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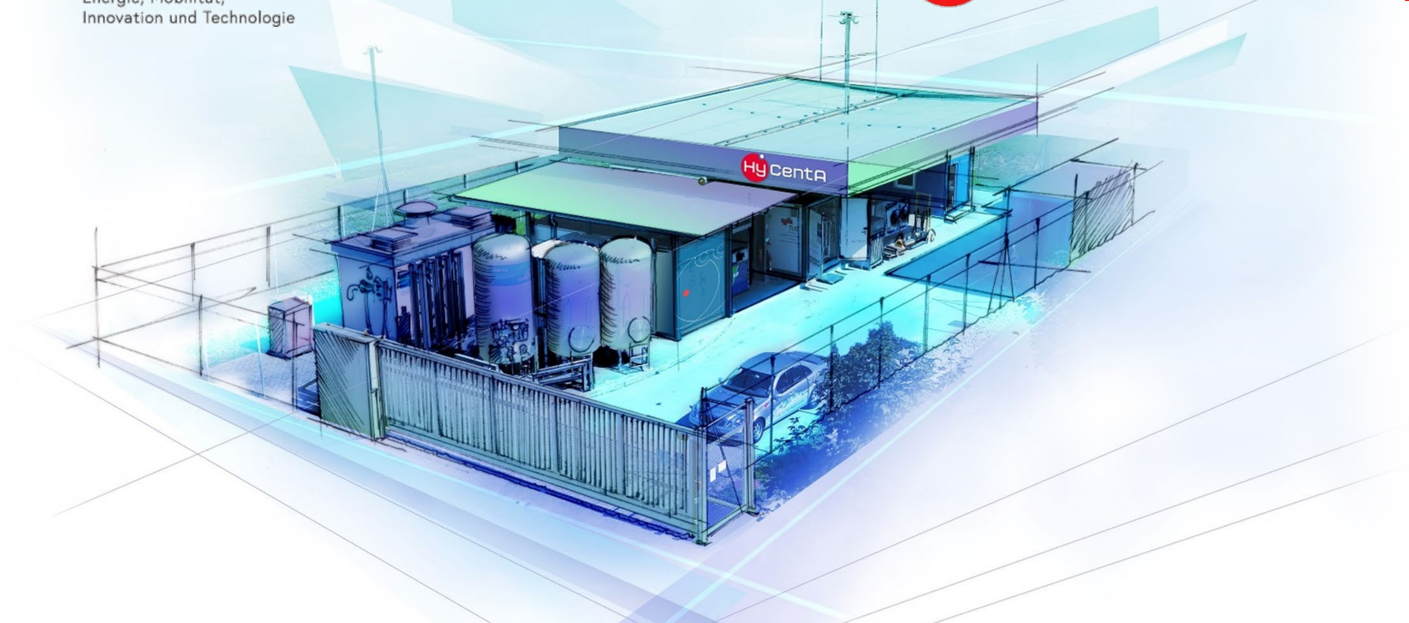


H_2 – der Stoff, aus dem die Zukunft entsteht?

Ass.Prof. DI Dr. Alexander Trattner

CEO and Research Director

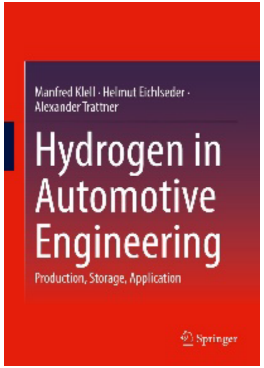
Graz, 30. September 2024

HyCentA Hydrogen Center Austria · TU Graz

HyCentA Research GmbH – COMET K1

Austria's Research Center for Hydrogen Technologies

- **100+ researchers from mechanical engineering, physics, chemistry, process engineering, electrical engineering**
- **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**

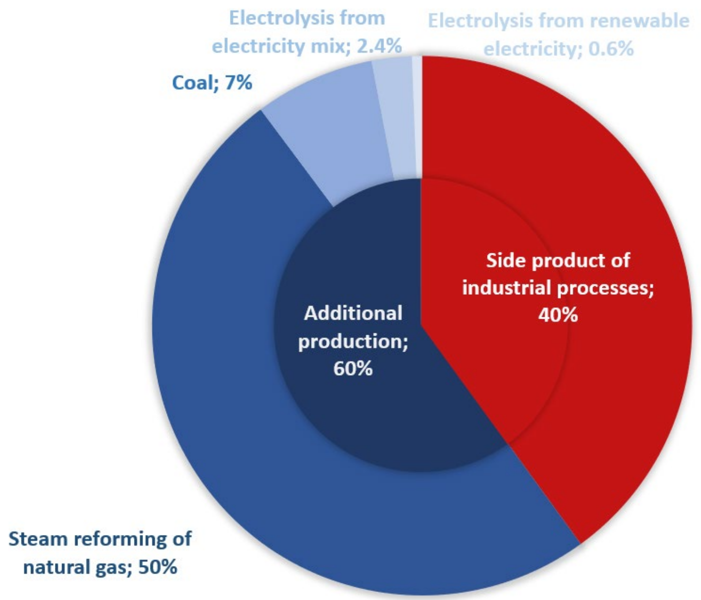


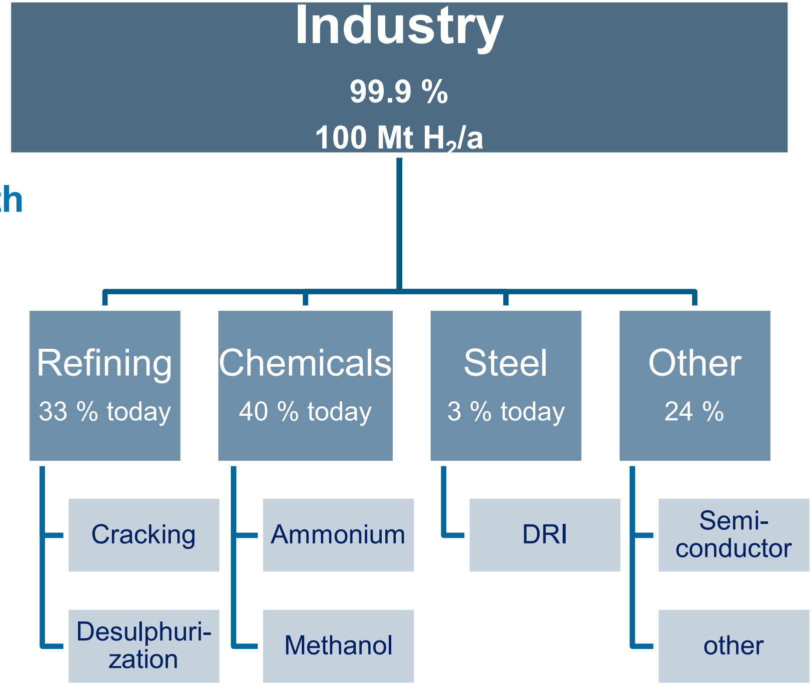
Extra-university research organization at Graz University of Technology

TU Graz FVT MAGNA OMV

Hydrogen production today

- **Annual global demand of 100 Mio. t**
  - 8 EJ corresponds to **2 % of the total global energy demand every year**
- **Market volume of 183 Mrd. USD (2022) ~ 5,5 % growth**





Source: IEA, The future of hydrogen, 2019

Extensive growth of electrolyzer market!

