Green Hydrogen: Best Uses, Supply and Demand, LCOH and Quality Risks.

pv magazine RTEU 2023

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December 6th, 2023

Company Snapshot

Clean Energy Associates is a technical advisory company that provides unrivaled insight into the solar PV, energy storage and hydrogen manufacturing industries to ensure the success of solar PV, storage and electrolyzer projects worldwide.

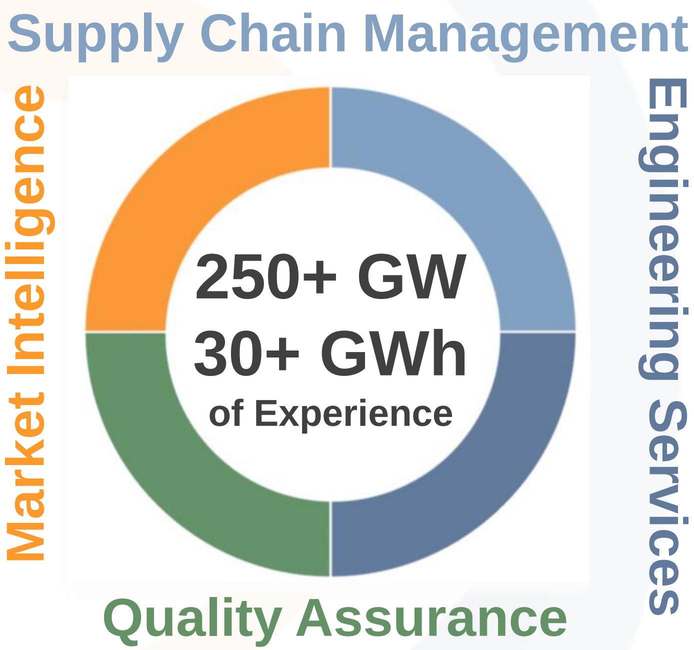
1,000+
Years of industry experience

225+
Professionals

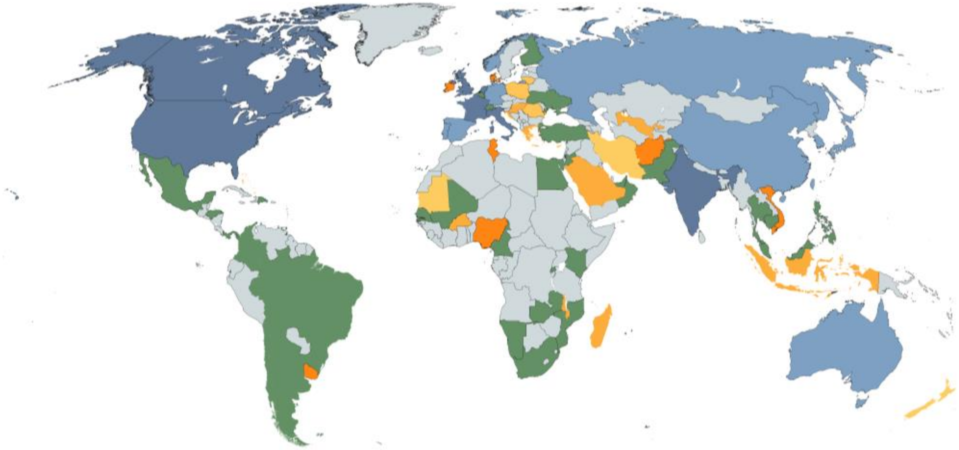
150+
Engineers

15
Year track record

15
Countries with a physical presence



Client engagements in **75+** countries



Engagements in **350+** solar and storage factories worldwide

Proud member of:

SEIA Solar Energy Industries Association Member | American Clean Power | SolarPower Europe | WRISE Women of Renewable Industries and Sustainable Energy

Technologies

PV Solar System

- PV Modules
- Mounting Structures & Racking

Battery Energy Storage System

- Cell
- Module
- Rack
- Integrated Container

Electrolyzer System

- Electrolyzer stack
- Gas-liquid separator
- Gas purification system
- Auxiliary Units

Balance of System

- Inverter/PCS
- Transformer

Some Key Figures

Hydrogen can be used in many ways, but may not always be the best solution

Hydrogen vs Natural Gas: Cost

Fossil-derived hydrogen cost:

$1/kg - $2/kg

Green hydrogen targets same cost levels, but $2/kg for green hydrogen is very, very hard to achieve, even by 2030.

