

Electrolyser innovations to reduce levelised cost of hydrogen (LCoH)

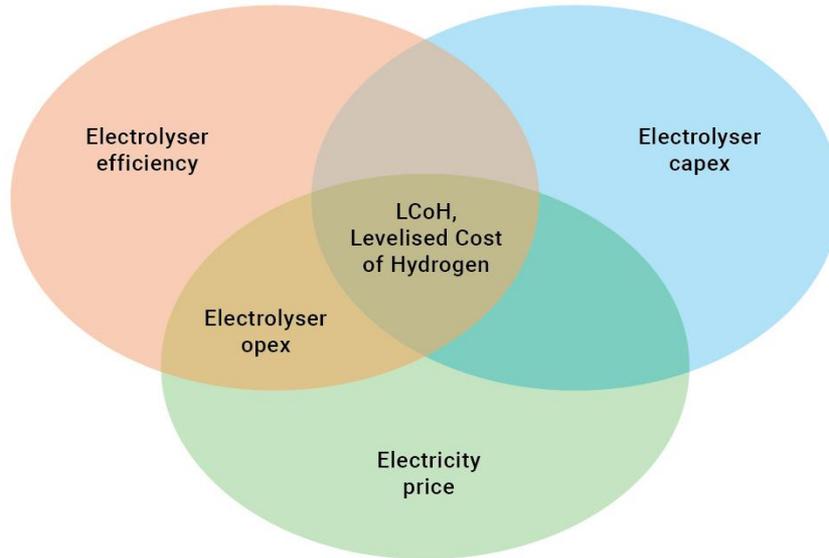
Hydrogen Value Chain Technology Webinar

Stephen B. Harrison, Managing Director, sbh4 consulting

5th March 2026

1) Intentionally intermittent electrolyser operation cuts electricity costs and reduces LCoH

The three main factors that govern the cost of electrolytic hydrogen

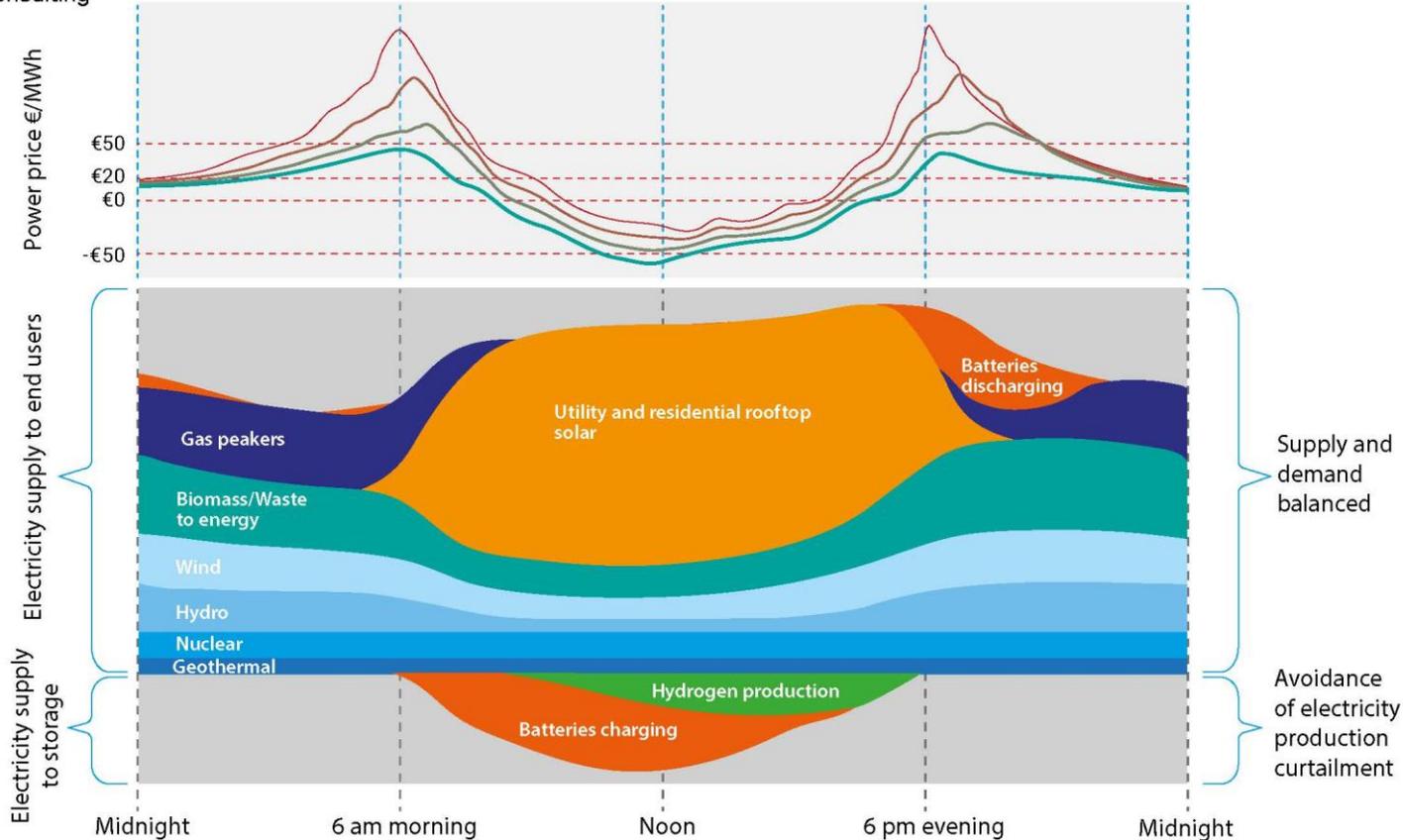


Over a 20-year operating period, the cost of electricity will dominate the cost of electrolytic hydrogen.

Notes

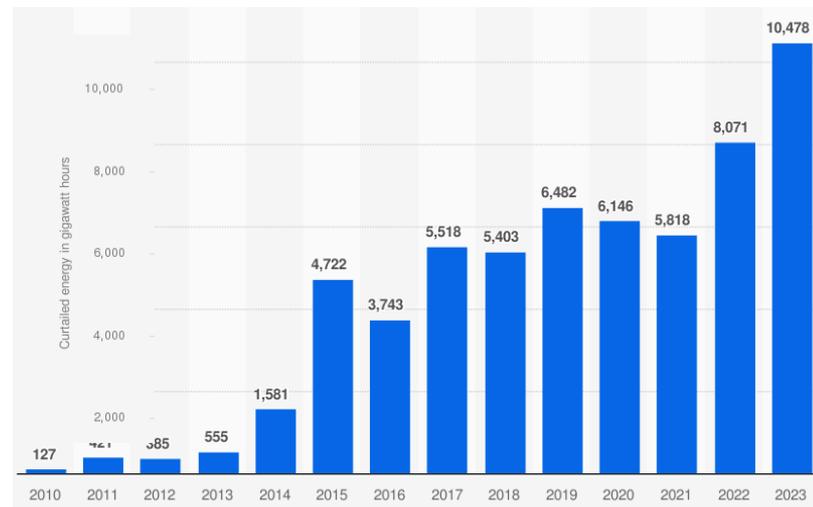
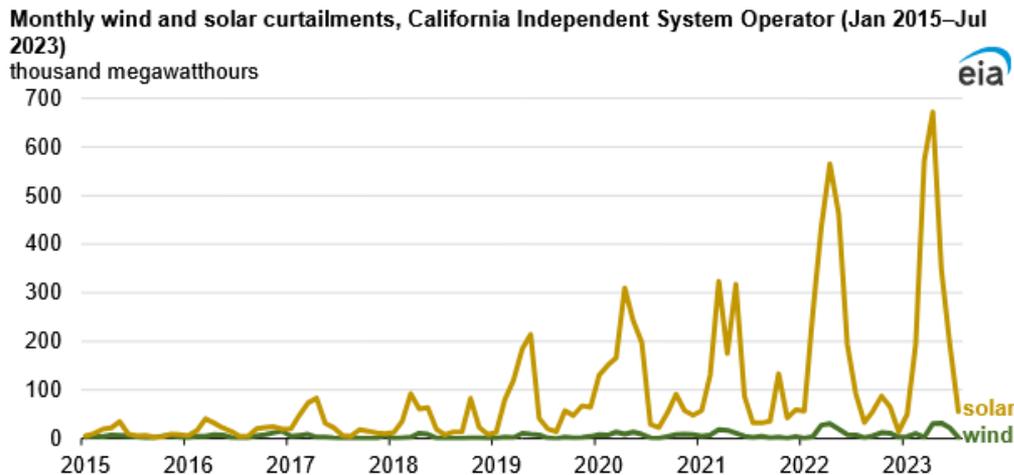
- Electrolyser efficiency: conversion of power to hydrogen (kWh/kg H₂)
- Electricity price: cost to purchase a unit of electricity (€/kWh)
- Electrolyser opex: incremental cash cost of hydrogen production (€/kg H₂)
- Electrolyser capex: the initial capital investment in the electrolyser system (€)
- Levelised Cost of Hydrogen (LCoH): the unit cost of hydrogen levelized over the operating period considering capital cost, depreciation over the operating period (eg 20 years) at the project capital depreciation rate (eg 8%), and the operating cost (€/kg H₂)
- Other operating costs such as labour and maintenance are incurred, but these are secondary to the cost of electricity