Grey Hydrogen in AUT – Steam reforming

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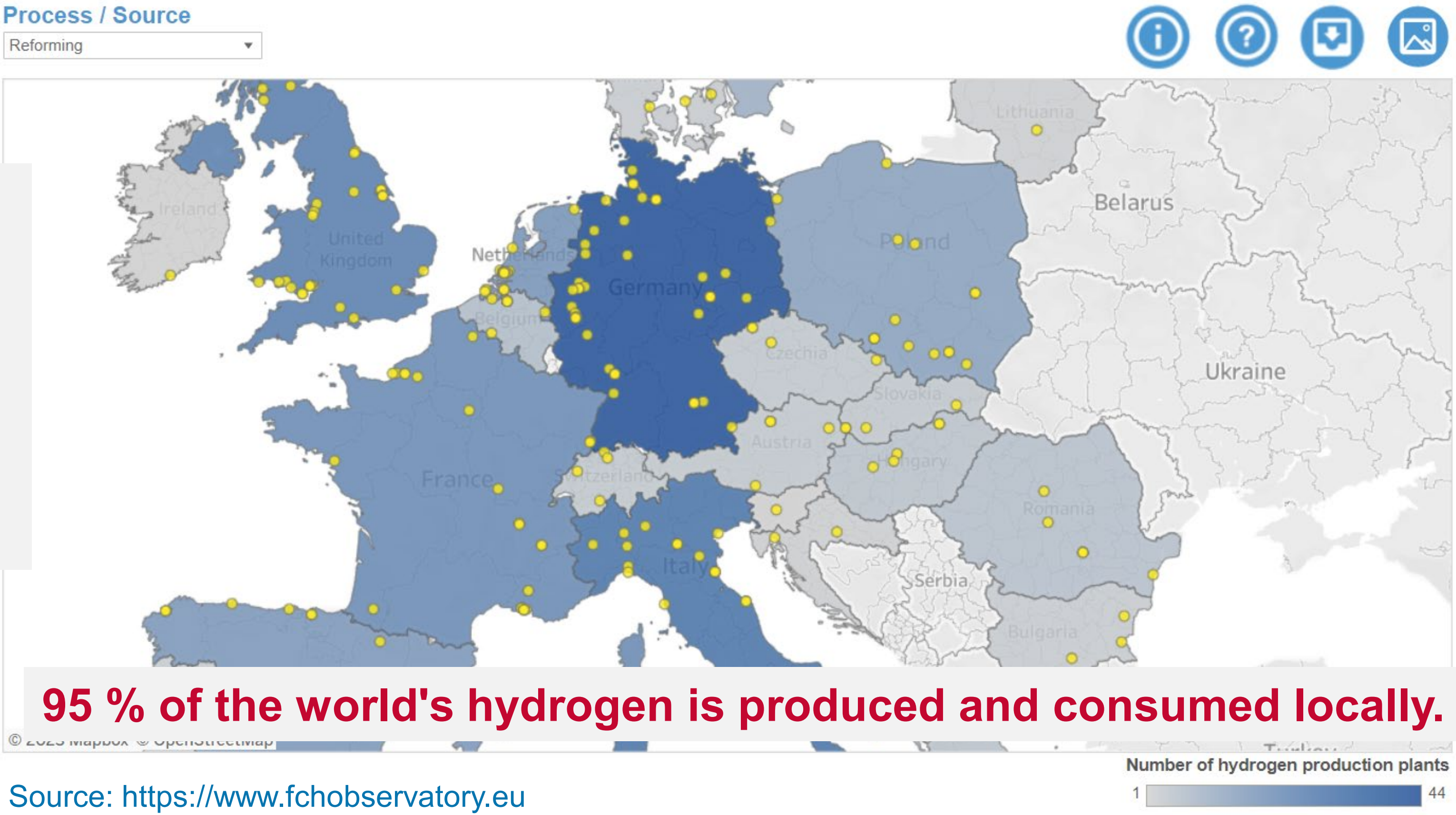
2020:
Austria
433 t/day

3 large-scale steam reformers



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

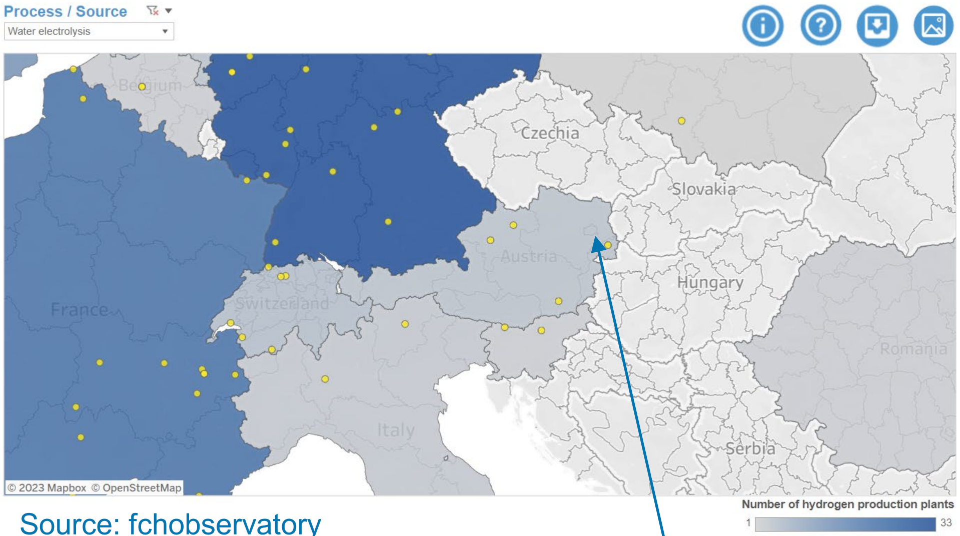
Source: https://www.fchobservatory.eu

Overview of H_2 in Industry - Austria

- Currently, the annual hydrogen demand of industry in Austria (primarily in the chemical and petrochemical industry) is **around 140,000 tonnes** (source: H_2 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)

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
- Wien Energie, 3 MW PEM
- H2Pioneer, K, 2 MW PEM



Source: fchobservatory

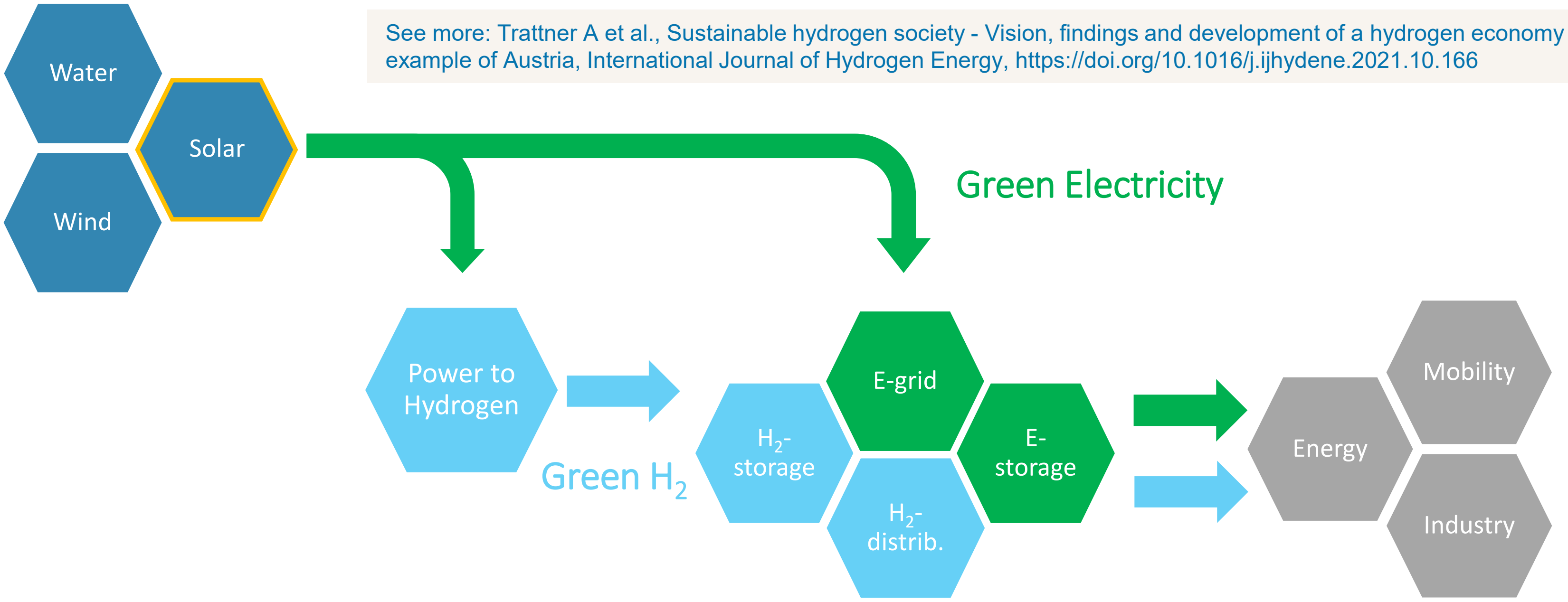
~ 18 MW installed, 12 MW in erection, >400 MW planned