Converting to energy, $2/kg is

$60/MWh

Henry Hub spot price of natural gas on December 1: $2.77/MMBTU or

$9.45/MWh

Hydrogen = X6 natural gas

So, clearly, burning hydrogen instead of natural gas is a bad idea economically.

Hydrogen vs Electricity: Efficiency

EV efficiency:

77%

FCEV efficiency:

42%

Power-to-diesel:

20%

Electricity is much more efficient to power vehicles than hydrogen fuel cells and even more so than synthetic fuels.

Hydrogen vs Liquid Fuels: Density

CGH_2 volumetric density:

1.25 kWh/L

LH_2 volumetric density:

2.36 kWh/L

Kerosene/diesel volumetric density:

9.7-10.7 kWh/L

Comparison

1	X1.9	X7.7 - 8.6
CGH2	**LH2**	**Kero/Diesel**

With big energy losses for compression and liquefaction/regasification, hydrogen as a fuel for airplanes or even ships poses substantial volume and efficiency constraints.

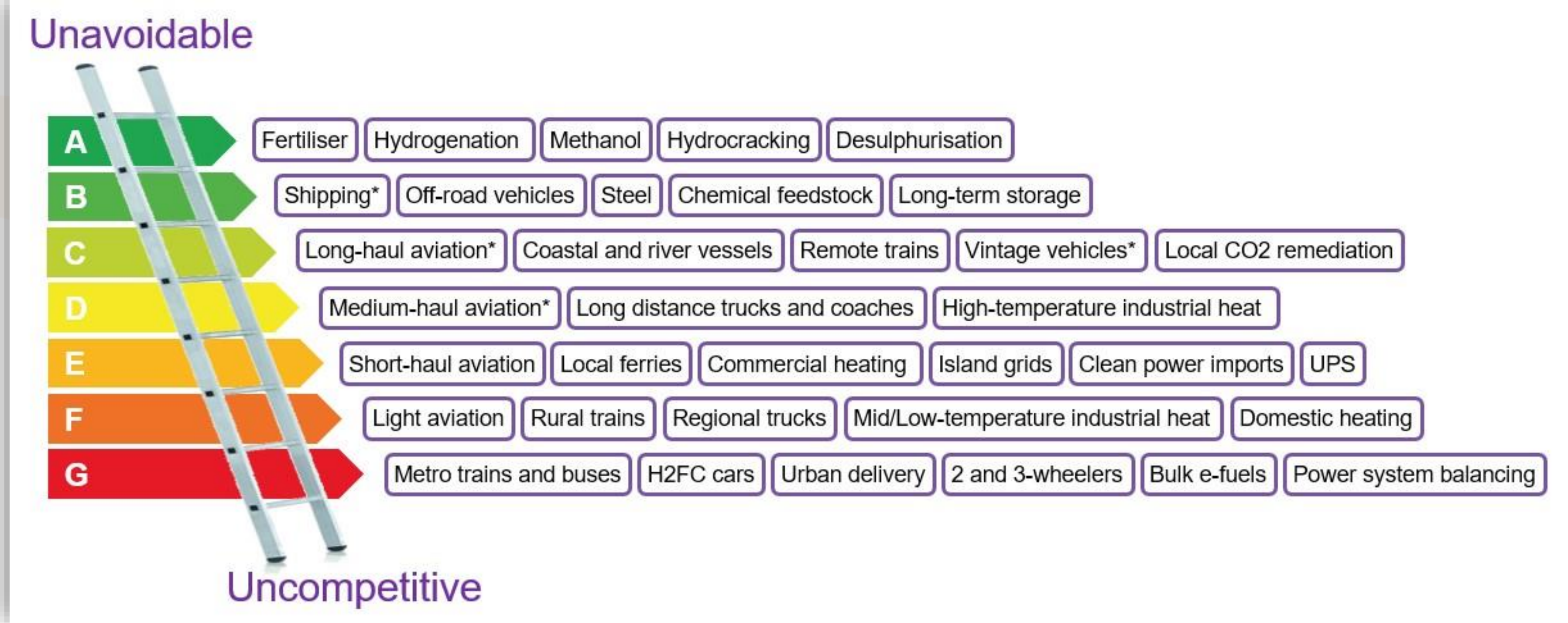
1 kg of H2 (LHV) = 33.33 kWh | 1 MMBTU = 0.293071 MWh | LH2: liquified hydrogen at -253 °C | CGH2: Compressed gaseous hydrogen at 700 bar | LHV: lower heating value | H2 energy values are LHV | Efficiency figures: Transport & Environment

