Bundesministerium Arbeit und Wirtschaft

Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie

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EUROPAS ENERGIEZUKUNFT
Sicher, leistbar, sauber!?

14.-16. Februar 2024 TU Graz, Österreich

Grüner Wasserstoff durch Elektrolyse: Wegbereiter der Energiewende in Energie, Industrie und Mobilität

Ass.Prof. DI Dr. Alexander Trattner

CEO and Research Director

Graz, 14. Februar 2023

HyCentA HYDROGEN CENTER AUSTRIA

TU Graz

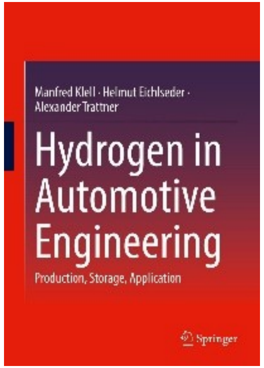
HyCentA Research GmbH – COMET K1

Austria‘s Research Center for Hydrogen Technologies

Extra-university research organization at Graz University of Technology

TU Graz FVT MAGNA OMV

- 90+ researchers from mechanical engineering, physics, chemistry, process engineering, electrical engineering
- More than 70 funding projects and 500+ industrial projects successfully completed
- More than 19 years of expertise
- State-of-the-art testing & fuelling infrastructure
- Teaching at TU Graz
- International network



Research Areas along the Entire Value Chain

The three distinguished technological areas and one cross-cutting area are closely linked and essential parts of the entire value chain research.

RESEARCH AREAS HYCENTA

!

Areas include **all steps** along the **value chain**, from production to distribution and followed by applications

HyCentA K1 COMET Centre

Area 1
Electrolysis and Power-to-X

Material research, new electrolysis technologies, alternative processes (from materials to industrial applications)

Area 2
Green Energy and Industry

Storage and distribution (gas storage, hydrides etc.), electrochemical compression, stationary fuel cells, safety

Area 3
Green Mobility

Fuel cell research on materials, cell, stack and system; optimisation of entire powertrain system including hydrogen storage

Area 4
Circularity and System Optimisation

Measurement and testing technologies, controls, diagnostics, modelling and simulation “digital twin”

Overview Hydrogen - Worldwide

- Around 100 million tonnes per year are currently produced worldwide
- 8 EJ ≙ around 2 % of total global energy consumption
- Market volume of around USD 183 billion (2022)
- Around 40 % comes from industrial processes as a by-product
- The remaining 60 % is produced: 95 % from hydrocarbons and 5 % from electricity

SHARE OF PRIMARY ENERGY SOURCES IN GLOBAL HYDROGEN PRODUCTION

Quelle: Shell Studie

Grey Hydrogen in AUT – Steam reforming

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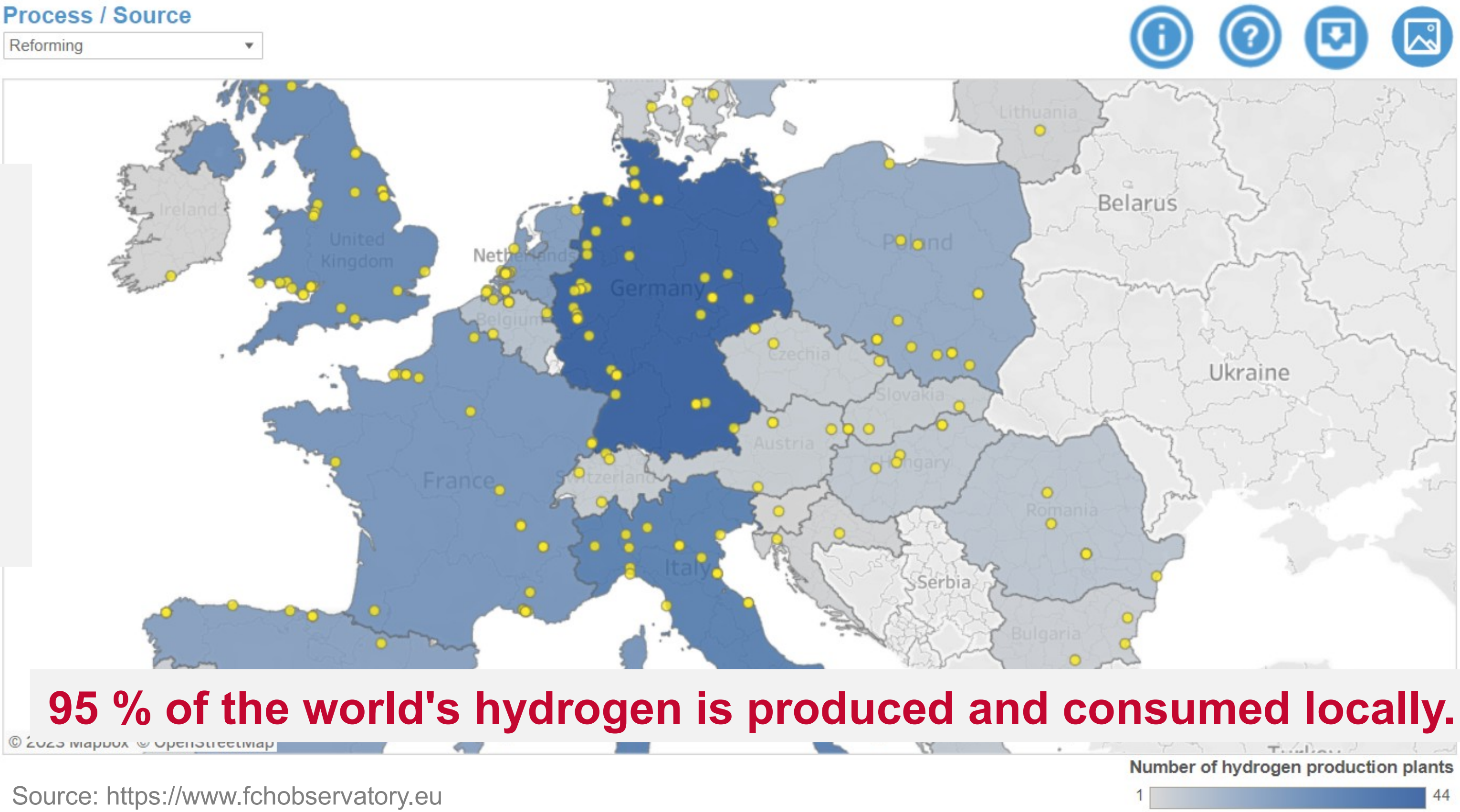
2020:
Austria
433 t/day

3 large-scale steam reformers



95 % of the world's hydrogen is produced and consumed locally.

