The Next Wave of Hydrogen Tech

A note about this e-book

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This e-book is an abridged version of our popular webinar “The Next Wave of Hydrogen Tech.”

For the full webinar, which provides more research and context, please visit our website here.

The Next Wave of Hydrogen Tech

Hydrogen's future depends on cutting costs through next-generation technologies that reduce or eliminate electricity dependence.

PRODUCT DESIGN & INNOVATION

Shift innovation toward low-cost hydrogen production by prioritizing Gen-2 and -3 technologies over traditional electrolysis.

SUPPLY CHAIN & OPERATIONS

Align operations with local energy realities, leveraging industrial byproducts, heat, and infrastructure to reduce hydrogen production costs.

BRAND

Position your brand as a forward-looking leader by investing early in breakthrough hydrogen technologies and credible decarbonization pathways.

GROWTH POTENTIAL

Unlock mass adoption by achieving less than USD 3/kg hydrogen, enabling scalable growth across industrial decarbonization and global energy markets.

Key takeaways

01

Deploy traditional electrolysis only for near-term projects.

Even though traditional electrolyzers exhibit poor performance, they are the only options for near-term commercial projects. Due to high production costs, governments will heavily support deployments.

02

Consider decoupled electrolysis and thermochemical water splitting for pilots.

Gen-2 and -3 technologies will play a key role in reducing the long-term levelized cost of hydrogen (LCOH) production, while microbial electrolysis and photolysis are not ready for engagement.

03

Grow corporate activity in the next-gen technology landscape.

Only startups currently pursue next-generation technology development, so scaling these technologies will require collaboration between industrial hydrogen consumers and technology developers.

THE SHIFT FROM AMBITION TO REALITY

Executive summary

***Key takeaway:** Cost, not ambition, is the primary barrier to scaling hydrogen today.*

Hydrogen is central to global decarbonization strategies, but progress is falling short of expectations — nowhere is this clearer than in the EU.

At the heart of the challenge is cost. Today's hydrogen production heavily depends on electricity, which drives most production expenses.

Rather than relying solely on traditional electrolysis, the industry is moving toward next-generation technologies that reduce or eliminate electricity use.

Three generations of innovation are emerging:

- **First:** Dominate today but remain costly
- **Second:** Improve efficiency and reduce electricity demand
- **Third:** Eliminate electricity dependency entirely

The future of hydrogen will depend not only on policy, but also on technologies that can deliver it affordably at scale.

GENERATION 1

Today’s baseline

***Key takeaway:** Gen-1 technologies are viable today but cannot meet future cost targets.*

First-generation hydrogen technologies, including alkaline and proton-exchange membrane electrolysis, form the backbone of current hydrogen production. These systems rely entirely on electricity to split water into hydrogen and oxygen.

Even with efficiency improvements, such as Thyssenkrupp’s zero-gap alkaline design, costs remain high due to electricity dependence.

Advanced systems can achieve efficiencies above 80%, but even in favorable conditions, hydrogen production costs exceed EUR 5/kg.

Despite these drawbacks, Gen-1 technologies will dominate deployment through 2030. They are the only mature solutions capable of supporting large-scale projects in the near term.

However, their role is transitional. Governments must provide subsidies and financial support to make projects viable, and long-term reliance on these systems is unlikely.

Gen 1

Only electricity for water splitting

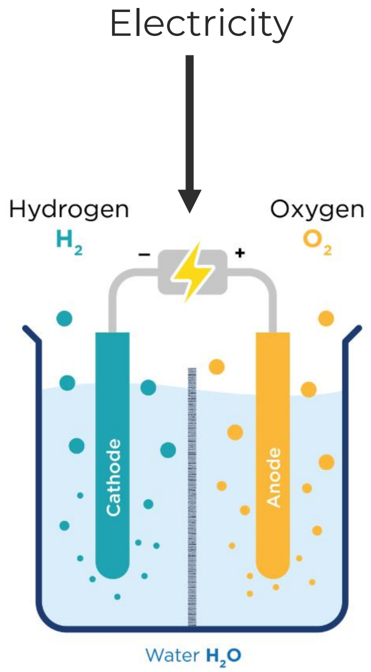


Image source: De Nora

CASE STUDY 1

Thyssenkrupp: Zero-gap configuration

Thyssenkrupp’s technology is an alkaline electrolyzer with a zero-gap configuration. There is virtually no gap between the membrane and electrodes, resulting in a claimed efficiency of more than 82% [higher heating value (HHV): 4.3 kWh/Nm^3 H_2].