Curtailed power for low-cost hydrogen



“Intentionally intermittent” electrolyser operation can exploit periods of negative and zero-priced electricity.

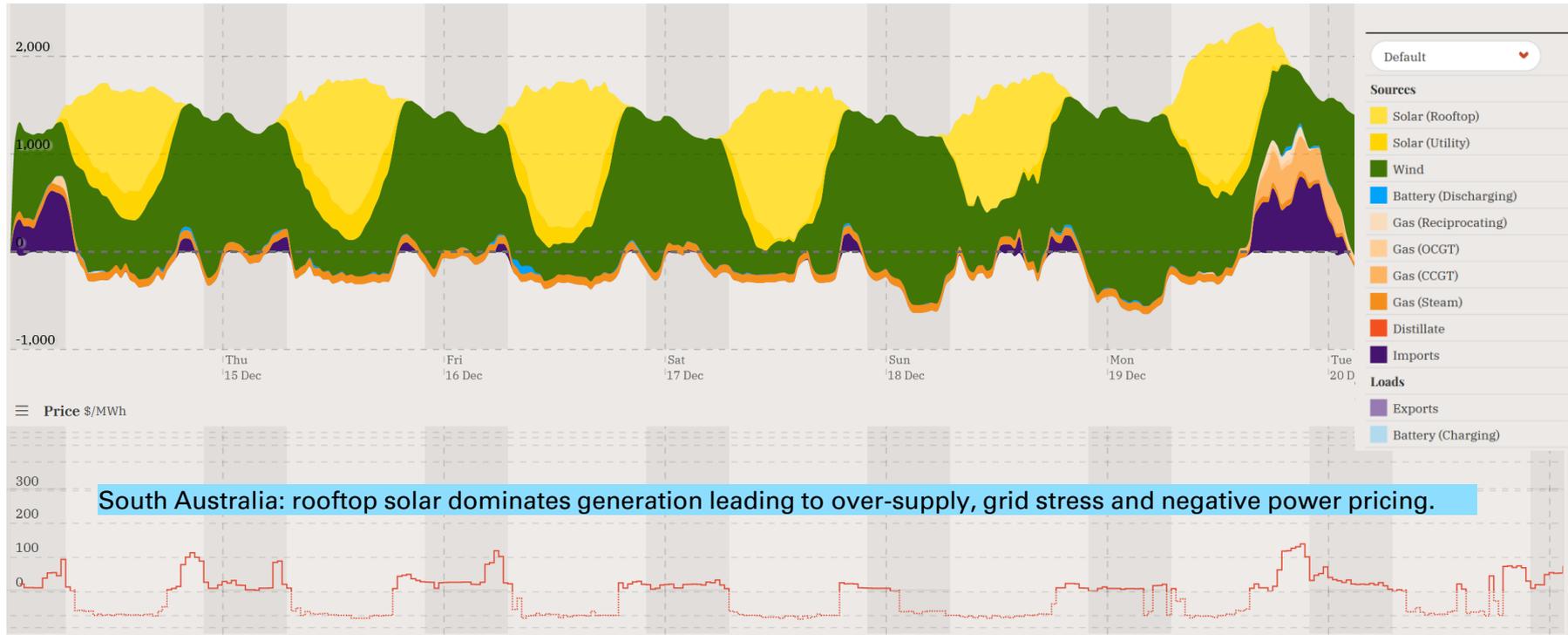
The amount and duration of Wind and solar renewable power curtailment in California, Germany and many other locations is increasing annually.



<https://www.eia.gov/todayinenergy/detail.php?id=60822>

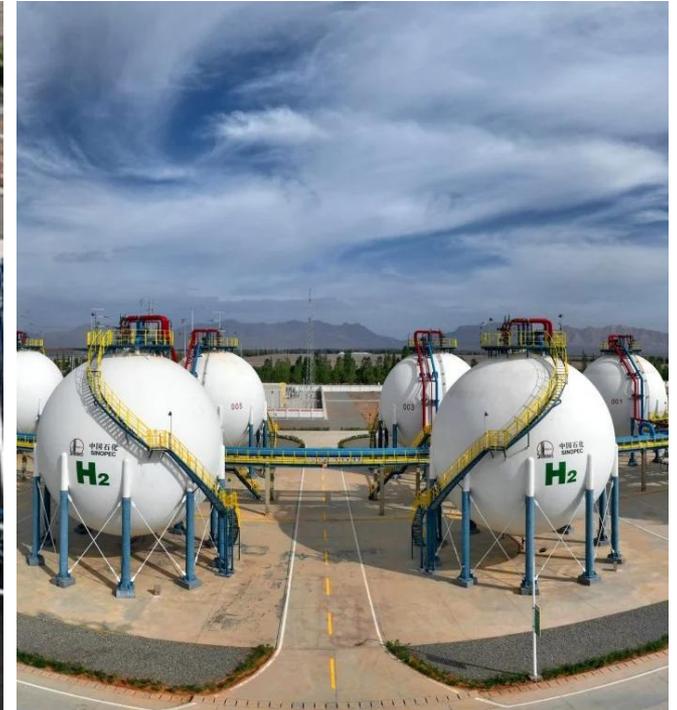
<https://www.statista.com/statistics/1332954/renewable-energy-power-curtailment-germany/>

We can see the “renewables penetration end-game” when we examine data from South Australia, where negatively priced power exists for around 10 hours per day during periods of solar power curtailment.