Source: https://www.fchobservatory.eu

Overview of H2 in Industry - Austria

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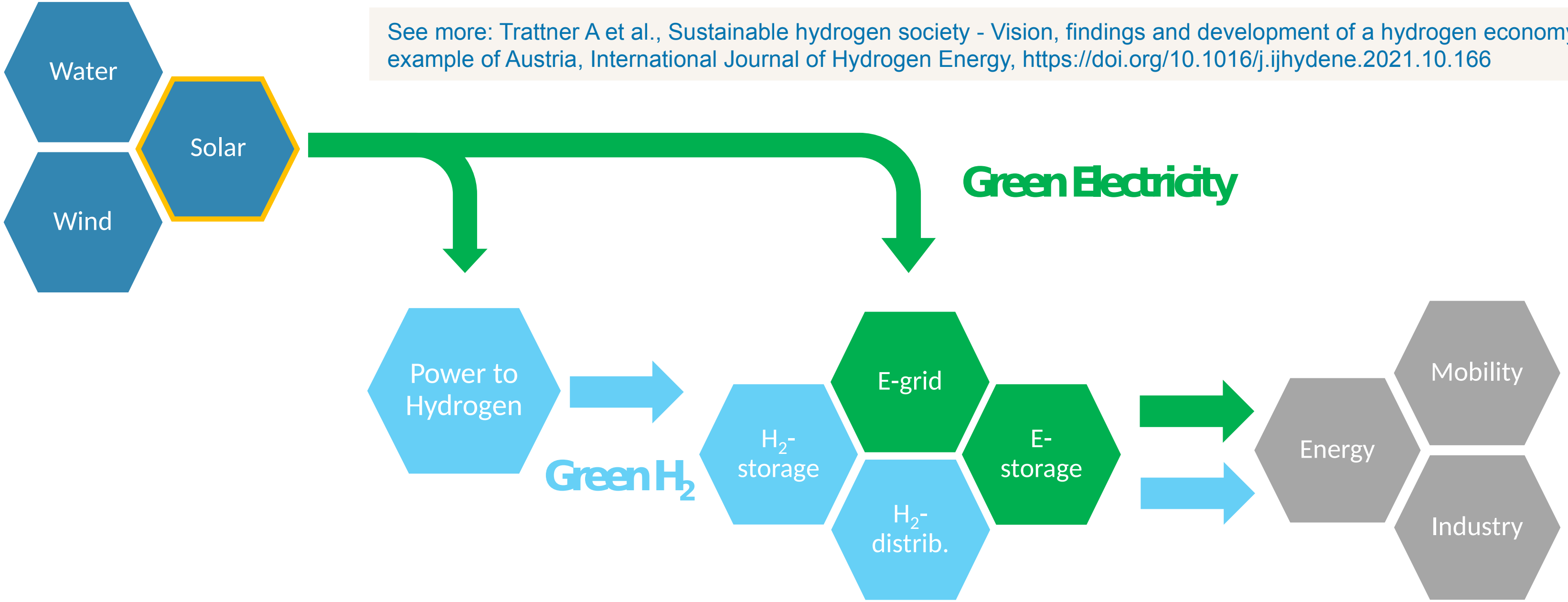
- Currently, the annual hydrogen demand of industry in Austria (primarily in the chemical and petrochemical industry) is **around 140,000 tonnes** (source: H2 Strategy AUT), which is produced from fossil sources (natural gas).
- **140,000 tonnes** = **5.6 TWh** (calorific value) ▭ 1.4 % share in the primary energy system (approx. 400 TWh)
- Would correspond to an **electrolysis capacity of approx. 830 MW** (8000 h/a - 70% efficiency)
- **Goal = 1 GW in Austria until 2030**

Hydrogen – a Key to the Energy Transition

See more: Trattner A et al., Sustainable hydrogen society - Vision, findings and development of a hydrogen economy using the example of Austria, International Journal of Hydrogen Energy, https://doi.org/10.1016/j.ijhydene.2021.10.166



Integration of renewables
- Integrate production surpluses
- Direct water splitting

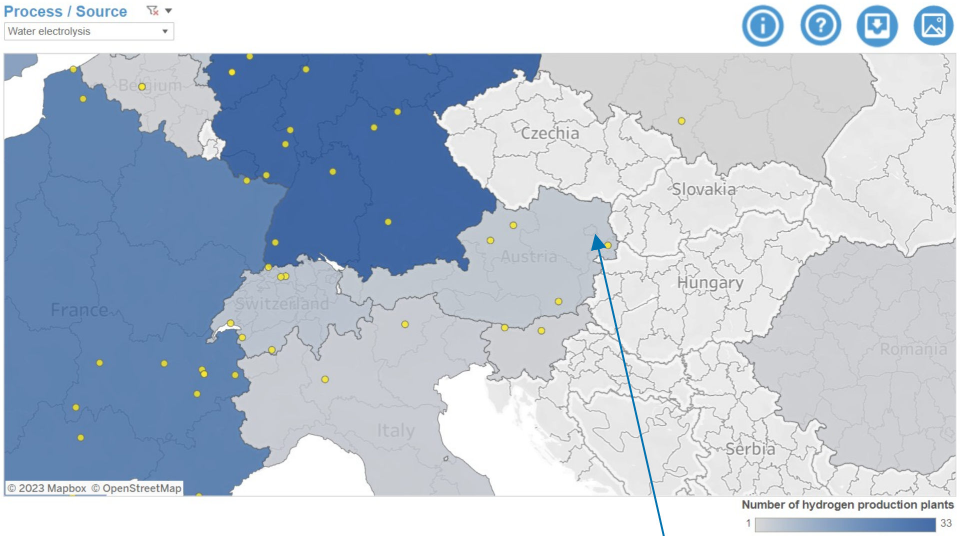
Energy conversion
- Electrolysis - compensate temporal volatility
- H2 as secondary energy carrier – energy storage

Storage and distribution
- Centralized and decentralized storage
- Long-term storage
- Efficient transport over long distances

Zero Emission Usage
- Energy Services – CHP
- Mobility with Fuel cells
- Industry and high-temperature processes

Green Hydrogen in AUT - Electrolysis

- H2FUTURE, Linz OÖ, 6 MW PEM
- USC, Pilsbach OÖ, 0,5 MW AEL
- HotFlex, Mellach Stmk., 0,15 MW SOEC
- RNG, Gabersdorf Stmk., 1 MW PEM
- SolHub, Herzogenberg NÖ, 0,3 MW PEM
- Demo4Grid, Völs T, 3,2 MW AEL
- USS2023, Gampern OÖ, 2 MW PEM
- HySnow, Hinterstoder OÖ, 0,01 MW AEM



