SUNERGY

European Innovation Council

SIEMENS energy

Shaping the future: renewable fuels and chemicals from solar energy for a climate-neutral Europe

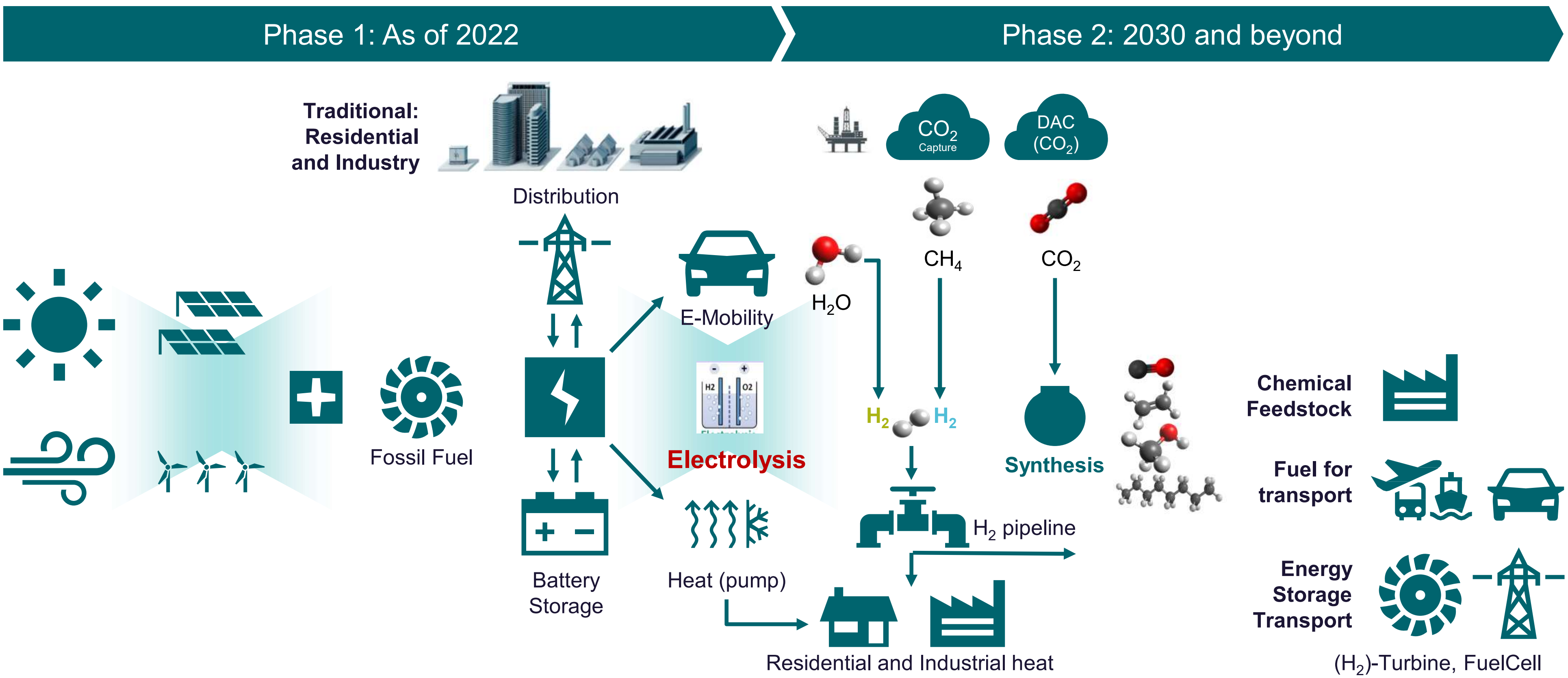
Joint roadmapping workshop on future milestones by SUNERGY, EIC and DG RTD

Brussels, 14/15 June 2022

The future of electrolyzer for the new energy system: The importance of integration

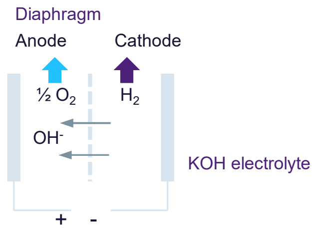
Max Fleischer

As Siemens Energy, we believe in an accelerating transition towards a sustainable and decarbonized energy world

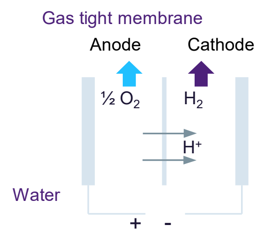


There are three considerable technologies of water electrolysis differing in their characteristics.

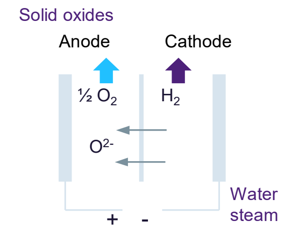
Alkaline Electrolysis



PEM Electrolysis



High temperature



	Alkaline Electrolysis	PEM Electrolysis	High temperature
Electrolyte	KOH[3]	Polymer membrane	Ceramic membrane
Circulated medium	KOH[3]	Water	Steam
Operational temperature[1]	60 – 90 °C	RT[4] – 80 °C	700 – 900 °C
Technical maturity[1]	Industrially mature	Industrially mature	Lab/demo
Field experience[1]	● Existing/available	● Existing/available	● Not possible, not available
Cold start capability[2]	● In development/limited	● Existing/available	● Not possible, not available
Intermittent operation[2]	● In development/limited	● Existing/available	● In development/limited
Scalability up to multi Giga Watt[2]	● Existing/available	● Existing/available	● In development/limited
Reverse (fuel cell) mode[1]	● Not possible, not available	● Not possible, not available	● Existing/available

