Dynamic Alkaline Water Electrolysis

The Pathway to Hydrogen Achieving Fossil Fuel Cost Parity

Green hydrogen, or hydrogen produced using electrolysis to separate water into hydrogen and oxygen, with zero carbon emissions, is necessary to decarbonize several difficult-to-abate industrial applications in oil refining, production of ammonia and fertilizers, mining, and steel. Green hydrogen is also a key input to sustainable aviation fuel (SAF), eFuels such as green methanol, ammonia and jet fuel, and is itself used in pure form as a fuel in long-haul transport. However, hydrogen electrolysis using conventional equipment today is expensive, which limits its adoption and economic attractiveness.

Conventional hydrogen electrolysis technology revolves around proton exchange membrane (PEM) and traditional liquid alkaline water electrolysis (AWE), with neither being ideally suited to cost effectively and safely scale up hydrogen production.

Dynamic AWE systems, such as Verdagy's eDynamic® are a breakthrough technology drawing upon decades of successful chlor-alkali electrolysis experience and innovated to be perfectly suited to capitalize on the increase in renewable energy. Dynamic AWE systems seamlessly integrate with renewable energy to provide a safe and low-cost pathway for scaling up hydrogen without the drawbacks of traditional AWE and PEM.

Traditional AWE was the first water electrolyzer technology to see commercialization in the 1930's. A traditional AWE system is characterized by two electrodes submerged in a liquid alkaline solution and separated by a porous diaphragm. The electrolyte is commonly potassium hydroxide (KOH) or sodium hydroxide (NaOH) with concentrations ranging from 20 – 40 wt.%.

Traditional AWE electrolyzers have been used for several decades and are generally considered mature, reliable and low cost. They also do not typically use precious metals such as platinum or iridium, which are required in PEM electrolyzers. However, traditional AWE electrolyzers still suffer from several disadvantages:

1. They exhibit low current densities (0.2 – 0.6 A/cm^2), resulting in lower productivity, or quantities of hydrogen produced per unit area. Low current densities also necessitate very large systems, increasing materials usage, real estate, and construction costs.
2. Traditional AWE electrolyzers suffer from high leakage or shunt currents from centralized manifolds with highly conductive electrolyte, which lowers their conversion efficiencies and increases operational costs. Depending on the stack size and load, shunt currents can reduce efficiencies by as much as 10 – 80% (Figure 1).[1]
3. Traditional filter-pressed, AWE electrolyzers also have limited dynamic operating range because of high gas crossovers, which limits their utilization when paired with intermittent renewable energy sources.

4. In addition, they are also susceptible to rapid degradation requiring expensive stack replacements and significant productivity losses. The inability to digitally monitor degradation on a component level leads to sporadic maintenance.

