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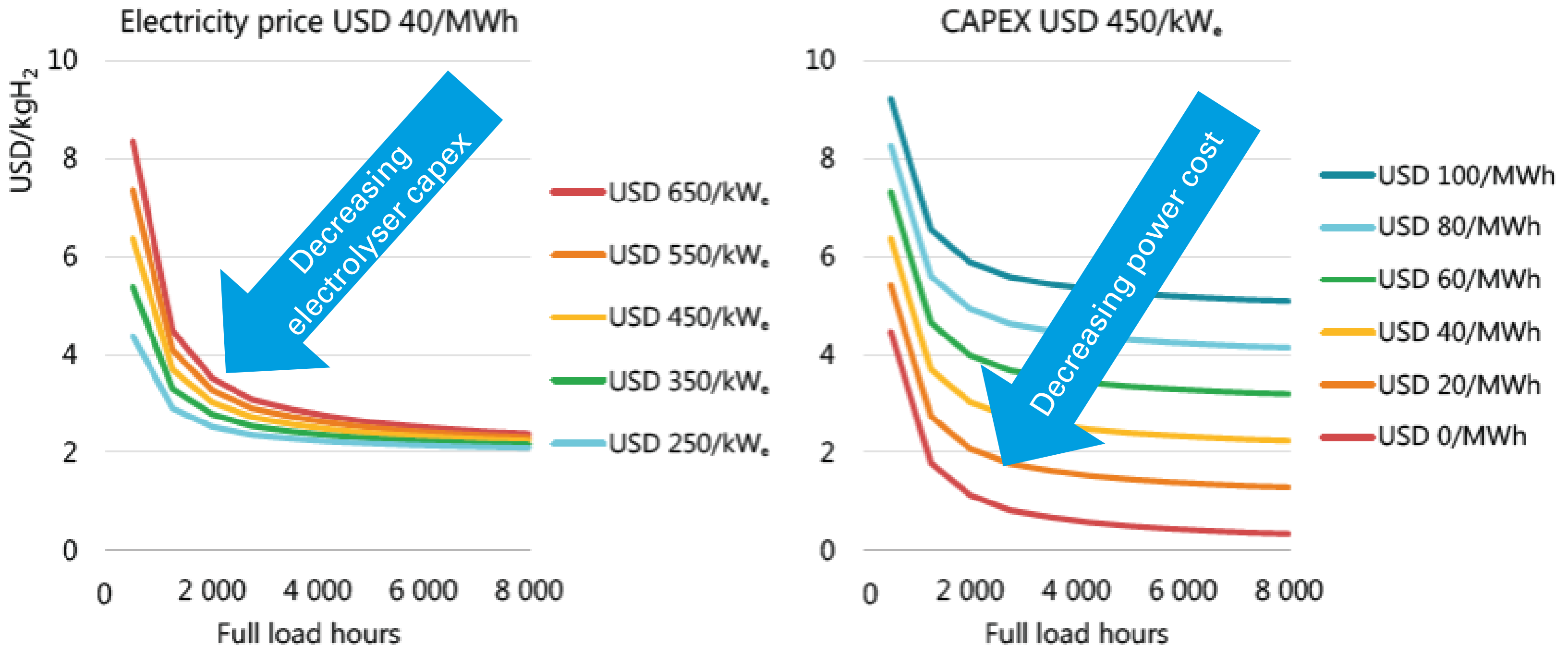
Low-cost green hydrogen from curtailed renewable electricity

The smarter E, Green Hydrogen Forum

Stephen B. Harrison, Managing Director, sbh4 consulting

Munich, 9th May 2025

Electrolyser capital cost and electrolyser utilisation play key roles in green hydrogen production cost. This favours high electrolyser utilisation projects in locations where additional renewable power capacity and capex is required to support green hydrogen production.



Notes: MWh = megawatt hour. Based on an electrolyser efficiency of 69% (LHV) and a discount rate of 8%.

At high electrolyser utilisation and dedicated additional renewables production, locations with excellent potential for integrated wind and solar will achieve the lowest LCOH.

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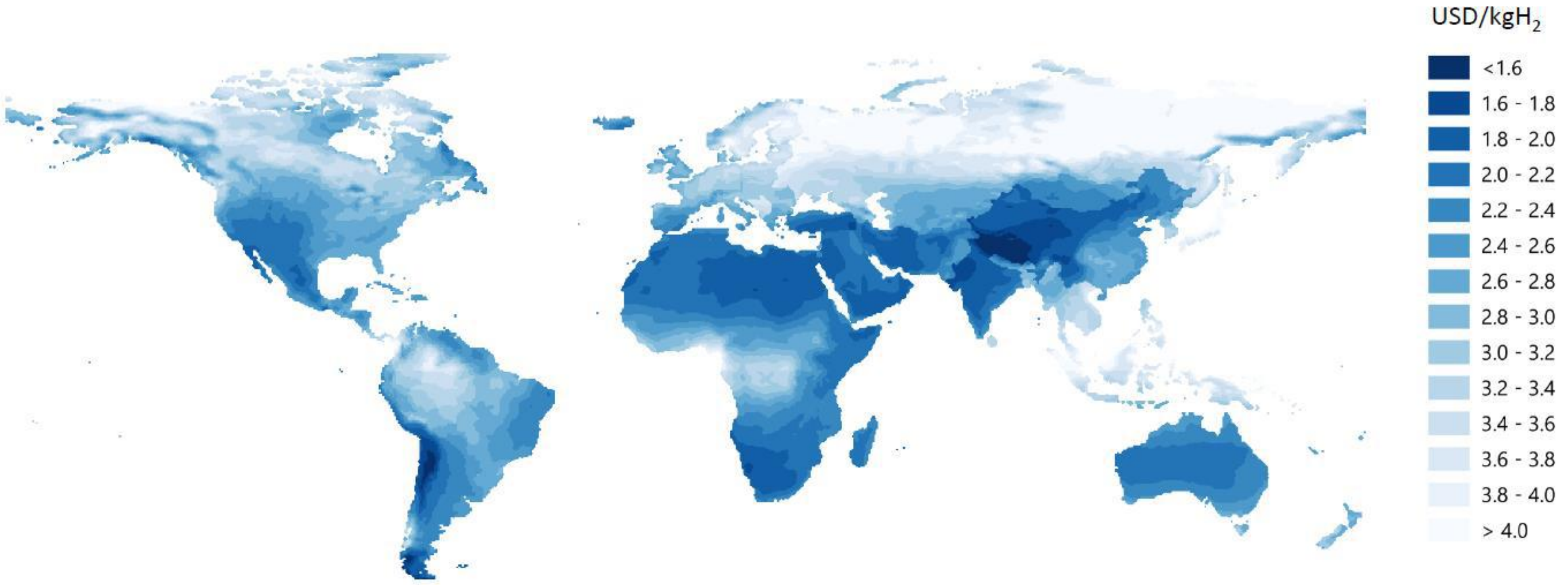