● Existing/available ● In development/limited ● Not possible, not available

Source: **1** Fraunhofer | **2** IndWede | **3** KOH: Potassium hydroxide | **4** Room temperature

Given the Volatility of Renewable Input, The Hydrogen Production needs to be Agile

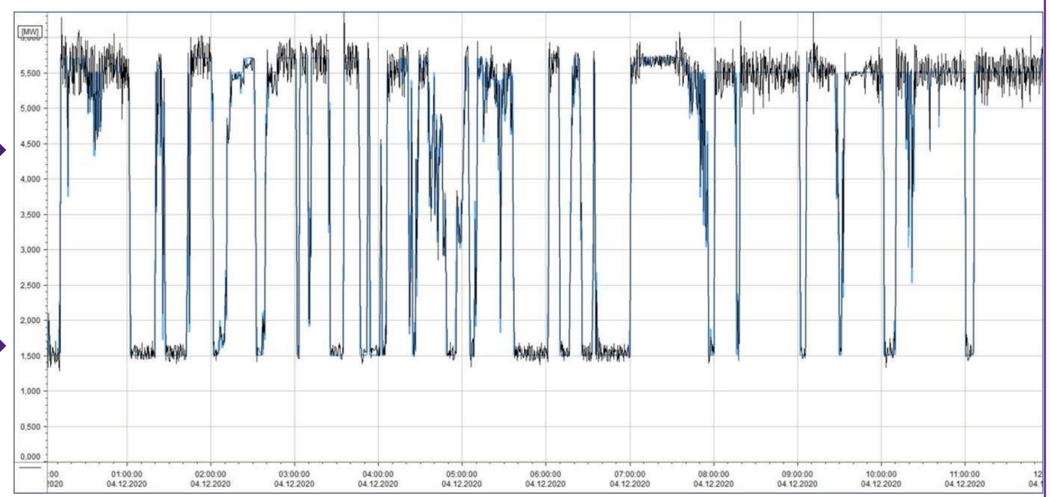
Infinitely variable plant operation

- Power controlled operation based on real power price with 15 min time frames (see example on right side)
- Dynamics: maximal ramp rate in array 10% per second power change possible
- Always fast ramp-up

Real plant data from an exemplary H2 Sielyzer

Target power selection

Power consump-tion electrolyzer



– Operating – Set point

Silyzer portfolio scales up by factor 10 every 4 – 5 years driven by market demand and co-developed with our customers

Silyzer portfolio roadmap

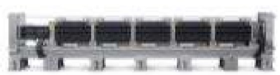
0.1 MW → **1 MW** → **10 MW** → **100 MW** → **1,000 MW**

2011

Silyzer 100
Lab scale demo
~20 kOH[1,]
~30 t of H_2

2015

Silyzer 200
~130 kOH[1]
~1700 t of H_2



World's largest Power-to-Gas plants with PEM electrolyzers in 2015 and 2017 built by Siemens Energy!

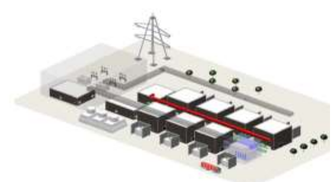
2019

Silyzer 300

Biggest PEM cell in the world built by Siemens Energy!

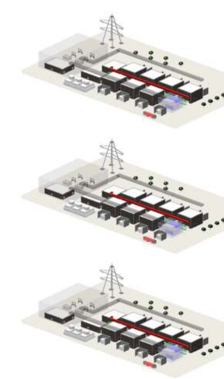
2023+

Next generation
Under development



2028+

First investigations in cooperation with chemical industry



1 1000 accumulated Operating Hours; Data OH & tons as of Oct 2020

Silyzer 300 – Full Module Array
The next paradigm in PEM electrolysis

Silyzer 300 – full module array (24 modules)