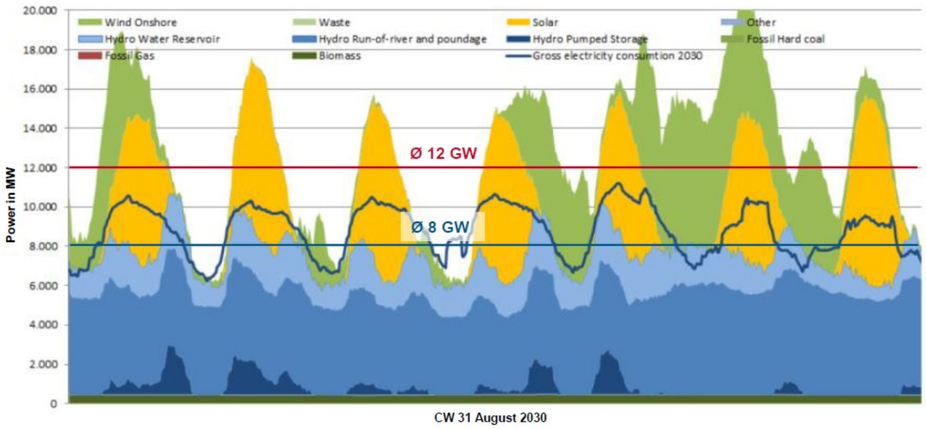
~ 13 MW installed, 12 MW in erection, >400 MW planned

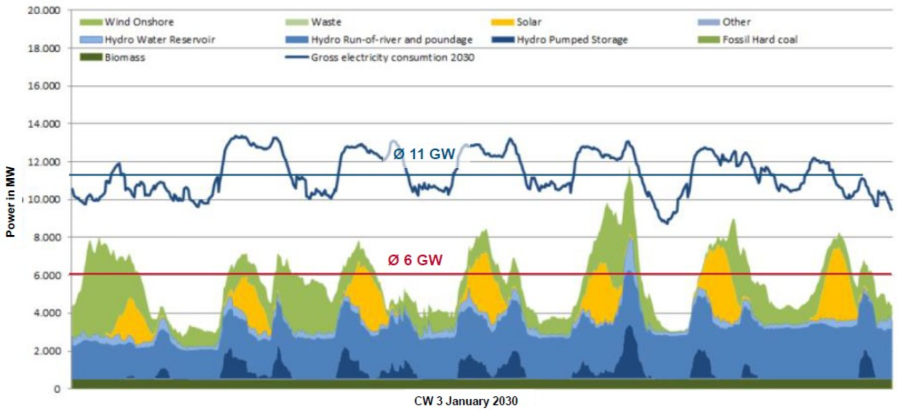
Goal 2030 ⇒ 1 GW

10 MW in erection at refinery **OMV** (Austria's largest PEM plant)

Challenge – Renewable Electricity AUT 2023

- **What does "only" on-balance renewable electricity mean in 2030?**
  - 4 GW too much in summer
  - 4 to 5 GW too little in winter





Quelle: AEA

- **Chemical energy storage systems are needed to cover this energy gap** as well as **imports.**

Historical alkal. Electrolysis Plants

Rjukan, Norway:

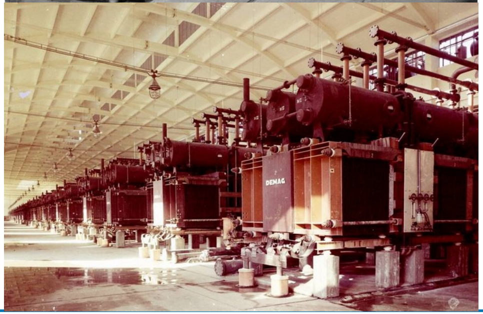
- **1927 - 1991** operated by Norsk Hydro (today: NEL)
- **125 MW** (27.900 Nm³/h) for Ammonia synthesis
- Electricity from hydro power

Glomfjord, Norway:

- **1947 - 1991** operated by Norsk Hydro (today: NEL)
- **380 MW** (84.000 Nm³/h) for Ammonia synthesis
- Electricity from hydro power

Aswan, Egypt:

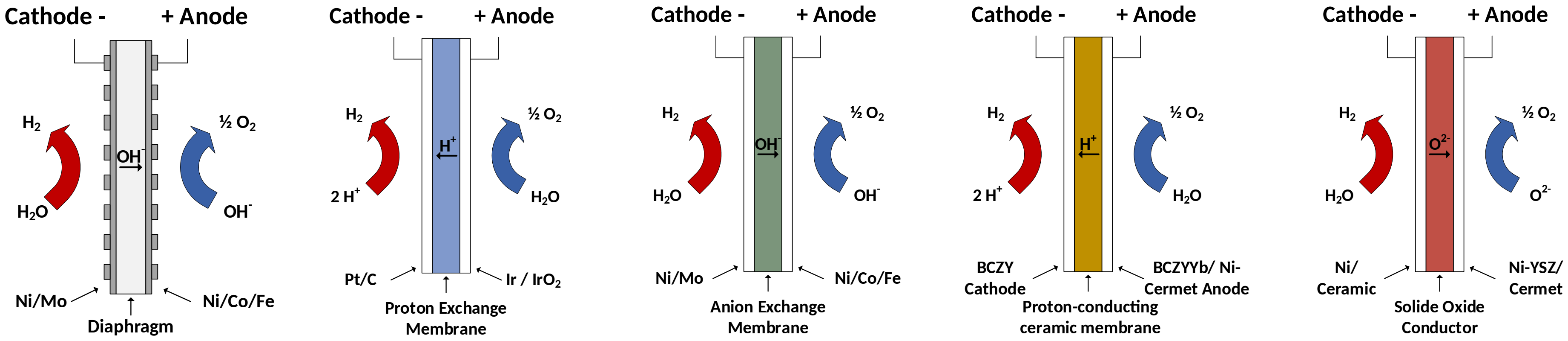
- **1977** build by Brown Boveri
- **162 MW** (32.400 Nm³/h) for Ammonia synthesis
- Electricity from hydro power Aswan dam



Source: Hydrogen Production by Electrolysis Wiley VCH

Electrolysis technologies

	AEL	PEM-EL	AEM-EL	PCC-EL	SO-EL
	Alkaline Electrolysis	Proton Exchange Membrane Electrolysis	Anion Exchange Membrane Electrolysis	Proton-Conducting Ceramics Electrolysis	Solid Oxide Electrolysis
Electrolyte	alkaline liquid	acidic solid	alkaline solid & liquid	H^+-conducting ceramic	O^{2-}-conducting ceramic
Temperature	70 - 95 °C	60 - 80 °C	40 - 80 °C	400 - 700 °C	700 - 1000 °C