Hydrogen has a wide range of applications

Not all applications are economical, feasible or mature

- The applications of hydrogen are in a wide range from chemical feedstock chemical feedstock to cleaning the steel industry, repurposing natural gas infrastructure and power stations, powering ships, aviation and transportation and even making green synthetic fuels.
- Many of these applications have already been utilized today in the coal chemical or fertilizer industry, however, hydrogen applications still need to address concerns in technological maturity and economical feasibility to compete with other green energy technologies.

Hydrogen's applications



Notes | The Hydrogen Ladder: source from Liebreich Associates.
*via ammonia or e-fuel rather than hydrogen gas or liquid.

LCOH Dependence on Capacity Factor and LCOE

Capacity factor (percentage of full load hours) is determined by the power supply conditions and directly impacts the operating time of the electrolyzer system.

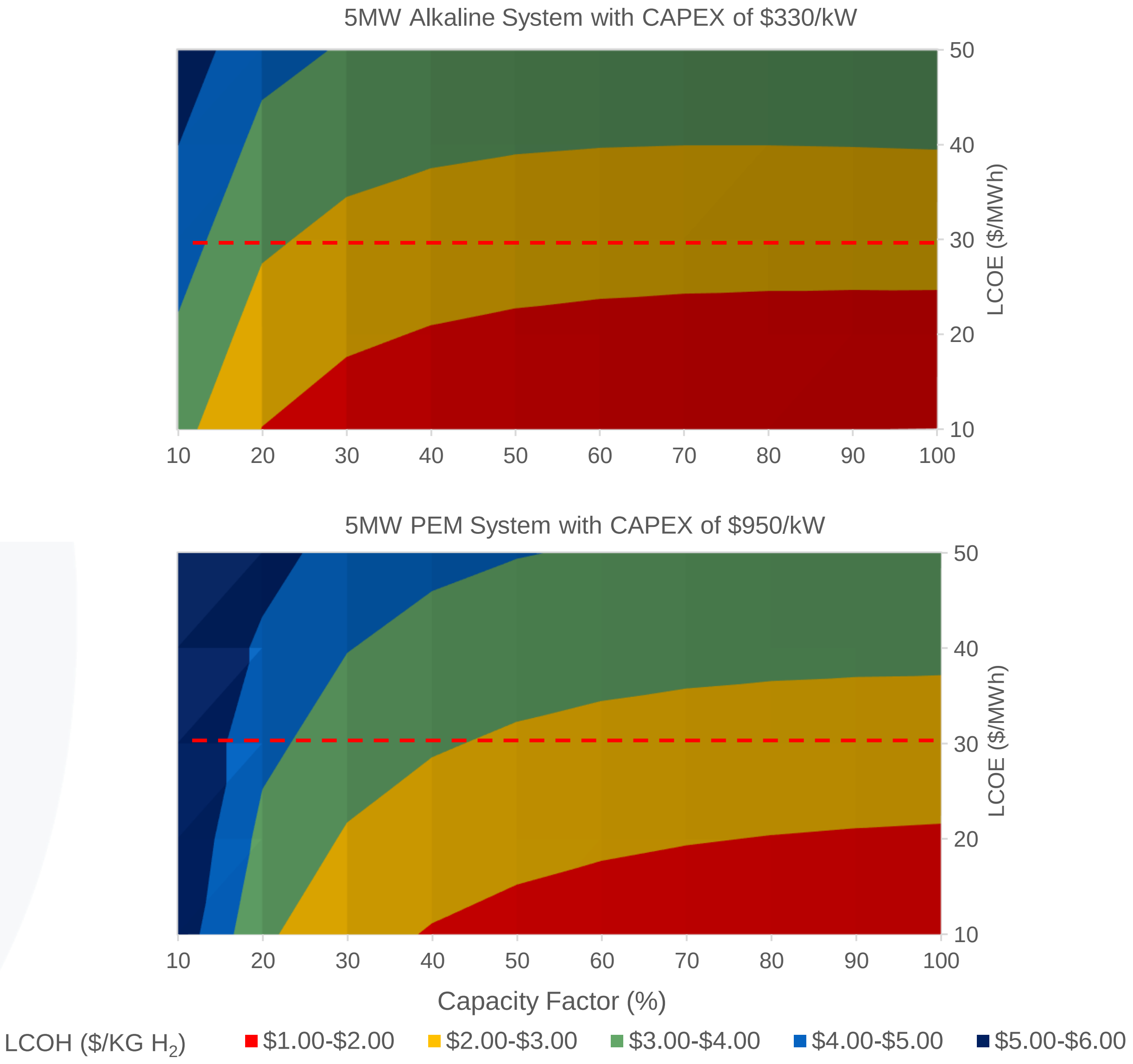
LCOE plays a dominant role in deciding LCOH at higher capacity factors.