17.5 MW
plant power demand

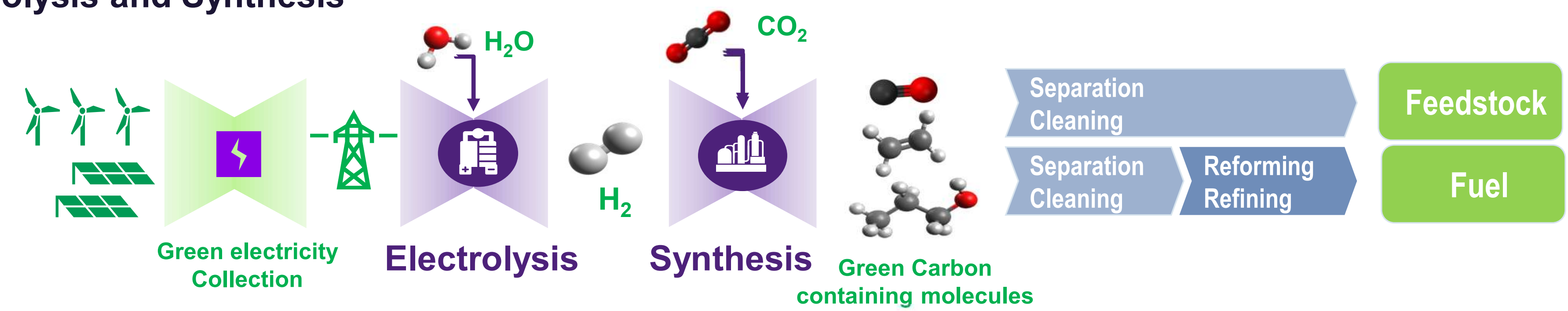
> 75.5 %
plant efficiency

24 modules
to build a full module array

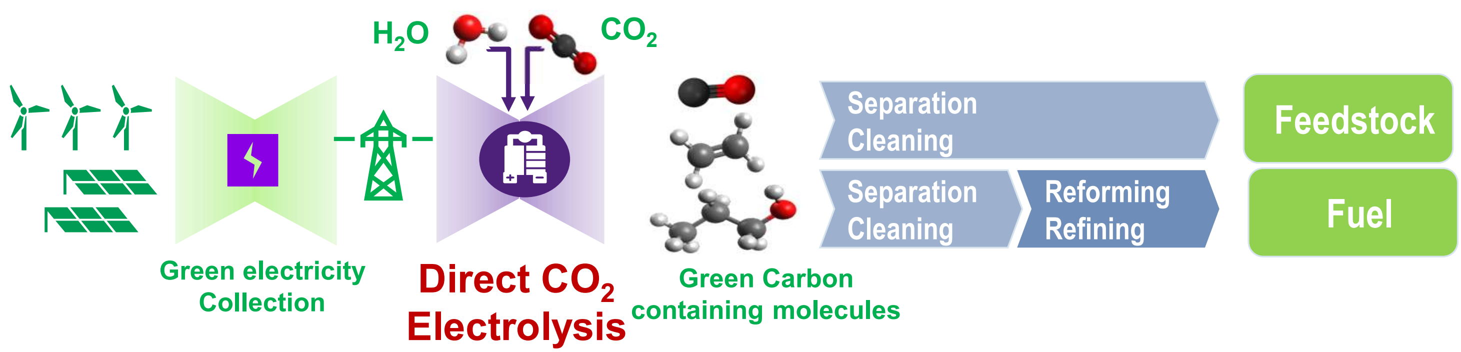
335 kg
hydrogen per hour

Simplifying the Process Chain: New Process to get to Green Hydrocarbons:

The conventional route via green hydrogen uses two different main conversion steps: Electrolysis and Synthesis

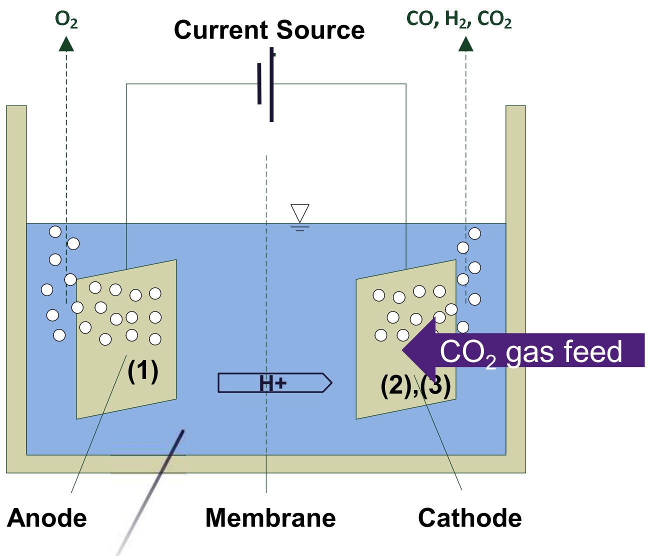


Our new and simpler route: Direct Electrochemical Conversion of CO_2 by one conversion step



Base Idea: A Novel Type of Electrolyzer is fed with CO_2 and H_2O at ambient conditions and directly reduces CO_2 .

Anode material: Platinum, Cathode material : Silver porous



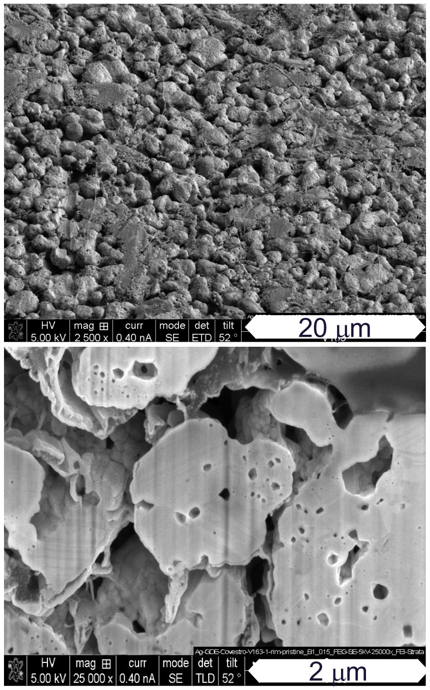
Anode Reaction:

$$2\,H_2O \rightleftharpoons O_2 + 4\,H^+ + 4\,e^- \quad (1)$$

Cathode Reaction:

$$CO_2 + 2\,e^- + 2\,H^+ \rightleftharpoons CO + H_2O \quad (2)$$

$$2\,H^+ + 2\,e^- \rightleftharpoons H_2 \quad (3)$$



Top view and cross section of silver catalyst

P. Jeanty, E. Magori, M. Fleischer, O. Hinrichsen, K. Wiesner-Fleischer, C. Scherer, Journal of CO2 Utilization 24 (2018) 454-462

What products can be made directly out of CO_2 and H_20?