https://gh2namibia.com/wp-content/uploads/2021/08/Green-Hydrogen-Opportunities-for-Namibia.pdf

But… renewable wind, solar and hydro power are all variable or intermittent on different time-frames.

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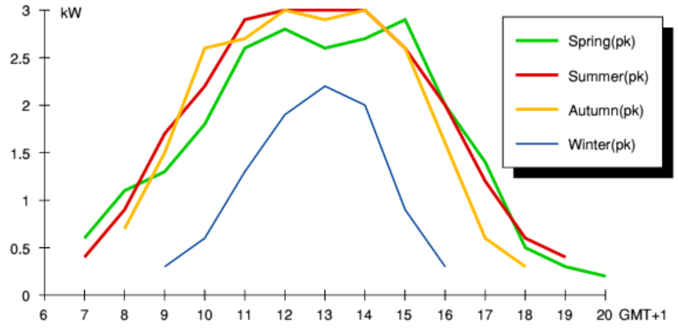
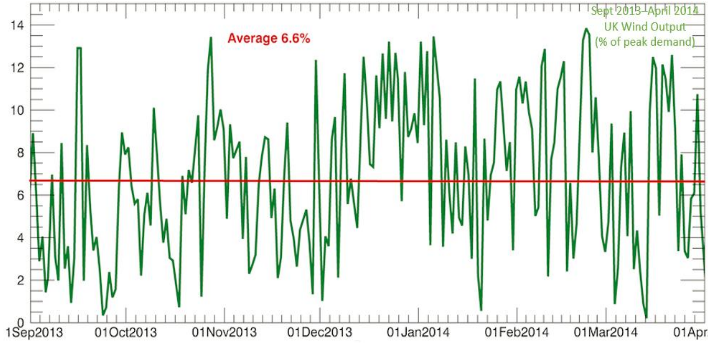
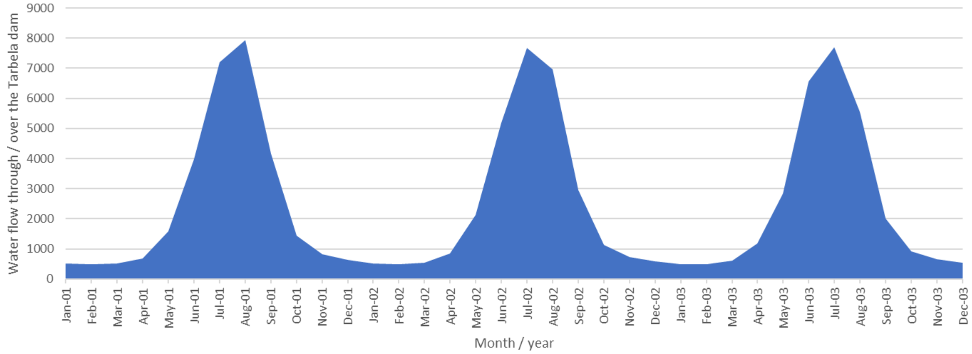


Wind Peak Energy UK





https://www.energyforgrowth.org/memo/power-to-gas-for-long-term-energy-storage/
https://jaharrison.me.uk/Misc/Solar/index.html
https://www.linkedin.com/posts/tobias-brunner-b524271a_wind-pv-windstrom-activity-6933787019324100608-fgf2/?utm_source=linkedin_share&utm_medium=ios_app
World Bank document: Report 60963-PK

And… additional renewable power for the purpose of hydrogen production is capital intensive.

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The EU Delegated Acts define what **renewable power** means for **green** hydrogen production when using a grid connection. Some simplified points…

- Proximity – electrolyser and renewable power in same bidding zone or, to avoid grid stress
- Additionality – new renewable power generation capacity
- Temporal Correlation – power generation and electrolyser operation in the same time period
- Or… draw power from a "green grid" - average share of renewable power within a grid – more than 90% of power per year
- Or… use of curtailed renewable power – reducing the need for dispatching during imbalance periods

https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/7046068-Production-of-renewable-transport-fuels-share-of-renewable-electricity-requirements-_en

Wind and solar renewable power curtailment in California is increasing annually.

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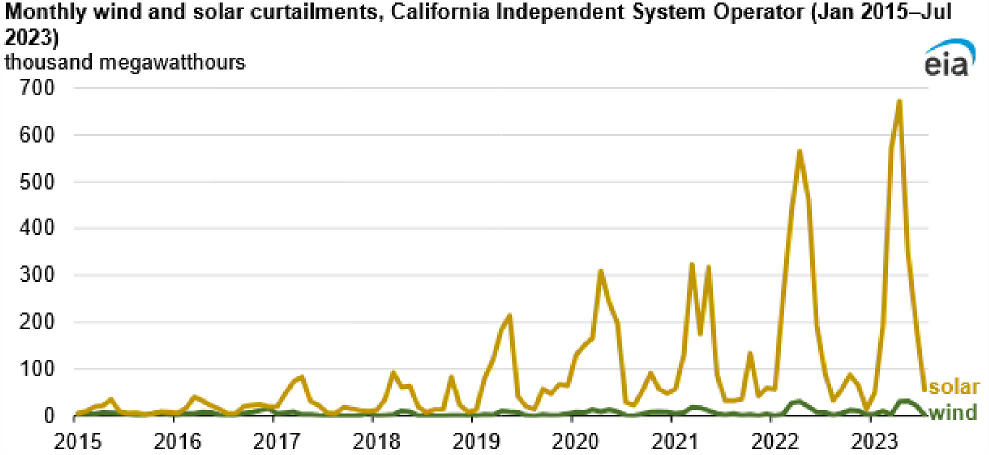