Alkaline electrolyzer with lower CAPEX shows better economies than PEM in a wide range for utilization rate and LCOE.

Designing for minimized LCOH is not always possible.

Physical limitations: water and power supply constraints.

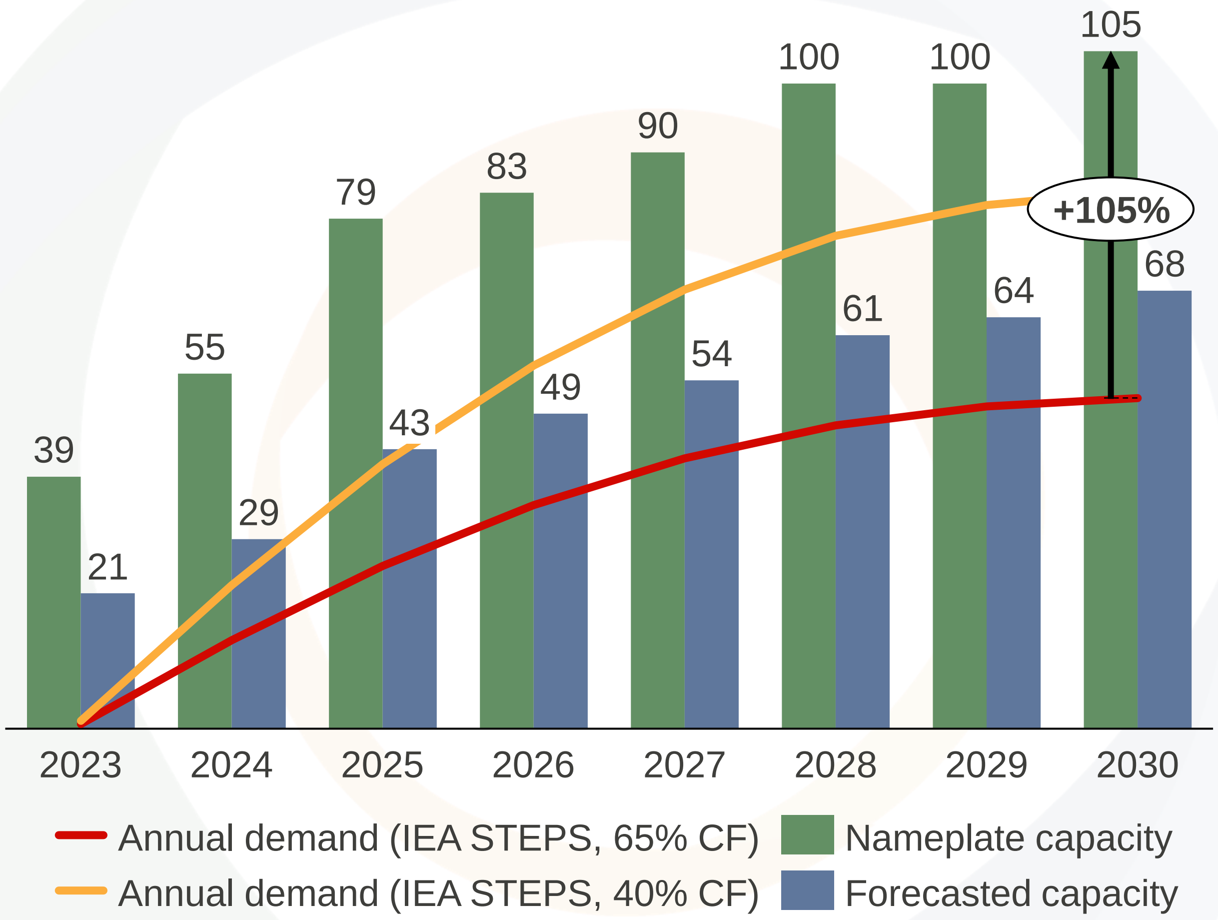
Commercial limitations: electricity PPAs and hydrogen offtake agreements.