Market development in electrolysis

Workhorse = Alkaline electrolysis

Racehorse = PEM electrolysis

Circus horse = SO electrolysis

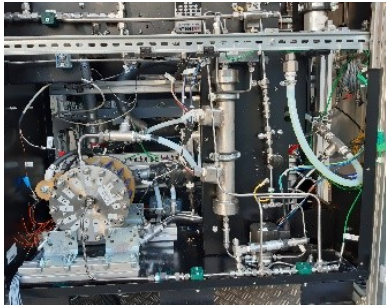
Foal = AEM electrolysis

In progress = PCC electrolysis

One-stop-shop Electrolyzer Development

Catalyst ink preparation

PEM Single Cell Test Bench

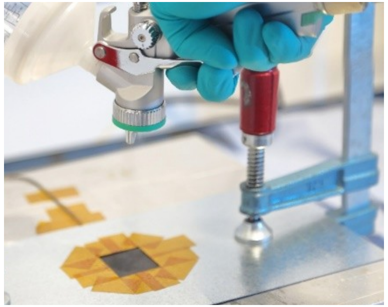


Stack Test Bench

System Test Bench

Component Manufacturing → Single Cell Testing → Stack Testing → System Testing

Electrode Manufacturing



AEM Single Cell Test Bench

Stack Test Bench

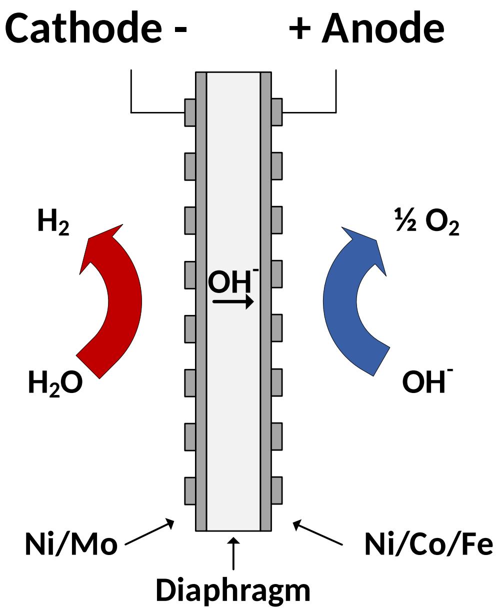
Gas Analysis

AEL Electrolysis

+ Low CAPEX
+ Low O&M cost
+ High durability
+ Mature and established technology in MW scale (TRL 9)
+ High recyclability of Ni based catalyst → no shortage

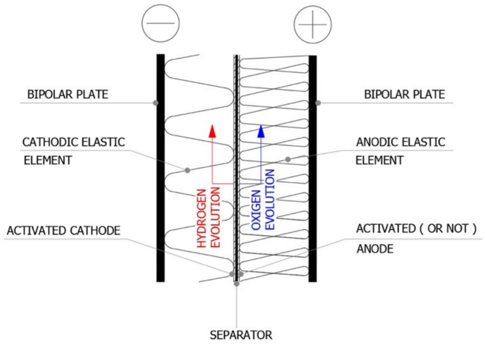
Atm. / sym. Pressurized – Anode under pressure
Spec. energy consumption: 50 – 60 kWh/kg @ 100 % power

- Problematic at low partial load operation (min. 15 – 30 %)
- Acc. to reviews: Lower gas quality (comparison with PEM)
- More space required (100 m^2/MW)

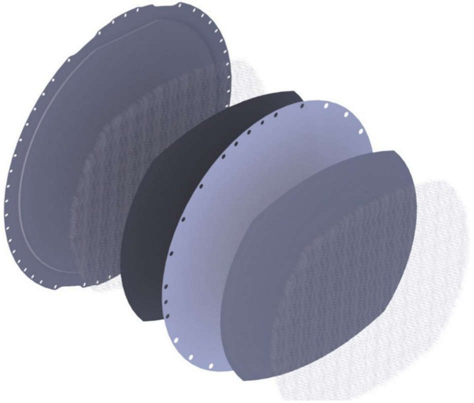


Activities in AEL

- **Stack and system evaluation and development**
- **Studies on degradation mechanisms**
- **Development and testing of cell components**



affected material	location: anode	location: cathode	location: diaphragm	location: BPP	influencing factors	severity	mechanism	consequences	causes of voltage loss: anode (OER +el)	causes of voltage loss: cathode (HER + el)	causes of voltage loss: electrolyte	causes of voltage loss: BPP	causes of voltage loss: bubbles
Ni Ni alloys	■			■	Cl^- impurities	3	oxidation of Cl^- beyond OH^- limiting current to Cl_2, that is highly corrosive to metals	electrode material decay and changes of its structure	■				■
stainless steel				■	very high current density	3		degradation of BPP and its coating				■	
Ni Ni alloys	■	■			long-time operation	2	dissolution of metal and metal compounds until its solubility product is reached. Further reactions of the ions are possible	minor electrode decay	■	■			■
ZrO_2 /PSU			■					BPP degradation esp. passive layer				■	
stainless steel				■	high temperatures	3	chemical degradation of polymers	decay diaphragm (ZrO_2, binder and support)			■		

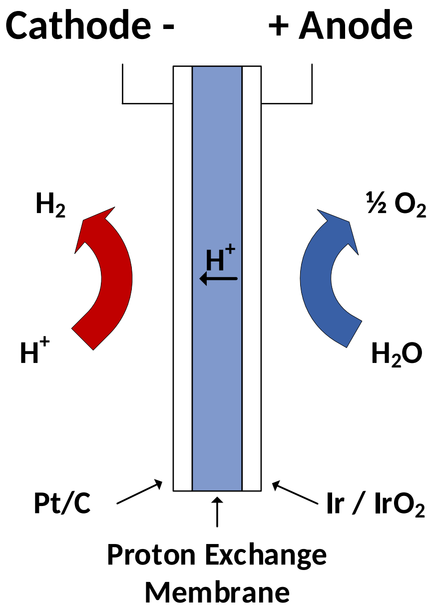


PEM Electrolysis

+ Highly dynamic (cold start ramp time: 60 s)
+ Operation on low partial load possible (5 – 10 %)
+ Compact design
+ Allows differential pressure and higher pressure for product gas (80 bar)
+ High gas purity (5.0 after drying and DeOxo)

Spec. energy consumption: 54 – 65 kWh/kg @ 100 %power

- Costs for catalysts (Iridium) are expected to increase
- High CAPEX and higher OPEX (stack replacement)
- Membrane on PFAS-basis (per- and polyfluoroalkyl substances) ⇒ Emission rate from stack and system

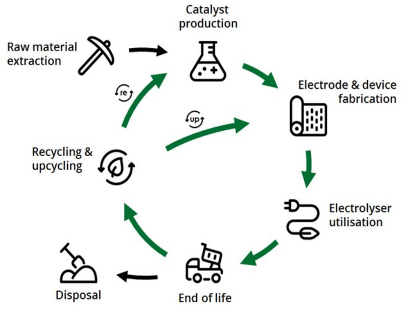


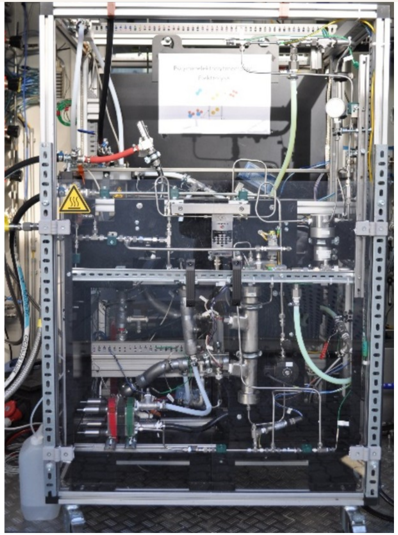
Project Recycalyse 2020 – 2023

RECYCALYSE aims to develop new electrocatalysts for PEM electrolyser systems with increased performance, reduced critical raw material usage, reduced environmental footprint and reduced total costs.