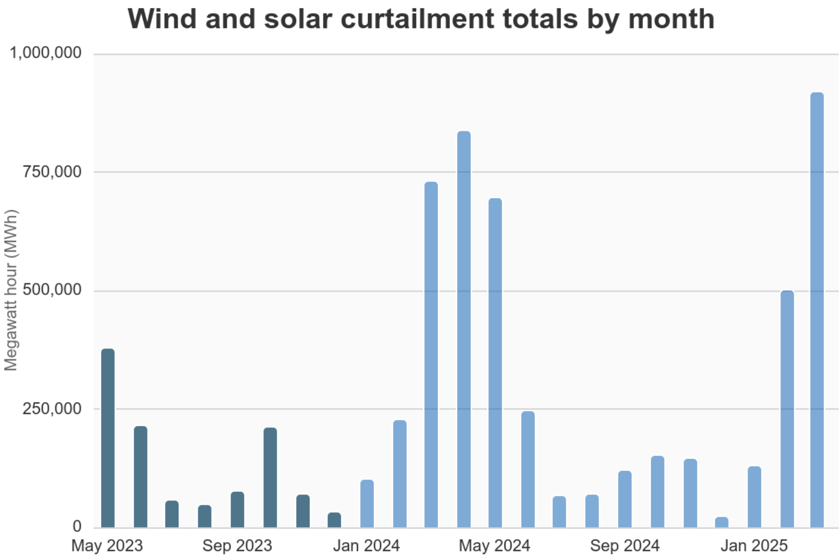

https://www.caiso.com/about/our-business/managing-the-evolving-grid
https://www.eia.gov/todayinenergy/detail.php?id=60822

The annual amount of curtailed power in Germany is also growing.

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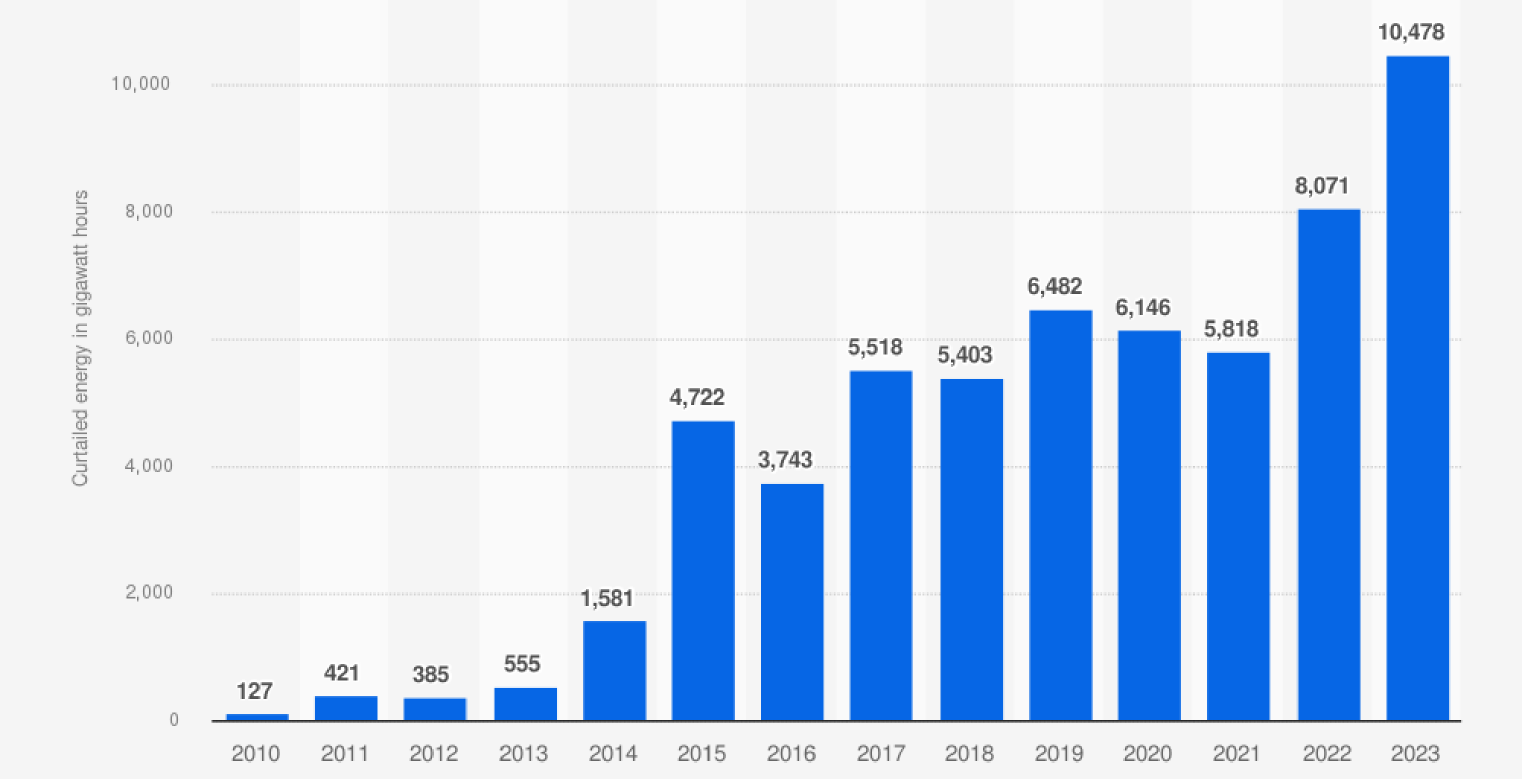

https://www.statista.com/statistics/1332954/renewable-energy-power-curtailment-germany/

Curtailment is managed with low, zero and negative electricity pricing in many markets, including Germany.

