegated Act 2021/2800	74.3%	2.4
Renewable Energy Directive (EU) 2023/2413	70%	2.8
CertifHy (voluntary) Certification Scheme (Europe)	60%	3.7

In the US, the Section 45V credit incentivizes investments that achieve a 60% GHG reduction threshold compared with hydrogen derived from fossil fuel sources.

The European Union (EU) is still in the process of developing financial incentives for green hydrogen production through the Hydrogen Bank.

The EU has published numerous regulatory documents that help to define the conditions for renewable fuels of non-biological origin (RFNBO). This helps to set legal clarity for investors, producers and consumers of green hydrogen.

The EU Delegated Act 2021/2800 sets a regulatory benchmark for economic activity in green hydrogen, defining it as a "clean investment" if it meets a 74.3% GHG emission reduction below hydrogen derived from fossil fuels.

The newly adopted Renewable Energy Directive (REDIII) 2023/2413 sets a benchmark for RFNBO's, mandating that they shall only be counted towards member states share of renewable energy targets if the GHG emissions savings from those are at least 70%.

These measure ensure a high standard of environmental sustainability while also promoting the credibility of the green hydrogen sector and fosters its integration into the growing efforts in meeting national renewable energy targets.

Report Contents: 52 Pages of In-Depth Reporting

CEA's **Supply, Technology, and Policy Report** applies a systems level thinking approach to provide comprehensive industry analysis. We report on current trends and have a pulse on the latest solar, energy storage and green hydrogen technologies set to disrupt the clean energy landscape.

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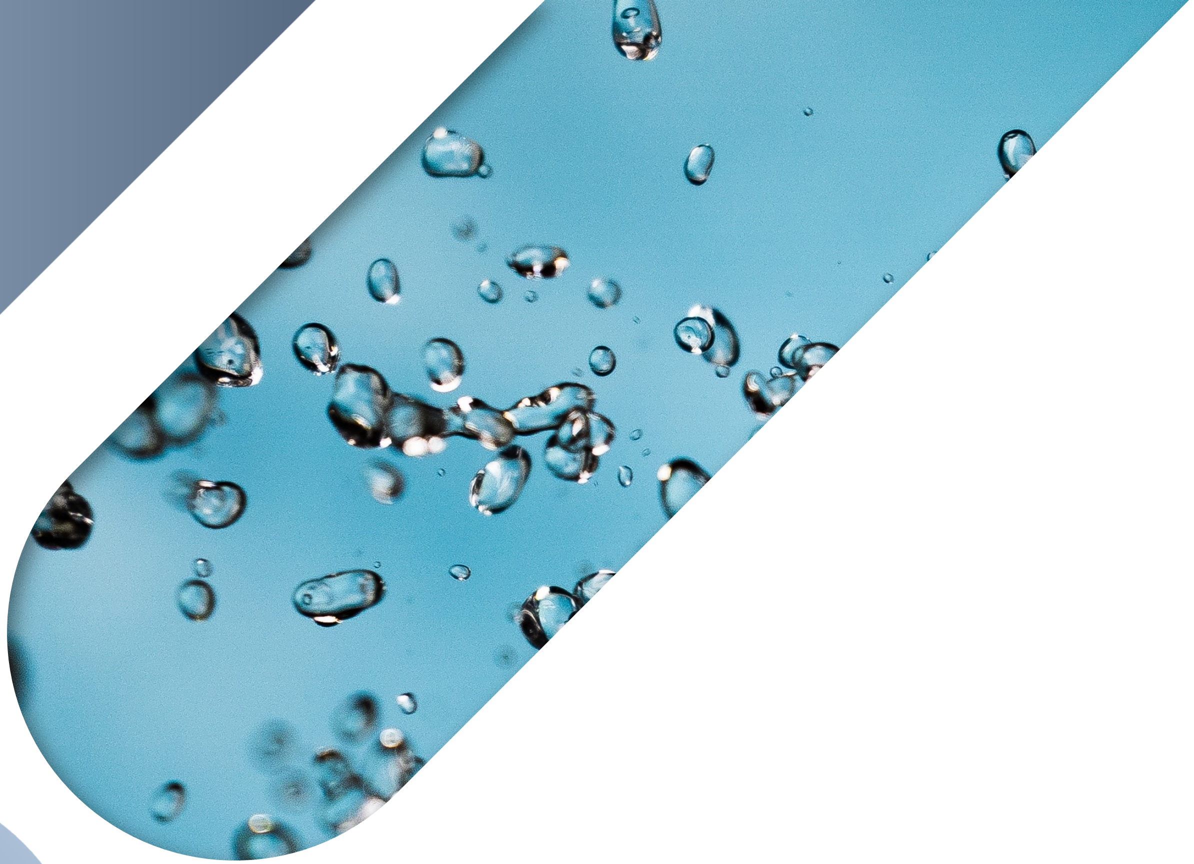

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