PEM vs. Alkaline

Re-examining market perceptions of electrolyzer technologies in an evolving landscape

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Introduction

Given significant advances in the electrolyzer industry, it is time to re-examine fundamental market perceptions about electrolyzer technologies and their hydrogen production costs. Project developers are making technology decisions today for hundreds of gigawatts of expected electrolysis deployments by 2030 [1]. In support of this critical decision-making period, this paper will revisit common industry perceptions and comment on their validity. The paper is grounded in Electric Hydrogen's learnings from discussions with developers of large-scale green hydrogen projects worldwide.

Statement #1: PEM plants are too expensive, alkaline is much cheaper

Verdict: *It depends*. The answer is no longer as simple as choosing between different technology types because of rapid advancements in proton exchange membrane (PEM) technology as well as the emergence of several ‘hidden’ project costs in the deployment of alkaline electrolyzer technology. Buyers need to evaluate each electrolysis Original Equipment Manufacturer’s (OEM) technology and product offering and deployment costs holistically as both PEM and alkaline technologies are evolving and supplier offers vary in scope and value.

Electric Hydrogen’s commercial analytics team used capital cost benchmarks from real green hydrogen projects to calculate total installed costs. The analysis found that the average total installed cost (TIC) of standard electrolysis plants are $2,300/kW and $2,550/kW for European & North American alkaline and PEM electrolyzer plants respectively for non Chinese-made electrolyzers. For Chinese-made alkaline electrolyzers deployed in these same regions, total installed costs are about $1,900/kW.

Total installed project costs shown in Figure 1 below reflect a fully installed and commissioned electrolyzer plant. This scope encompasses all project requirements from the medium voltage AC power input to the project output of 30 bar gaseous green hydrogen. Costs shown include all development, engineering, equipment, site works and construction costs for the plant.

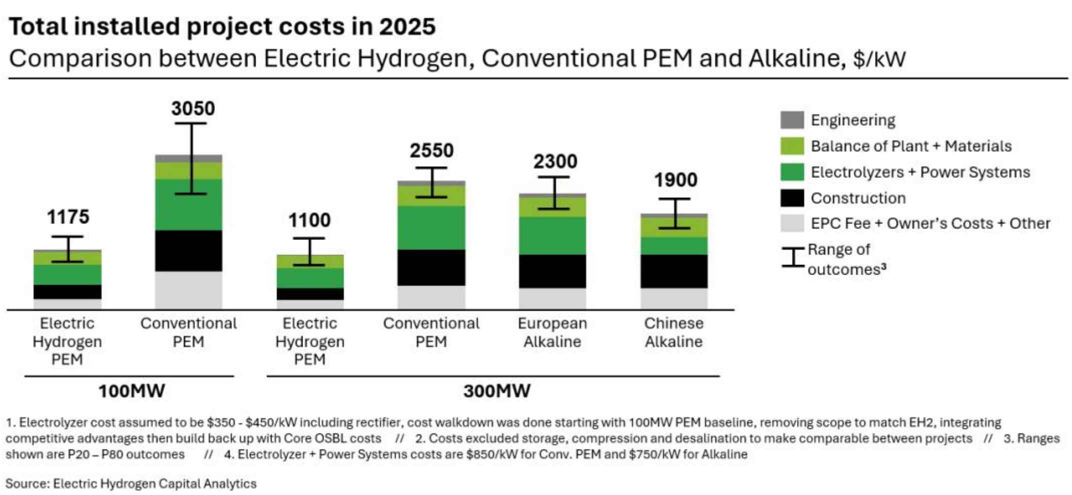


Figure 1: 2025 project total installed cost comparison for various technologies using capital cost benchmarks

As seen in Figure 1, the cost of alkaline projects are higher than the headline price of the equipment alone would suggest. Despite announced alkaline prices around $300/kW or lower, there are hidden costs that add to the overall expense of implementing alkaline electrolysis systems. Two critical hidden cost areas are:

- Lower stack pressure for most alkaline OEMs – Atmospheric hydrogen output requires adding a compressor to feed into any application that requires higher pressure, such as refining, ammonia or SAF. Compressor costs add an estimated $100 - $300 /kW to bring atmospheric H2 up to a pressure of 30 bar.