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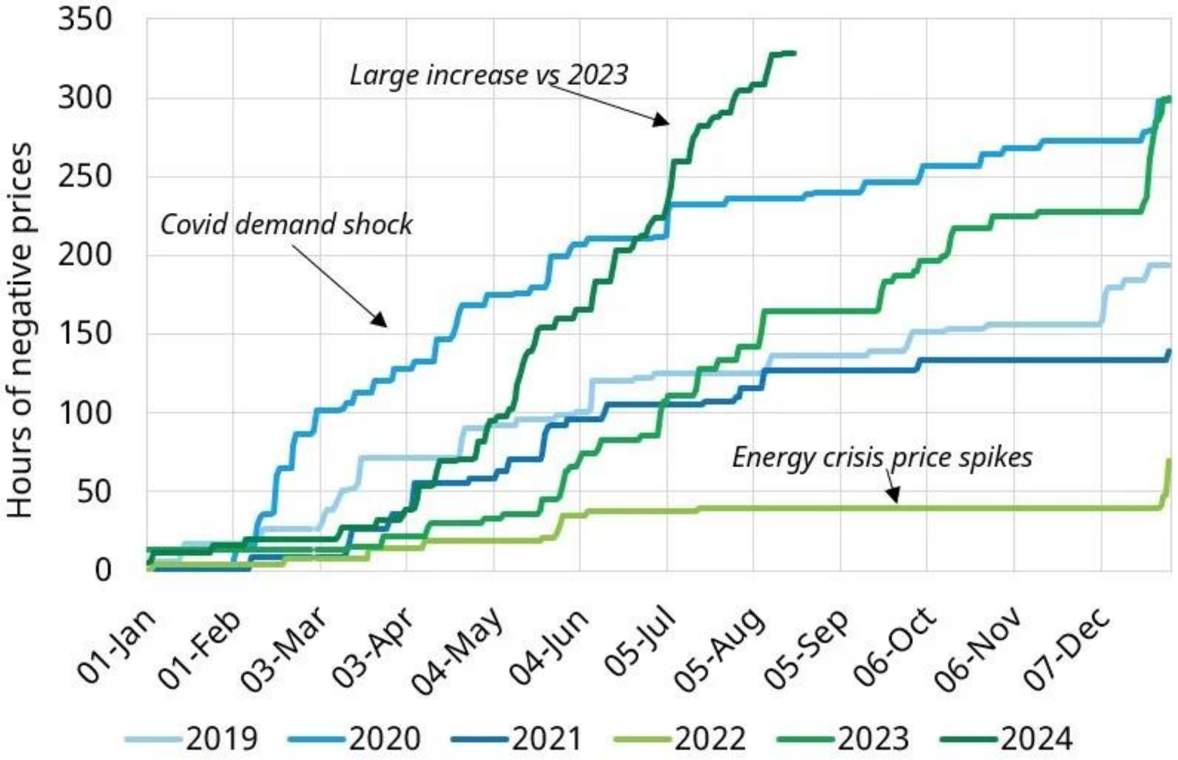

https://timera-energy.com/blog/strong-growth-in-negative-prices-a-german-case-study/

Beyond Germany, the number of hours per year of negatively priced electricity is also growing in several European countries.

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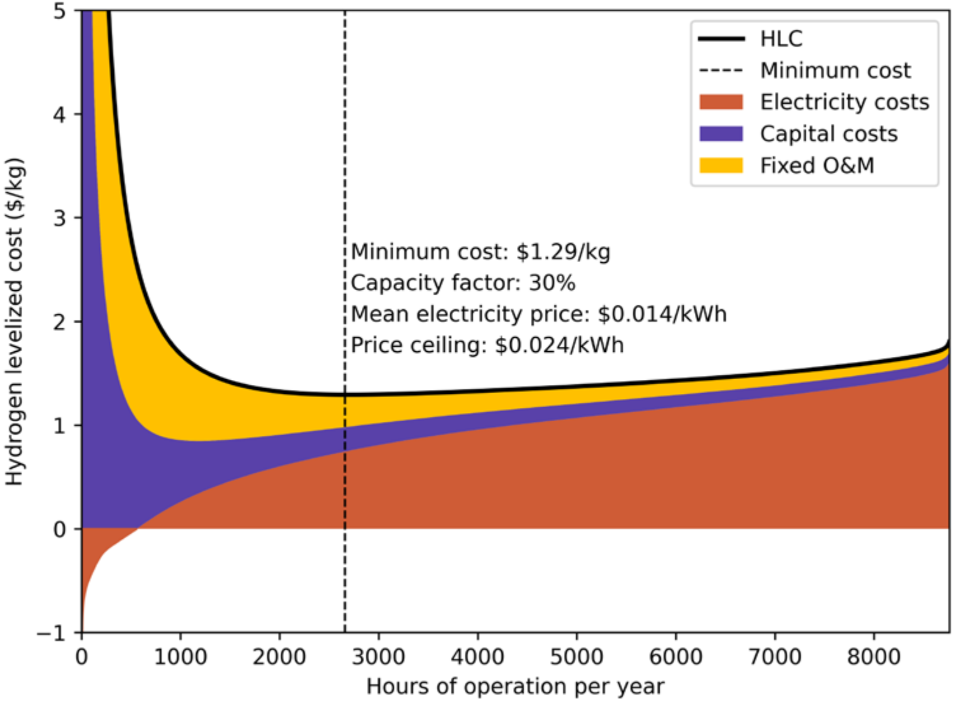
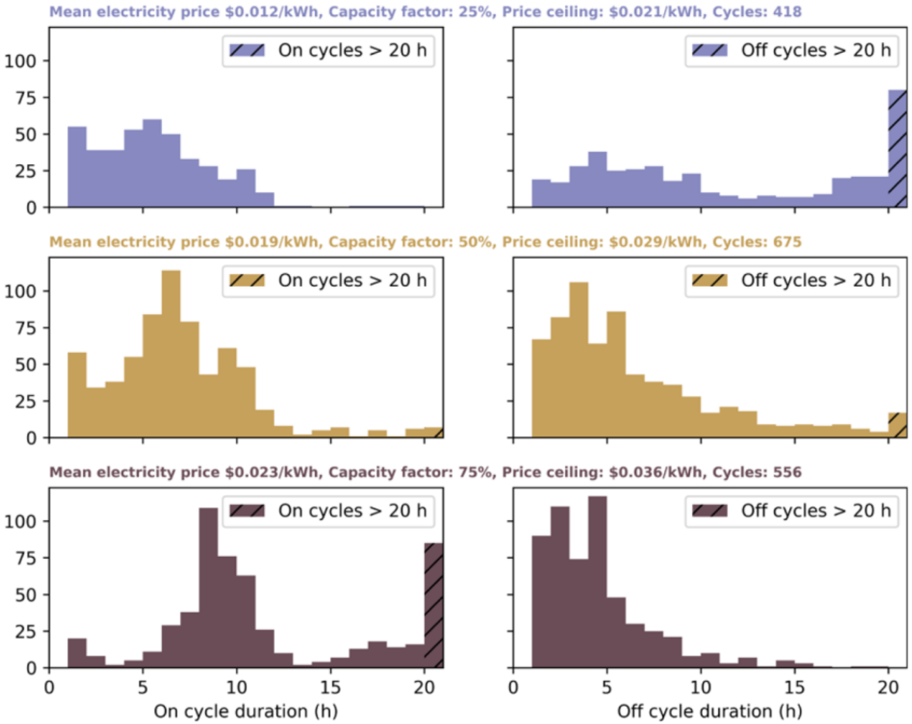
https://timera-energy.com/blog/strong-growth-in-negative-prices-a-german-case-study/

