# Electrolyzer Evolution

## Outlook on Electrolyzer Innovation and Scaling

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Nel Hydrogen with support from
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# How Electrolyzers Work: The Science Behind Green Hydrogen

An electrolyzer splits water ($H_2O$) into its constituent elements — hydrogen ($H_2$) and oxygen ($O_2$) — using an electric current. When that current comes from renewable sources like hydro, wind, or solar, the process produces green hydrogen with near-zero carbon emissions. The hydrogen is then captured, compressed, stored, and distributed for end uses ranging from heavy-duty transport to industrial processes.

Nel manufactures two core electrolyzer technologies, both of which are central to Pacific Northwest applications:

## PEM (Proton Exchange Membrane) Electrolyzers

PEM systems use a solid polymer membrane to conduct protons. They respond to variable power inputs within seconds — making them ideal for pairing with fluctuating renewable sources like wind. PEM systems also produce hydrogen at elevated pressures (up to 30 bar in Nel's latest generation), reducing the need for costly downstream compression. Nel's North American PEM manufacturing headquarters is in Wallingford, Connecticut, which reached 500 MW annual production capacity in 2025 and can produce cells at 10 times the output of the previous facility at 30% lower cost.

## Alkaline Electrolyzers (Atmospheric and Pressurized)

Alkaline electrolysis is the world's most established hydrogen production technology. Nel's atmospheric alkaline systems have powered industrial hydrogen production for nearly a century. More importantly for the Pacific Northwest, Nel's next-generation pressurized alkaline platform — set for commercial launch in the first half of 2026 — targets a 40-60% cost reduction and 80% footprint reduction versus the current generation, opening up a dramatically wider range of deployment scenarios at the scale that PNWH2 Hub projects require.

# Electrolyzer Performance Improvements: What's Changed and Why It Matters to PNW Projects

The last five years have produced some of the most significant electrolyzer engineering advances in the technology's history. For developers, utilities, and policymakers in the Pacific Northwest planning hydrogen projects, these improvements change the investment calculus in important ways.

## Higher Current Density — More Hydrogen Per Square Meter

Nel's next-generation PEM stack design is capable of 20% higher current density compared to standard operating conditions. In plain terms: the same physical stack produces more hydrogen. For PNW project developers working within constrained site footprints — at ports, transit depots, or industrial facilities — this means more hydrogen output without proportional increases in capital cost or land use.

## High-Pressure Output — Cutting Compression Costs

Nel's latest PEM electrolyzers produce hydrogen at up to 30 bar. Compression is one of the most energy- and capital-intensive steps in the hydrogen supply chain. Producing hydrogen at high pressure directly from the electrolyzer stack significantly reduces the size and cost of downstream compression equipment — a direct operating cost benefit for hydrogen fueling stations and industrial supply systems across Washington and Oregon.

## Extended Stack Life — Bankable Long-Term Performance

Nel's current PEM systems have demonstrated operational lifespans exceeding 80,000 hours with minimal degradation. For the long-term infrastructure investments that the PNWH2 Hub represents, this level of demonstrated durability is what enables project financing. Lenders and investors need to know that the core technology will perform reliably over a 20-year asset life — and Nel's stack performance data provides that foundation.

## Dynamic Response — Matching the PNW's Variable Renewable Profile

As Eastern Washington and Oregon expand their wind generation capacity, electrolyzers that can follow variable power inputs become increasingly valuable. Nel's PEM systems can ramp from zero to full load within seconds — enabling hydrogen producers to act as a flexible load that absorbs renewable surplus, smooths grid variability, and produces low-cost hydrogen when electricity prices are at their lowest.