Goal 2030 → 1 GW

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

Hydrogen – 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

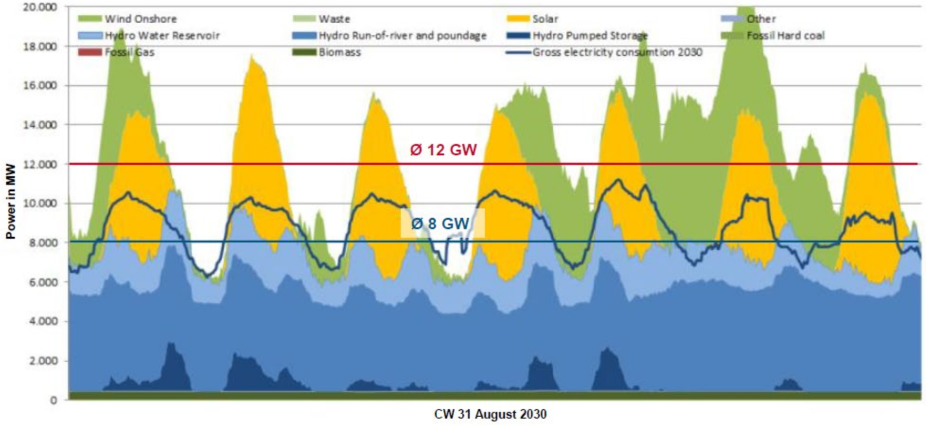
Energy conversion
- Electrolysis - compensate temporal volatility
- H2 as secondary energy carrier – energy storage

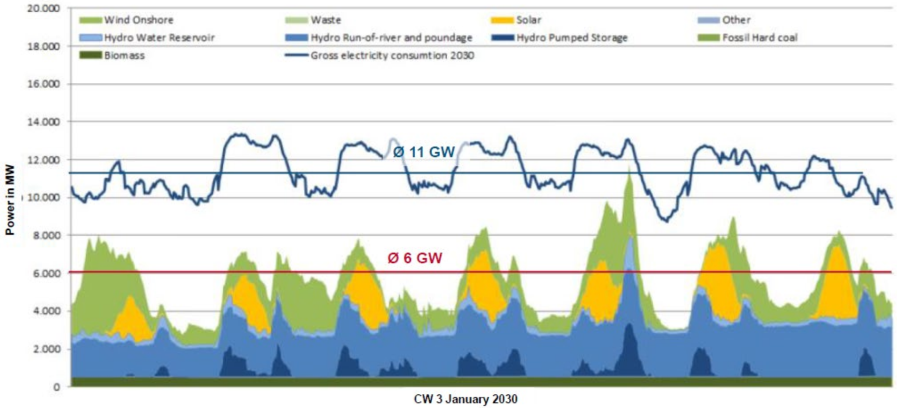
Storage and distribution
- Centralized and decentralized storage
- Long-term storage
- Efficient transport over long distances

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

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

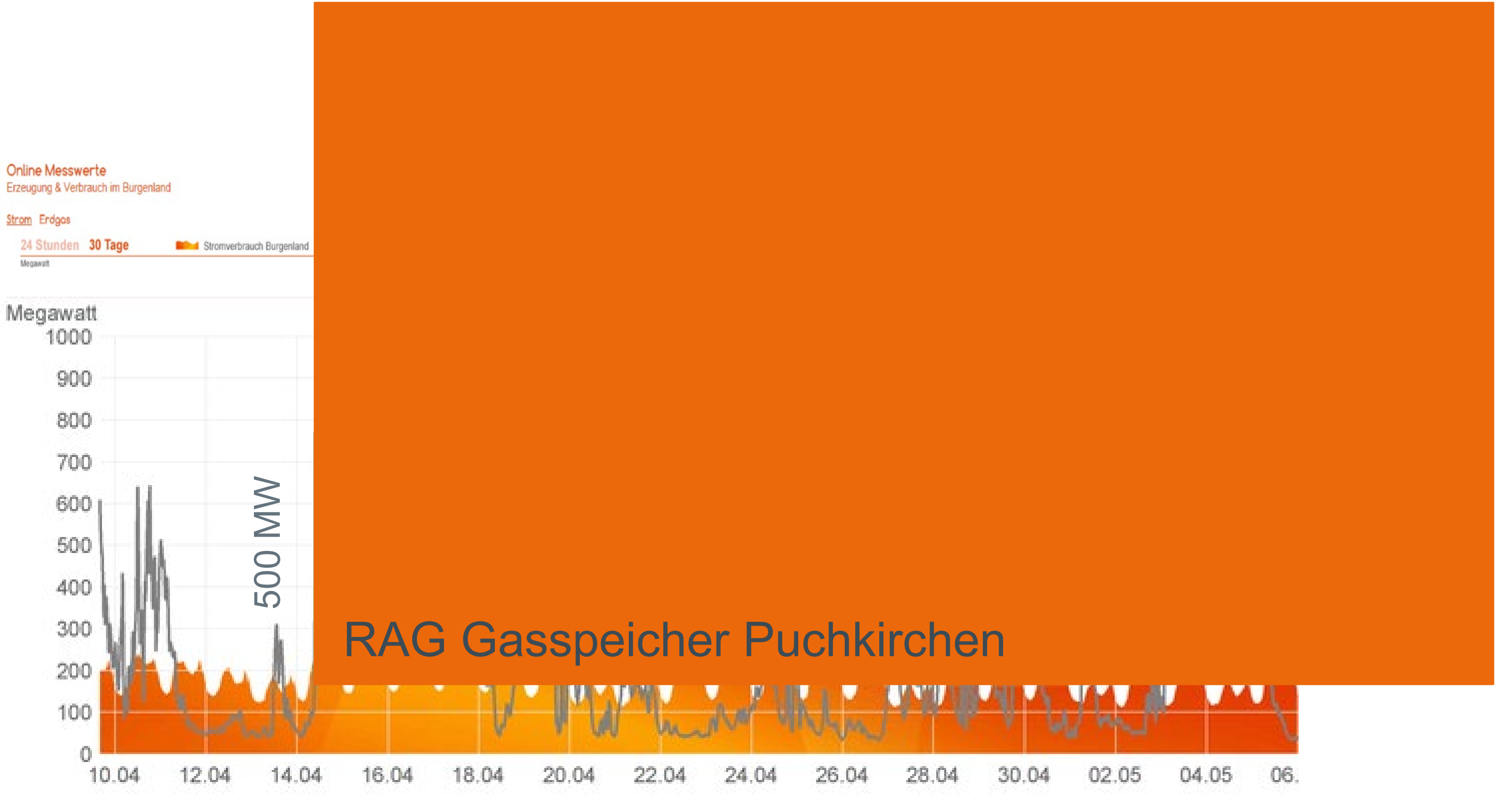




Quelle: AEA

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

H_2 als Energiespeicher



Quelle: RAG, Bauer, Mitteregger

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

Herausforderungen

- **Große Lücke zwischen “Willingness to pay” und Gestehungskosten von grünem Wasserstoff**
  - Sektorkopplung von Mobilität und Industrie beschleunigt den Markthochlauf
- **Beide Versorgungspfade** aus Sicht von AUT **verfolgen**:
  1. Import von H2
  2. Teilweise vor Ort Produktion in AUT mit mittelgroßen Anlagen 10-500 MW Anlagen