To exploit low-cost (otherwise) curtailed power means intermittent hydrogen production. Despite the implications for reduced electrolyser utilisation, this can result in a lower cost of hydrogen production.





Badgett, A., Ruth, M. and Pivovar, B. (2022) 'Chapter 10 -Economic considerations for hydrogen production with a focus on polymer electrolyte membrane electrolysis', in Smolinka, T. and Garche, J. (eds) Electrochemical Power Sources: Fundamentals, Systems, and Applications. Elsevier, pp. 327–364.

In South Australia, negatively priced power exists for around 10 hours per day during periods of solar power curtailment. If this electricity is used for hydrogen production, the electrolyser must be able to ramp quickly and tolerate idle periods without stack damage.

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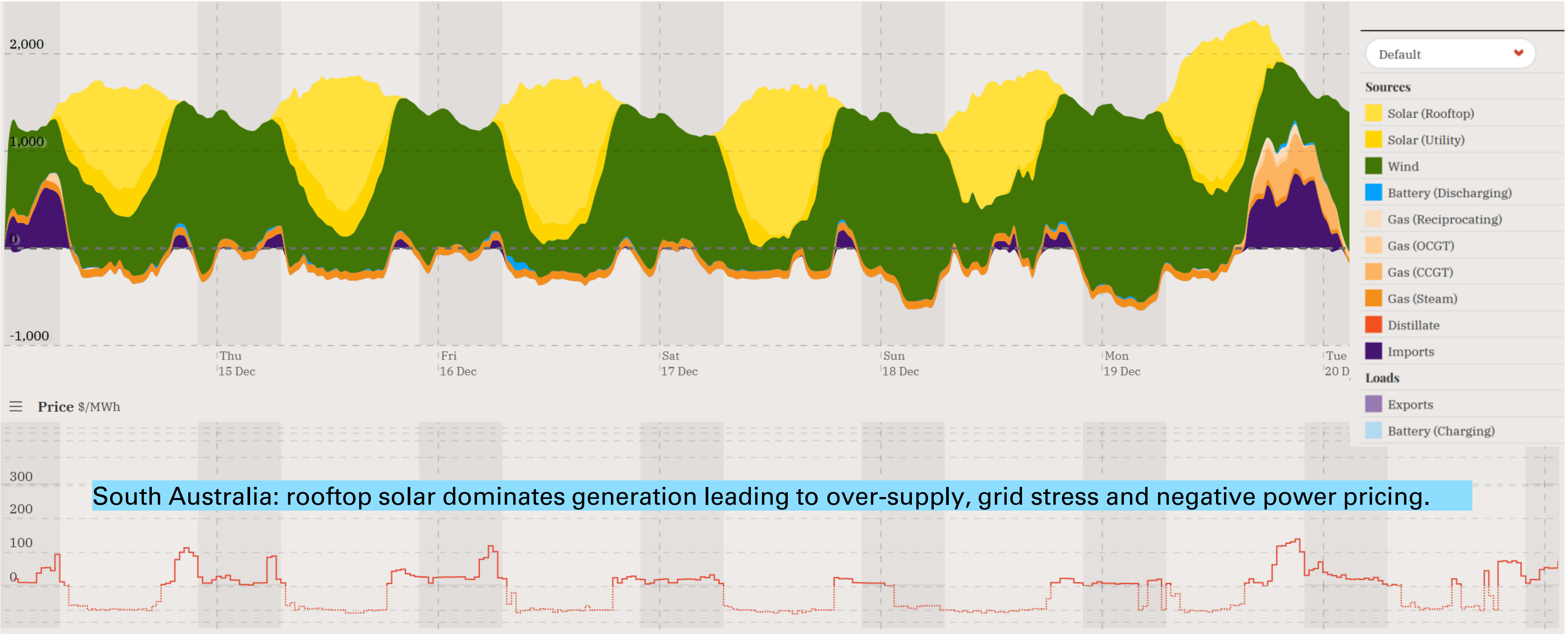

South Australia: rooftop solar dominates generation leading to over-supply, grid stress and negative power pricing.

Many moder electrolysers have good load following capability between 30 and 100% load conditions to follow daytime variable renewable power generation. However, many electrolysers prefer not to shut down to avoid electrode degradation. The electrolyser must be selected and specified carefully for frequent intermittent operation.