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)

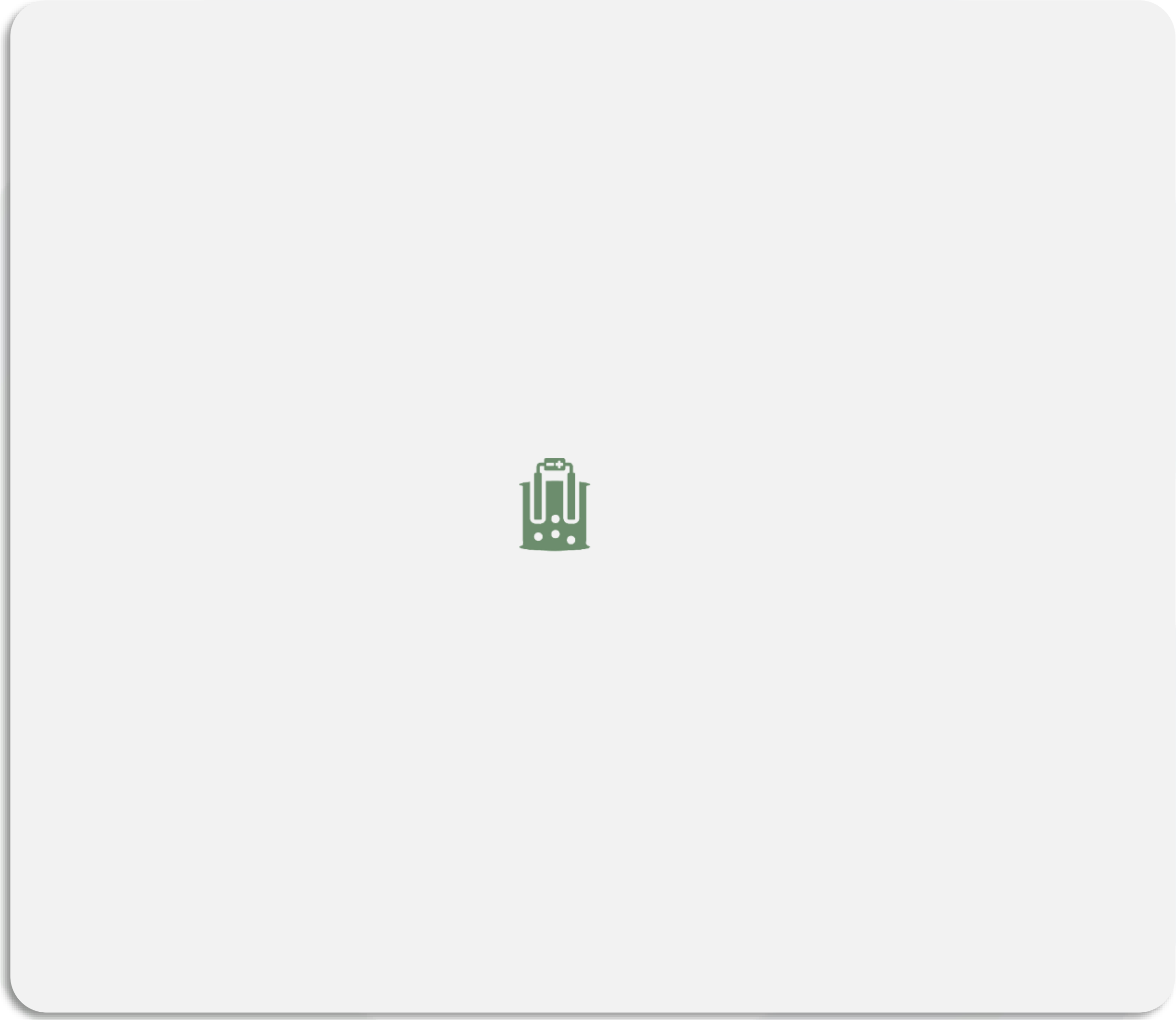


Notes | Information and data aggregated from CEA data, and International Energy Agency (IEA).

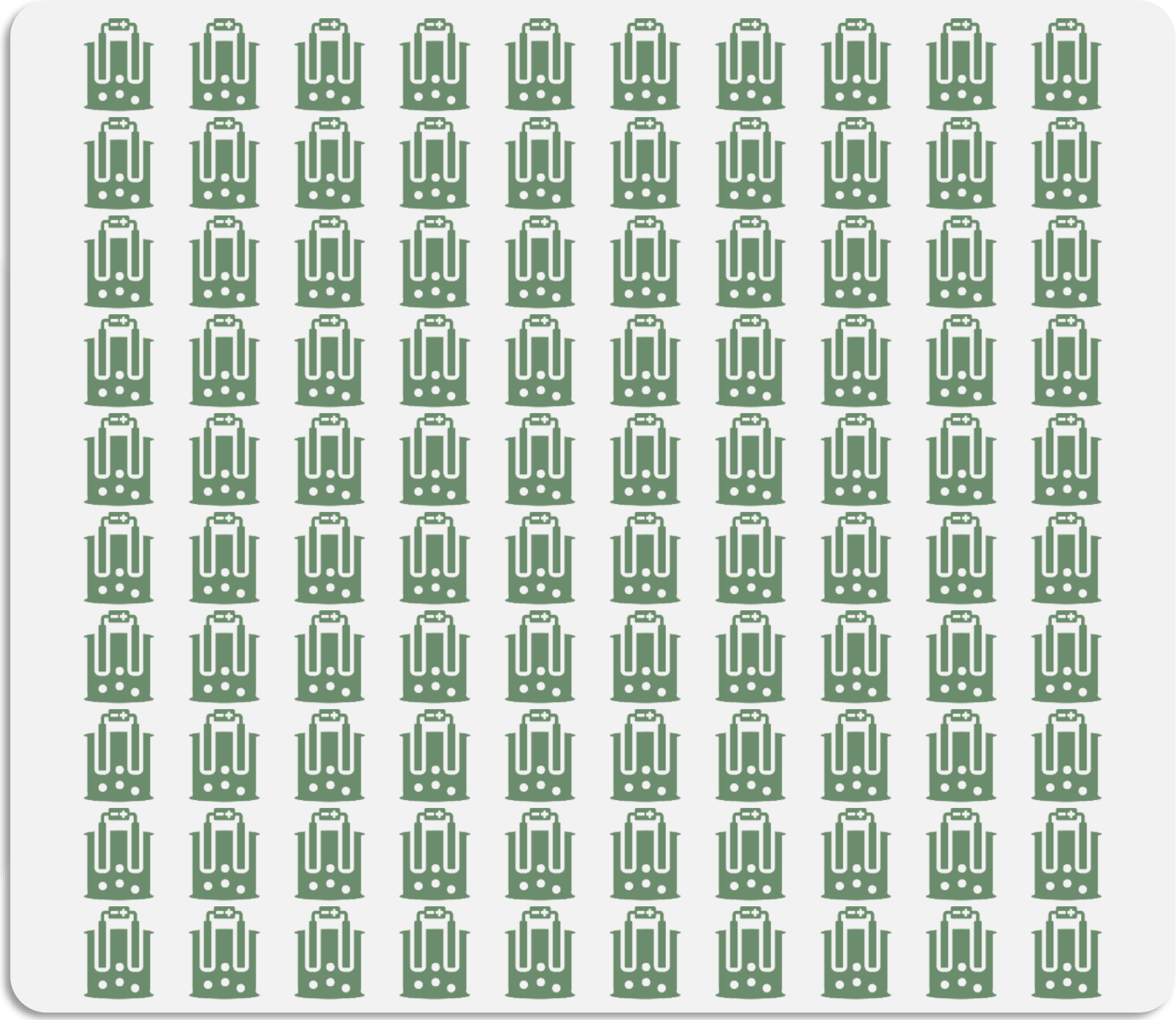
- According to global supplier announcements, the global nameplate manufacturing capacity will reach 79 GW by 2025 and 105 GW by 2030, with more than 50% of the manufacturing capacity coming from China. Many of the announced capacities will be realized by the expansion of existing plants. Due to market uncertainty, many of these expansions or new plants may be delayed or canceled. Most suppliers only have short-term capacity expansion plans up to 2025, while the long-term capacity is unclear.
- 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.
- Approximately 75% of global annual nameplate capacity can meet IEA STEPS scenario hydrogen demand with 40% CF, but only 50% of nameplate capacity is needed to meet hydrogen demand with 65% CF.