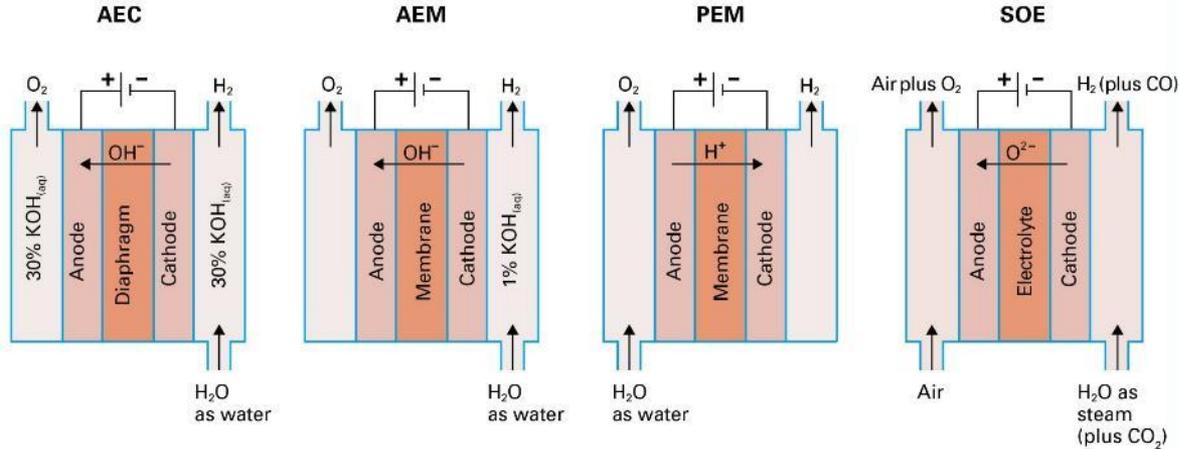
2) Electrolyser technology selection for intentionally intermittent operation

Cockerill Jingli (120MW), Longi (80MW) and Peric (60MW) pressurised alkaline electrolyzers at Sinopec's Kuqa project could only turn down of circa 50% of name plate capacity. Hydrogen cross over into the oxygen, due to inherent design attributes of pressurised alkaline electrolyzers, was the root cause.



Notes:

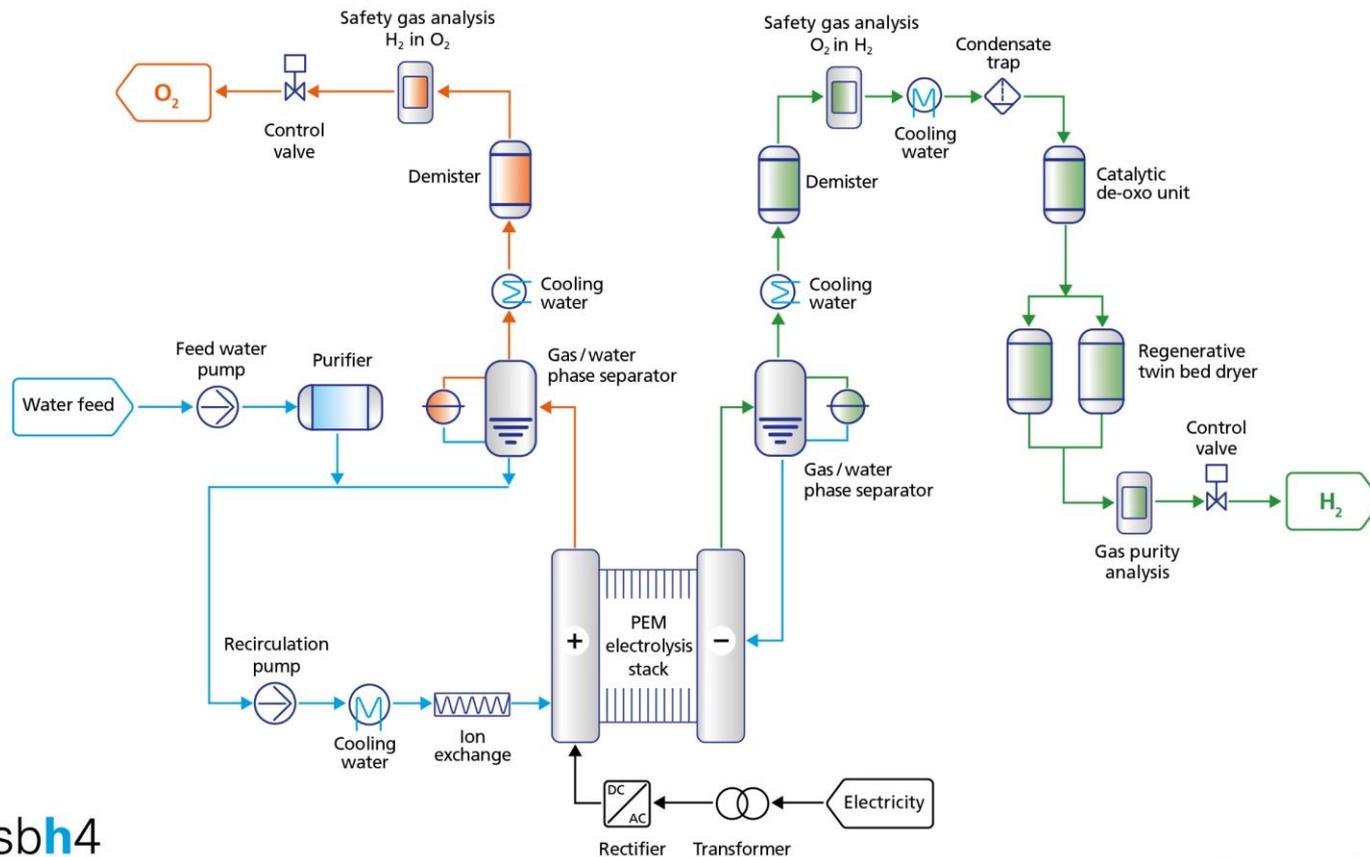
- In the AEC, AEM and PEM, lye or water flow from the electrolyser cell with the oxygen and/or hydrogen gases. These liquids are mixed and recirculated to the electrolyser.
- Air is used to purge the SOE anode to avoid oxygen accumulation which may present a hazard at the high operating temperature.
- Bipolar plates made of stainless steel (titanium for PEM) are used to stack adjacent cells in each electrolyser type.



	Alkaline Electrolysis Cell AEC	Anion Exchange Membrane / Alkaline Electrolyte Membrane AEM	Polymer Electrolyte Membrane/ Proton Exchange Membrane PEM/PEMEC	Solid Oxide Electrolysis Cell SOE/SOEC
Electrode material	- Cathode: Ni, Co or Fe - Anode: Ni	- Cathode: Ni / Ni alloys - Anode: Fe, Ni, Co oxides	- Cathode: Pt/Pd - Anode: IrO ₂ /RuO ₂	- Cathode: Ni - Anode: La/Sr/MnO (LSM) or La/Sr/Co/FeO (LSCF)
Electrolyte	Lye: 25-30% Potassium Hydroxide solution in water	Anion Exchange ionomer (e.g. AS-4)	Fluoropolymer ionomer (eg Nafion, a DuPont brand)	Zirconium Oxide with ~8% Yttrium Oxide
Energy source	100% electrical power	100% electrical power	100% electrical power	~25% heat from steam, ~75% electrical power
Current density	Up to 0.5 A/cm ²	0.2 – 1 A/cm ²	Up to 3 A/cm ²	Up to 0.5 A/cm ²
Hydrogen or syngas product	Hydrogen	Hydrogen	Hydrogen	Hydrogen (or syngas if fed with steam and CO ₂)
Gas outlet pressure	Up to 40 bar	Up to 35 bar H ₂ , 1 bar O ₂	Up to 40 bar	Close to atmospheric
Cell temperature	~80 °C	~60 °C	~60 °C	~750 to 850 °C