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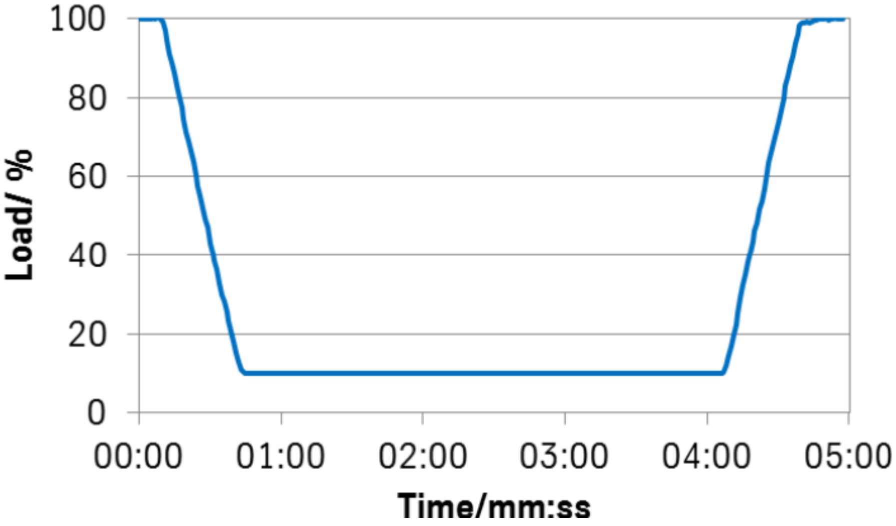

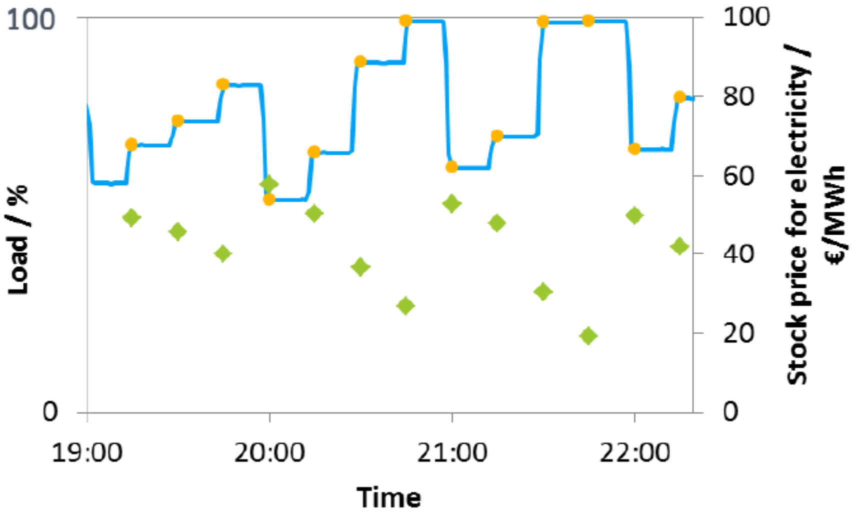

Atmospheric pressure AWE performance data from thyssenkrupp nucera

https://www.ammoniaenergy.org/wp-content/uploads/2020/12/Tobias-Birwe.pdf

Using (otherwise) curtailed power for RFNBO Green hydrogen production in the EU means additional renewable power capacity investment is not required. However, hydrogen distribution and storage investments are essential for intermittent production.

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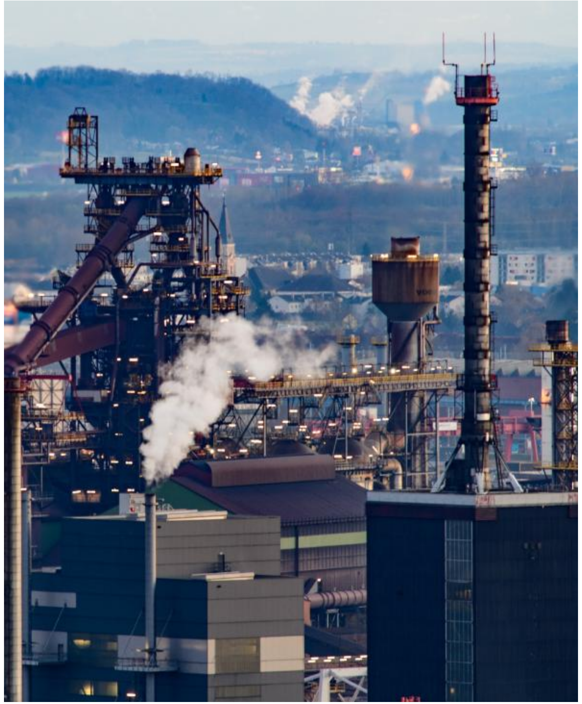
Offtakers in industries such as ammonia production, refineries and iron / steel making need continuous hydrogen supply. There must be a large hydrogen storage buffer to balance intermittent production with continuous offtake.



There is potential for high-capacity underground hydrogen storage (UHS) in salt caverns in some parts of Europe. Unfortunately, there is not a good geographic overlap with low-cost renewables in Norway, Finland and Iberia. Rock caverns may be required.

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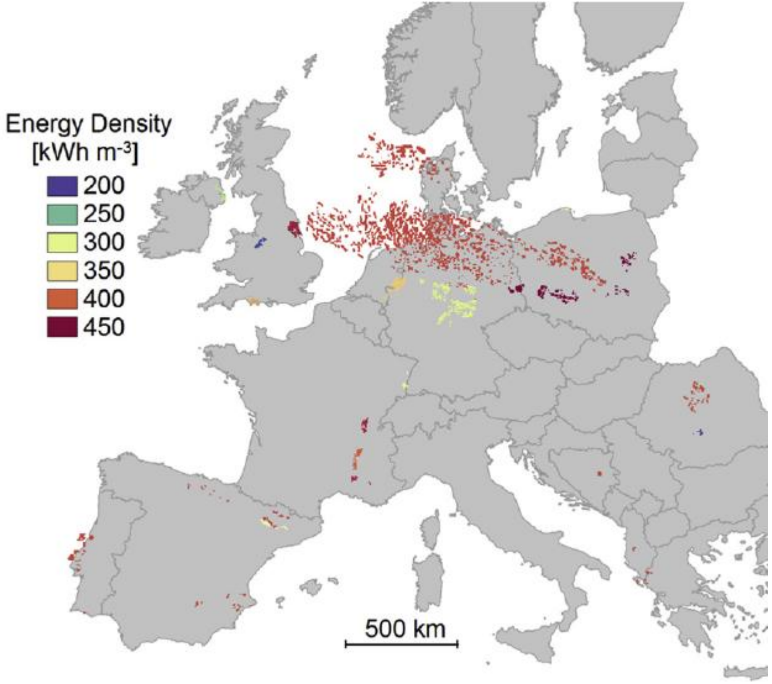