See more: Dr. Julia Melke et al., Recycalyse – New Sustainable and Recyclable Catalytic Materials for Proton Exchange Membrane Electrolysers, https://doi.org/10.1002/cite.202300143

- Process development for large scale recycling of the critical raw materials
- Application of sustainable materials derived from earth abundant elements
- Implementation of a circular economy in which the CRM will be recovered and regenerated
- Analysis of the entire value chain from catalyst manufacturing to system integration and demonstration, end-of-life recycling and supply of raw materials for the catalyst manufacturing





Project wind2hydrogen 2014 – 2017

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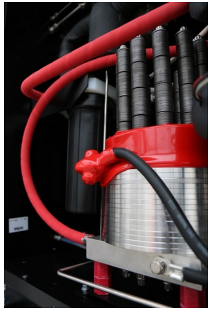
- Conversion of renewable electricity into hydrogen for storage purposes and transport into the existing natural gas grid
- Development of a dynamic high pressure PEM electrolyzer (163 bar)
- Construction of a 100 kW pilot plant
- Operative experiences of a power-to-gas plant with real life load cases of renewable energy and feed-in of H_2 into the natural gas grid
- Production of green hydrogen for H_2 mobility

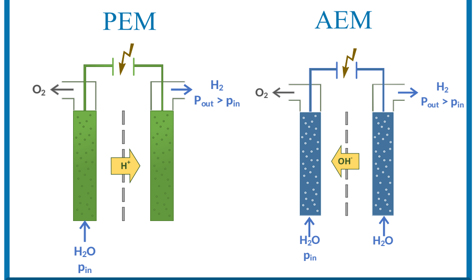


OMV EVN Fronius ENERGIE INSTITUT powered by klima+ energie fonds

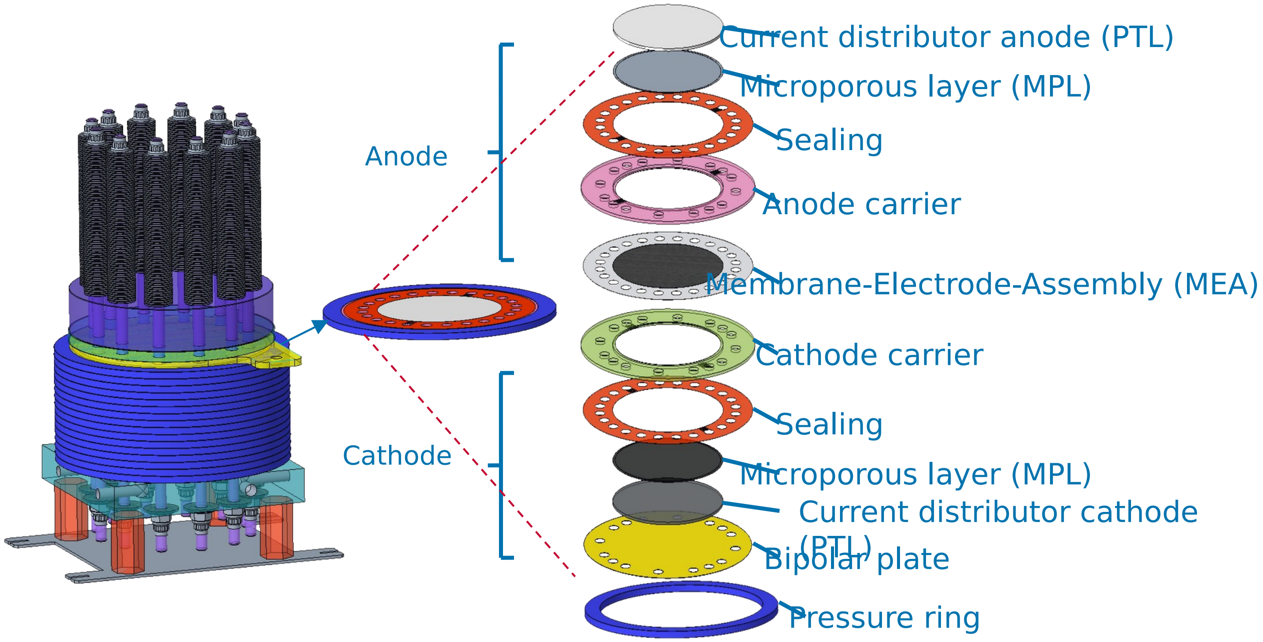
Energy Globe STYRIA AWARD 2017

High Pressure Electrolysis

High Pressure Electrolysis – HPEL



- H_2O-supply with low pressure p_{in}
- p_{in} > atm ⇒ η ↑
- Δp accross membrane
- H_2-output $p_{out} > p_{in}$
- O_2-input bei p_{in}

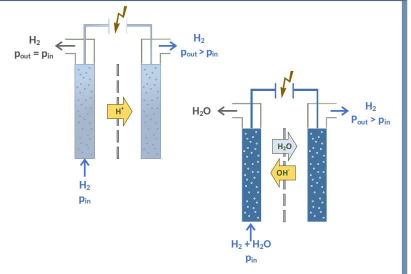


See more: Sartory, M., Wallnöfer-Ogris, E., Salman, P., Fellinger, T., Justl, M., Trattner, A., Klell, M.: “Theoretical and Experimental Analysis of an Asymmetric High Pressure PEM Water Electrolyser up to 155 bar”, International Journal of Hydrogen Energy, 2017.