- Higher shipping costs – As shown in Table 1, Alkaline electrolyzers can weigh 30,000 - 90,000 kg when skidded and are as large as railcars so shipping costs and transit times are high.

Table 1: Aggregated reporting of electrolyzer stack weight / MW

OEM	Stack / Capacity (MWe)	Technology and Pressure	Mass reported	Metric tonne / MWe	Source
NEL	A485 / 2.2 MW	Atm. Alk	71.4 (*)	32.5 (*)	NEL document 0000-ENG-EL-15620 Rev A (retrieved June 2024) Link
John Cockerill	DQ 1000 / 5 MW	30 barg Alk	58 (*)	11.6 (*)	John Cockerill DQ 1000 spec sheet. Retrieved June 2024. Link
HydrogenPro	5.5 MW	15 barg Alk	90 (*)(**)	16.4 (*)	From HydrogenPro delivered stack image. Retrieved June 2024. Link
Siemens Energy	Elyzer P-300 / 0.73 MW	Atm. PEM	2.1 (wet)	2.9 (wet)	Siemens Energy, OAPEC Symposium Session 2. July 2021. Retrieved June 2024. Link
Plug Power	Allagash / 1MW	40 barg PEM	1.7 (*)	1.7 (*)	WBUR Article July 2022 (link)
Electric Hydrogen	Undisclosed	30 barg advanced PEM	Undisclosed	0.3 (dry)	Electric Hydrogen

** Unclear if reported value is for dry or wet stack ** includes skid*

Electric Hydrogen's technology is at least 40% lower in total installed costs (TIC) than the average large-scale alkaline plant and 60% lower than large-scale North American & European PEM technology plants. Electric Hydrogen's 100MW complete solution uses its proprietary high-power PEM electrolyzers that are co-optimized with the Balance-of-Plant (BOP) in a standardized design. By offering a complete plant solution, Electric Hydrogen is able to capitalize on the plant cost reductions enabled by its high-current density electrolyzer technology. Integration costs are sizeable when a developer uses any other electrolyzer technology because their EPC is designing a custom, one-of-a-kind and first-of-a-kind solution around a partial offering. Electric Hydrogen is further able to reduce total installed cost through its design once, built many or "plant-as-a-product" approach.

More on the Electric Hydrogen approach

The 40-60% advantage in total installed costs can be broken down into these sources:

a. Innovations in electrolysis to produce a low-cost stack - ~40% of advantage

b. Associated BOP reduction from electrolysis technology - The same innovations yield dramatic reductions in quantities of equipment, piping, wire and concrete throughout the project - ~25% of advantage

c. Standardization – Reduction in engineering, procurement and integration, as well as plant design optimization - ~30%

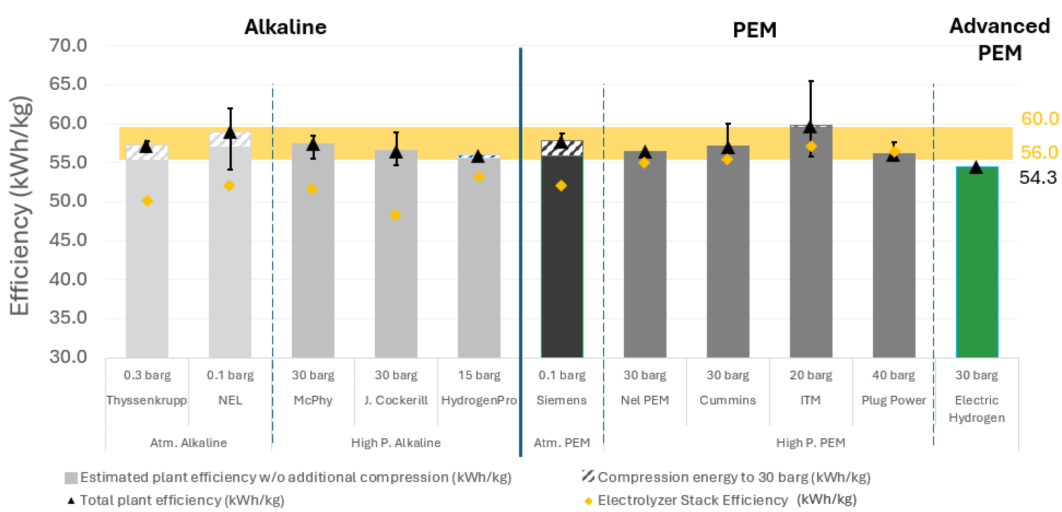
d. Modularization of the plant onto skids for construction in factory and fast and certain deployment at the project site – 5%