The core IP centers on a plastic spacer fabric coated with a metallic layer or integrated with woven metal wires to maintain elasticity and electrical contact.

Lux Take

Zero-gap configuration is a significant advance to the efficiency of traditional alkaline electrolysis that typically exhibits 50%–60% efficiency. Thyssenkrupp is a key player in the space with proven technology that is ready for commercial deployment.

thyssenkrupp

Image source: Thyssenkrupp

GENERATION 2

Reducing electricity dependence

***Key takeaway:** Gen-2 technologies lower costs by partially replacing electricity.*

Second-generation hydrogen technologies aim to reduce electricity consumption by integrating alternative energy inputs such as heat, chemical reactions, or biological processes.

One leading example is decoupled electrolysis, where hydrogen and oxygen production occur in separate steps.

These systems can reduce electricity consumption significantly, bringing hydrogen costs down modestly compared to Gen 1.

Other approaches include:

- Metal oxide cycles
- Biomass-based electrochemical processes
- Microbial electrolysis (though still limited by scalability)

While promising, many Gen-2 technologies remain at pilot stage. Researchers must still address challenges around scale, reliability, and system complexity.

Gen 2

Partially replacing electricity with other energy sources

Electricity + Heat
Microbes
Metal oxides

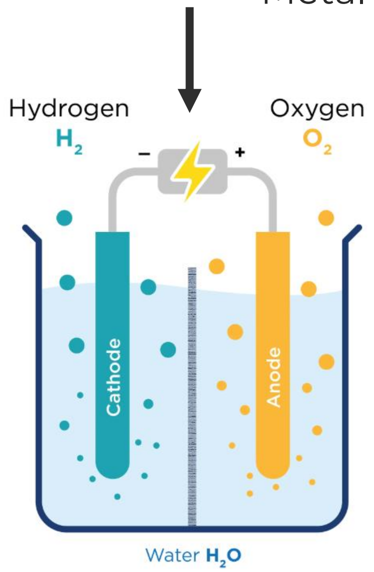


Image source: De Nora

CASE STUDY 2

H_2Pro: E-TAC-decoupled electrolysis

H_2Pro's technology centers on an electrochemically and thermally activated (E-TAC) anode that absorbs OH– during hydrogen evolution at 25 °C. During discharge, the system cuts power, and the E-TAC anode releases oxygen at 95 °C.

The company claims a maximum electricity consumption of 44 kWh/kg of hydrogen (~90% HHV) for E-TAC. There is no membrane or precious metals in the stack.

Lux Take

H_2Pro is currently scaling the first-generation system to pilot scale; the second generation, which will incorporate E-TAC, can lead to much lower LCOH compared to conventional electrolysis.