**Figure 1: Nel Electrolyzer Technology Comparison — Performance Parameters and Pacific Northwest Applications**

| Technology | Performance Gain (Next-Gen) | Best PNW Use Case | Nel Platform |
|---|---|---|---|
| PEM Electrolyzers | Up to 20% higher current density; up to 30 bar output pressure; 80,000+ hr stack life | Variable hydropower & wind pairing; rapid ramp response | Nel M-Series PEM (Wallingford, CT) |
| Pressurized Alkaline | 40–60% cost reduction target; 80% smaller footprint vs current gen | Large baseload industrial facilities (fertilizer, refinery, transit) | Nel Next-Gen Pressurized Alkaline (launching 2026) |
| Atmospheric Alkaline | Proven, mature; 1 GW/yr capacity online | Established industrial $H_2$ supply; large volume applications | Nel A-Series Alkaline (Herøya, NO) |

# Nel's R&D Programs: The Pipeline That Will Power PNW Hydrogen

Performance improvements at the level described above do not emerge from routine engineering iteration. They are the product of targeted, well-funded R&D programs that Nel has been executing over the past several years — programs now entering their commercialization phase at exactly the right moment for the Pacific Northwest.

## Next-Generation PEM: The General Motors Partnership

In 2022, Nel entered a joint development agreement with General Motors, bringing together Nel's electrolyzer expertise with GM's deep fuel cell manufacturing heritage. The partnership is focused on automating PEM stack production and reducing per-unit costs through advanced manufacturing techniques. The incremental results are already visible: Nel's expanded Wallingford facility, officially opened in October 2024, produces PEM stacks at 10 times the previous volume and 30% lower cost per unit. This is American-made electrolyzer technology, and it is available to Pacific Northwest projects today. At the same time, the Nel-GM team has developed a breakthrough stack design which will reduce the cost another 50% as well as increasing efficiency by over 10%. At subscale, the design meets the targets and has moved to a full scale prototype phase.

## Next-Generation Pressurized Alkaline: A Commercial Breakthrough in 2026

After more than five years of development and successful full-scale prototype testing, Nel's board granted final investment approval in December 2025 to industrialize its next-generation pressurized alkaline platform at the Herøya facility in Norway. The targets are transformative:

- 40–60% cost reduction versus the current generation
- ~80% reduction in physical footprint
- Initial annual manufacturing capacity of 1 GW, scaling to 4 GW
- Commercial launch planned for the first half of 2026

This platform has attracted up to €135 million in EU Innovation Fund support — one of the largest grants ever awarded for electrolyzer industrialization. The cost reductions achieved through this program flow directly into the economics of US projects, including those in the PNWH2 Hub pipeline.

## The DOE H2NEW Program and America's National Electrolyzer Push

Nel's R&D work is closely aligned with the U.S. Department of Energy's H2Nuc program, which brings together national laboratories including NLR (formerly NREL), PNNL (based in Richland, WA), and Argonne to advance both PEM and alkaline electrolyzer technology. The program's targets — $2/kg hydrogen by 2026 and $1/kg by 2031 under the DOE's Hydrogen Shot — directly inform Nel's commercial roadmap. Pacific Northwest National Laboratory's deep involvement in this program is a particular asset for the region's hydrogen ambitions.

Figure 3: Nel R&D Program Overview —
Key Milestones and Pacific Northwest Relevance

| Programme / Milestone | Key Details | Status / Timeline |
|---|---|---|
| Next-Gen PEM (GM Partnership) | Joint development leveraging GM fuel cell manufacturing expertise; automation focus; 10× output vs prior Wallingford factory at 30% lower cost | Active — Wallingford 500 MW facility opened Oct 2024 |
| Next-Gen Pressurized Alkaline | 40-60% cost reduction; 80% footprint reduction; 1 GW/yr initial capacity scaling to 4 GW; FID granted Dec 2025 | Commercial launch H1 2026 |
| EU Innovation Fund Grant | Up to €135M for industrialization at Herøya; supports global cost-down benefiting US projects | Awarded — execution underway |
| DOE H2Nuc Program | US national labs + industry; $2/kg by 2026 target; $1/kg by 2031 (H2 Shot); PEM & alkaline focus | Under Review — directly supports PNWH2 cost targets |

# The Science Behind the Savings: R&D in Materials, Chemistry, and System Design

The cost and performance trajectory of electrolyzers is not simply a function of manufacturing scale. It is driven by fundamental advances in the materials, electrochemistry, and system architecture that define how an electrolyzer cell actually works. This is where the most transformative — and least publicly visible — research is taking place, and it is where Nel's technical teams, in collaboration with leading national laboratories and universities, are making significant contributions.