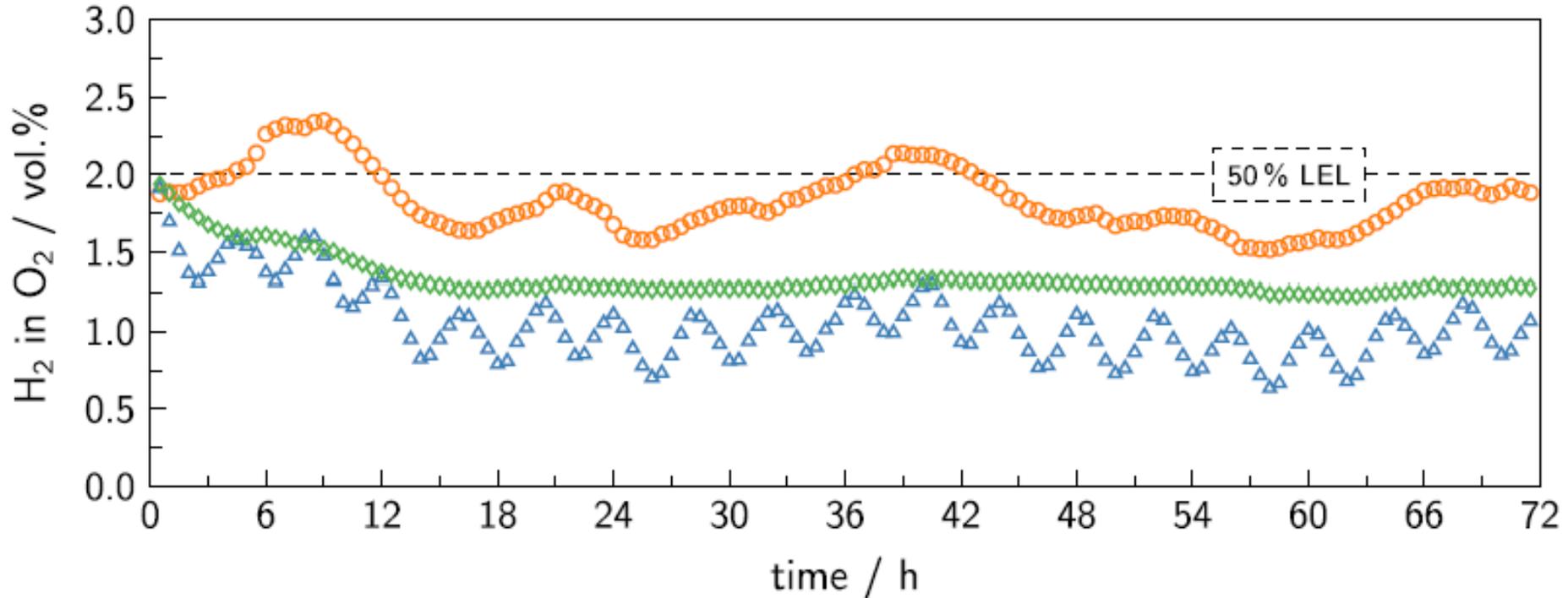
- When opportunistic negatively priced electricity is used for hydrogen production, the electrolyser must be able to ramp quickly, operate safely at turndown and tolerate long idle periods without stack degradation.
- PEM electrolyzers have traditionally been the default choice for direct coupling to renewables and intentionally intermittent operation.

Pressurised PEM electrolysis process

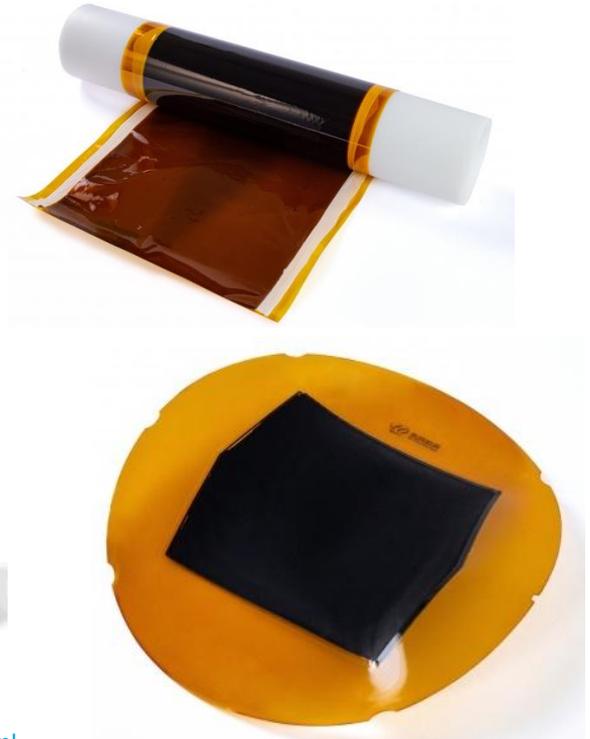
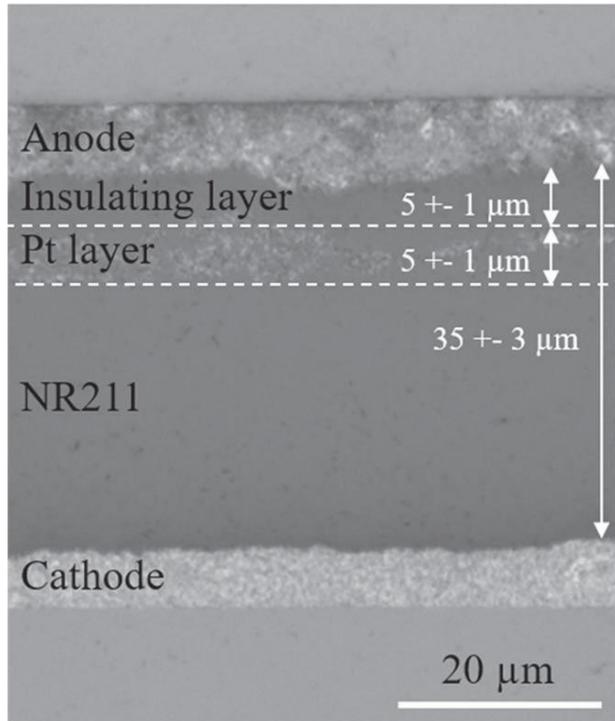


Continuous analysis of hydrogen in the oxygen is essential for safe process control.

For safety management and electrolyser process control, a measurement range of 0 to 5% may be suitable. The maximum safe H₂ in O₂ concentration is generally considered to be 2% (50% of the LEL).



A platinum-based catalyst recombination layer is commonly used in the MEA in the PEM stack. The recombination layer converts hydrogen and oxygen at the anode to water to reduce the risk of an explosive gas mixture being formed. This recombination layer is not currently integrated into alkaline electrolyser diaphragms.



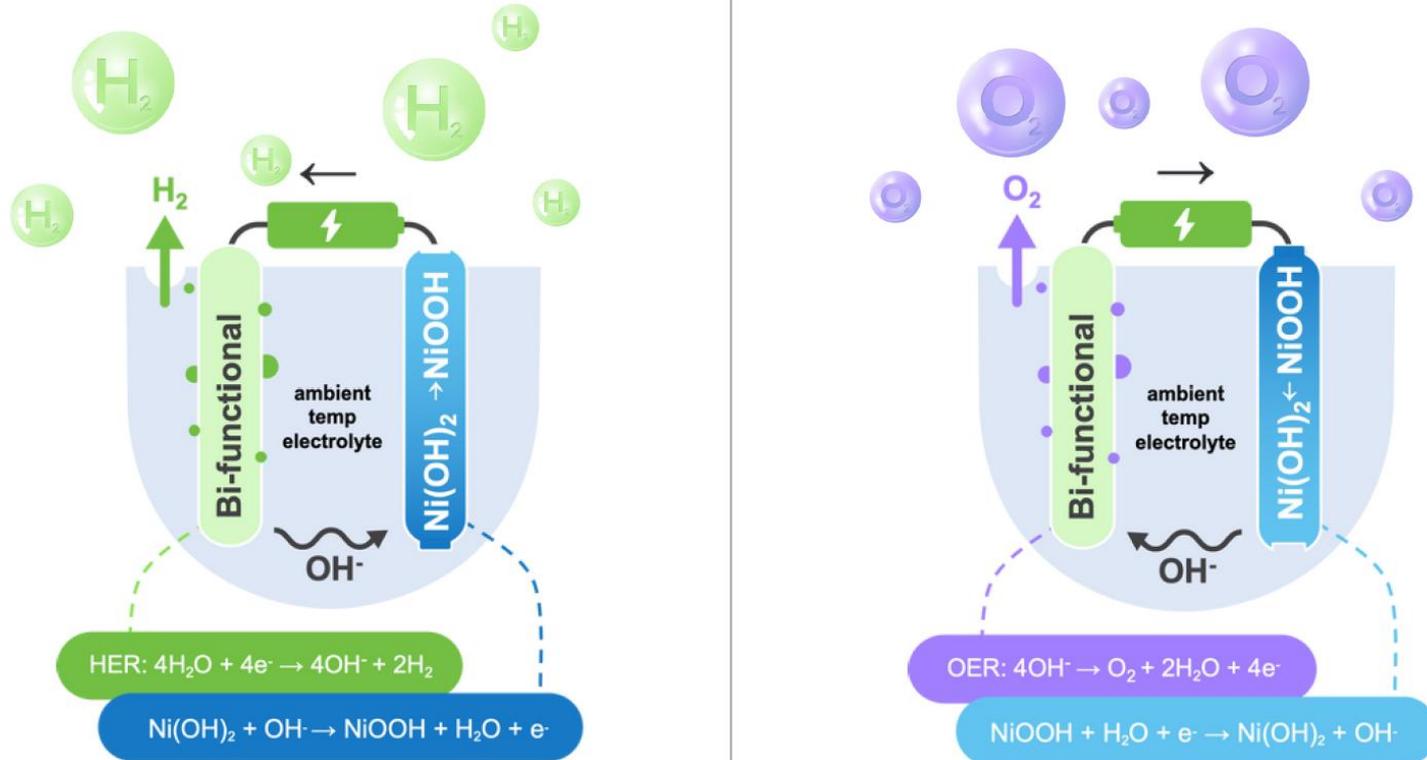
<http://www.brihynergy.com/en/Content/2190700.html>