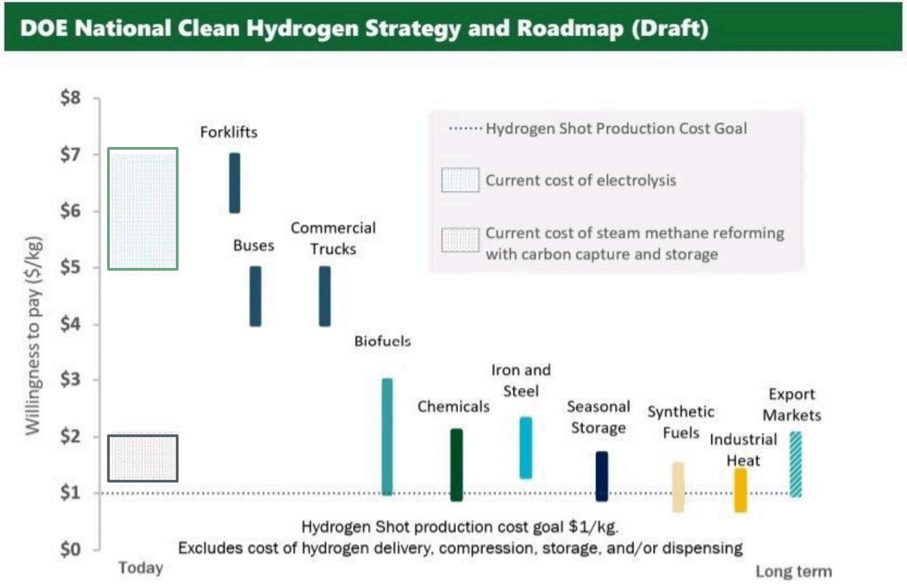
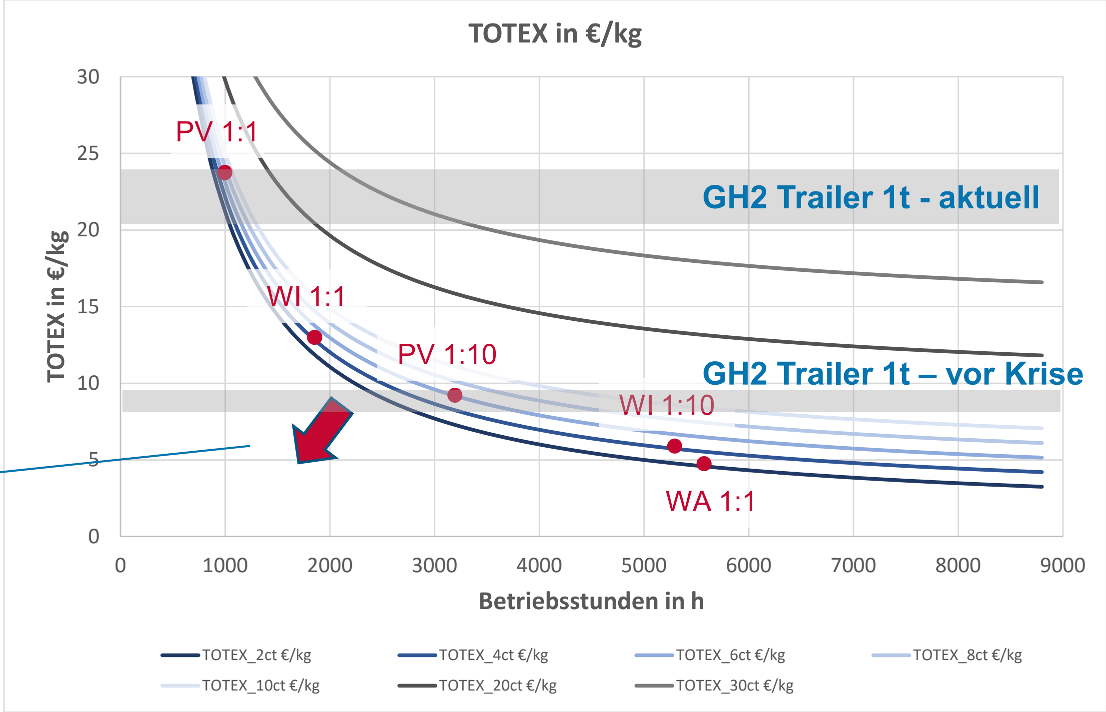


Figure 10: Willingness to pay, or threshold price, for clean hydrogen in several current and emerging sectors (including production, delivery, and conditioning onsite, such as additional compression, storage, cooling, and/or dispensing).[48]

Quelle: DOE, USA

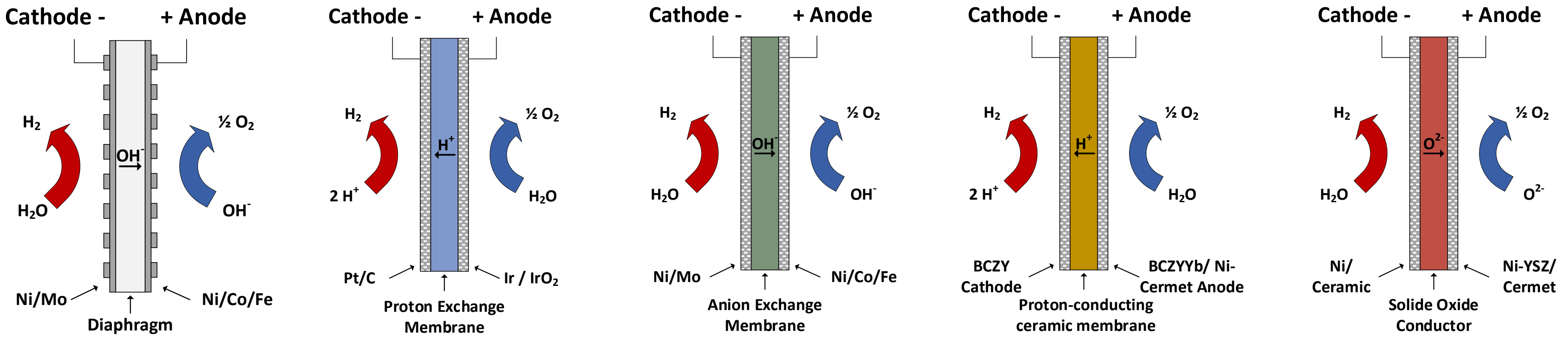
Herausforderungen

- **Gestehungskosten von erneuerbarem Wasserstoff**
  - Beispiel Elektrolyse in AUT
    - Investition 3 M€/MW bei Größen ~ 10 MW (1,6 M€/MW f. Ely.)
    - 8 Jahre Abschreibung
    - Inkl. Wartung etc.
    - Keine Speicher berücksichtigt
- **Investitionskosten müssen durch Industrialisierung und F&E sinken**
- **Scale-up / Größere Anlagen**
- **Bewirtschaftung von Gegenden mit hohen erneuerbaren Potenzialen**



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



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

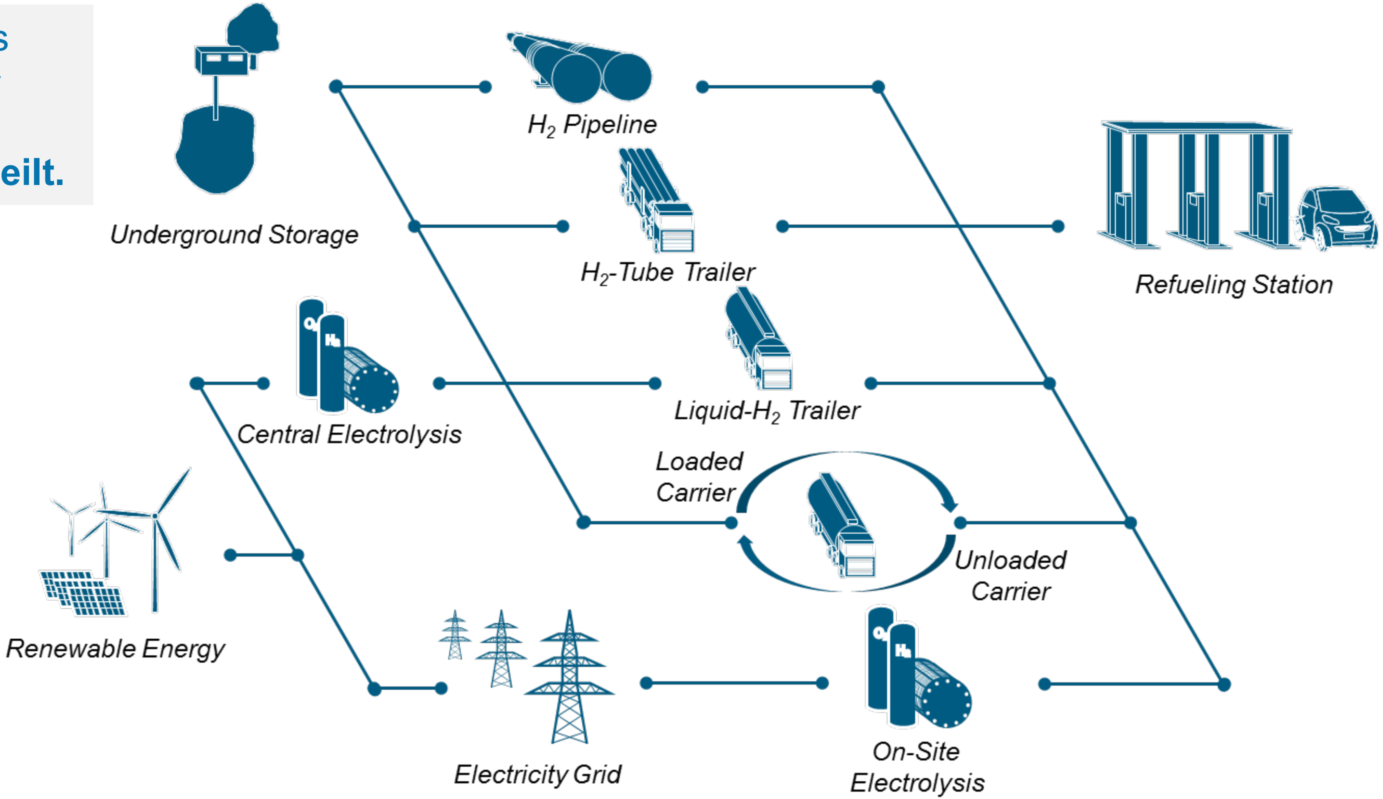
Circus horse = SO electrolysis

Foal = AEM electrolysis

In progress = PCC electrolysis

Wasserstoffinfrastruktur: Verteilung

Aktuell werden 95 % des Wasserstoffs am Ort der Erzeugung verbraucht.
5% werden aktuell verteilt.