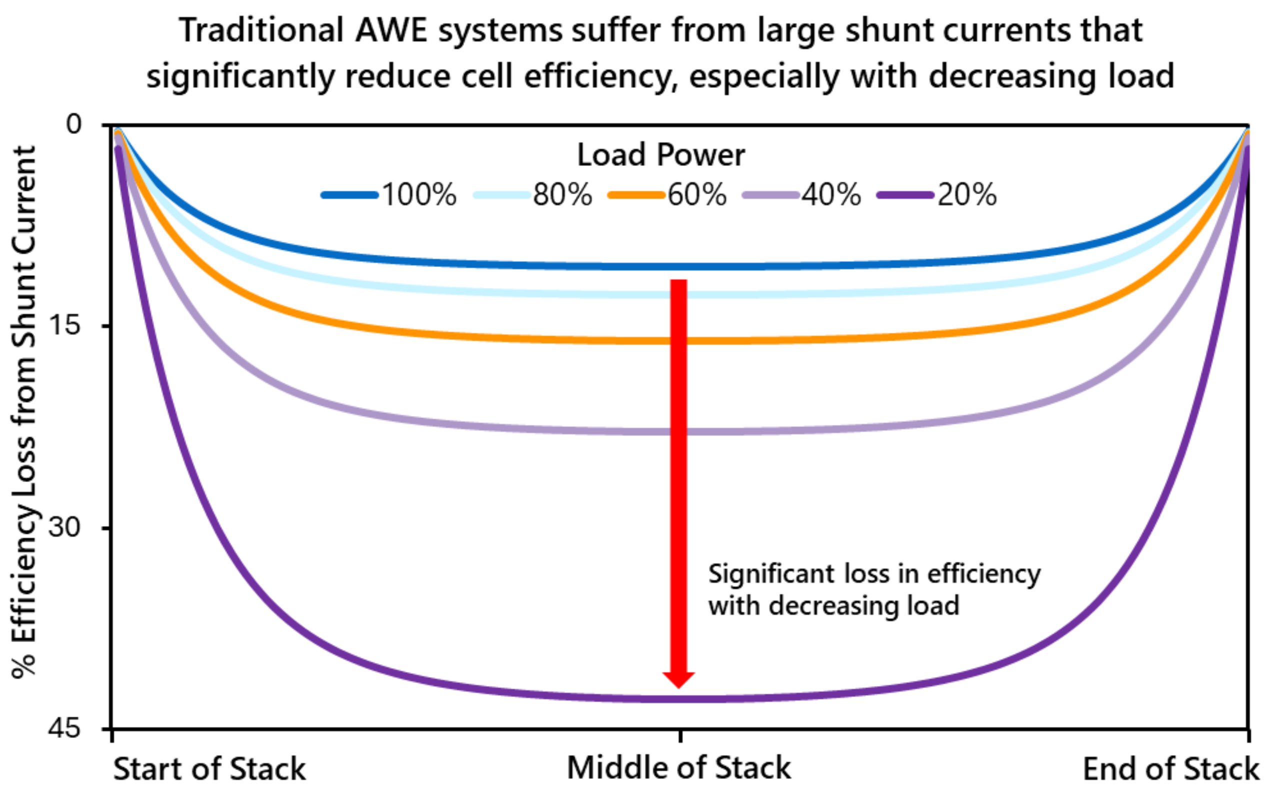


Figure 1: **The result is a limited dynamic range and increasing costs of hydrogen production**

PEM water electrolysis is an acidic system developed in the 1960's that offers dynamic and high current density operation in a compact footprint. Even after decades of innovation, the operation has largely remained the same with the acidic environment necessitating the use of precious materials, such as platinum, iridium, and ruthenium, which are often applied as catalysts to internal flow field components, such as porous transport layers (PTLs) and gas diffusion layers (GDLs). These flow field components assist with control of liquid and protons (H^+) and the improved transport within the system allow a PEM electrolyzer to be operated with a dry cathode (electrolyte only flows to the anode chamber). The dry cathode allows for easier pressurized operation along with higher current densities, greater dynamic range, and more compact footprints than traditional AWE electrolyzers.

However, PEM electrolyzers have their own set of disadvantages:

1. PEM electrolyzers typically have relatively small areas that results in significantly more cells and components needed to match the same area as dynamic AWE cells, which makes PEM substantially more expensive and uneconomical for most hydrogen electrolysis applications.

2. In addition to their initial higher costs, they also require precious metal catalysts that are expensive and scarce, increasing operational costs. Suppliers are attempting to reduce the use of platinum group metals (PGMs) by using thinner MEAs; however, this lowers system reliability and manufacturing yields.
3. PEM electrolyzers suffer from lower durability of membranes, which significantly increases operational costs and decreases availability.
4. Like filter-pressed, traditional AWE systems, PEM electrolyzers also do not have the ability to be digitally monitored at the component level. This means that degradation is not monitored or controlled at the component level and the only option to deal with significant degradation is to replace entire electrolyzer stacks, leading to significant operational expenses and lost productivity.

Dynamic AWE systems are based on a single-cell, zero-gap architecture in which individual electrolytic cells are electrically connected but chemically isolated. Dynamic AWE systems incorporate cell designs that confer several advantages:

