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Towards GW-scale Hydrogen electrolysis

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EQ Electrolysis Conference

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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 control. Hydrogen and CCUS are fundamental pillars of his consulting practice.

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 hydrogen and carbon dioxide from commercial, technical, operational and safety 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 experience in the energy and clean-tech sectors. Private Equity firms and investment fund managers are regular clients. He is also the international hydrogen expert and team leader for an ADB project related to renewable hydrogen deployment in South Asia.

As a member of the H2 View and **gas**world editorial advisory boards, Stephen advises the direction for these international publications. Working with Environmental Technology Publications, he is a member of the scientific committee for CEM 2023 - the leading international conference for continuous emissions monitoring and air quality.

Why hydrogen?

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- Hydrogen production is possible from renewable resources
- Hydrogen can be produced from fossil fuel resources and decarbonised using CCS
- Low-carbon hydrogen can support corporate, national and international climate change targets
- Hydrogen has excellent long term energy storage ability for time-shifting for annual power supply security
- Hydrogen is a clean source of energy at the point of use
- Hydrogen has similar handling and safety characteristics to natural gas and existing gas infrastructure can be modified and leveraged

Hydrogen utilisation can support decarbonisation of heavy industry

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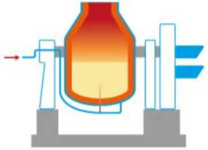
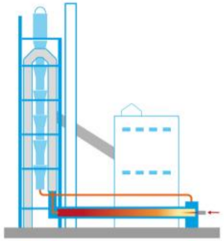
Notes:
- CO_2 emissions are also associated with the energy and power requirements for this industry sector – the focus in this table is CO_2 emissions from within the process
- CCS to capture CO_2 from the process and / or the associated energy production is possible