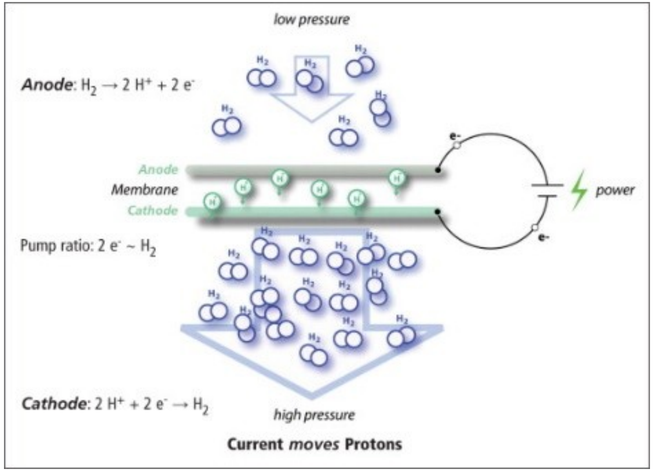
Electrochemical Compressor (EHC)

Compact, modular and efficient compression with high efficiencies and no moving parts (noise) & purification

Electrochemical Hydrogen Compression – EHC

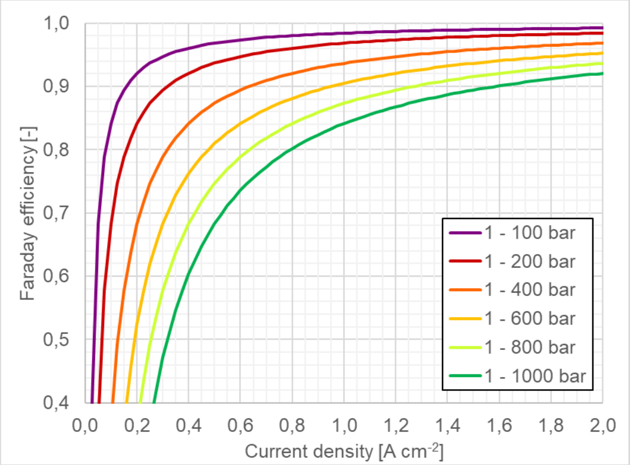


- H_2 supply at atmospheric or low pressure p_{in}
- Δp across membrane
- H_2 at $p_{out} > p_{in}$
- Possible with PEM or AEM



Source: HyET

- Humidification of supplied hydrogen
- Optimised stacking
- Durable seal concepts
- Integration in H_2 systems and infrastructure



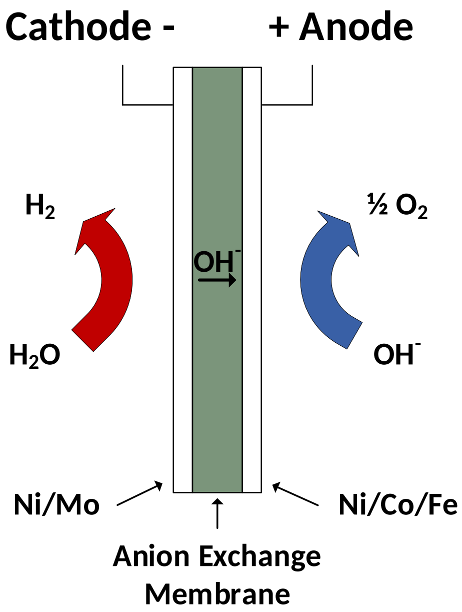
Source: HyCentA, on-going PhD Michael Richter

AEM Electrolysis

+ Capable of partial load operation
+ Compact design
+ Differential pressure
+ Low CAPEX
+ non-PGM catalysts
+ High recyclability of Ni based catalyst ⇒ no shortage

Spec. energy consumption: 60 kWh/kg @ 100 % power

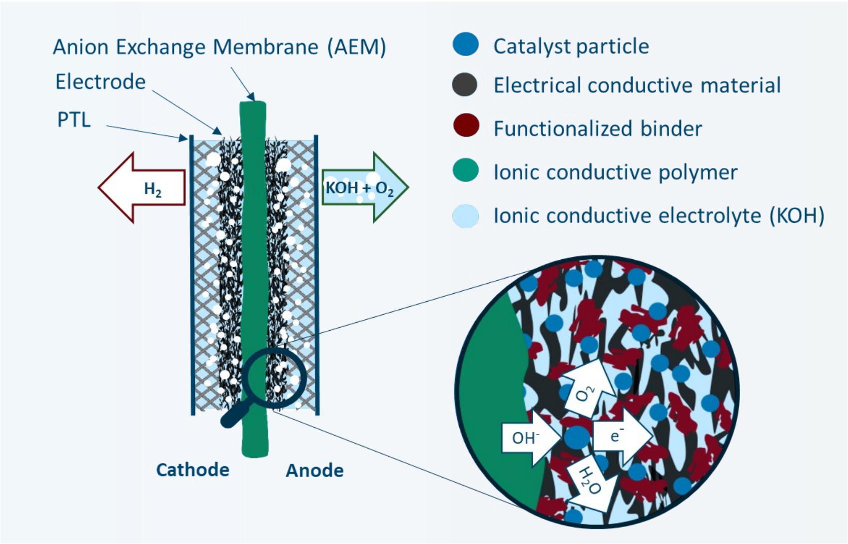
- Far from MW scale
- Lifetime of membrane



Project AEM Neo 2022 – 2024

Modification of inner layer with ionically conductive polymers to increase performance

- Systematic experiments generate a comprehensive understanding of the transport mechanisms
- Fabrication of electrodes with modified polymers and the subsequent characterization of the electrodes in the assembled cell
- Chemical-physical analysis of the electrode is performed to identify degradation effects and mechanisms

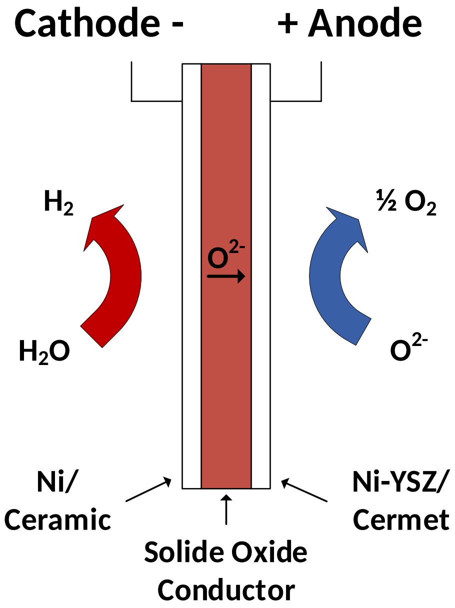


SO Electrolysis

+ Low specific energy consumption (40 kWh/kg @ rated power; heating not included, requires additional 10 kWh/kg)
+ Yttrium stabilized zirconia – no critical mineral
+ Economically favorable where waste heat is available

High operation temperature 700 – 1000 °C
TRL: 7
Needs further development to become reliable technology