1. Dynamic AWE systems achieve current densities **up to 400% higher** than those of traditional AWE electrolyzers. These high current densities, coupled with large cell areas, allow dynamic AWE systems to achieve very high rates of hydrogen production in compact footprints.
2. Dynamic AWE systems achieve the widest dynamic operating ranges in the industry, irrespective of technology type, to enable seamless coupling with intermittent energy sources, which leads to high utilization factors, lower hydrogen production costs, and the lowest carbon intensities. The pairing of single-cell architecture also ensures **an efficiency loss of only 0.1% – 2%** from shunt currents throughout the entire operating range (Figure 2).[1]
3. The single-cell architecture of Dynamic AWE systems **eliminates the need for stack replacements**, a significant expense inherent to PEM and traditional AWE electrolyzers (Figure 3). Equally importantly, digital monitoring of individual electrolytic cells allows for easy performance upgrades to maximize plant revenues and profitability, and proactive maintenance to maximize plant utilizations.
4. Dynamic AWE systems build on several decades of experience in the chlor-alkali industry to enable robust, **low-cost, highly reliable systems optimized for hydrogen electrolysis**. The capital expenditure or first cost of Dynamic AWE systems is significantly lower than that of PEM electrolyzers, and comparable to those of traditional AWE electrolyzers while offering higher productivity, higher electrolytic (or conversion) efficiency, field upgradable performance, and significantly smaller footprints and installation costs.

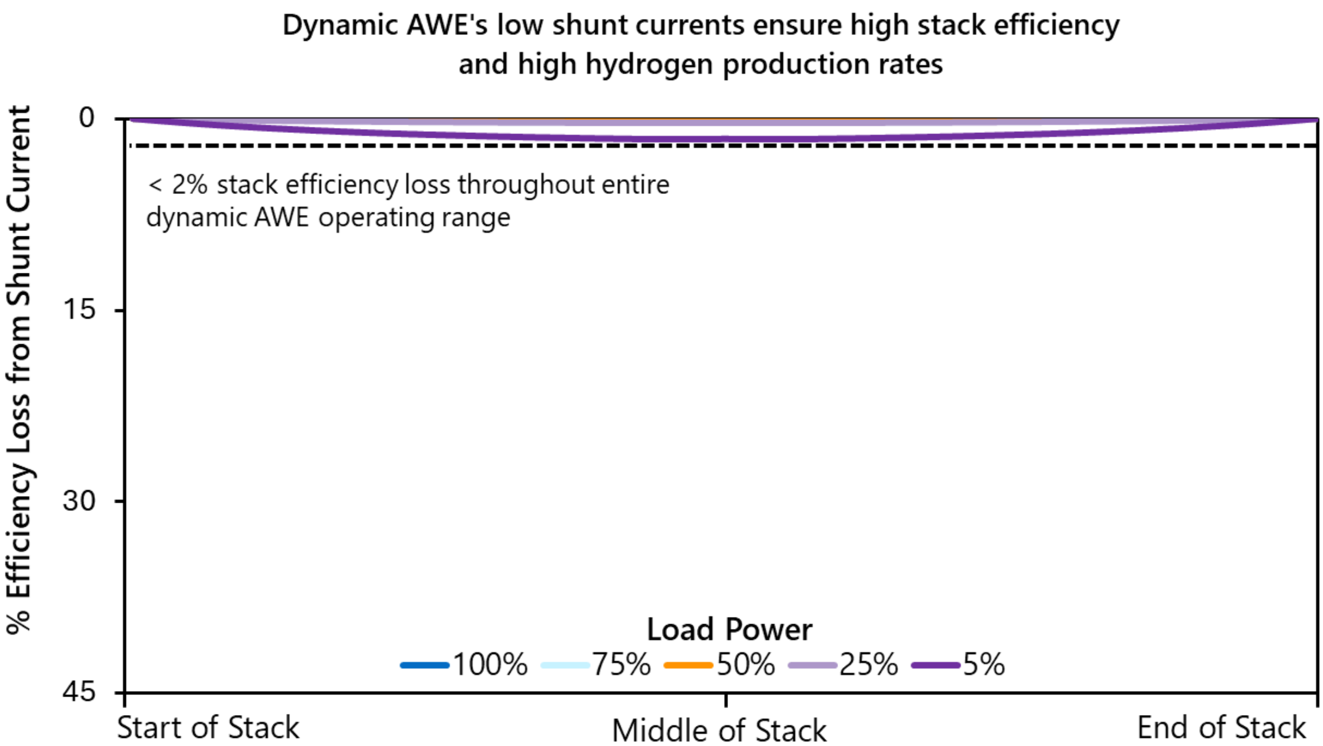
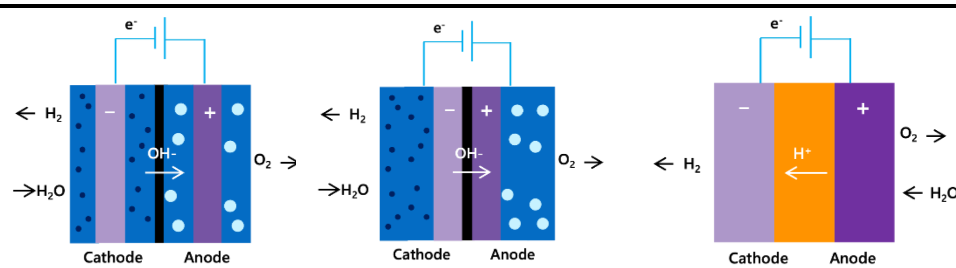