<https://chinahydrogen.substack.com/p/brihynergy-inaugurated-1gw-pem-electrolyser>

<https://iopscience.iop.org/article/10.1149/1945-7111/ac5c9b/pdf>

3) Decoupled water electrolyser (DWE) technologies are formidable challengers to PEM for direct connection to renewables

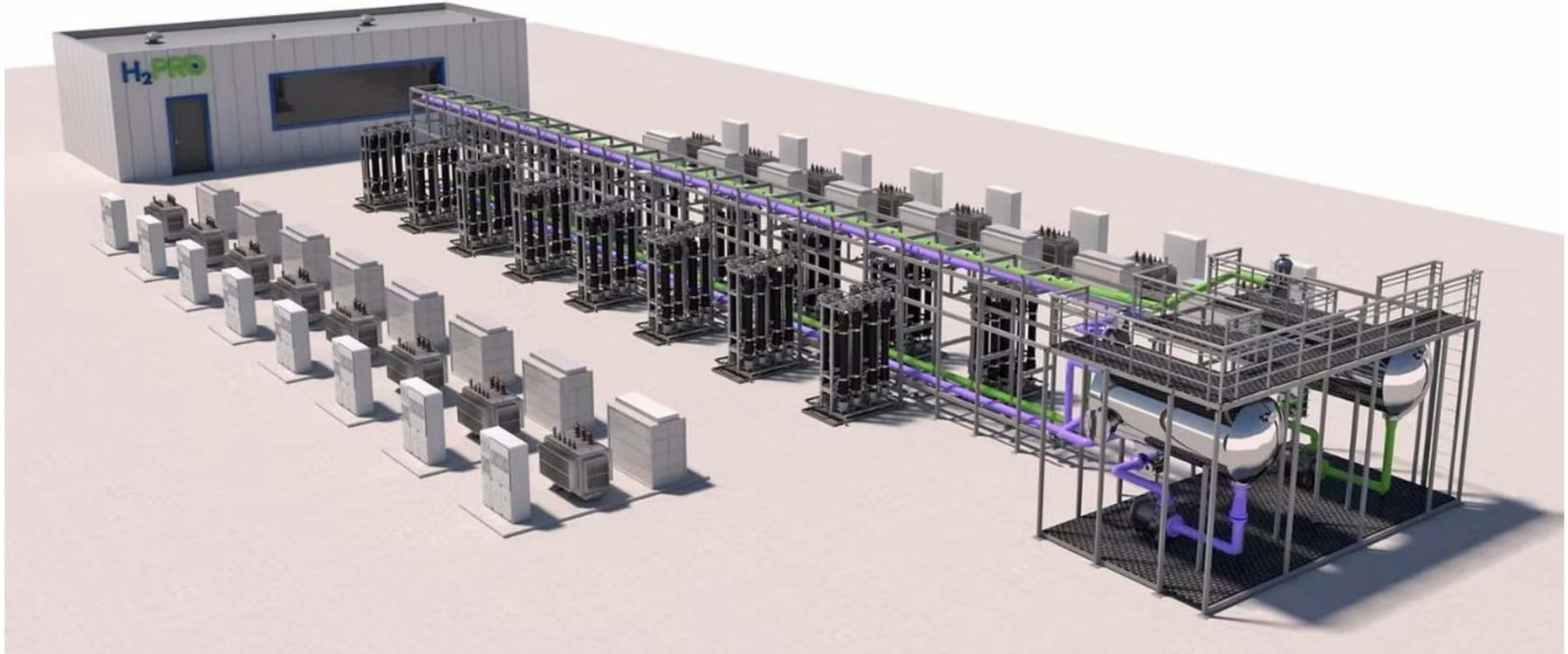
DWE operates by switching between hydrogen and oxygen evolution at the same electrode. The switching means that the system can shut down at any switch. The electrodes are built to cope with intermittent operation.



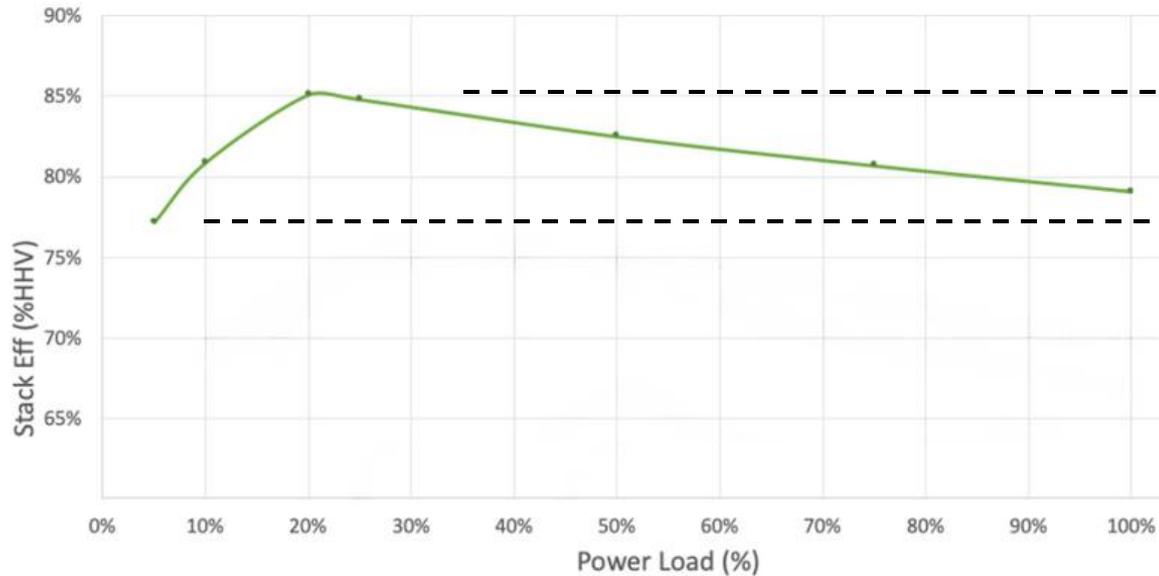
In DWE, the electrodes are built to cope with intermittent operation. H2Pro DWE electrodes operate in an alkaline medium. The electrodes are manufactured and assembled in-house, using proprietary technology.