For Pacific Northwest stakeholders, understanding this research frontier matters: it is the reason that the electrolytic hydrogen cost trajectory is genuinely downward, not merely aspirational.

## 1 I Membrane Electrode Assembly (MEA) Engineering: The Core of PEM Performance

The membrane electrode assembly is the functional heart of a PEM electrolyzer — the site where water is split, protons are conducted, and hydrogen is produced. It consists of a proton-exchange membrane (typically ~100-150 μm thick) and two catalyst layers.  Some integrated MEAs may also have one or two porous transport layers (one anode / one cathode) and/or subgaskets included in the assembly. *As a landmark 2025 review published in* Chemical Reviews noted — a paper that included direct contributions from Nel Hydrogen's Wallingford team — achieving GW-scale PEM Water Electrolysis (PEMWE )deployment requires simultaneous improvements across every MEA component: membrane selectivity, catalyst loading reduction (lower “consumption” of platinum group metals), transport layer optimization, and manufacturing scalability. This is not incremental improvement; it is system-level co-engineering.

Nel's researchers have been central to this effort. A widely cited 2023 paper in the Journal of the Electrochemical Society — co-authored by Nel's Wallingford scientists alongside colleagues at NLR and Argonne — characterized catalyst layer resistance and utilization in PEM electrolysis at low iridium loadings, providing critical insights into how voltage losses and degradation mechanisms are distributed within the anode catalyst layer. These findings directly inform how Nel designs its next-generation MEA configurations to minimize energy loss and extend stack life.

The DOE's H2NEW consortium has formalized this collaborative approach. A 2025 paper in the International Journal of Hydrogen Energy — produced by NLR, PNNL, and Lawrence Berkeley National Laboratory — harmonized a standardized PEM electrolyzer benchmarking protocol using a "Future Generation MEA" (FuGeMEA) baseline that features significantly lower catalyst loadings than commercial systems. This protocol, developed with industry input from companies including Nel, is now the shared research foundation across the US national laboratory network — enabling direct comparison of results and dramatically accelerating progress.

## 2 I Iridium Catalyst Chemistry: Addressing the Critical Materials Constraint

Iridium is the cornerstone catalyst for the oxygen evolution reaction (OER) in PEM electrolyzers — and it is one of the rarest elements on Earth. Current commercial systems require 1–3 mg of iridium per square centimeter of electrode area. At projected GW-scale deployment, this loading level would exhaust available global iridium supply. Reducing iridium loading while maintaining performance and durability is therefore *the* defining materials challenge for PEM electrolysis.

Nel's researchers have published directly on this problem. The 2023 Journal of the Electrochemical Society paper on catalyst layer resistance — co-authored by Nel Hydrogen's Wallingford team — examined how ionic and electronic resistance within low-iridium anode catalyst layers limits performance, and proposed in-situ measurement methods for characterizing these losses. Understanding where voltage is lost at low loadings is the prerequisite for designing catalyst architectures that overcome it.

Complementary research published in ACS Applied Energy Materials (2024) demonstrated a composite anode approach using a conductive additive alongside low-iridium catalyst, achieving a 95% reduction in iridium loading and 80% reduction in anode catalyst material cost while maintaining equivalent cell performance at 1.8 V. For the Pacific Northwest's large planned electrolysis projects — which will require hundreds of MW of installed PEM capacity — the ability to use dramatically less iridium per kilowatt is not a laboratory curiosity. It is the difference between a viable supply chain and a critical materials bottleneck.

The DOE's own target, as outlined in its Hydrogen Shot Water Electrolysis Technology Assessment (2024), calls for iridium loading to be reduced to 0.125 $mg/cm^2$ — roughly a 10× reduction from today's commercial levels. Achieving this requires fundamental advances in catalyst support materials, nanostructure engineering, and interface design that are currently the subject of active research across Nel's teams and the broader H2NEW consortium.