Figure 2: **Dynamic AWE systems maximize hydrogen production efficiency and lower capital energy costs as compared with traditional AWE and PEM systems.**

Comparison Chart of Low Temperature Electrolysis Technologies



		Traditional AWE	**Dynamic AWE**	PEM
System	Cell area (cm^2)	3,000 – 30,000	3,000 – 30,000	100 – 3,000
	Temperature (°C)	65 – 100	65 – 100	70 – 90
	Pressure	Atm – 30 bar	Atm – 30 bar	30 – 80 bar
	Efficiency (%HHV*)	60 – 80	70 – 95	44 – 65
	Electrolyte	20 – 40 wt.% KOH	20 – 40 wt.% KOH	PFSA^
	Supply chain maturity	Mature	Mature	Commercial

Operation	Electrode-membrane configuration	Fixed gap	Zero-gap	←	Zero-gap
	Operating conditions	Steady state	Steady state and dynamic	←	Steady state and dynamic
	Current density (A cm^{-2})	0.2 – 0.6	0.1 – 2	←	0.8 – 2.5
	Ramp time (minutes)	15 – 60	1 – 2	←	~ 1
	Serviceability	Stack replacement	During operation		Stack replacement

→Arrows in table demonstrate how Dynamic AWE can leverage system benefits of Traditional AWE with operational benefits of PEM, while also having differentiated features from either system with continued serviceability.

*HHV = higher heating value, based on 1.481 V

^PFSA = perfluoro sulfonic acid

Verdagy's Dynamic AWE

Verdagy has designed and optimized its refinery-grade, Dynamic AWE eDynamic electrolyzers for industrial scale applications in demanding applications like oil refineries, ammonia and chemical production plants, mining and steel. Verdagy's electrolyzers have the highest current densities and hydrogen production rates of any alkaline electrolyzers, provide real-time load matching to intermittent energy sources such as renewables and varying electrical grid prices in order to maximize asset utilization, completely eliminate stack replacements and dramatically reduce operating costs through the use of electrolytic cells that have lifetimes of over 20 years, and offer the lowest installation costs and commissioning times because of their modular designs.

In addition, each individual cell in Verdagy's refinery-grade electrolyzers is digitally monitored and can be **field upgraded to offer continuously improving performance** and electrical conversion efficiency. While all other hydrogen electrolyzers suffer from annual degradations in performance that leads to significant increases in annual energy expenses, Verdagy's electrolyzers are capable of providing annual performance improvements that significantly reduce annual energy costs, the single largest operating expense in a hydrogen electrolysis plant.

Verdagy's industrial-scale, refinery-grade electrolyzers thus offer the lowest levelized cost of hydrogen (LCOH), high reliability, low installation and construction costs, maximum operating flexibility, and among the smallest footprints.