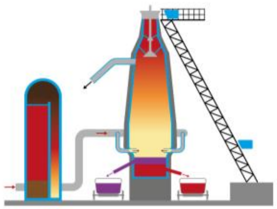
Steam Methane Reformer



Aluminium smelting



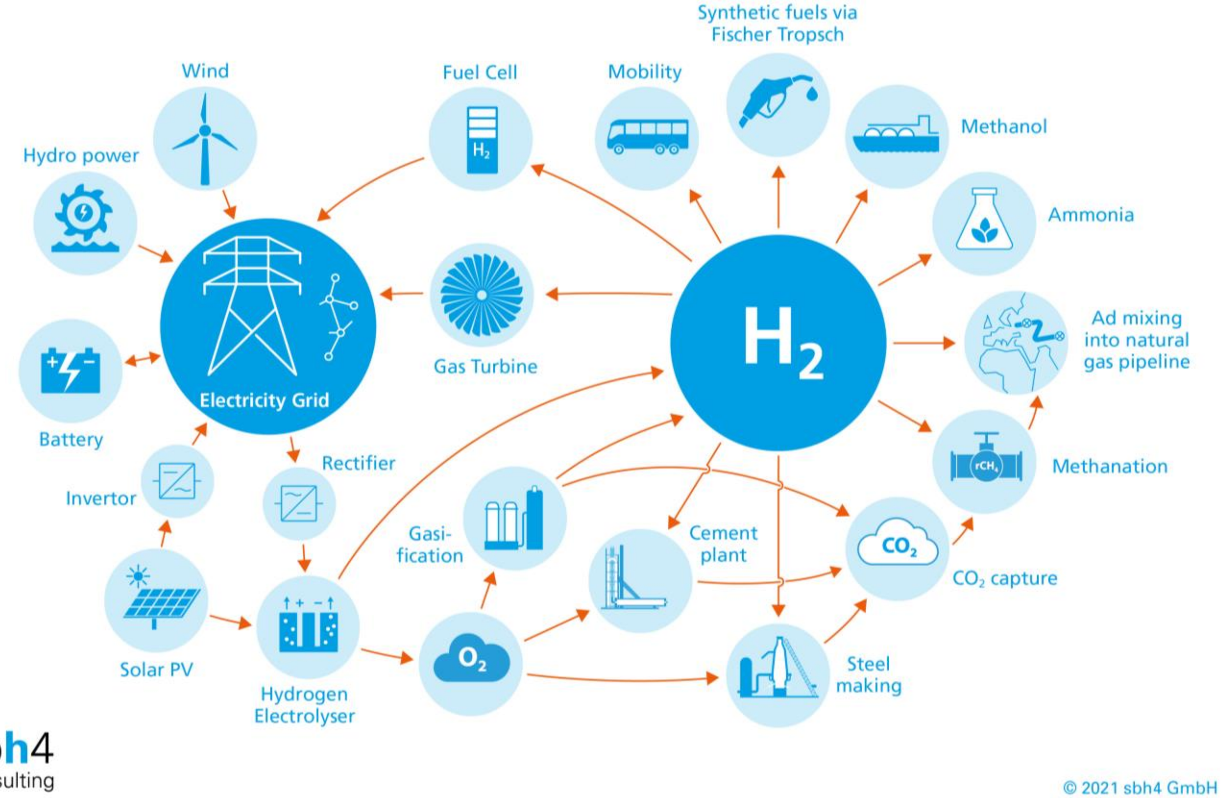
Calciner tower & clinker kiln



Blast furnace

	Oil refining	Aluminium smelting	Cement making	Iron making
Application that releases CO_2	Hydrogen production from methane reforming for fuels desulphurisation	Reduction of alumina to aluminium using graphite electrodes	Reduction of limestone to calcium oxide	Reduction of iron ore to iron using coke
Chemical reaction producing CO_2	$CH_4 + H_2O \rightarrow CO + 3H_2$ $CO + H_2O \rightarrow CO_2 + H_2$	$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$	$CaCO_3 \rightarrow CaO + CO_2$	$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$ $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
Decarbonisation approach	Use turquoise hydrogen or green hydrogen to avoid the reforming reaction; or feed the reformer with biomethane instead of natural gas	Use carbon from turquoise hydrogen production instead of carbon from fossil fuels to make the electrodes	Replace a portion of the limestone with alternative materials such as calcined clay to make clinker for cement	Use turquoise hydrogen or green hydrogen instead of coke; or substitute coke with carbon from turquoise hydrogen production
Reactions for the decarbonised process	As above using renewable methane	As above using renewable graphite electrodes	Above reaction can only partially be avoided	As above using renewable carbon, or use hydrogen: $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$
Other industries with similar applications	Ammonia, Urea, Methanol, Gas-to-liquids	Gold and silver refining, electric arc furnace to melt scrap steel	Lime making Refractory bricks, $MgCO_3 \rightarrow MgO + CO_2$	None

Hydrogen and oxygen from electrolysis can support decarbonisation of heavy industry



Hydrogen is not 'magic'...

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- Hydrogen is derived from biomass, power or fossil fuels – there are inherent conversion costs and energy losses
- Direct use of renewable power can be more cost effective – but electricity storage is difficult and expensive, hydrogen can help
- Hydrogen alone is not the answer – it deserves to be part of an appropriate and sustainable mix of solutions
- Only low-carbon hydrogen will reduce climate change – grey and black hydrogen are dominant in the world today and this must change

Low-carbon hydrogen: a rainbow of colours

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Turquoise – methane pyrolysis with solid carbon

Purple – coal (or petcoke) gasification with CCS

Blue – natural gas reforming with CCS

Green – biomethane reforming

Green – renewable power and electrolysis

Pink – nuclear power and electrolysis

Black (or brown) hydrogen from coal or petcoke gasification and grey hydrogen from natural gas reforming are dominant in the world today – both have a significant carbon dioxide emissions footprint

Cost benchmarking of grey, blue & green hydrogen production

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- Assessed on 9th April 2021 using Altroleum (www.altroleum.com)
- Costs shown are per kg of hydrogen, including capex depreciated over plant lifespan of 25 years
- Grey and blue: 100 Tonnes day production, subjected to EU ETS carbon tariffs in the UK case, calculated using month ahead natural gas futures evaluated at the closest hub, CCS costs assume likely costs for proposed future CCS schemes
- Green: 25 Tonnes day production (~50 MW plant), electrolysis, calculated using month ahead electricity futures evaluated at the closest hub

Pink and green hydrogen are produced on electrolysers

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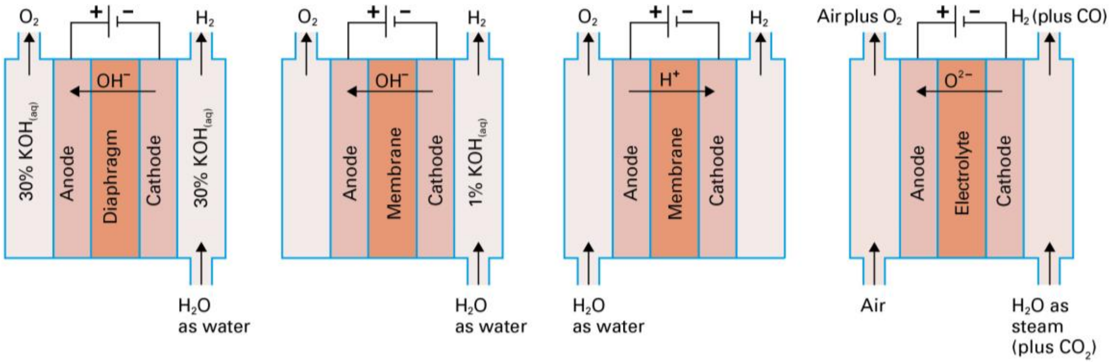
Notes:
- In the AEC, AEM and PEM, lye or water flow from the electrolyser cell with the oxygen and/or hydrogen gases. These liquids are mixed and recirculated to the electrolyser.
- Air is used to purge the SOE anode to avoid oxygen accumulation which may present a hazard at the high operating temperature.
- 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/cm²	0.2 – 1 A/cm²	Up to 3 A/cm²	Up to 0.5 A/cm²
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