## 3 I Porous Transport Layers and Cell Architecture: Managing Flow at Scale

The porous transport layer (PTL) on the anode side of a PEM electrolyzer is a titanium structure that must simultaneously conduct electricity, allow water access to the catalyst, and permit oxygen gas to escape — all while resisting the highly acidic, oxidizing conditions at the anode. PTL design is one of the most active areas of electrolyzer materials research, and one where Nel has made documented technical contributions. A 2024 review published in ChemElectroChem noted that a recent technical report by Nel Hydrogen showed that porous transport electrodes (PTEs) — an alternative architecture where the catalyst is deposited directly onto the PTL — can better utilize low-loading catalysts, potentially reducing both iridium requirements and overall stack resistance.

This work is representative of a broader systems design philosophy: rather than optimizing individual components in isolation, the most impactful advances come from co-designing the MEA architecture so that membrane, catalyst, and transport layer work together as an integrated system. Nel's engineering teams in Wallingford have been at the forefront of applying integrated approaches to commercial-scale stack design — now reflected in the higher current densities and extended lifetimes of Nel's latest PEM products.

## 4 I Alkaline Electrolyzer Materials: Advancing Established Technology

While PEM research attracts significant attention, Nel's work on alkaline electrolyzer materials is equally consequential — particularly given the importance of the next-generation pressurized alkaline platform to large-scale PNW applications. The key materials challenges for alkaline electrolysis center on electrode catalyst activity, separator membrane performance, and electrolyte management. A 2024 paper in the International Journal of Hydrogen Energy — produced as part of the IEA's Technology Collaboration Program on Advanced Fuel Cells, with NLR participation — addressed the critical need for standardized alkaline electrolyzer testing protocols, noting that poor comparability across laboratory setups has significantly slowed research progress. Nel's engagement with international standardization efforts reflects its commitment to elevating the entire alkaline electrolyzer research ecosystem.

On the electrode side, recent research has demonstrated that multi-metal nickel-based catalyst architectures — such as Ni-Fe-Co hierarchical electrodes — can reduce operating overpotential by approximately 9% versus baseline nickel electrodes at industrial current densities, improving reaction kinetics through synergistic electronic effects between metal dopants. Nel's next-generation alkaline platform incorporates advances in electrode surface design and three-dimensional current collector geometry that reflect this research lineage.

## 5 I Multi-Scale Degradation Modeling: Understanding and Predicting Stack Aging

Durability is the other side of the performance coin. An electrolyzer that degrades rapidly requires more frequent stack replacement, raising lifecycle costs and reducing bankability. Nel's participation in the H2NEW consortium's degradation research — which includes dedicated tasks on accelerated stress test (AST) development and multi-scale degradation modeling — provides the scientific underpinning for the 80,000+ hour stack life claims that are central to Nel's commercial value proposition.

AST protocols are particularly important: they allow researchers to simulate years of electrolyzer operation in weeks of laboratory testing, by applying controlled stress cycles that accelerate the degradation mechanisms seen in the field. Developing ASTs that are both accelerated and predictive — so that laboratory aging mirrors real-world aging faithfully — is a significant scientific challenge. Nel's field data from thousands of deployed systems provides a unique empirical foundation for validating these protocols, creating a virtuous cycle between commercial deployment and research insight.

## 6 I Manufacturing Science: From Research to Gigawatt-Scale Production

Materials and chemistry advances only create value when they can be manufactured reliably at scale. This is where Nel's investment in the Wallingford facility — and the Roll-to-Roll (R2R) manufacturing consortium supported by the DOE's Bipartisan Infrastructure Law — is particularly significant. The R2R approach applies continuous, high-throughput coating processes (similar to those used in printed electronics or battery electrode manufacturing) to the fabrication of catalyst-coated membranes. As the NLR manufacturing cost analysis (2024) demonstrated, transitioning from batch spray-coating to slot-die roll-to-roll CCM production is one of the highest-impact pathways to reducing PEM electrolyzer stack costs — enabling potential manufactured cost reductions to below $450/kW at scale, compared to $890/kW at low-volume production rates. This is just one of the many component level cost reductions Nel is pursuing.