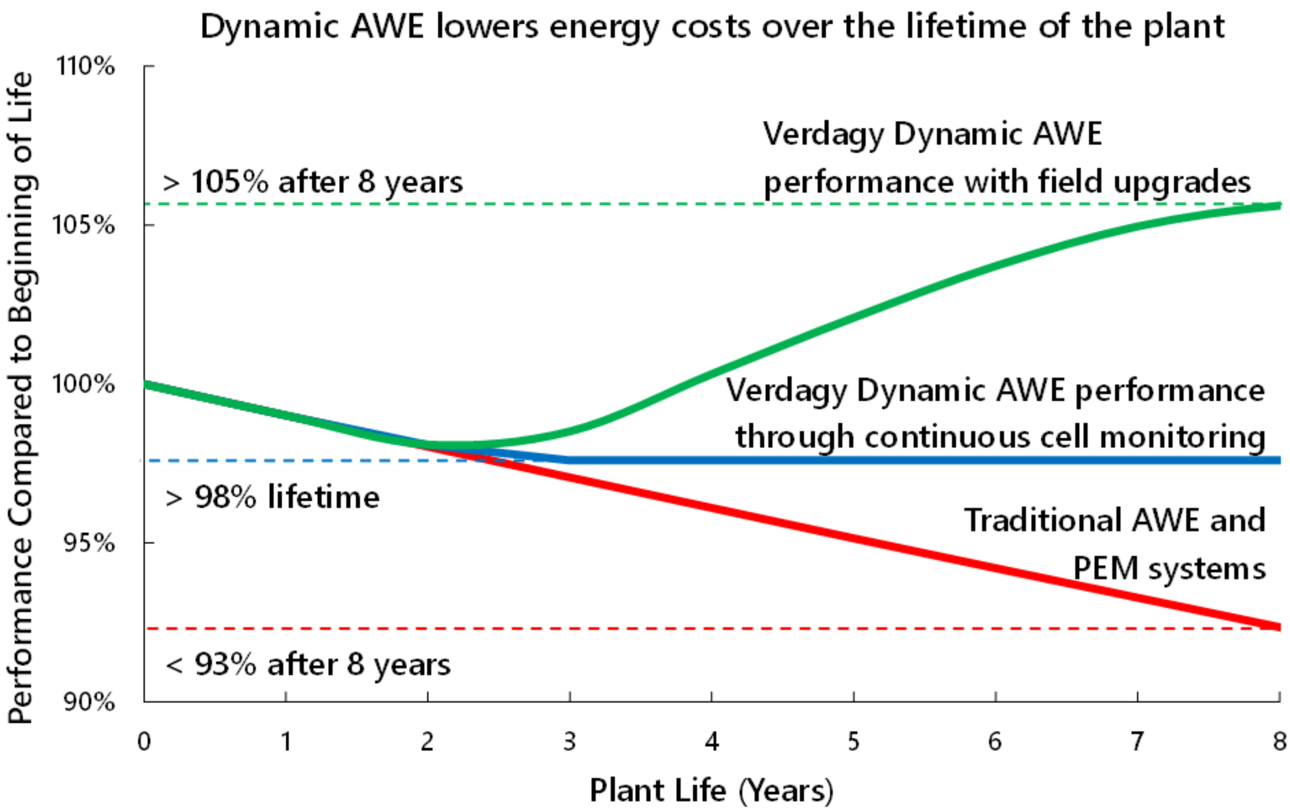


Figure 3: **Verdagy's Dynamic AWE electrolyzers provide continuous performance improvements leading to the lowest energy and operating expenses for hydrogen electrolysis plants.**

Verdagy's Dynamic AWE electrolyzers are able to provide maximum flexibility and direct coupling with renewable sources due to low gas crossover throughout the entire operating range. Traditional AWE and PEM systems suffer from unsafe amounts of gas crossover (above 2% hydrogen to oxygen (HTO)) as the load is reduced, which limits the total operating range and requires full shutdown when not enough power is available. Altering the operating conditions and components can limit the gas crossover for these systems, but at the sacrifice of efficiency. As systems move towards thinner membranes in hopes of improving cell efficiency, this only increases the amount of gas crossover. Gas recombination layers are being explored to combat unsafe amounts of gas crossover; however, this requires additional catalyst costs and reduces the amount of hydrogen produced.

In contrast, Verdady's Dynamic AWE electrolyzers can **safely operate without sacrificing efficiency or requiring additional measures.** The low gas crossover not only makes the system safe, but **lower gas crossover also increases the purity and production rates of hydrogen.**