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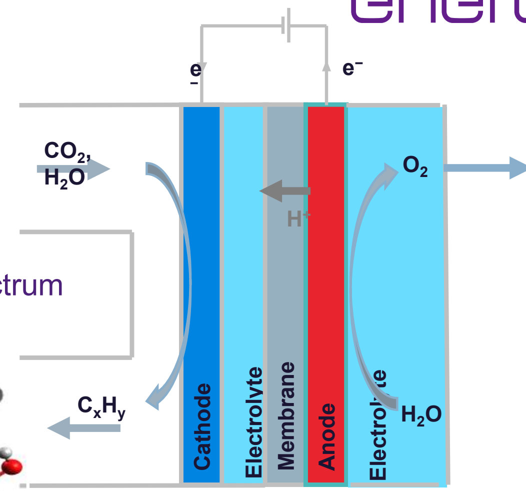
Products using gas diffusion-based CO_2 electrolyzers

Silver catalyst based: *stable catalyst, upscale of electrolyzer stack*

- Production of **CO** (>95%) for local CO supply
- Production of **CO / H_2 mixtures (Syngas)** for chemical synthesis – Fischer Tropsch process for hydrocarbons.

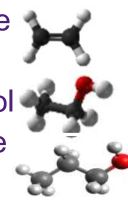
Copper catalyst based: stable catalyst in development*, include this catalyst in CO-stack

- Target: **Ethylene** production for chemical production
- Target: Mix of **C2/C3 components (Ethanol, Ethylene, Propanol)** selectivity > 75% + CO/H_2 as green fuel precursor



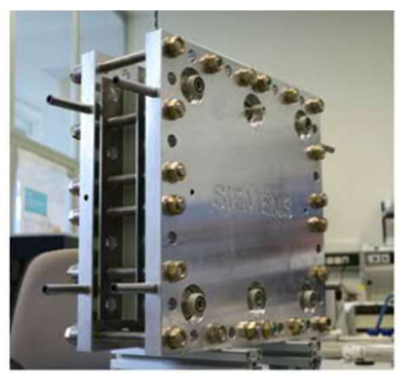
Main product spectrum

- Ethylene
- Ethanol
- Propanol
- Formate
- Acetate



Side product: H_2

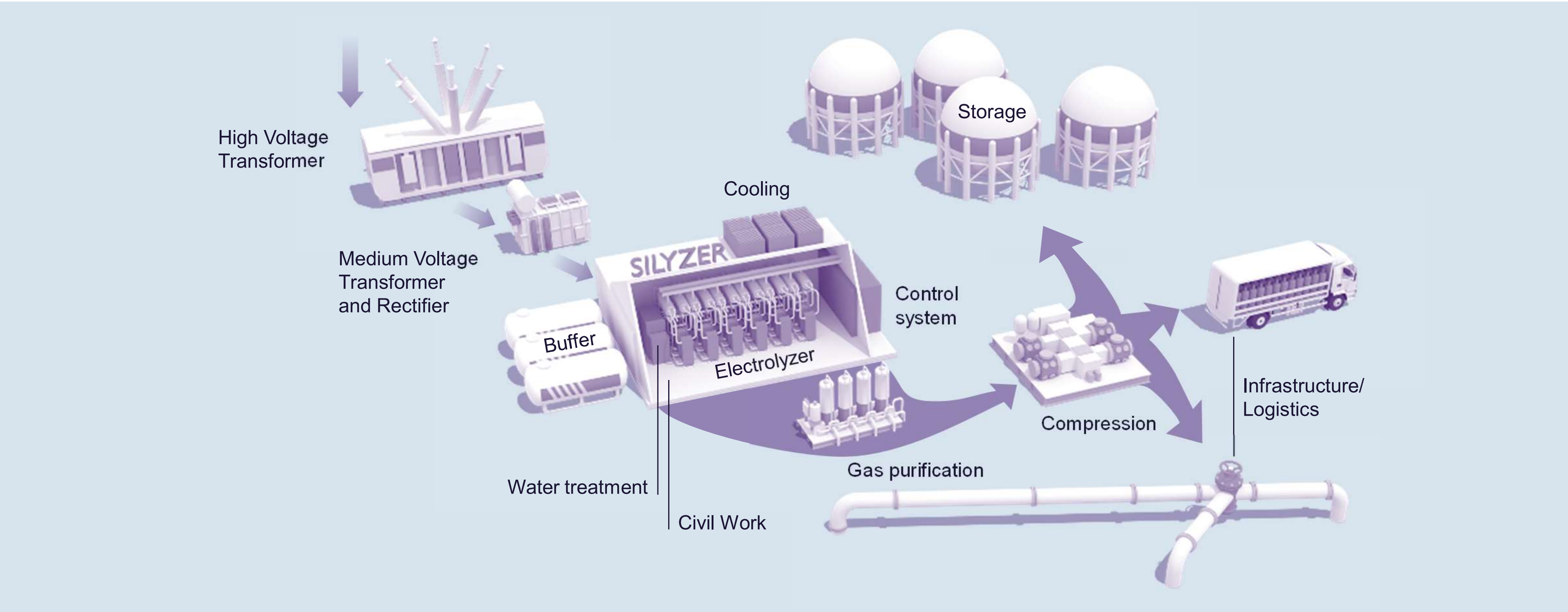
Scale-up for CO **(Rheticus)**
10 cell stack of 300cm² cell