H2Pro DWE electrodes are assembled into cell packs, and multiple packs are integrated with common balance of plant to ensure low-capex scaling to Multi-MW scale.

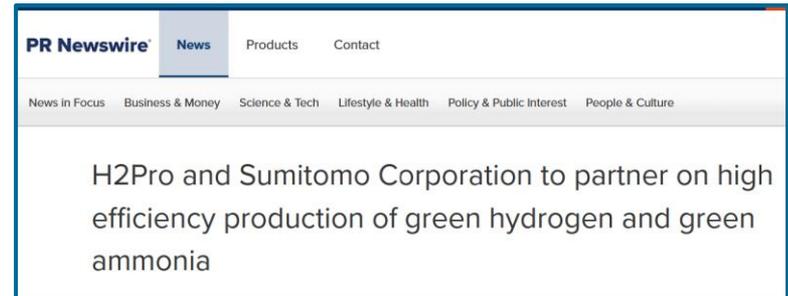
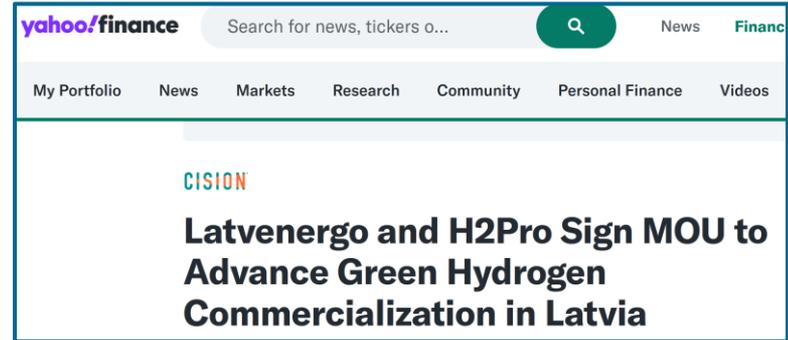


Safety and durability are not the only considerations when operating in a “hyper-flexible” mode through a variable load range... electrolyser efficiency matters also. A flat curve with a high efficiency is ideal.



H2Pro DWE efficiency within the load range of 5 to 100% is both high (up to 85%), and consistent (>76%).

Demonstration and early commercialisation of the H2Pro DWE system is in progress. Ready for Multi-MW projects later this decade.

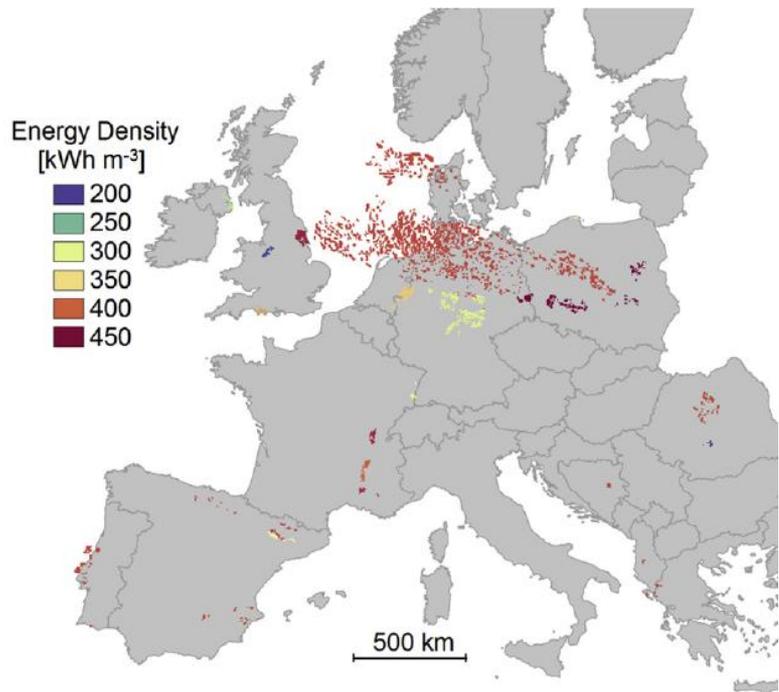


4) Intermittent electrolyser operation needs buffer storage to match variable hydrogen generation with continuous demand

Offtakers in industries such as ammonia production, refineries and iron / steel making need continuous hydrogen supply. There must be a large hydrogen storage buffer to balance intermittent production with continuous offtake.



There is potential for high-capacity underground hydrogen storage (UHS) in salt caverns in some parts of Europe.



	Gaseous state		
	Salt caverns	Depleted gas fields	Rock caverns
Main usage (volume and cycling)	Large volumes, months-weeks	Large volumes, seasonal	Medium volumes, months-weeks
Benchmark LCOS (\$/kg) ¹	\$0.23	\$1.90	\$0.71
Possible future LCOS ¹	\$0.11	\$1.07	\$0.23
Geographical availability	Limited	Limited	Limited

UHS projects are proceeding in many European locations and often re-purpose natural gas UGS infrastructure.



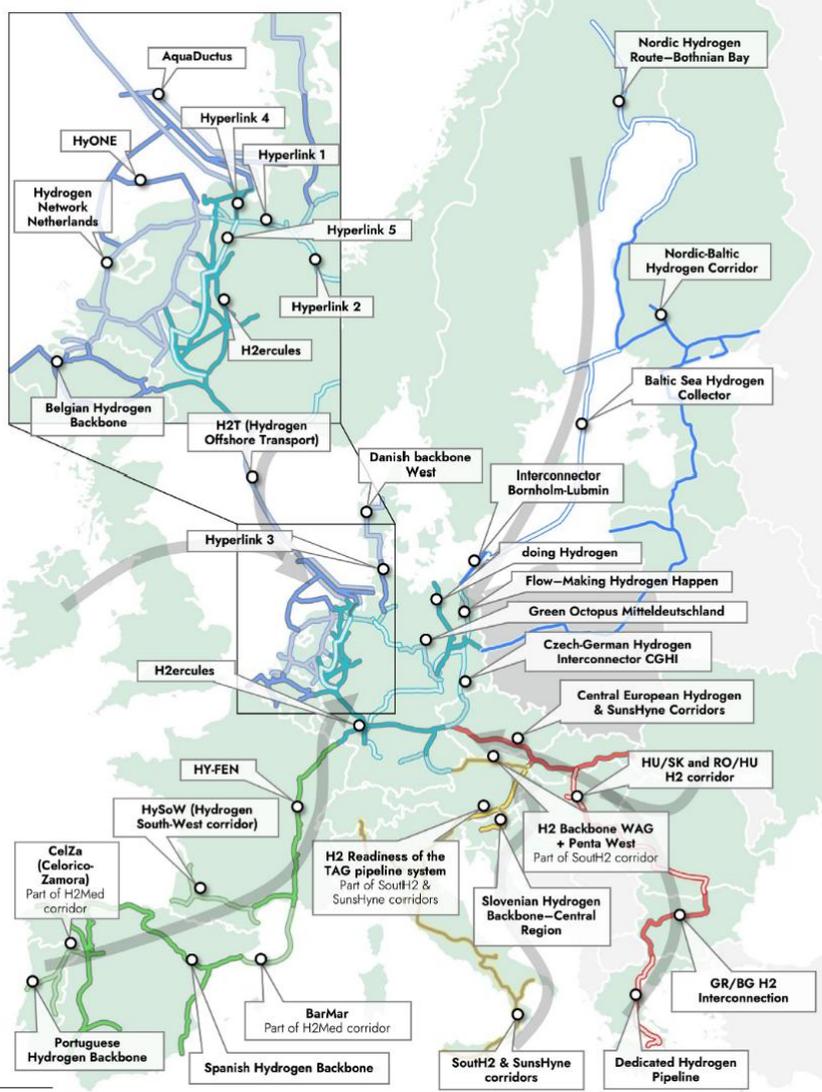
Harsefeld UGS, Hamburg, Germany will be expanded to include 5,000 tonnes UHS in new salt caverns in the SaltHy project.