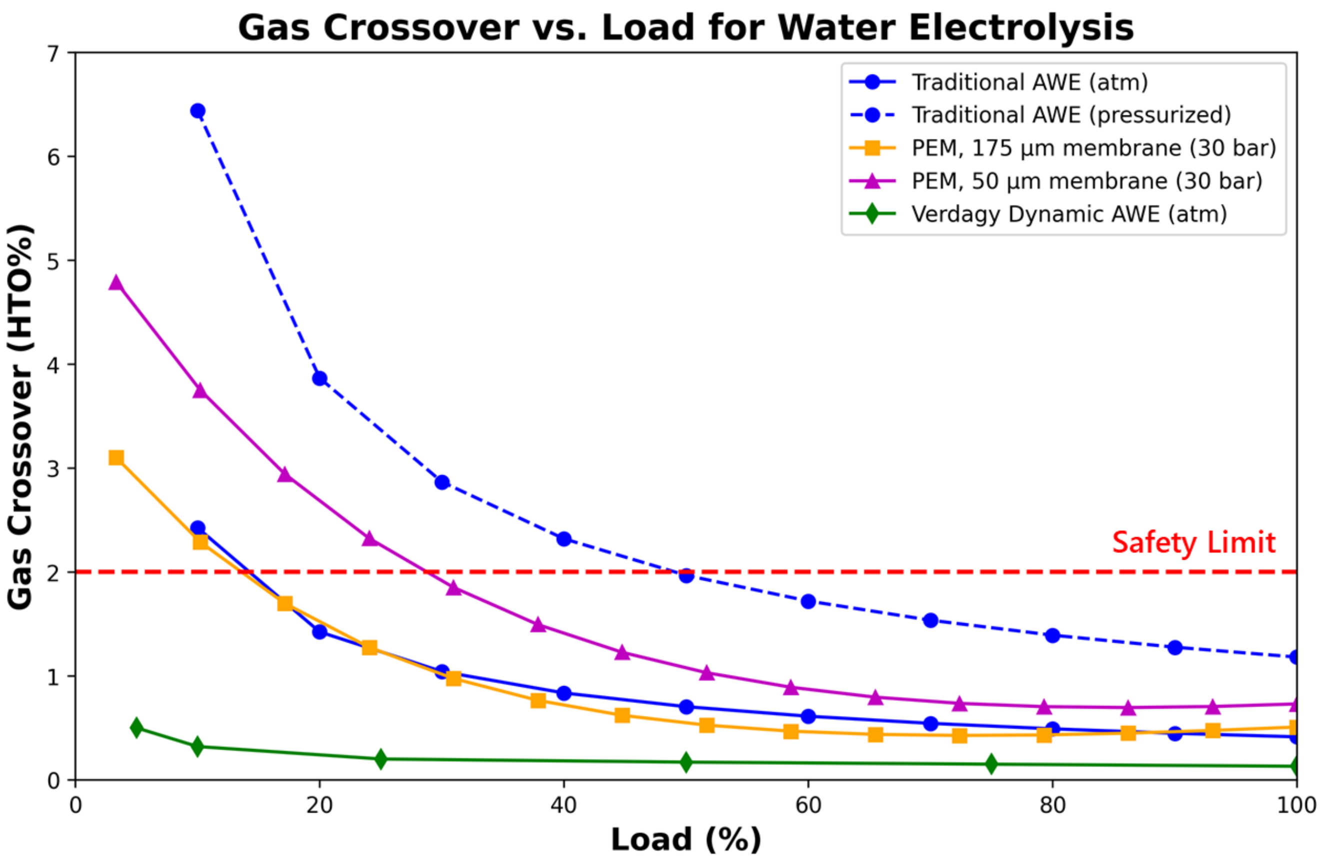


Figure 4: **Verdagy's Dynamic AWE maintains low gas crossover throughout entire load range for safe and pure production of hydrogen gas.**

In summary, Dynamic AWE electrolyzers can be characterized as combining the reliability, robustness and low-cost materials of construction of traditional AWE systems with the fast responsiveness and wider dynamic range of PEM systems, while designing out the disadvantages of both. Verdagy's Dynamic AWE electrolyzers use single-cell architecture to virtually eliminate loss of efficiency from degradation and shunt currents. In addition, Verdagy's dynamic AWE electrolyzers are also the only electrolyzers in the world today that continually improve performance after being installed, compared to all other electrolyzers that degrade each year. This combination provides customers the lowest LCOH in the world today, with the assurance that they will always have state-of-the-art performance, and the fastest path to fossil parity costs.

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References:

[1]Thomas H. McWaid, PhD, CTO, Verdagy, COMSOL Lumped Element Analysis, 2025