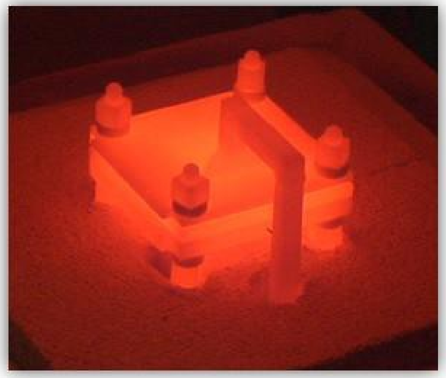
- Low dynamic (cold start ramp time: 12 h)
- Low partial load operation possible (5 %)
- Lifetime
- Stack size



COMET Project – CoGen 2023 – 2026

Optimisation of SOEC-technology for long-time implementation and higher power classes, including CO_2- and Co-Electrolysis

- **SOEC testing**
  - Single cell testing and optimization
  - Co- and CO_2-electrolysis for different application scenarios
  - Benchmarking of different materials
  - Short stack testing (up to 3 kW)
- **Optimization by simulation**
  - Thermal management and system integration
  - BoP components
  - Control strategies and grid integration



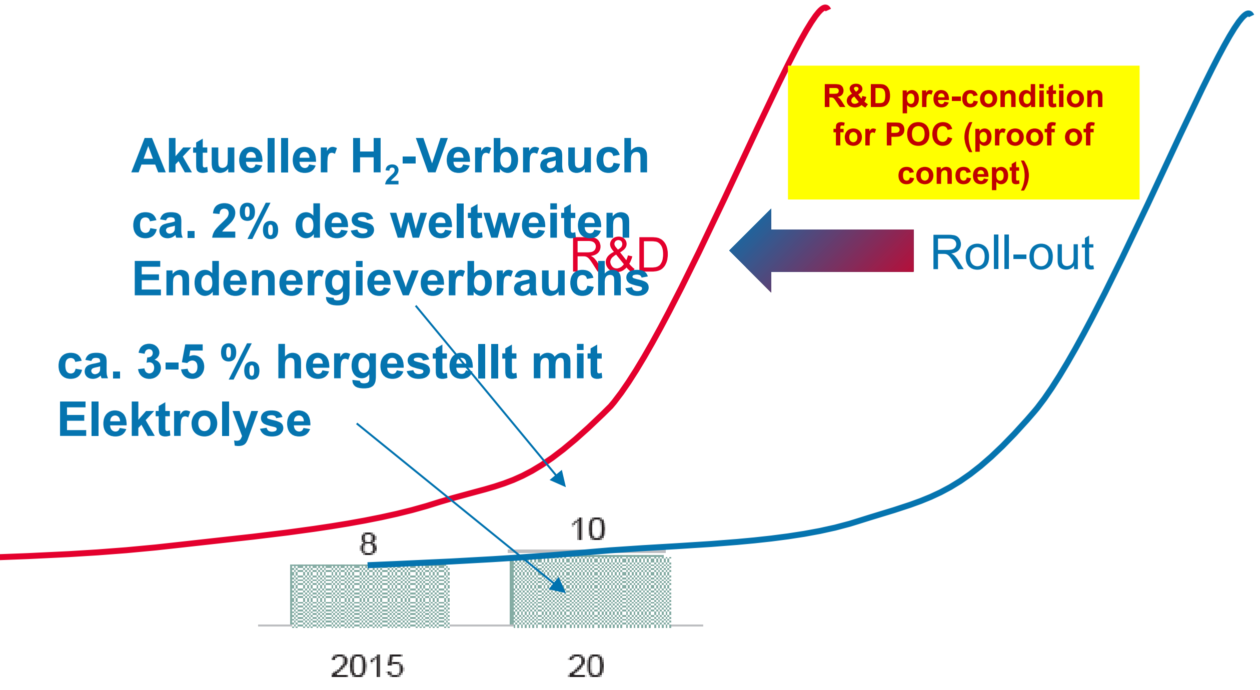
Source: IWT, TU Graz

Wasserstoffwirtschaft

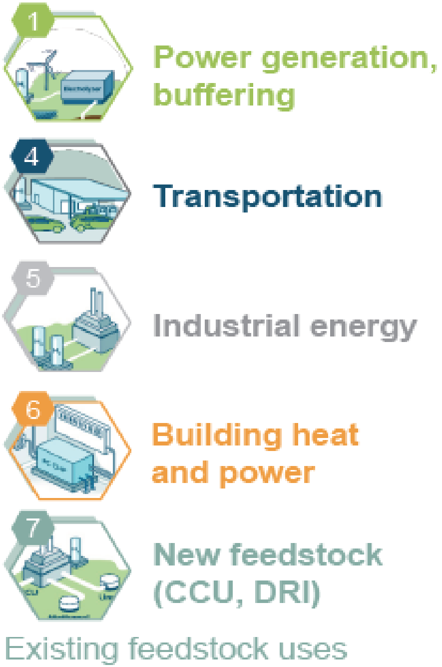
"H_2 weist ein langfristiges Potenzial von 20-30 % aller Energieträger auf"