Nel's Wallingford facility has incorporated advanced automated manufacturing processes informed by this research — a direct translation of laboratory science into commercial production capacity. For Pacific Northwest project developers, this means that the cost reductions projected in DOE research reports are not hypothetical: they are being realized in the stacks that Nel is shipping today.

### Figure 4: Nel Hydrogen R&D Contributions — Materials, Chemistry, and System Design (Key Published References)

| R&D Focus Area | Key Findings / Relevance to PNW | Key Reference |
|---|---|---|
| MEA Engineering (PEM) | Nel Wallingford co-authors on landmark Chemical Reviews 2025 roadmap for GW-scale PEMWE; guides next-gen stack design | Zenyuk et al., Chem. Rev. 2025 (incl. Nel Hydrogen) |
| Iridium Catalyst Layer Resistance | In-situ methods for low-Ir anode characterization; identifies voltage loss mechanisms; enables 10× Ir loading reduction pathway | Padgett, Bender, Haug et al. (Nel), J. Electrochem. Soc. 2023 |

| R&D Focus Area | Key Findings / Relevance to PNW | Key Reference |
|---|---|---|
| Composite Low-Ir Anode | 95% Ir loading reduction; 80% anode material cost reduction; equal cell voltage performance at 1.8 V | ACS Appl. Energy Mater. 2024 (NLR/industry) |
| Porous Transport Electrode (PTE) Design | Nel technical report shows PTEs improve low-loading catalyst utilization; informs next-gen stack architecture | ChemElectroChem review, 2024 (cites Nel) |
| Alkaline Electrolyzer Standardization | IEA AFC TCP round-robin establishes reproducible alkaline testing; critical for benchmarking next-gen alkaline advances | Int. J. Hydrogen Energy 95 (2024); NLR/IEA |
| AST & Durability Modeling | DOE H2NEW multi-scale degradation models validate 80,000+ hr stack life claims; enable bankable project financing | DOE H2NEW Task 1 & 8 (2024 AMR) |
| Roll-to-Roll CCM Manufacturing | Slot-die R2R production enables <$450/kW manufactured cost target; directly reflected in Wallingford facility capabilities | NLR Manufacturing Cost Analysis, 2024 |

# What Improved Electrolyzer Technology Means for Pacific Northwest Stakeholders

The R&D programs and performance improvements described above are not abstract technology milestones. They translate into concrete benefits for every stakeholder in the Pacific Northwest hydrogen ecosystem.

## For Hydrogen Producers and Project Developers

Lower-cost, higher-performance electrolyzers directly reduce the levelized cost of hydrogen (LCOH) — the key metric that determines project viability. Nel's next-gen pressurised alkaline platform's 40–60% cost target, combined with the 45V credit and the region's low electricity costs, creates a pathway to hydrogen production economics that can compete with conventional alternatives in key applications.  The next-gen PEM platform, which would follow commercially 2-3 years later, will provide even lower CAPEX and OPEX.

## For Utilities and Grid Operators

Large-scale electrolyzers are a flexible, dispatchable load — they can absorb excess renewable generation during periods of low demand and curtailment. For Bonneville Power Administration and Pacific Northwest utilities managing an increasingly variable generation mix, electrolyzer fleets represent a new tool for grid balancing, energy storage, and long-duration energy arbitrage.

## For Heavy Transport and Freight Operators

The PNWH2 Hub specifically targets heavy-duty transportation as a priority end-use sector. Hydrogen fuel cell trucks offer competitive range and rapid refueling for freight operations — and the electrolyzer cost reductions underway will directly reduce the cost of the fuel these trucks run on. Oregon and Washington's freight corridors along I-5, I-82, and US-97 are natural candidates for the region's first hydrogen truck fueling network.

### For Tribal Nations and Rural Communities

The PNWH2 Hub has placed tribal relations, labor, and community benefits at the center of its mission. Renewable hydrogen projects sited in partnership with tribal nations — particularly in central Washington and eastern Oregon — can create lasting economic development, clean energy sovereignty, and high-quality jobs in communities historically dependent on resource extraction industries.