Scale up for CO
(Kopernikus)
5000cm² cell

** In lab devices:*
several 100hs of stability

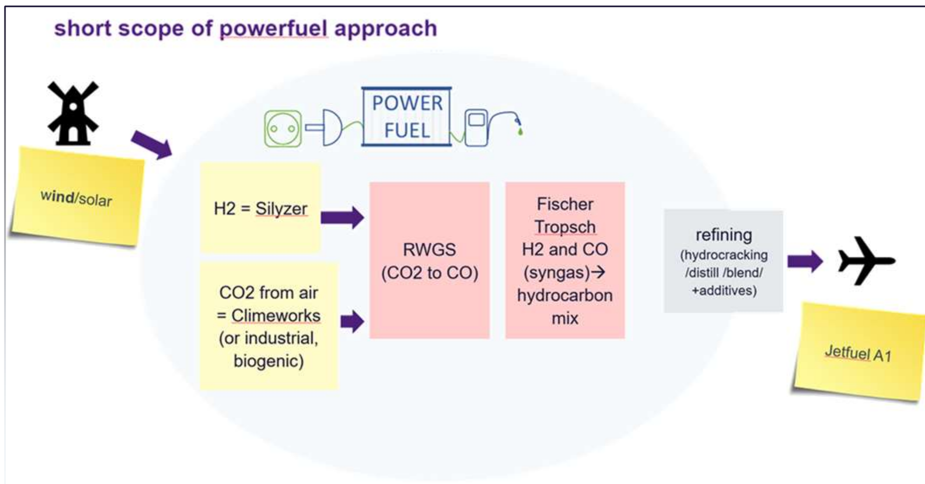
Industrialized Electrolysis is more than just an electrolyzer



Water electrolysis directly connected to renewables in island mode: Economic operation (e.g. PV) leads to significant no load periods of electrolyzer

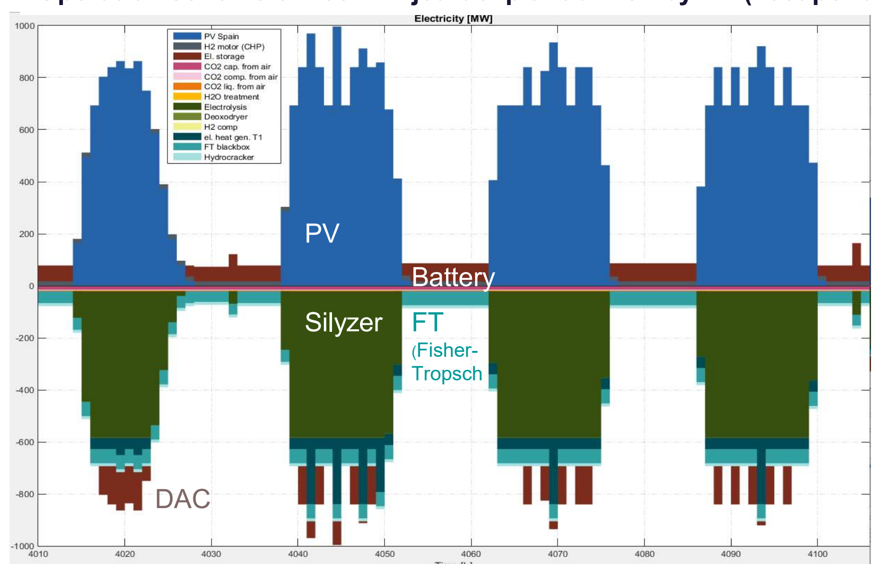
Todays cost optimum of overall CAPEX vs. electricity costs is agile electrolyzer operation with no buffering by batteries

POWERFUEL German funded simulation project for the Generation of SAF (Jet Fuel)



Simulation Scenario:
Separate consideration Wind(various) /PV(Spain) + Battery, Electrolysis, DAC, RWGS, FT Synthesis, Refining → cost of Jet Fuel mimimized

Operation scheme of 100 MW jet fuel plant driven by PV (200t per day)



*Battery buffering of electrolysis not economic.
Batteries only used for buffering of synthesis

Water electrolysis connected to grids: Economic operation requires steep load ramps and complete turn-off

Wind$_2$Hydrogen onshore

(OMV: Funded H_2 production with grid connection)