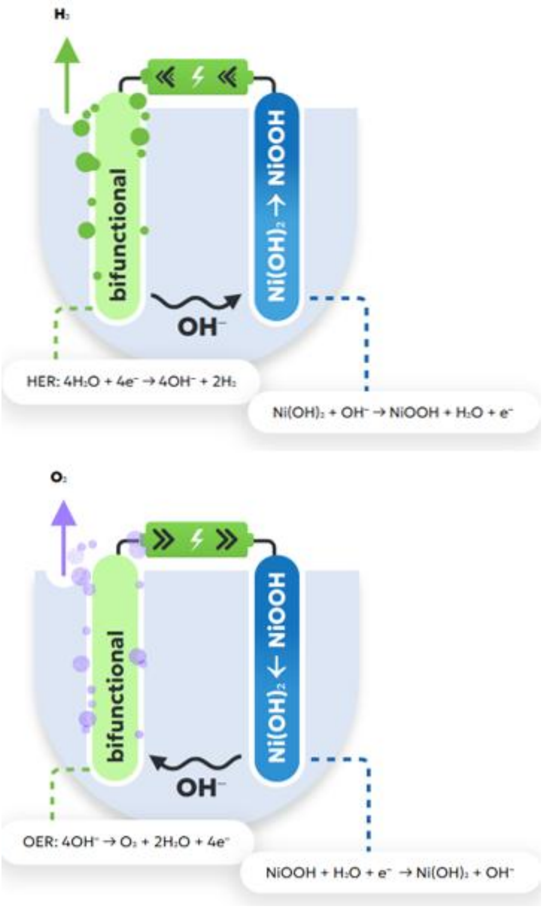


Image source: H_2PRO

GENERATION 3

Hydrogen without electricity

***Key Takeaway:** Gen-3 technologies unlock the cost reductions needed for adoption.*

Third-generation hydrogen technologies represent the biggest shift: eliminating the need for electricity in water splitting.

These systems rely on alternative energy sources like:

- Thermal energy
- Industrial offgases
- Solar-driven reactions

For example, thermochemical systems can use heat and industrial gases to drive hydrogen production, removing electricity as the primary cost driver.

This shift has a dramatic impact on economics. Hydrogen costs can drop to around EUR 2.66/kg — nearly half that of first-generation systems.

However, these technologies are still emerging, and challenges remain around integration, scalability, and application fit.

Gen 3

Eliminating electricity fully thanks to other energy sources

Heat
Solar energy

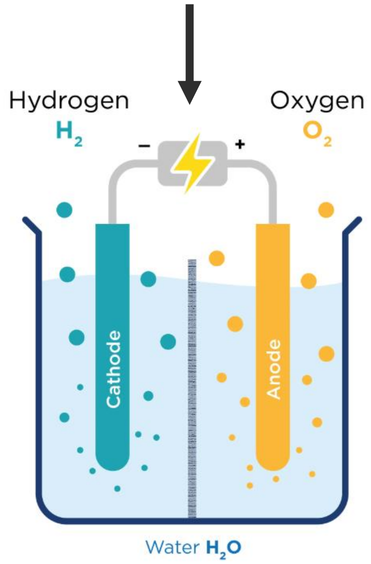


Image source: De Nora

CASE STUDY 3

Utility: Electricity-free water splitting

Utility's proprietary, tubular, solid-oxide cells leverage the electrochemical reaction between steam and offgasses at the cathode and anode, respectively. Steam and industrial offgasses at 600 °C react with water to produce H_2 and CO_2.

Utility completed piloting the H_2 generator that was directly coupled to a steel blast furnace in Ontario, Canada. The reactor ran for 3,000 h and produced 10 kg H_2/d.

Lux Take

Although the company must pair this approach with carbon capture to achieve full decarbonization, the technology offers a viable retrofit solution for hard-to-abate sectors because it requires no electricity and produces a highly concentrated CO_2 stream that costs less to capture than emissions directly from the facility.