Quelle: NOW

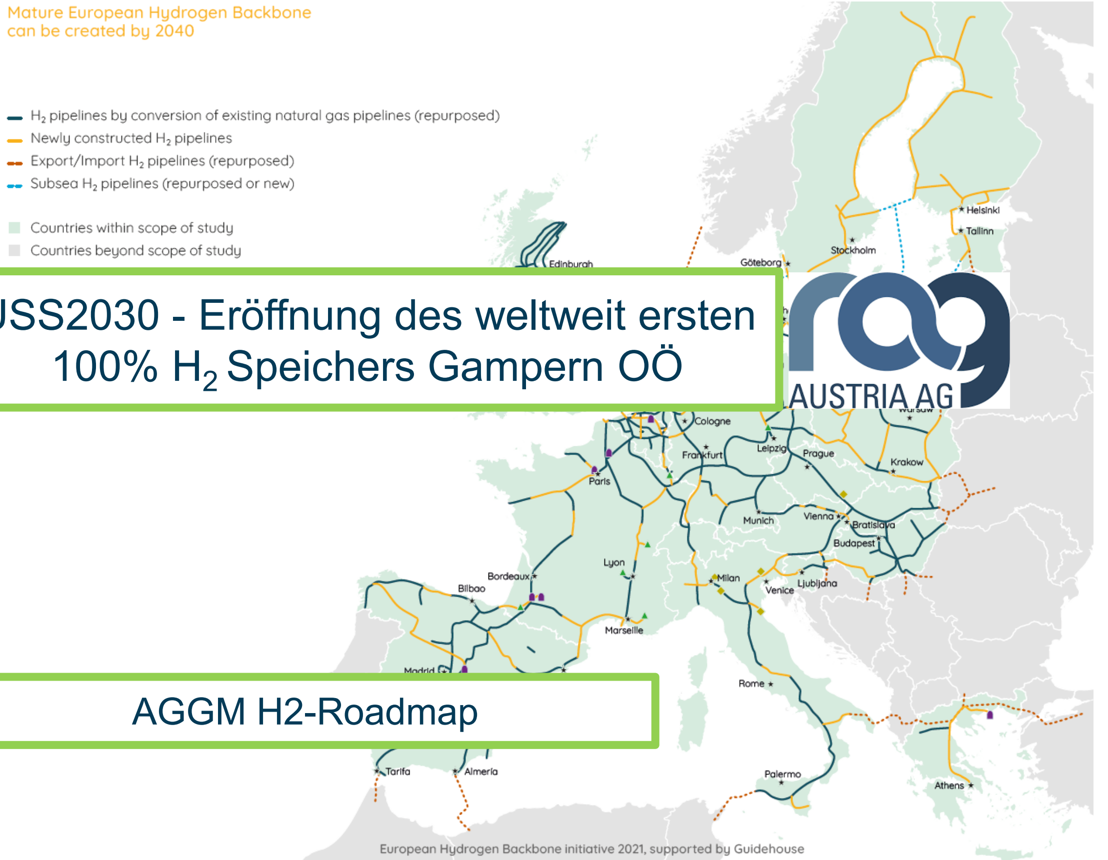
Speicherung und Distribution

- **Druckgasspeicherung ist Stand der Technik und seit Jahrzehnten eingesetzt**
- **LH2 (Flüssigwasserstoff ~ -253°C) für Sonderanwendungen**
- **Saisonale großtechnische Speicher wie in Untergrundspeichern**

USS2030 - Eröffnung des weltweit ersten 100% H_2 Speichers Gampern OÖ

- **Alternativen wie LOHC und Hydridspeicher nehmen an Bedeutung zu → F&E**
- **Distribution**
  - GH_2 und LH_2 Trailer
  - Pipelines
  - Schiffe

AGGM H2-Roadmap



Quelle: https://gasforclimate2050.eu/sdm_downloads/extending-the-european-hydrogen-backbone/

H_2 Gas quality: HyGrid Pilot Study

1995, MOP70 | **1972, MOP70** | **1965, MOP6**

1980 , 2018 MOP70

H_2 Quality in used Pipelines

Experimental determination of H_2 quality in the Boltzmann Lab

What H_2 quality can be achieved during transport in used high-pressure pipes?

- **Strong influence of age, gas history, preparation**
- **Odorants are visible (ppb level!)**
- **Natural gas residues**
- **Higher HCs from solid deposits**
- **Grade A can easily be achieved**

Investigated Pipeline Element No. 5

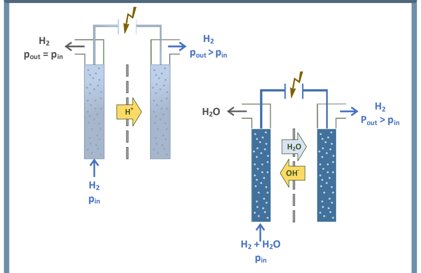
Measurement Setup at HyCentA Boltzmann Lab (IMR-MS, bottom right; FTIR, up right)

Source: Stöhr et. alt, Hydrogen Quality in used Natural Gas Pipelines, 2023, https://doi.org/10.1016/j.ijhydene.2023.09.305

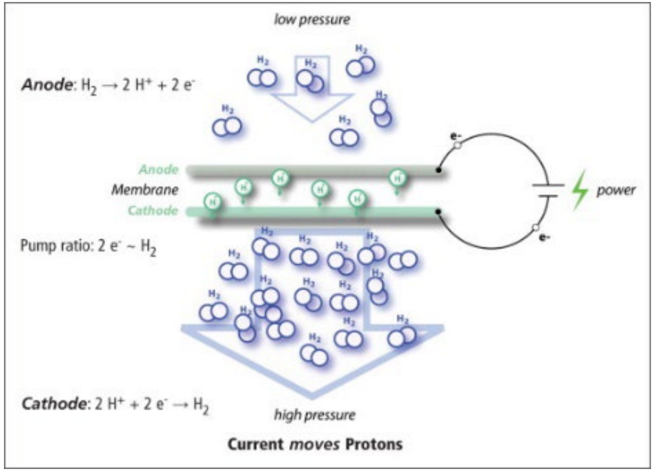
Electrochemical Compressor (EHC)

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

Electrochemical Hydrogen Compression – EHC

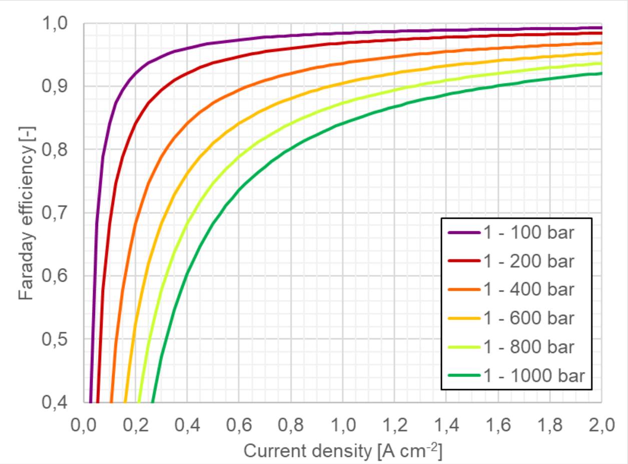


- H_2 supply at atmospheric or low pressure p_{in}
- Δp across membrane
- H_2 at $p_{out} > p_{in}$
- Possible with PEM or AEM