	Gaseous state		
	Salt caverns	Depleted gas fields	Rock caverns
Main usage (volume and cycling)	Large volumes, months-weeks	Large volumes, seasonal	Medium volumes, months-weeks
Benchmark LCOS ($/kg)[1]	$0.23	$1.90	$0.71
Possible future LCOS[1]	$0.11	$1.07	$0.23
Geographical availability	Limited	Limited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

https://www.sciencedirect.com/science/article/abs/pii/S0360319919347299?via%3Dihub
https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

UHS projects are proceeding in many European locations.

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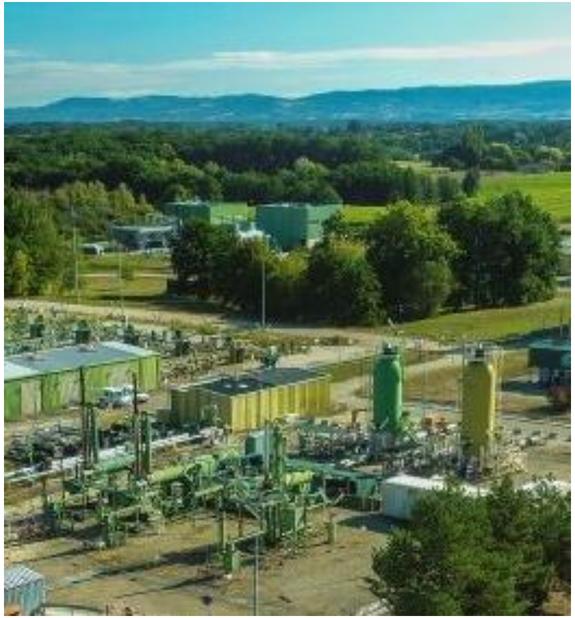
Harsefeld UGS, Hamburg, Germany will be expanded to include 5,000 tonnes UHS in new salt caverns in the SaltHy project.



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.

https://innovation.engie.com/en/news/interview/new-energies/hypster-an-engie-group-innovation-goes-to-industrial-scale/29098
https://www.engie-deutschland.de/en/magazine/natural-gas-storage-facilities-clever-technology-security-supply-germany
https://amp-theguardian-com.cdn.ampproject.org/c/s/amp.theguardian.com/environment/2022/dec/18/sse-begins-work-on-hydrogen-storage-cavern-on-yorkshire-coast

Hydrogen must also be distributed from the production sites to offtakers at low cost. Pipelines are essential.

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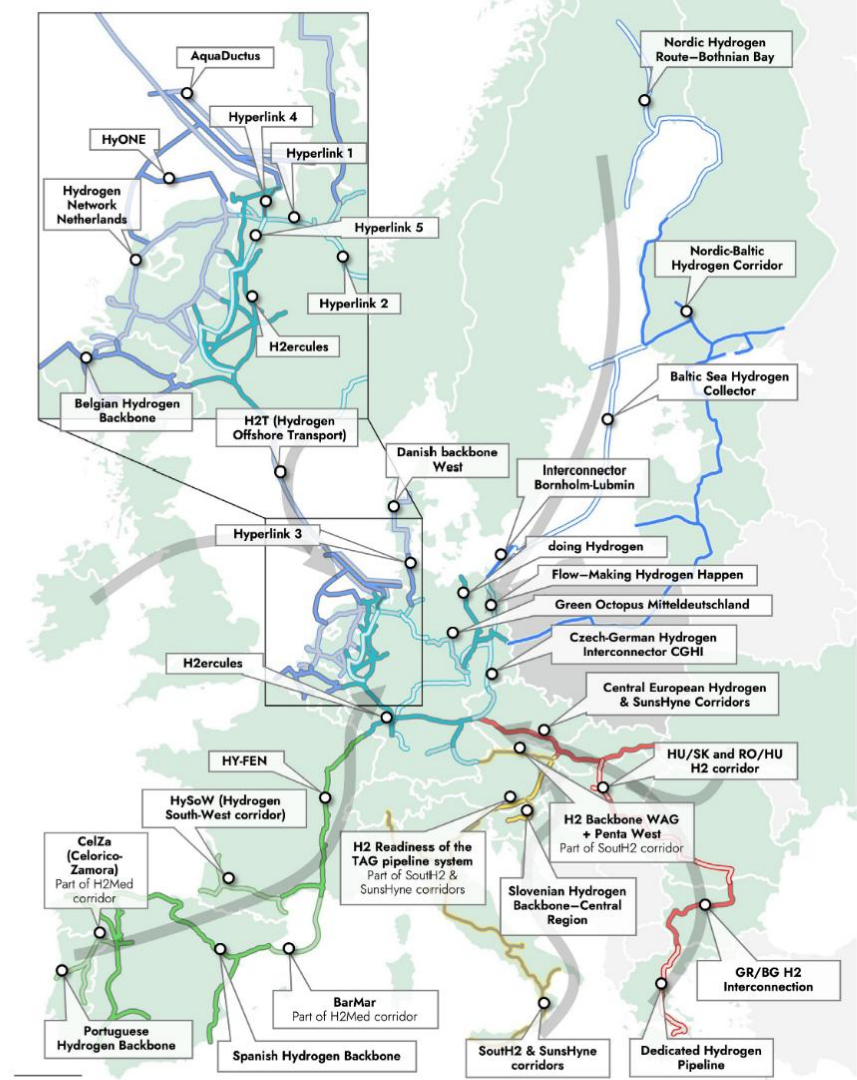
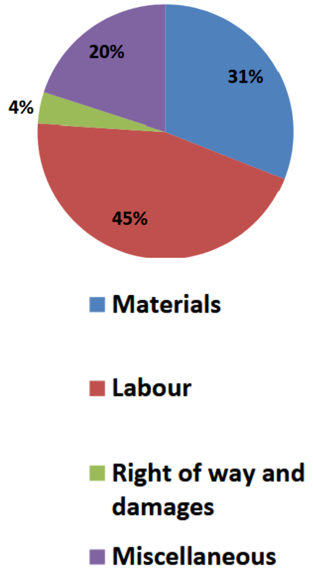
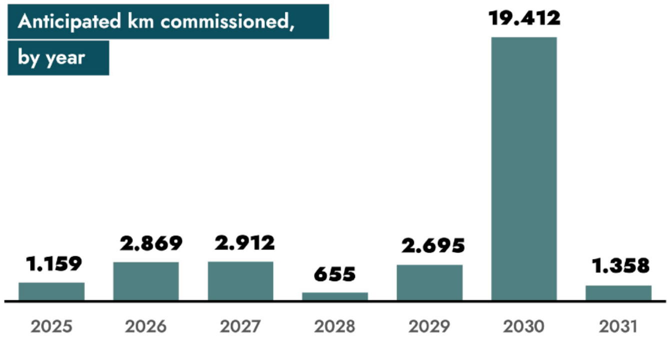