https://www.energy-innovation-austria.at/article/wind2hydrogen-w2h/

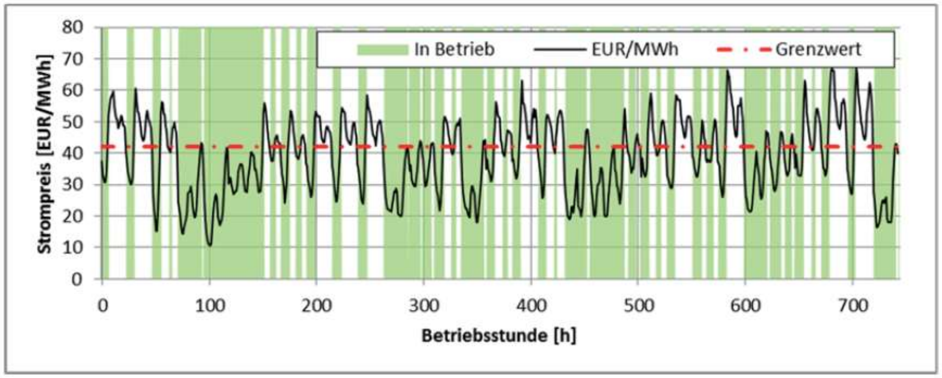


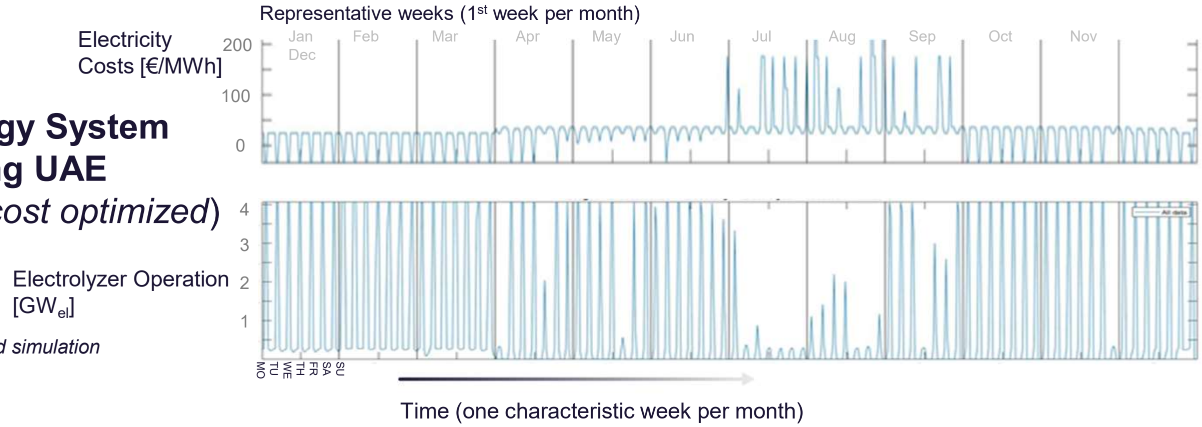
Abbildung 6: Betriebsweise mit Strompreis als Führungsgröße; die grün markierten Bereiche stellen die Betriebszeiten des Elektrolysesystems dar; Strompreisverlauf aus [4]

Electrolyzer operates only in times with positive business case (i.e. high portion of fluctuating renewables)

Similar: **Audi eGas plant** Werlte

Green CNG for passenger cars 2013-2021

SE Energy System Modelling UAE *(overall cost optimized)*



Source: SE owned simulation

The cost optimum of electrolyzer CAPEX vs. electricity costs requires agile electrolyzer operation

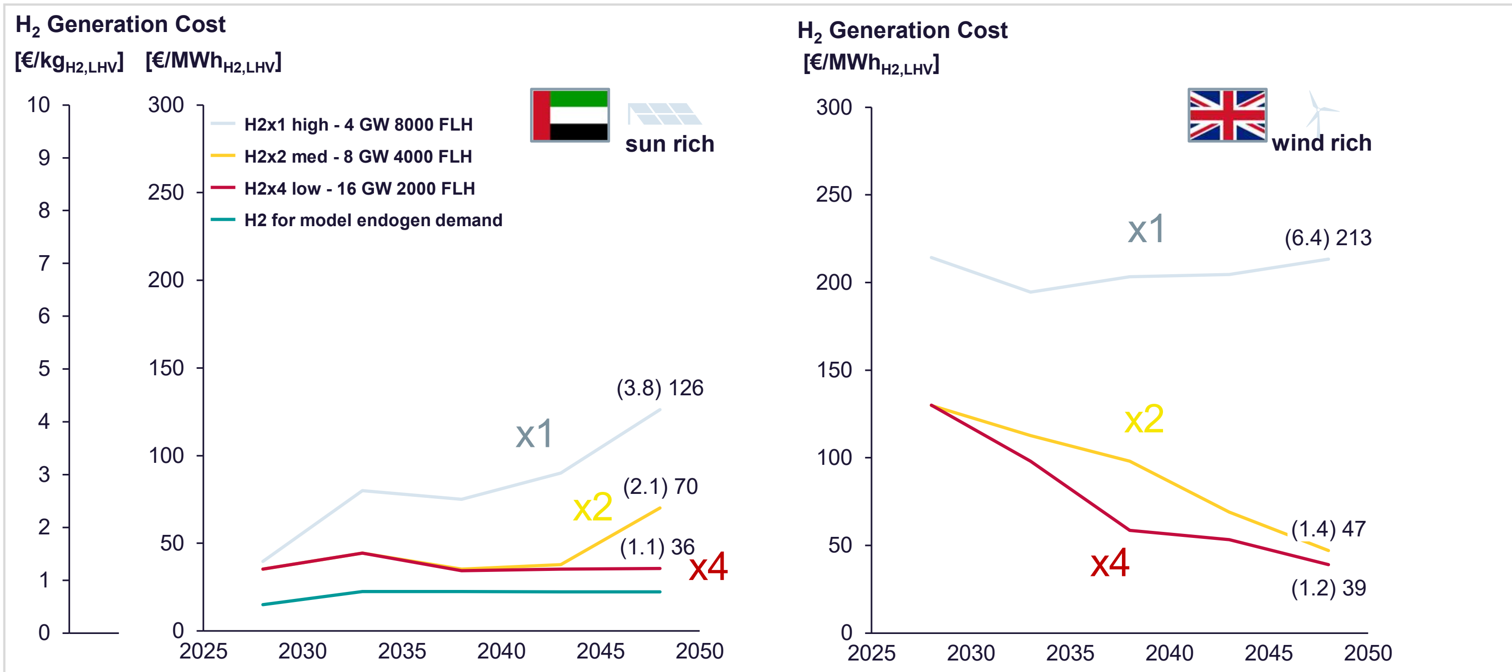
Energy System Modelling on National Level: Comparing a Sun rich (UAE) and a Wind rich (UK) country to determine green H_2 production costs.