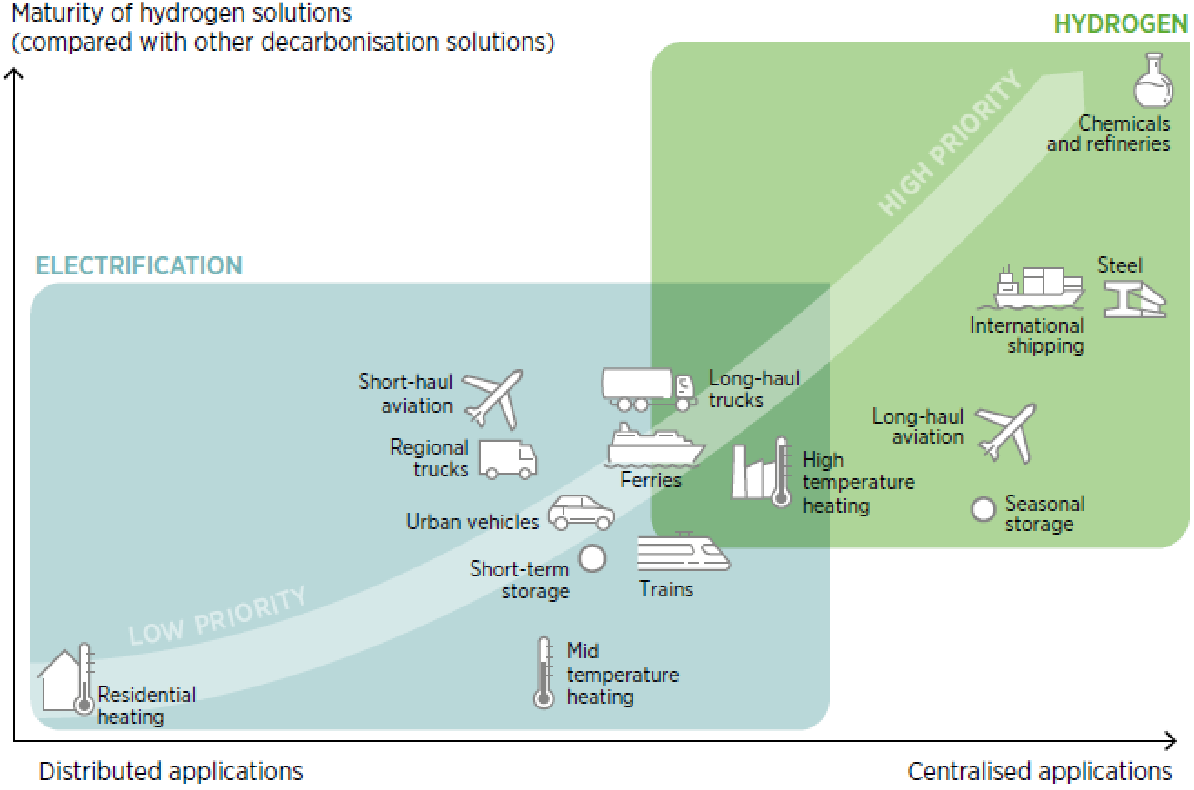
Source: HyET

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



Source: HyCentA, on-going PhD Michael Richter

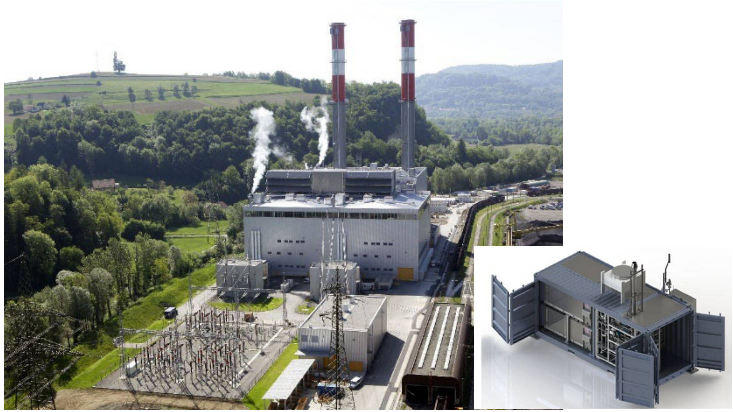
Suitable application areas Hydrogen



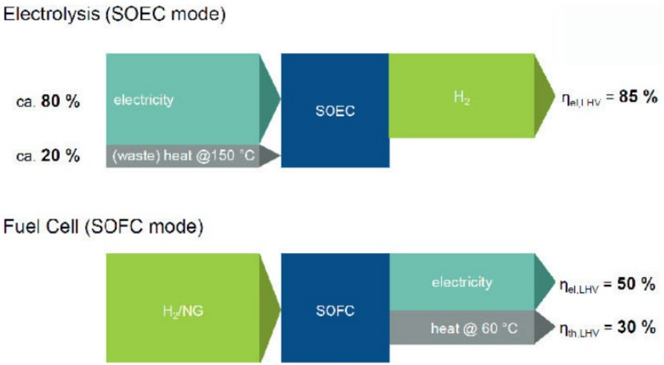
Source: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jan/IRENA_Geopolitics_Hydrogen_2022.pdf

Energy sector – heat & power

- H_2 technologies particularly relevant for sector coupling
- Balancing energy market with electrolysis and fuel cells (reversible operation with HT - SOE)
- Combined heat and power
- Self-supply e.g. houses
- Emergency power supply
- Power generation with: ICE / turbine / fuel cell



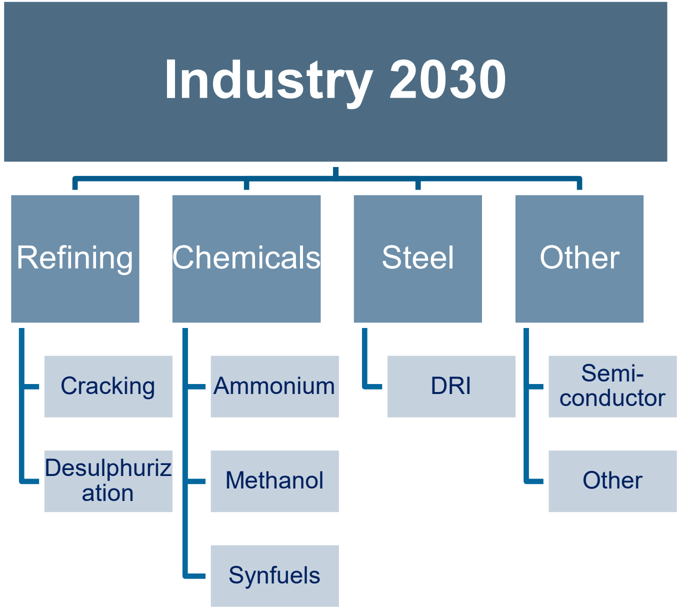
Source: Verbund, Gaskraftwerk Mellach, HotFlex



Quelle: Sunfire

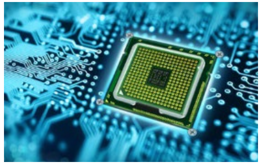
Industry

- H2 in use for decades - wide range of gas qualities (x.x - 8.0)
- Conversion of existing processes from grey H2 to green H2
- New processes with H2 for decarbonisation
- Material utilisation
- High-temperature processes: Heat exchangers and burners