Parameter		CAPEX costs (M€/km for pipelines and M€/MWe for compressors)
New pipelines	20″ onshore pipes	1.80
	36″ onshore pipes	3.20
	48″ onshore pipes	4.40
	36″ offshore pipes	5.44
	48″ offshore pipe	7.48
Repurposed pipelines	20″ onshore pipes	0.54
	36″ onshore pipes	0.64
	48″ onshore pipes	0.88
	36″ offshore pipes	1.09
	48″ offshore pipe	1.50
Compressor station		4.0





https://ehb.eu/files/downloads/EHB-2023-20-Nov-FINAL-design.pdf
https://www.oxfordenergy.org/wpcms/wp-content/uploads/2023/11/ET27-Hydrogen-pipelines-vs.-HVDC-lines_HG_AP_2.pdf

The "perfect storm" for low-cost green hydrogen from low-cost curtailed power in Europe may exist from circa 2030. Projects can be planned now to exploit this.

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1) In "conventional" projects, electrical power is overwhelmingly the major cost for Green hydrogen production.
2) Low, zero, or negative cost power is essential for low-cost green hydrogen.
3) Moving power is expensive and may complicate "green" certification if the distances are too long. Site location selection close to low-cost power is essential.
4) The "conventional" green hydrogen production paradigm (high utilisation) may work for regions with excellent renewable power generation (Australia, Middle East and Chile from wind / solar, South America from hydro).
5) In Europe, renewable power is expensive due to non-ideal environmental conditions.
6) As renewables contribute more to European grids, periods of excess power generation are increasing.
7) Using (otherwise) curtailed renewable power in Europe for hydrogen production can reduce hydrogen production costs and can assist with "green" hydrogen certification.
8) The intentional use of intermittent (otherwise) curtailed power influences electrolyser technology selection.
9) Hydrogen storage in UHS and line pack is essential to balance production and consumption at low-cost.
10) UHS in salt caverns is the lowest cost mode of hydrogen storage and is possible in many European locations.
11) Hydrogen pipelines will be essential to link producers and consumers at low-cost.

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Introduction to Stephen B. Harrison and sbh4 consulting

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Stephen B. Harrison is the founder and managing director at sbh4 GmbH in Germany. His work focuses on decarbonisation and greenhouse gas emissions reduction. E-fuels, hydrogen, ammonia and CCTUS are fundamental pillars of his consulting practice.

In support of the European Commission through CINEA in 2023, Stephen evaluated seven CCS, hydrogen and e-fuels submissions to the Third Innovation Fund. The fund allocated €2 billion to large-scale decarbonisation projects in Europe. In 2024 he supported the European Commission's EISMEA with venture capital investment due diligence services.

Stephen has served as the international expert and team leader for three ADB projects related to CCTUS and renewable hydrogen deployment in Pakistan, Palau and Viet Nam. He has also supported the IFC and work bank on e-fuels and green hydrogen strategy development projects in Namibia and Pakistan. In 2021, he specified more than 2GW of electrolyser capacity for green hydrogen projects.

With a background in industrial and specialty gases, including 27 years at BOC Gases, The BOC Group and Linde Gas, Stephen has intimate knowledge of e-fuels, hydrogen, ammonia and carbon dioxide from commercial, technical and operational perspectives. For 14 years, he was a global business leader in these FTSE100 and DAX30 companies.

Stephen has extensive buy-side and sell-side M&A due diligence and investment due diligence advisory experience in the energy and clean-tech sectors. Private Equity firms and investment fund managers and green-tech start-ups are regular clients. He also supports operating companies in their mission to decarbonise their scope 1, 2 and 3 GHG emissions.

As a member of the H2 View and **gas**world editorial advisory boards, Stephen advises the direction for the leading hydrogen-focused international publications. Through H2 VIEW, World Hydrogen Leaders and Sustainable Aviation Futures, he has led Masterclasses covering many hydrogen, SAF and hydrogen derivatives themes in virtual and live sessions.

Stephen served on the Scientific Committee for CEM2023 in Barcelona and chaired the session related to CEM from clean energy systems. Stephen was session chair for the e-fuels and hydrogen propulsion track at the Bremen Hydrogen Technology Exhibition in September 2023 and will chair the same stream at that conference in Berlin in 2024. He was also conference chair for day-2 of the CO2 utilisation Summit in Hamburg in 2023. Stephen also served on the Technical Committee for the Green Hydrogen Summit in Oman in December 2022 and the Advisory Board of the International Power Summit in Munich in September 2022.