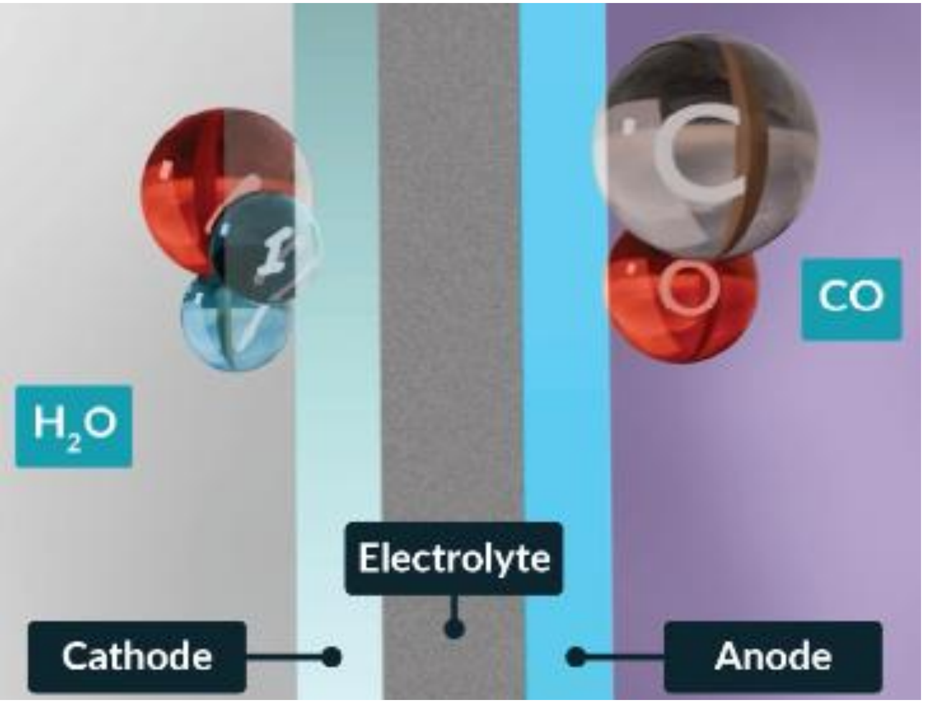


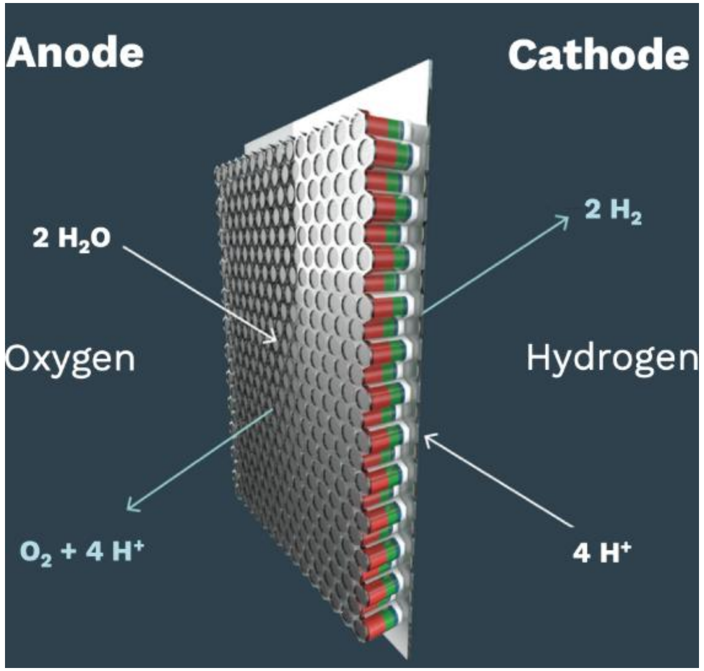
Image source: Utility

CASE STUDY 4

SunHydrogen: Photocatalytic water splitting

SunHydrogen develops photoelectrosynthetically active heterostructures (PAHs) that are composed of multiple layers of oxidation and reduction electrocatalysts. The company assembles PAHs in larger panels.

It tested a 100-cm^2 panel at Honda's R&D facility in Japan, demonstrating 10.8% solar-to-hydrogen (STH) efficiency, while the most recently built 1,200 cm^2 panel showed 9% STH efficiency.



Lux Take:

While SunHydrogen claimed 3× higher STH than the market range in 2021, it has not yet proven this claim as STH went down as the company scaled up. While this is an inherent challenge of photocatalysis, the company must attain higher STH for commercialization.

Image source: SunHydrogen

Path to cost parity

***Key Takeaway:** Hydrogen must fall below USD 3/kg to compete.*

For hydrogen to scale across industries, it must compete with existing fossil-based alternatives.

Across key applications, the breakeven price for green hydrogen ranges from USD 2–USD 3/kg.