## Conclusion: The Electrolyzer as the Pacific Northwest's Clean Energy Engine

The Pacific Northwest has everything it needs to become the leading renewable hydrogen region in the United States: world-class renewable resources, strong state policy frameworks, a network of committed industry and tribal partners, federal hub funding, and a rapidly maturing electrolyzer technology base.

Nel's role in that story is to keep pushing the electrolyzer performance frontier — delivering systems that are more efficient, more durable, lower-cost, and better matched to the region's unique renewable energy profile. From the PEM production line in Wallingford to the next-generation pressurized alkaline platform launching in 2026 and game-changing PEM innovation to follow, our R&D investments are timed precisely for the Pacific Northwest's build-out moment.

The Renewable Hydrogen Alliance has been the connective tissue of this regional ecosystem since before hydrogen was fashionable. We are proud to be part of that community — and committed to contributing the technology breakthroughs that will make the Pacific Northwest a model for renewable hydrogen development worldwide.

*Explore Nel's electrolyzer portfolio and contact our US team at nelhydrogen.com →*

#### About Nel Hydrogen

Nel Hydrogen is the world's leading dedicated electrolyzer company, with more than 3,800 systems delivered across 80+ countries since 1927. Nel manufactures PEM and alkaline electrolyzers for industrial, transport, and Power-to-X applications at its US facility in Wallingford, Connecticut, and its Herøya, Norway plant. Nel is listed on the Oslo Stock Exchange (ticker: NEL).

#### About the Renewable Hydrogen Alliance (RHA)

The Renewable Hydrogen Alliance is the Pacific Northwest's leading renewable hydrogen advocacy and industry organization, hosting the annual Northwest Renewable Hydrogen Conference and serving as a key partner of the PNWH2 Hub. Learn more at renewableh2.org.

# References & Further Reading


Renewable Hydrogen Alliance — renewableh2.org

PNWH2 Hub Overview — Pacific Northwest Hydrogen Association

DOE: Pacific Northwest Hydrogen Hub (PNWH2)

Nel's Expanded PEM Facility in Wallingford Officially Opened (Oct 2024)

Nel Secures up to €135M EU Innovation Fund Grant (Offshore Energy)

Pacific Northwest Hub Is Essential to Driving a Hydrogen Future — Rep. Dan Newhouse

PNWH2 Newsletter: March 2025 (45V Letter, Strategic Priorities)

DOE H2NEW Programme — NREL

Another Hydrogen Developer Exits PNW Regional Project (Washington State Standard, Sep 2025)

2026 Northwest Renewable Hydrogen Conference — Wenatchee, WA (June 16-18)


# Technical Papers & R&D References


Zenyuk et al. (incl. Nel Hydrogen, Wallingford): PEM Water Electrolysis Cell-Level Considerations for GW-Scale Deployment - Chemical Reviews 2025

Padgett, Bender, Haug, Lewinski (Nel Hydrogen) et al.: Catalyst Layer Resistance and Utilization in PEM Electrolysis - J. Electrochem. Soc. 170, 084512 (2023)

Parimuha et al. (NREL/PNNL/LBNL, H2NEW): Harmonized PEM Electrolyzer Benchmarking Protocol and FuGeMEA - Int. J. Hydrogen Energy 114 (2025)

NREL: Composite Anode for PEM Water Electrolyzers - 95% Ir Loading Reduction - ACS Applied Energy Materials 2024

NREL/Colorado School of Mines: Characterization of Porous Transport Layers (cites Nel PTE technical report) - ChemElectroChem 2024

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DOE Hydrogen Shot: Water Electrolysis Technology Assessment - Iridium Loading Targets and RD&D Pathways (2024)

NREL: Manufacturing Cost Analysis for PEM Electrolyzer Stacks - Roll-to-Roll and Economies of Scale (2024)

DOE H2NEW 2024 Annual Merit Review - Task 1: Durability and AST Development

DOE H2NEW 2024 Annual Merit Review - Task 8: Multi-Scale Degradation Modeling