Compared to UK, H_2 production prices in UAE are usually lower – overbuilding can reduce generation costs

Model comprises Electricity System and sector coupling model

considering Mobility & Heating

incl. associated energy vectors, demands, technologies, and storages



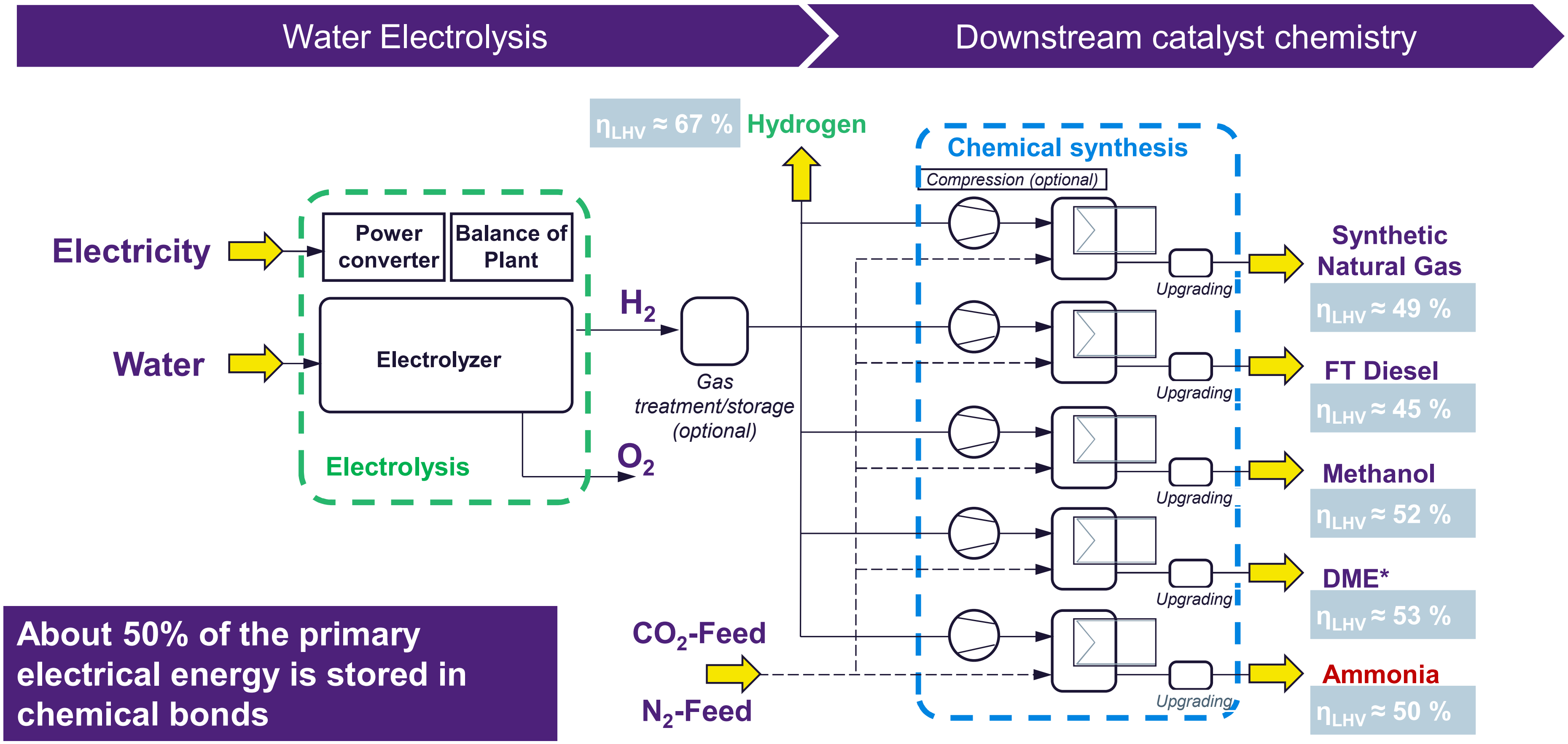
Overbuilding of Electrolyzer capacity compared to export target:

x1 x2 x4

allows to use temporarily cheap electricity

Source: SE owned simulation

The conversion efficiency over the whole value chain including with Downstream Synthesis to Fuel needs to be optimized?



About 50% of the primary electrical energy is stored in chemical bonds

Courtesy: A.. Tremel, calculations using optimistic assumptions

*Ethylenglycoldimethylether

Thank you for your time!

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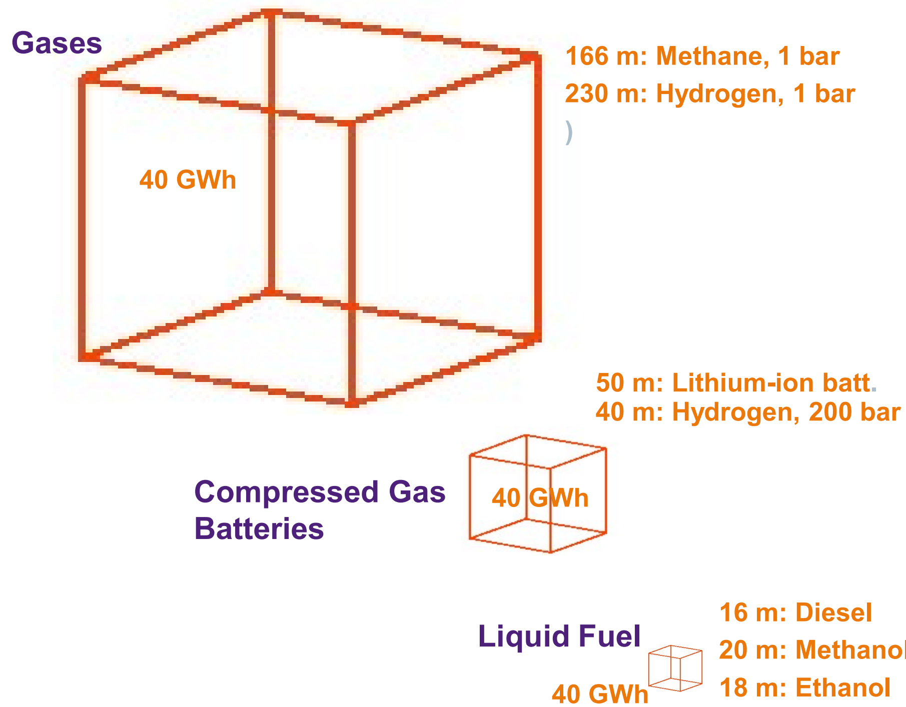
Energy densities in storage:
Chemical storage (green fuel) shows the Utmost Energy Density for long-term energy storage and transport