Statement #2: Alkaline is more efficient than PEM

Verdict: Not true. Nearly all PEM and Alkaline efficiencies are within the same range if compared on the same basis. Efficiency numbers on specification sheets are not readily comparable because each OEM's scope of supply and output product vary greatly. Efficiency figures must also be reported at full load to be comparable. Some OEMs only provide partial load efficiency figures when operating at turndown in order to suggest better efficiency. In alkaline, more manipulation occurs, as BNEF reports that Chinese manufacturers provide efficiency numbers that only account for some of the expected losses, leading to overestimation of efficiency numbers by 10-20% [5,6].

Electrolyzer efficiency is best measured and compared on a plant-wide basis, taking into account: (1) comprehensive stack efficiencies, (2) transformers and rectifiers losses, (3) bus bars and wiring losses (4) the load of all other balance of plant components like pumps, cooling fans and controls, (5) hydrogen losses.

As the electrolysis industry lacks standardization in reporting plant-level efficiencies, Electric Hydrogen has conducted a market analysis of the total plant efficiency of major OEMs by aggregating data from over 50 publicly available spec sheets, brochures, presentations and project press releases with OEMs (where information on plant power capacity and expected H2 production are reported) to provide a comprehensive view on system efficiencies (Figure 1). Outliers and projects that include liquefaction are not included (liquefaction adds about 10-12 kWh/kg). A reference hydrogen pressure of 30 bar is assumed – electrolyzers that produce atmospheric H2 incur an additional 2 kWh/kg of energy use associated with compression (here using a multistage isentropic compression model validated using H2 compression supplier data). Several OEMs, mostly Alkaline but also some PEM providers like Siemens, require compression from atmospheric to 30 bar.



Source: Electric Hydrogen Commercial Analytics

Figure 2: Total plant and stack efficiencies of PEM and Alkaline OEM's. Data is compiled based on an internal market review of over 50 publicly available sources.

When developers are quoted an efficiency value by an OEM, it is not always clear what losses are included. Figure 2 shows the differences between estimated plant efficiencies (black triangles) and reported stack efficiencies (yellow diamonds) from different electrolysis equipment manufacturers' spec sheets. Often, developers are quoted with stack efficiencies (~50 kWh/kg) which are significantly lower than total plant efficiencies. Our analysis finds that based on announced project press, the total plant efficiencies to get to 30 bar hydrogen for alkaline and most PEM technologies realistically falls in the 56 to 60 kWh/kg range. This demonstrates how plant-wide efficiency is reliant on the EPC's integration and optimization of BOP loads, making up 10-20% of the efficiency losses. In contrast, Electric Hydrogen's high-pressure electrolyzers directly output 30 bar and its 100 MW Plant has been designed in an integrated fashion to minimize the BOP loads so whole plant efficiency is 54 kWh/kg at full load. By comparing the wide range of plant efficiencies in both alkaline and PEM, statement #2 can be debunked.

Statement #3: Alkaline is easier and lower cost to service – PEM requires more work and capital

Verdict: Yes, alkaline is "easier" if you are only looking from the perspective of full stack replacements but the actual costs require a more nuanced investigation.