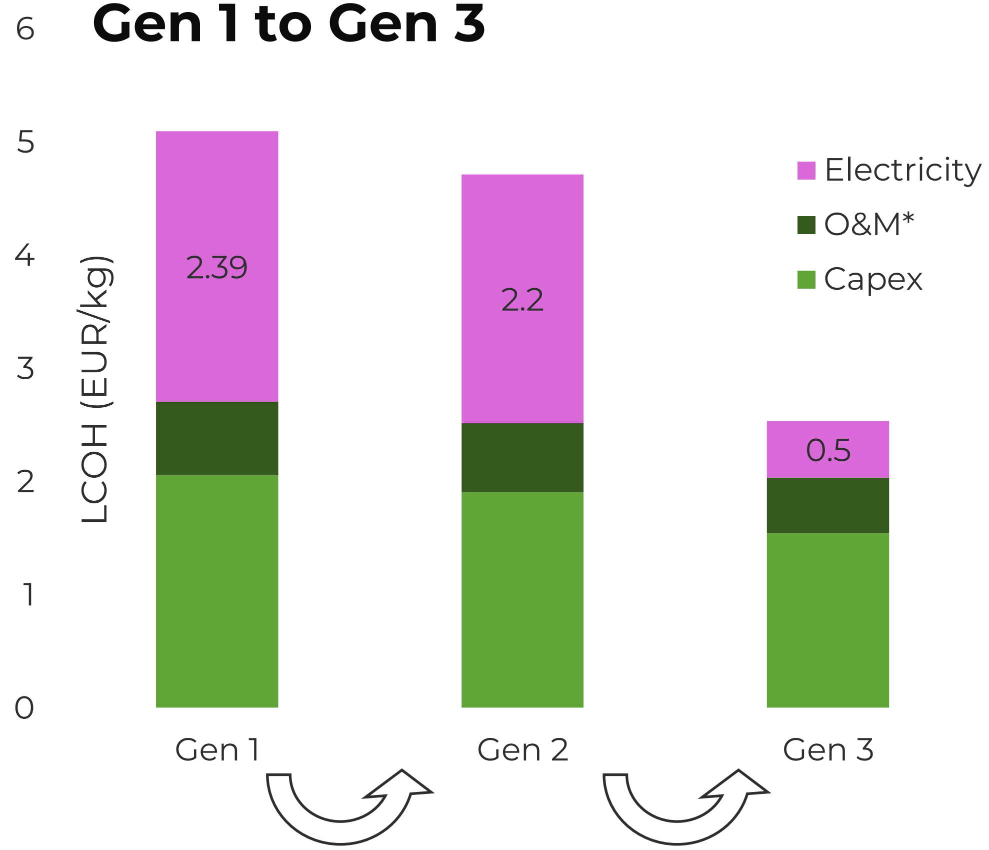
At current costs, most hydrogen technologies fall short of this threshold:

- Gen 1: Too expensive
- Gen 2: Incremental improvements
- Gen 3: Approaching viability

This analysis explains why next-generation technologies are critical. Without them, hydrogen will remain limited to niche or subsidized applications.

It also highlights the importance of targeting the right use-cases. Not all sectors will adopt hydrogen at the same pace — willingness to pay varies significantly by application and region.

79% of Electricity Saved from Gen 1 to Gen 3



8% reduction in the cost of electricity

71% reduction in the cost of electricity

*O&M, operations & maintenance

PRIORITIES FOR ADOPTION

Where hydrogen wins first

***Key Takeaway:** Industry, not mobility, will drive early hydrogen demand.*

Hydrogen's role in the energy transition varies by application, but industrial use-cases are the most critical in the near term.