HypSTER, Ertrez France. 50 tonnes of hydrogen in EZ53 cavity will be followed by additional caverns to 6,700 tonnes.



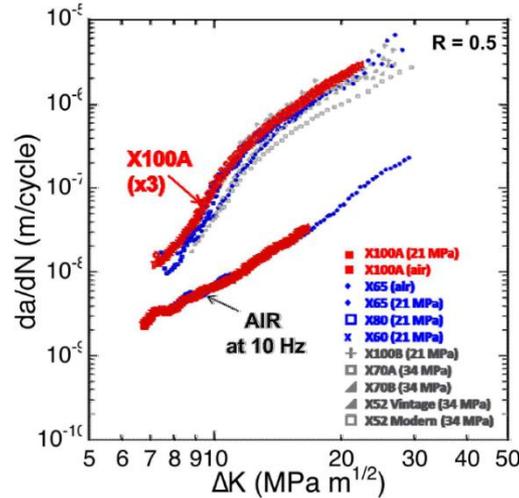
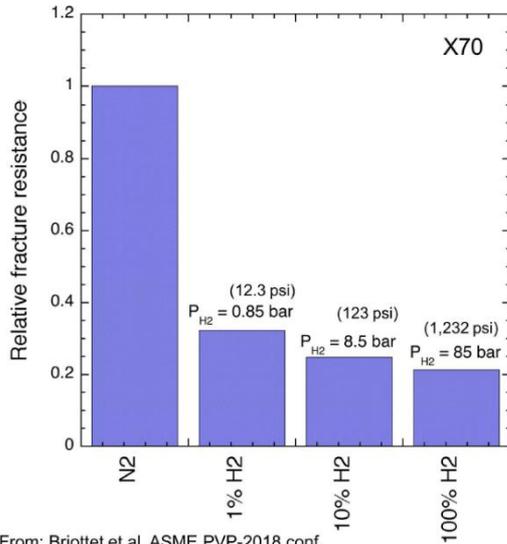
UHS to be implemented at an existing SSE site in Aldbrough on the Yorkshire coast in the UK.



- Pipelines will absorb some hydrogen storage capacity in “linepack”.
- They are also essential to distribute hydrogen to end-users.
- The European hydrogen backbone proposes to build new hydrogen pipelines and re-purpose existing natural gas pipelines.

5) When re-purposing UGS to UHS and natural gas pipelines to hydrogen, essential safety factors must be considered.

Embrittlement of steel is a potential issue with consequences for material compatibility when handling hydrogen. Not all grades of steel used with natural gas are suitable for hydrogen.



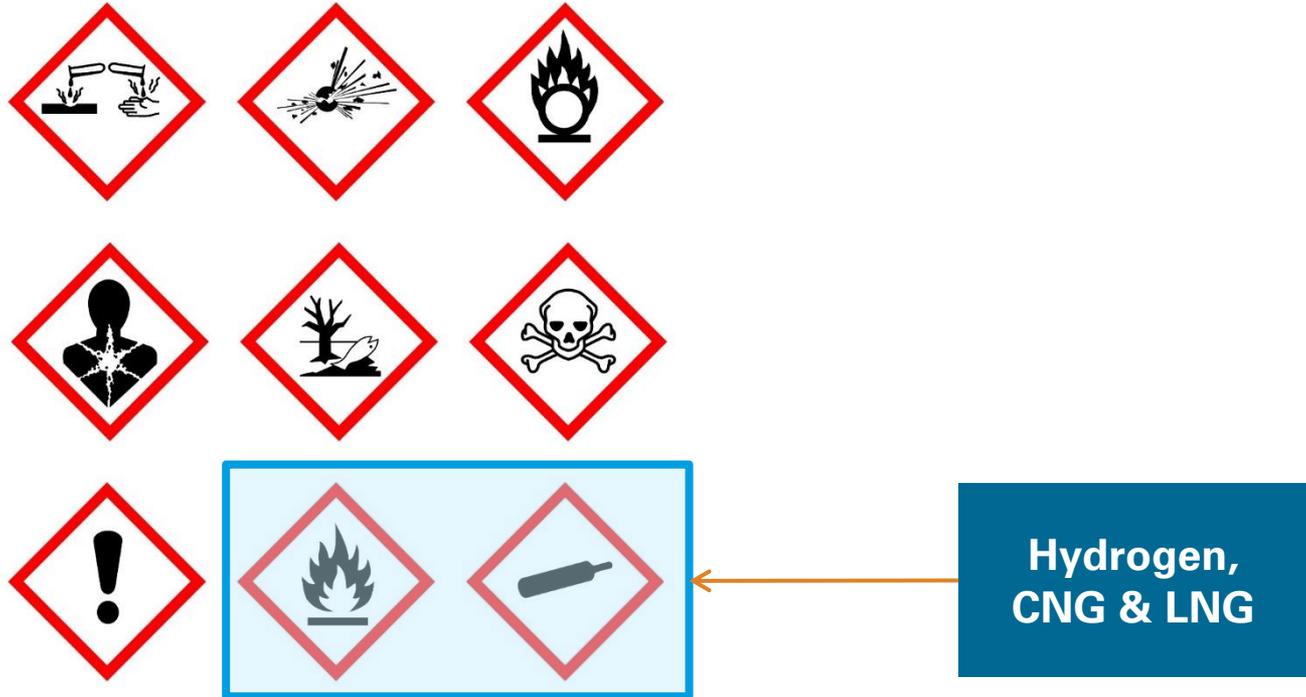
- Even 1% of hydrogen brings an increased risk of fracture. Higher concentrations make the situation even worse.
- Pressure cycles, as with hydrogen storage and hydrogen transmission pipeline operation make the situation worse through fatigue cracking.
- Higher operating pressures, essential, for high-capacity hydrogen storage, increase the fatigue crack growth rate.



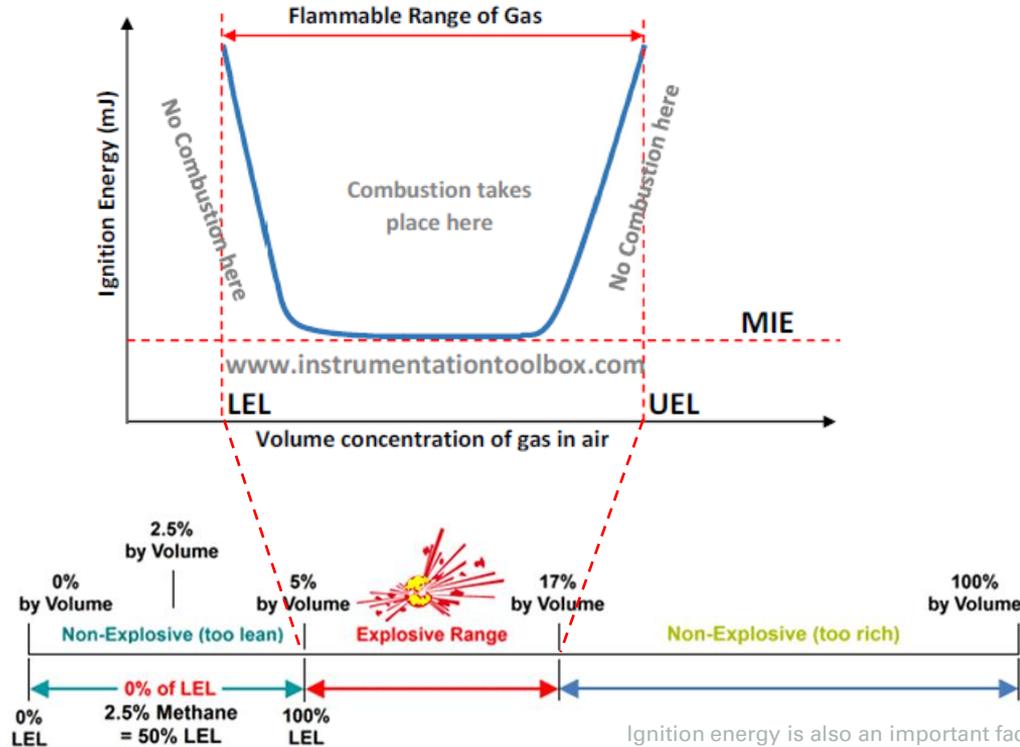
Hydrogen Effects on Pipeline Steels and Blending into Natural Gas

Joe Ronevich and Chris San Marchi, Sandia National Laboratories, Livermore, CA
American Gas Association, Sustainable Growth Committee, November 6th, 2019

It would be easy to **FALSELY** assume that safety precautions for natural gas and hydrogen are the same. They both have the same CLP Hazard identification pictograms.