Aktueller H_2-Verbrauch ca. 2% des weltweiten Endenergieverbrauchs

ca. 3-5 % hergestellt mit Elektrolyse

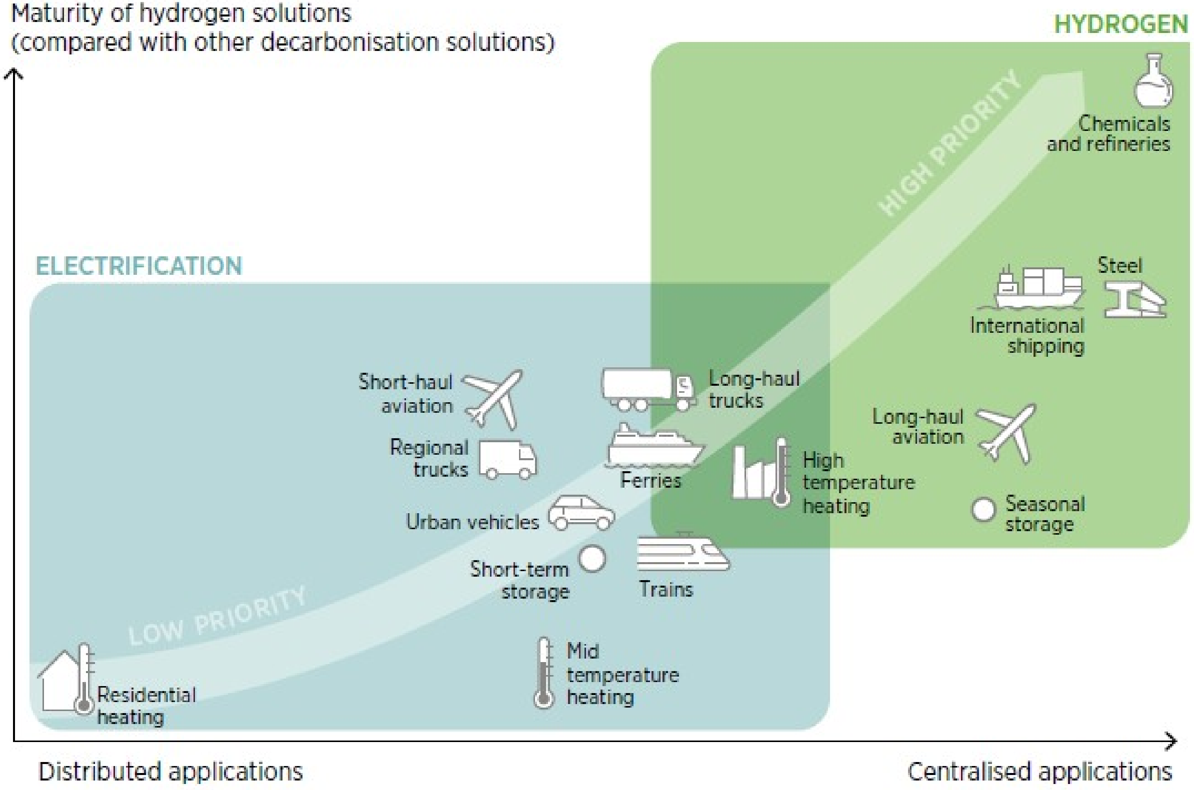


Global energy demand supplied with hydrogen, EJ



Marktprognose des Hydrogen Council
Quelle: https://hydrogencouncil.com/en/

Suitable application areas Hydrogen



Source: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jan/IRENA_Geopolitics_Hydrogen_2022.pdf

Chancen für Österreich

- **Nachhaltige Energieversorgung: Die Investitionen in Wasserstofftechnologien unterstützen den Übergang zu einer kohlenstoffarmen Wirtschaft.**
- **Steigerung der Effizienz:**
  Elektrochemie erreicht hohe Wirkungsgrade
- **Innovationsführerschaft: Entwicklung neuer Wasserstofftechnologien forcieren. Dies würde die Wettbewerbsfähigkeit der österreichischen Industrie auf dem globalen Markt stärken und könnte zur Entwicklung von Patenten und einzigartigen Technologien führen.**
- **Wirtschaftswachstum und Arbeitsplätze: Die Entwicklung von Wasserstofftechnologien kann zur Schaffung neuer Arbeitsplätze in Forschung, Entwicklung, Produktion und Wartung führen. Dies fördert das wirtschaftliche Wachstum und die technologische Entwicklung in Österreich.**
- **Exportpotenzial: Hochentwickelte Wasserstofftechnologien haben ein großes Exportpotenzial.**
- **Netzwerk- und Partnerschaftsmöglichkeiten: Die Zusammenarbeit in F&E-Projekten kann Partnerschaften zwischen Universitäten, Forschungseinrichtungen, Industrie und der Regierung stärken.**
- **Weniger Energieabhängigkeit: Die Entwicklung einheimischer Wasserstoffproduktionskapazitäten könnte Österreich weniger abhängig von Energieimporten machen, insbesondere in Zeiten geopolitischer Unsicherheit.**

Source: https://sdgs.un.org/goals

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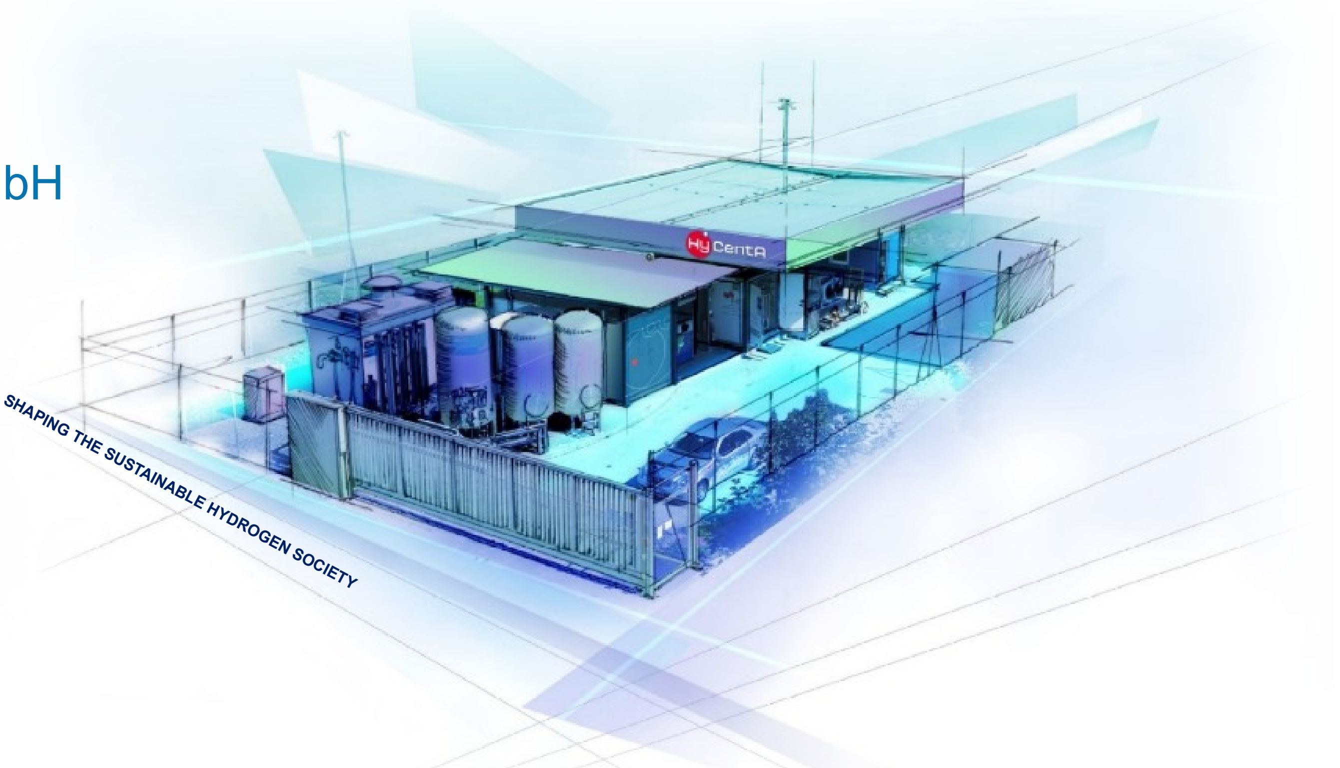

The COMET Centre is funded within COMET – Competence Centers for Excellent Technologies – by BMK, BMAW as well as the co-financing federal provinces Styria, Upper Austria, Tyrol and Vienna. The COMET programme is managed by FFG. www.ffg.at/comet