Chemicals

Glas



Semi-Conductor

Petrochemical

Metals

Hydrogen and Fuel Cells - Today

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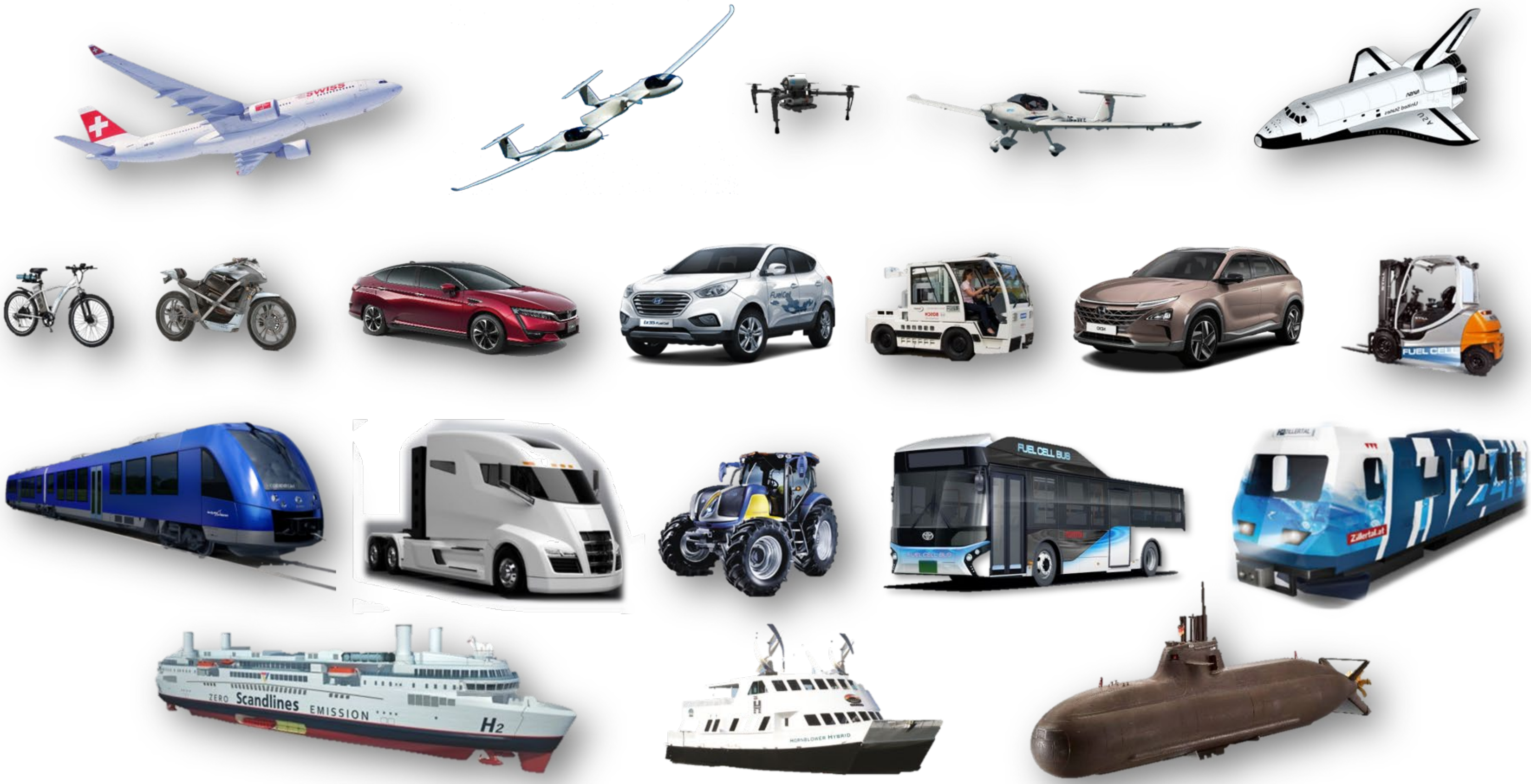
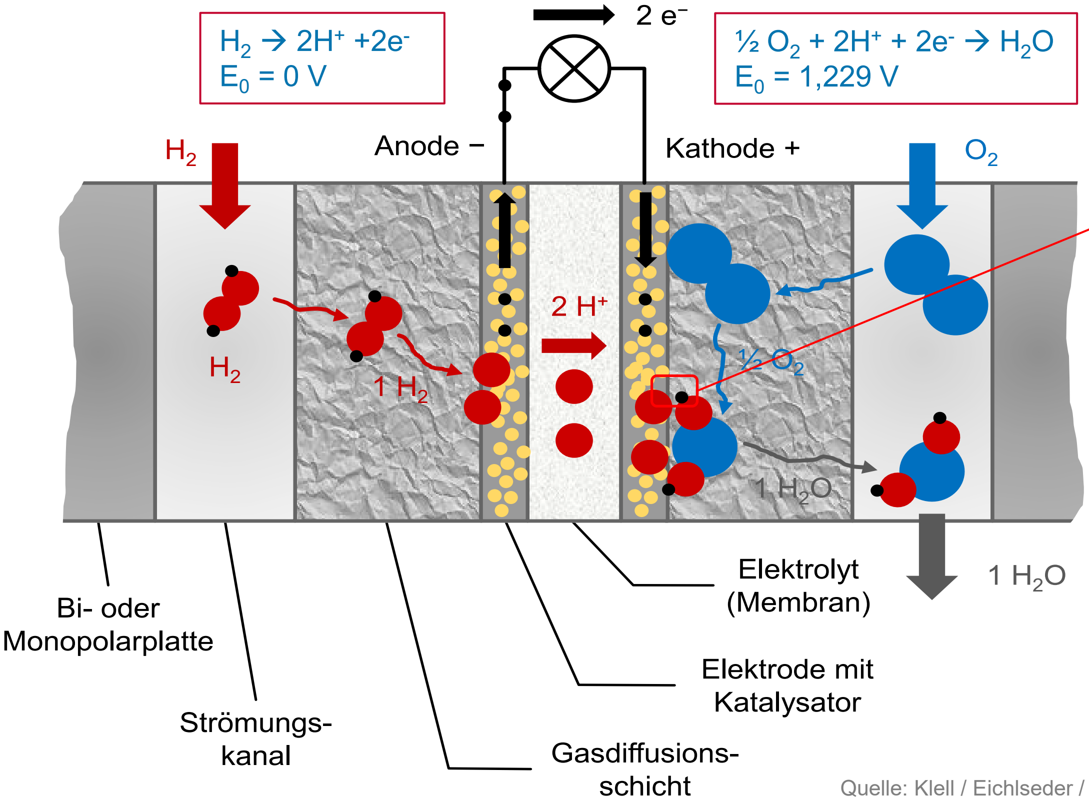
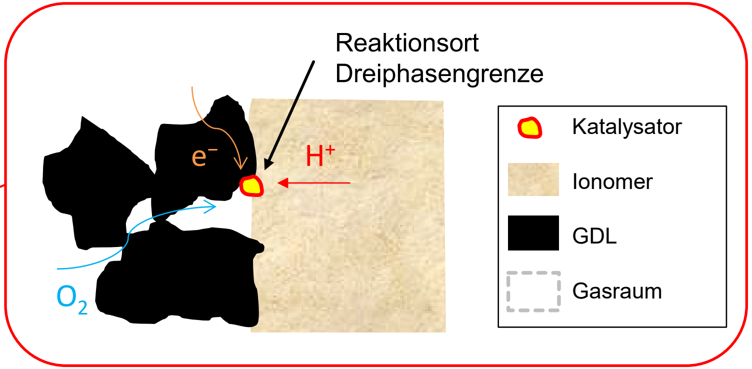


Prinzip der PEM-Brennstoffzelle - Mobilität



Quelle: Klell / Eichlseder / Trattner

½ $O_2 + 2H^+ + 2e^- \rightarrow H_2O$ $E_0 = 1{,}229$ V



Quelle: Klell / Eichlseder / Trattner

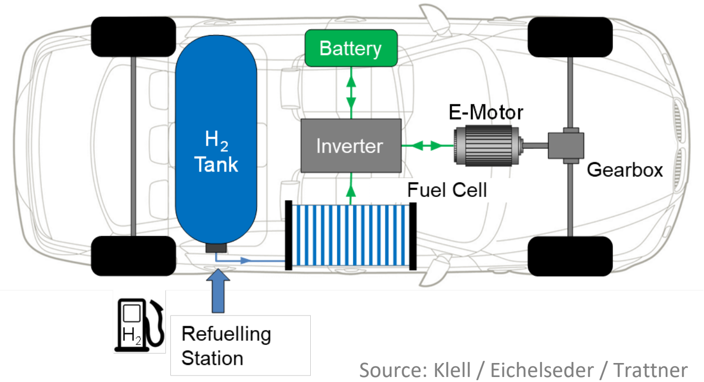
Dreiphasengrenzfläche

- Aufeinandertreffen von **Gasraum**, **Katalysator** (Beschleunigung der Reaktion und Elektronenleitung) und **Ionomer** (Protonenleitung)
- Nur wenn die ionenleitende Phase, die elektronenleitende Phase, der Katalysator und die Reaktanten **gleichzeitig in Kontakt** stehen, kann die Reaktion ablaufen

FCV Antriebsstrang

Dominanter Brennstoffzellenantrieb

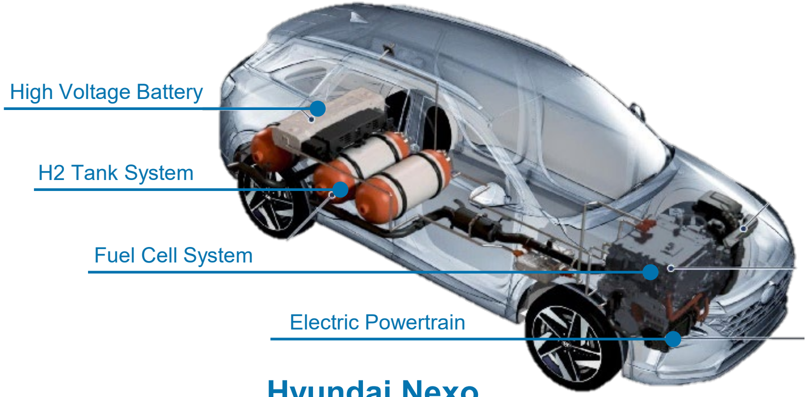
- Hybrid aus Batterie und Brennstoffzelle
- Leistungsbedarf durch Brennstoffzelle gedeckt
- HV Batterie für Rekuperation und Leistungsunterstützung



Source: Klell / Eichelseder / Trattner

Specifications:

- Fuel Cell Power: 95 – 150 kW
- HV Battery Power: 25 – 40 kW
- HV Battery Capacity: 1 – 2 kWh
- H2 Tank: 5 – 6.5 kg → Driving ranges up to 750 km



Hyundai Nexo

Source: Hyundai

See more: Trattner, A., Brandstätter, S., Pertl, P. et al.: "Advanced Methods of Optimising Fuel Cells on System Testbed", 14th International AVL Symposium on Propulsion Diagnostics, 2020.