Hydrogen has a very low ignition energy and a very wide explosive range. It is significantly more hazardous than methane.



Common Combustible Gas LEL's and UEL's

		LEL	UEL
Acetone	(CH ₃) ₂ CO	2.15%	13.0%
Acetylene	C ₂ H ₂	2.5%	100%
Benzene	C ₆ H ₆	1.2%	8.0%
Butadiene	C ₄ H ₆	1.1%	12.5%
Ethane	C ₂ H ₆	3.0%	15.5%
Ethyl Alcohol	CH ₂ H ₅ OH	3.3%	19.0%
Ethyl Ether	(C ₂ H ₅) ₂ O	1.7%	36.0%
Ethylene	C ₂ H ₄	2.7%	36.0%
Hexane	C ₆ H ₁₄	1.1%	7.5%
Hydrogen	H ₂	4.0%	75.6
IsoButane	C ₄ H ₁₀	1.8%	8.5%
Isopropyl Alcohol (IPA)	(CH ₃) ₂ CHOH	2.0%	12.7%
Methane	CH ₄	5.0%	15.0%
Methanol	CH ₃ OH	6.0%	36.0%
Pentane	C ₅ H ₁₂	1.5%	7.8%
Propylene	C ₃ H ₆	2.0%	11.1%
Toluene	C ₇ H ₈	1.2%	7.0%

Ignition energy is also an important factor.

The background matrix gas (air, argon, CO₂) also makes a difference.

LEL data is generally presented assuming a background matrix of air.

Traditional catalytic bead sensors detect flammable gases in air. However, MEMS (Micro Electro-Mechanical System) is more reliable for hydrogen gas detection to detect explosive gas mixtures in air.

Inaccurate gas detection measurements lead to...

- False alarms which cause process disruption and revenue loss
- A loss of confidence in the safety system by the operators
 - The operators begin to “ignore” alarms
 - The safety system is no longer protecting people and assets



Flame detection equipment selection



- Most flame detection equipment looks for heat, smoke or the IR signature of CO₂



- A hydrogen flame burns to make H₂O, not CO₂, but H₂O is not IR active in the same way that CO₂ is. Flame detection equipment must be compatible with hydrogen flames.



**Specific sensors
for inorganic
hydrogen flame**

Safety Integrity Levels (SIL) increase as the safety of components in a system increases.



Stephen B. Harrison

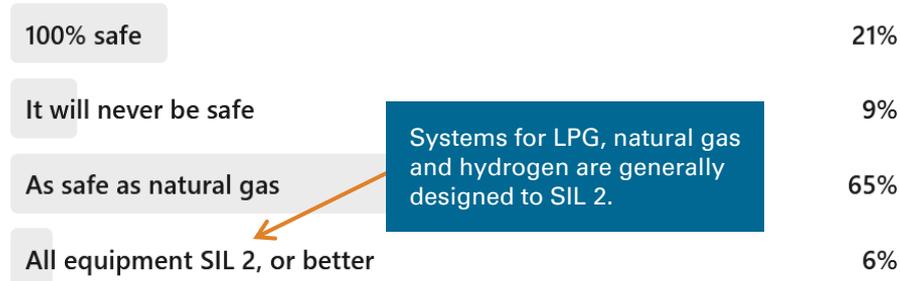
Founder, Managing Director at sbh4 GmbH
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...

Are [#safety](#) concerns holding [#hydrogen](#) back as an [#alternativeenergy](#) vector?
Do established [#energy](#) sector engineering practices have the answers?

How safe does hydrogen need to be to ensure the "hydrogen economy" develops successfully?

You can see how people vote. [Learn more](#)



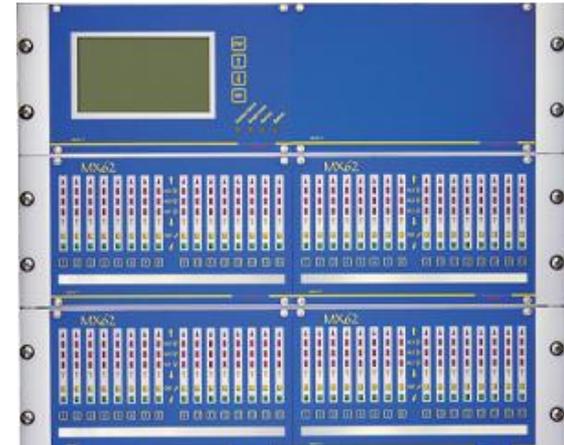
Systems for LPG, natural gas and hydrogen are generally designed to SIL 2.



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Gas detectors and controllers (eg Teledyne Gas and Flame Detection MX62 shown) must meet the functional safety level to achieve a SIL2 system.



LinkedIn survey posted 19th Sept 2021

<https://www.teledynegasandflamedetection.com/en-us/mx-62-multichannel-gas-detection-controller>

Conclusions for safe, sustainable and profitable electrolytic hydrogen generation from 'intentionally intermittent' operation exploiting low-cost and curtailed renewable power.

1. Intentionally intermittent electrolyser operation exploits low-cost electricity to produce low-cost green hydrogen.
2. Electrolyser technology selection for intermittent operation favours technologies that have low-capex, high efficiency, flat load/efficiency curves and safe operation at turndown.
3. Intermittent electrolyser operation must be combined with high-capacity hydrogen storage to balance supply and demand.
4. Re-purposing underground natural gas storage and natural gas pipelines may be possible.
5. Technical and safety considerations such as grades of steel and gas/flame detection must be validated to ensure natural gas infrastructure is safe to use with hydrogen.
6. Safety systems must be designed to a suitable safety integrity level (SIL) so that all links in the chain are equally strong.

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Introduction to Stephen B. Harrison and sbh4 consulting

Stephen B. Harrison is the founder and managing director at sbh4 GmbH in Germany. His work at sbh4 over the past 8 years has focused on hydrogen, industrial decarbonisation, CCU/S, biofuels, e-fuels and clean fertilizers.

With a background in industrial gases, including 27 years at BOC Gases (AFROX), The BOC Group and Linde Gas, Stephen has intimate knowledge of hydrogen and many other gases from commercial, technical, operational and safety perspectives. For 14 years, he was a global business leader in these FTSE100 and DAX30 companies.

Stephen supports the IFC to track down and evaluate the most attractive green hydrogen, biofuels and decarbonisation projects worldwide. He has also supported EIB and ADB on several hydrogen and CCS initiatives.

Stephen has extensive due diligence and investment advisory experience in the clean-tech sector. Private Equity firms, investment fund managers and green-tech start-ups are regular clients.

Industrial corporations often seek his guidance on their industrial decarbonisation plans and growth strategies to offer products and services to the emerging hydrogen economy and energy transition.

Startups are increasingly turning to Stephen to guide their technology development roadmaps from a solid techno-economic basis. He also advises and supports their tech-to-market strategies.