While Alkaline stacks arguably last up to 10 years, the turnaround event to replace the highly caustic electrolyte is recommended by the US DOE to be yearly [2]. This differs from the misperception that Alkaline doesn't need servicing for the first 10 years of operation. For a representative 100 MW plant, the primary OpEx costs associated with Alkaline electrolyte replacement include (1) the electrolyte costs, (2) transportation of 120,000 kg of dry KOH, (3) neutralization and disposal of electrolyte, (4) labor cost of maintenance technician, as well as the cost of plant downtime. Related OpEx are estimated around $175,000/year, according to Electric Hydrogen's bottom-up cost build.[1]

Moreover, additional capital investment in the balance of plant equipment is required for alkaline plants – storage tanks for make-up electrolyte, spill containment required for hazardous material and a scrubber to protect downstream equipment.

With PEM, because the stack and its electrolyte are replaced at the same time, the servicing is much simpler but happens every 5-10 years, depending on how the electrolyzers are operated. For a 1MW stack, similar to what Plug Power and Siemens have on the market, a 100MW plant will require changeouts of anywhere between 100-130 stacks with each having several interconnections to re-commission. This leads to long and complex turnaround periods.

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[1] Assumptions include 100 MW plant with 1 KOH replacement per year, 128 metric tons of KOH/plant, 500 miles of ground transportation, and $1600 per truck per trip.

In comparison, Electric Hydrogen's 100MW Plant only has a dozen stacks for a similarly sized plant because of its high-power proprietary PEM technology. Moreover, the entire plant layout and electrolyzer enclosures are designed for quick stack changeouts that can be completed within a shift. This reduces complexity and avoids lengthy outages for turnarounds. The high power density stacks are so compact and relatively light that they are easily transportable using fork lifts and don't require the cranes needed for 30,000- 90,000 kg stacks (see table 1).

Bringing it all back to LCOH

The levelized cost of hydrogen (LCOH) is the number that tells the true story of where the comparison will net out. Electric Hydrogen has taken the TICs and electrical efficiencies discussed in this paper to model unsubsidized LCOHs by technology profile for a 100MW plant, using its comprehensive EH2-LCOH+® tool.