Europe: PEM leads by number of projects, AEM leads by MW capacity

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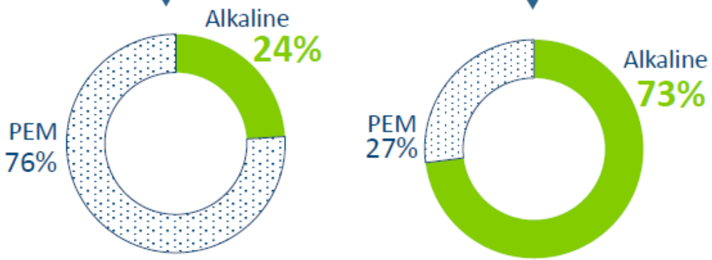
Distribution of hydrogen projects in Europe

By number of projects | **By MW installed**



Pressurized alkaline electrolysis is the most selected technology to answer the broad-scale needs of decarbonization.

Pressurized alkaline technology highlights

- Proven-technology (200+ yrs)
- Long term resilience and stability
- Lower CAPEX (precious metals avoidance, ..)
- Compacity
- Flexibility suited to integration with renewables
- Better suited to large projects

Pressurized alkaline: the best way to move towards large-scale green hydrogen

GW-scale hydrogen electrolysis project proposals and concepts

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Project	Power	Location	Power source
Asian Renewable Energy Hub	14GW	Pilbara, Western Australia	Onshore wind and solar
NorthH2	10GW	Eemshaven, Netherlands	Offshore wind
AquaVentus	10GW	Heligoland, Germany	Offshore wind
Murchison Renewable Hydrogen	5GW	Kalbarri, Western Australia	Onshore wind and solar
Beijing Jingneng Inner Mongolia	5GW	Eqianqi, Inner Mongolia, China	Onshore wind and solar
Helios Green Fuels Project	4GW	Neom, Saudi Arabia	Onshore wind and solar
Pacific Solar Hydrogen	3.6GW	Callide, Queensland, Australia	Onshore wind and solar
H2-Hub Gladstone	3GW	Gladstone, Queensland, Australia	Onshore wind and solar
HyEx	1.6GW	Antofagasta, Chile	Onshore wind and solar
Geraldton	1.5GW	Geraldton, Western Australia	Onshore wind and solar

5 put of the top-10 project proposals worldwide are in Australia
8 out of the top 10 project proposals worldwide will incorporate PV Solar

Optimising PV Solar scheme output will be essential for competitive economics

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Solar panels and arrays are generally connected in series, not in parallel

- Uneven power output from an individual solar panel holds back the whole PV Array
- Large amounts of the solar park under-perform if only a few panels under-perform

Underperformance can be from a range of factors

- Uneven shade from clouds or structures
- Uneven aging of solar panels
- Cell replacement with unmatched solar panels
- Uneven dust or snow coverage

Power management and data provision solutions from CQSola can improve power output, reduce maintenance costs and extend the solar panel life, imace copyright CQSola

Scaling up by several orders of magnitude towards GW-scale electrolysis projects

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Current scale of operation

- 10 to 20MW electrolysers

Current scale of projects with, or close to, FID

- 100 to 200MW electrolysers
- (10x larger than current operation)

Project proposals and concepts

- 1 to 20GW electrolysers
- (100x and 1000x larger than current operation)

Scale up will rely on several pillars, including more people!

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Invest in TECHNOLOGY

- Ensure state-of-the-art safety of the systems
- Maintain leadership in electrolyzers and hydrogen stations

Build up strong REFERENCES

- Increase bankability of value proposition through emblematic references

Improve COMPETITIVENESS

- Grow capacities to achieve economies of scale
- Achieve cost out roadmap

Invest in PEOPLE

- Professionalize organization structure and processes
- Hire key talents and capitalize on them

McPhy

Innovating towards GW-scale electrolysis projects

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Newer electrolysis technologies are maturing

- SOE
- AEM

Additional electrolysis technologies are in sight

- Membrane-less electrolysis
- Sea water electrolysis
- Pulsed-plasma electrolysis

Green hydrogen from electrolysis is part of the team… blue hydrogen, renewable power, ammonia, e-fuels…

Many technologies will be complimentary to hydrogen in a diversified sustainable energy infrastructure

An affordable, decarbonised future will require a mix of appropriate technologies

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And the transition will be worth the investment and effort, to guarantee a sustainable future for the children of the world

Acknowledgements

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Altroleum – www.altroleum.com

McPhy – www.mcphy.com

CQSola – www.cqsola.com.au

Altroleum designs and evaluates meaningful benchmarks for emerging low carbon asset classes, including hydrogen, ammonia, synthetic fuels and carbon assets. Those metrics can be delivered instantaneously via online software or bespoke scenarios can also be considered.

McPhy produces electrolysers for the production of industrial hydrogen on-site, on demand, according to your specifications.

CQSola provides new technology to extract up to 25% more power from your Solar Farm. CQSola 1500V Solar Power Controllers convert power at 99.2% - 99.5% efficiency, and allow each panel to operate separately. This captures power from each panel individually, and combines to each string without power loss.

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