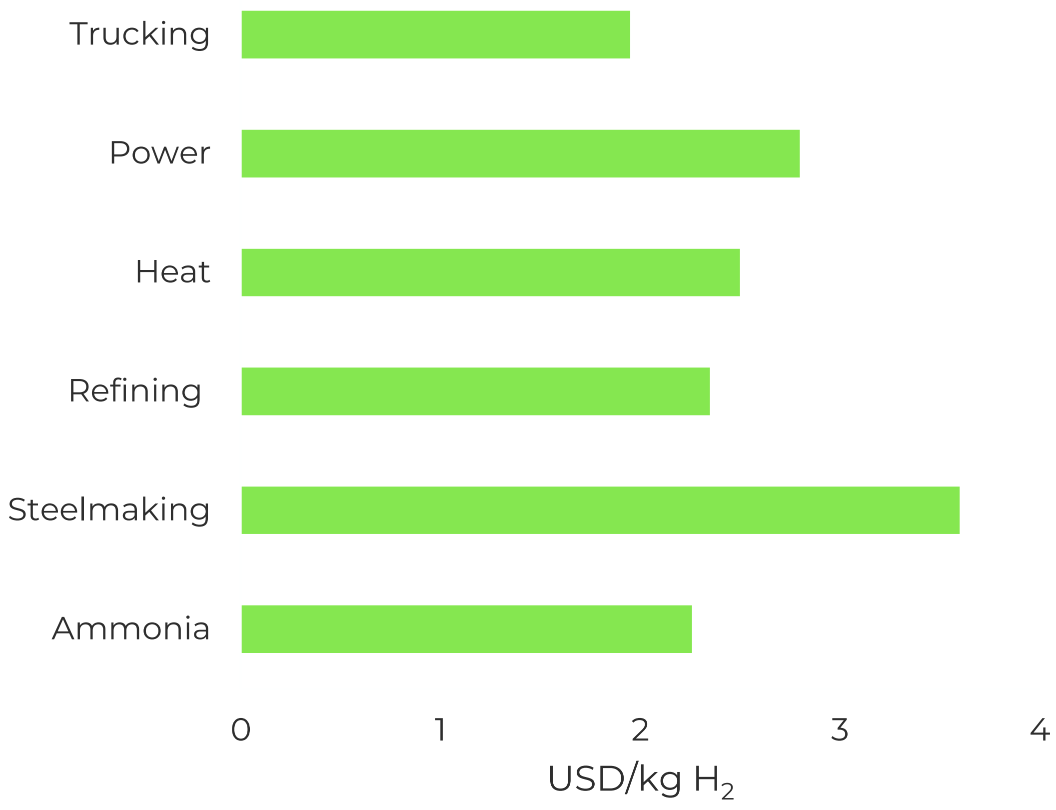
The EU, for example, prioritizes replacing grey hydrogen in industrial processes, with mandates targeting significant adoption by 2030.

Key sectors include:

- Chemicals and refining
- Steel production
- Heavy industry

These applications have both high emissions and few viable alternatives. In contrast, sectors like mobility face stronger competition from electrification and other technologies.

Breakeven Hydrogen Production Cost for Cost Parity with the Fossil Incumbent



What comes next

Key Takeaway: *Organizations must act now to stay ahead of the transition.*

The hydrogen industry is entering a pivotal phase. While first-generation technologies will dominate near-term deployment, the long-term future belongs to next-generation systems.

Organizations should take a balanced approach:

- Deploy existing technologies where viable
- Pilot emerging solutions to prepare for future scale
- Monitor early stage technologies like photolysis before investing

Not all innovations are ready. Some, like microbial electrolysis and photolysis, face significant technical barriers and require further development.

No single breakthrough will define the future of hydrogen; instead, a portfolio of evolving technologies will shape its development.

Those that understand this transition — and act accordingly — will be best positioned to lead in the hydrogen economy.

About Lux

Lux Research fuels innovators to not only imagine what's possible in the future but also operationalize innovation success in the near term. We deliver research and advisory services to inspire, illuminate, and ignite innovative thinking that reshapes and grows businesses. Using quality data derived from primary research, fact-based analysis, and opinions that challenge traditional thinking, our experts focus on finding truly disruptive innovations that are also realistic and make good business sense.

The "Lux Take" is trusted by innovation leaders around the world, many of whom seek our advice directly before placing a bet on a startup or partner — our clients rely on Lux insights to make decisions that generate fantastic business outcomes. We pride ourselves on taking a rigorous, scientific approach to avoid the hype and generate unique perspectives and insights that innovation leaders can't live without.

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