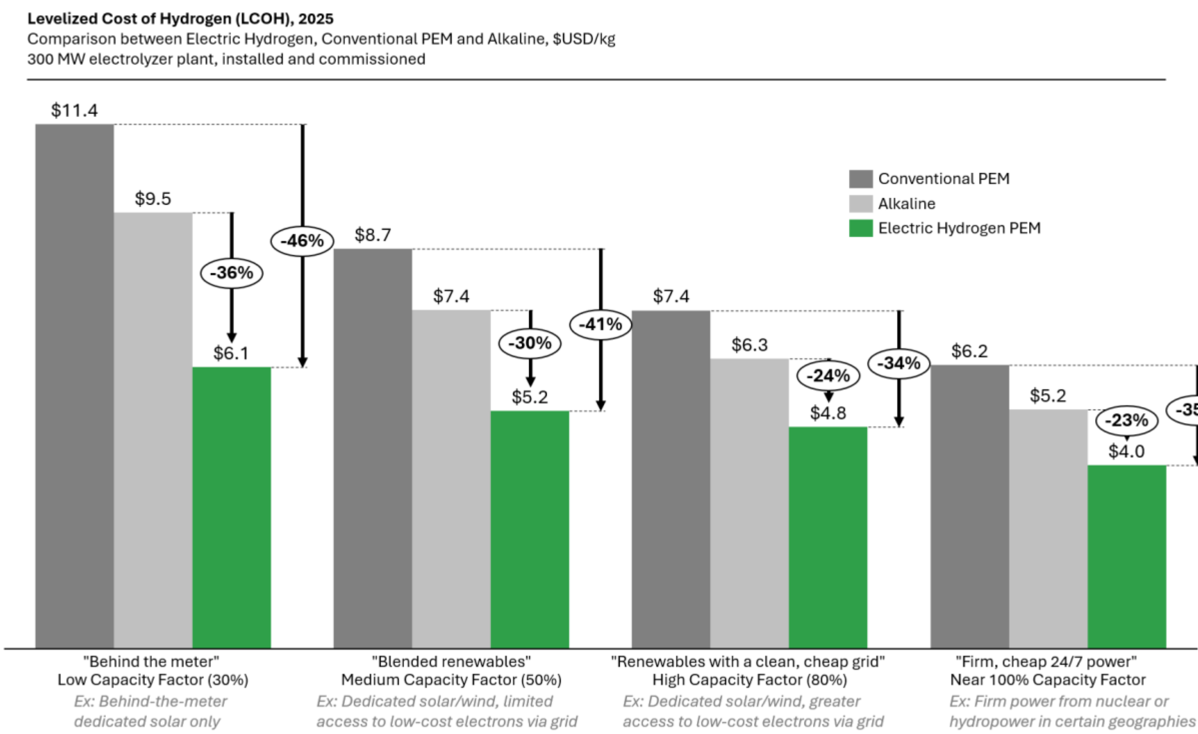

Figure 3: LCOH comparison on a 100MW electrolyzer plant over various project cases (see Appendix for full modeling assumptions)

Conventional PEM is in the $7-11/kg range, while European and North American alkaline is in the $6-9/kg range. LCOH using Electric Hydrogen's complete plant solution is $4-6/kg, which moves the industry a massive step closer to cost-competitiveness with gray hydrogen. The higher the capacity factor, which usually means higher availability of clean electrons, the less of an impact the total installed costs have per unit of hydrogen produced due to the improved utilization of the capital investment. Nevertheless, even when modeling nearly 24-7 operations, alkaline has a 16%

advantage over conventional PEM while Electric Hydrogen PEM retains a 23% advantage over alkaline. We believe the Electric Hydrogen difference can turn an uneconomic project into an economic one today, by opening up more competitive offtake opportunities.

With improvements to technology and system design being brought to market by electrolysis manufacturers like Electric Hydrogen while more projects are advancing into FEED and construction, it is important to note that the paradigm between Alkaline and PEM electrolyzer technology has changed. Technology choice must be re-examined as new possibilities emerge in order to achieve the lowest possible cost of hydrogen.

To learn more about Electric Hydrogen's complete solution 100MW electrolyzer plant, get in touch at sales@eh2.com

References

[1] Global Hydrogen Review, **International Energy Agency (IEA).** October 2024 (link).

[2] Advanced Liquid Alkaline Water Electrolysis Experts Meeting, ***US Department of Energy***. January 2022. (link)

[3] State-of-the-art and future targets – Renewable Hydrogen production] Annex 2 - **Clean Hydrogen Joint Undertaking** (25 February 2022): Strategic Research and Innovation Agenda 2021 – 2027 (link).

[4] World's largest green hydrogen project 'has major problems due to its Chinese electrolysers, ***Bloomberg energy finance (BNEF)***. December 2023.

[5] "Buying a Chinese Electrolyser? Triple-Check Its Efficiency", ***Bloomberg energy finance (BNEF)***. October 24th 2024.

[6] "Chinese hydrogen electrolyser makers are exaggerating their stacks' efficiencies by 10-20%: BNEF", ***Hydrogen Insight*** article.

Appendix

Figure 3 technology assumptions in Levelized Cost of Hydrogen (LCOH) calculations are below:

Variable (unit)	Conventional PEM plant	Alkaline plant	Electric Hydrogen
Stack replacement cost (% of TIC)	20%	15%	20%
CapEx $/kW	3,000	2,100	1,175
Fixed O&M ($/kW-year)	45	54 [3]	45
Electrolyzer minimum turndown to (% of load)	10%	30% [4]	15%
Plant efficiency (from reports above)	58	58	54

Figure 3 power prices in Levelized Cost of Hydrogen (LCOH) calculations are below:

Capacity Factor	Power price	Model Source:
"Behind the Meter" Low Capacity Factor (30%)	40 $/MWh	PEM, Alk, EH2
"Blended Renewables" Medium Capacity Factor (50%)	45 $/MWh	PEM, Alk, EH2
"Renewables with a Clean, Cheap Grid" High Capacity Factor (80%)	55 $/MWh	PEM, Alk, EH2
"Firm Cheap, 24/7 Power" Near 100% Capacity Factor	45 $/MWh	PEM, Alk, EH2