Calibration of HRS: UpHy-I & II

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Drive expansion of H_2 refueling station network by developing solutions for the official verification of gas quality and dispensed hydrogen mass at the refulling station

- **10 MW electrolyzer at OMV refinery Schwechat**
- **Development of ISO 14687 compliant H_2 gas analysis laboratory Boltzmann and**
- **Sampling device for H_2 quality metering along the entire supply chain from ely to HRS and**
- **Calibration standard for HRS dispense quantity**
- **Scenarios and concepts for the expansion of green H2 production and associated H2 logistics**

OMV | ENERGIE INSTITUT an der Johannes Kepler Universität Linz | V&F Analyse- und Messtechnik GmbH | WIVA P&G Energy Model Region | powered by klima+ energie fonds | FFG Forschung wirkt.

H_2 FC Aviation Application

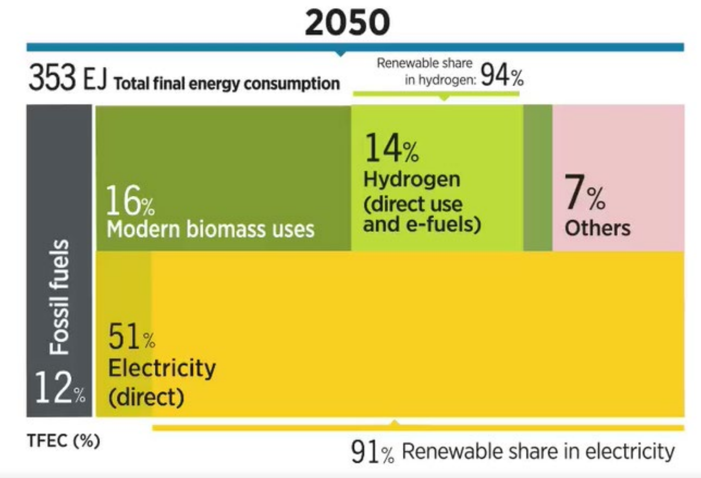
Airbus ZEROe

Electrical propulsion powered by Fuel Cells

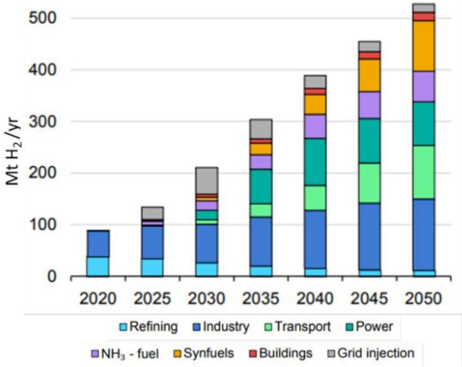
Source: Airbus, https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen/zeroe

Further prognosis

- ca. 10% in 2020 –> International Energy Agency (IEA)
- ca. 14 % in 2050 → International Renewable Energy Agency (IRENA)



Source: IRENA



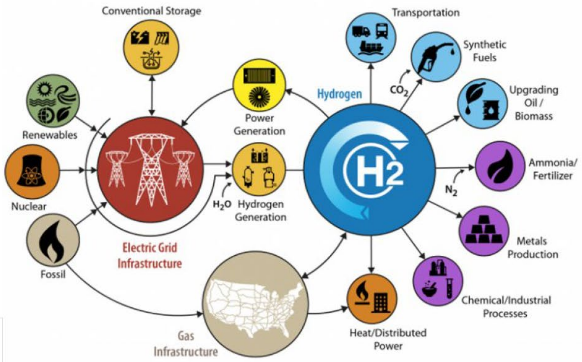


Figure 1: Projected hydrogen use by sector (left)

Source: IEA Global Hydrogen Review 2021

Source: U.S. Department of Energy

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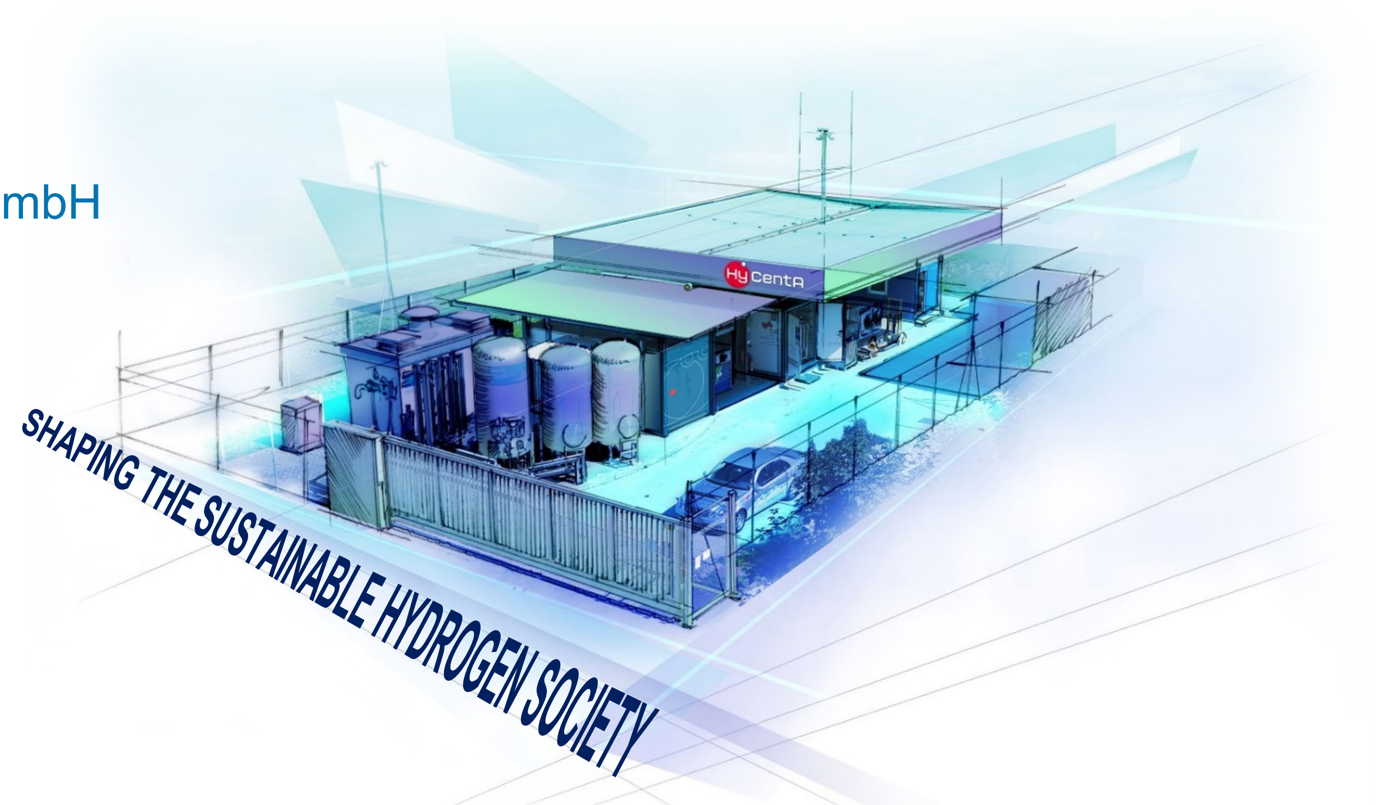

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