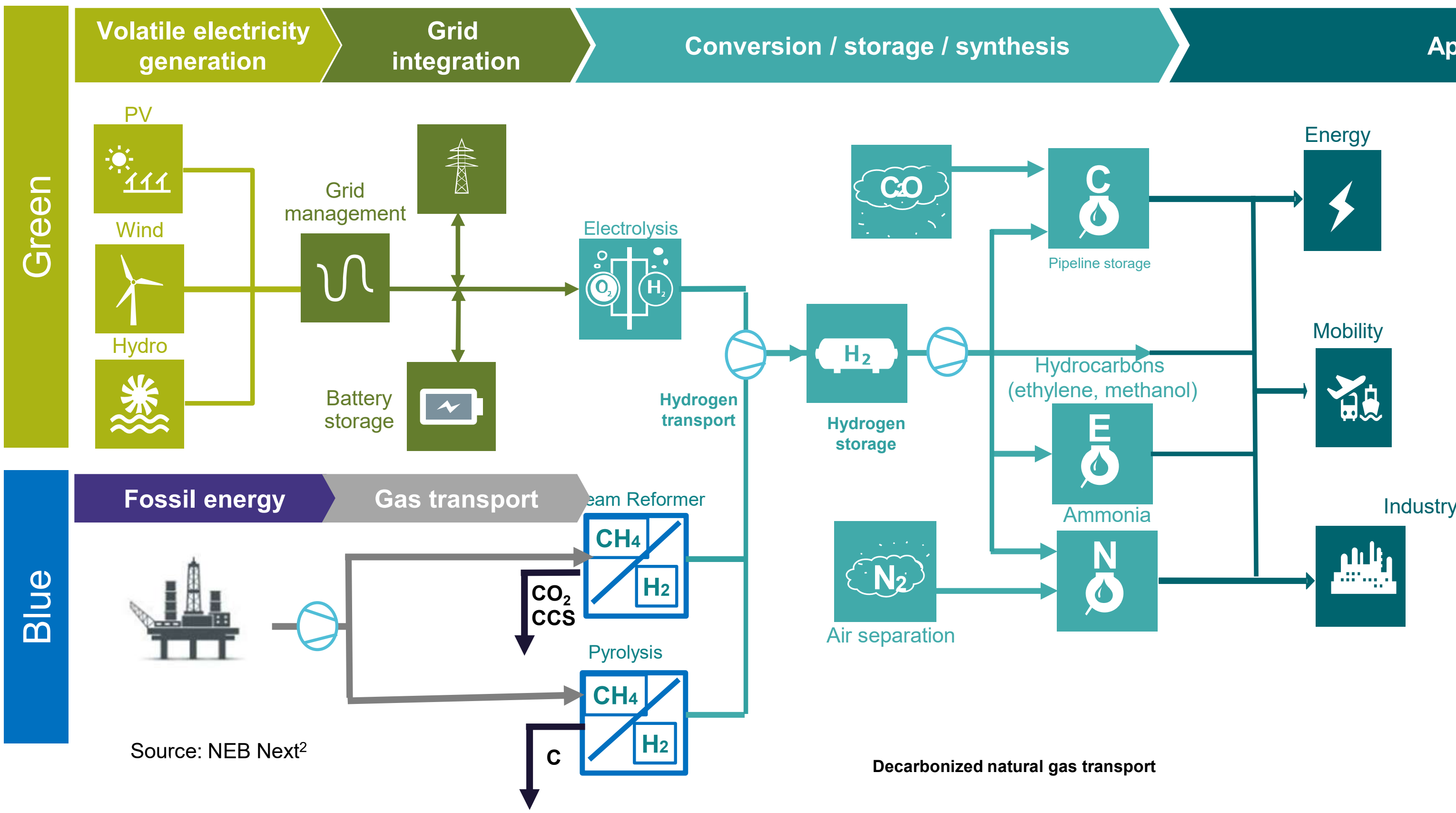
9 pumped Hydro Power Plants in Germany can store 40 GWh with gravimetric storage

Footprint for storage of 40 GWh in chemical bonds



Given the Volatility of Renewable Input, the Production along the Whole Value Chain needs to be Optimized and Buffered

Overview on hydrogen economy (schematic)



- Hydrogen energy storage by gas grid blending
- Hydrogen for heating and household usage
- Hydrogen for re-electrification by FC and H2 GTs

- Hydrogen: e.g. H_2 fuel cell mobility
- Synthetic fuels for aviation and marine

- Hydrogen for steel and cement
- Hydrogen for industrial heat
- Urea for fertilizer
- Ethylene, Propylene

Source: NEB Next[2]