Scaling up Challenge: Electrolyzers Shipments ~100X by 2030

2022 (~1 GW)



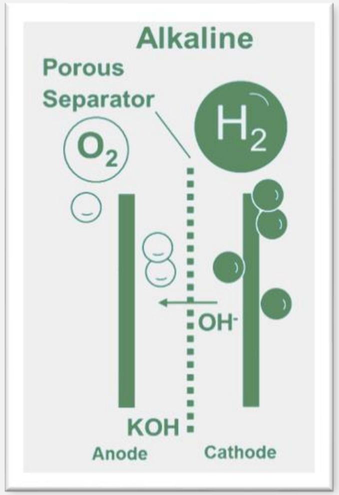
2030 (close to 100 GW)

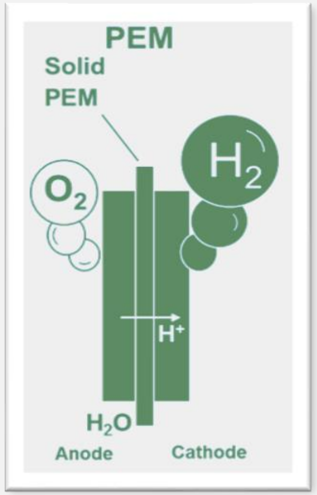


Understanding the Electrolyzer Technology and Quality

Technology Choice

- Alkaline is lower cost but less flexible/power dense
- PEM is higher cost but more flexible/power dense





Quality Risks

- Fracture of pressurized pipes and compartments
- Membrane failures
- Welding failures
- Pipe and stack leaks

Environmental, Health, & Safety Risks

- Highly flammable
- Can easily leak
- Explosive mixture risks
- Corrosive alkaline solutions and risk of skin burns

What Are The Consequences When There Are Missteps?

Downtime & Lost Production

- The longer the downtime, the higher the cost of lost production
- Penalties in purchase agreements

Maintenance & Repair

- Early replacement of expensive equipment or components
- Lack of regional servicing and maintenance capability

Safety Risks

- Hydrogen leaks or mixing can cause an explosion or fire.
- Leakage of high-temperature alkaline lye.
- Improper waste alkali solution handling can cause environmental pollution.

Reputation Damage

- Failures can damage the reputation of the company and reduce customer confidence. This can lead to a decrease in sales and revenue.

Regulatory Non-Compliance

- Release of hydrogen into the environment or improper treatment of waste alkali liquid may result in regulatory non-compliance and fines or penalties.

Thank You

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