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Electrolyzer Technology -
Application areas and related cost targets

Siemens AG, PD LD HY, 91058 Erlangen

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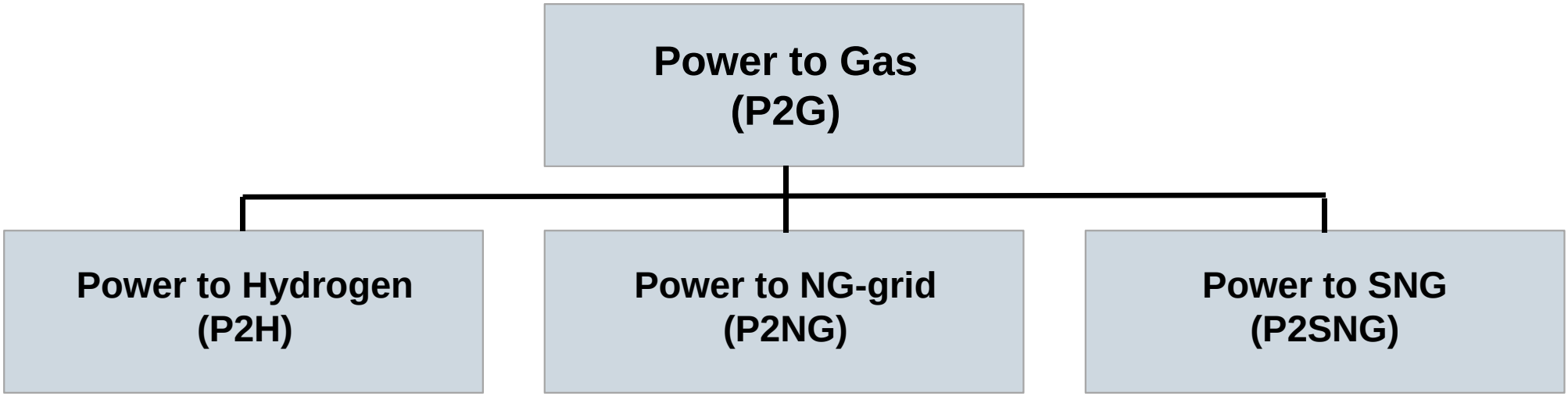
“Power to Gas” needs a common understanding



use of hydrogen as a valuable material
- directly as fuel
- chemical syntheses
- process gas

injection into the natural gas grid

reaction with CO_2 to methane subsequent
- use as fuel
- injection into the NG grid

The business cases of the individual P2G approaches differ notably.

Hydrogen is a multi-purpose energy carrier for industry, mobility and grid services

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H_2 production: no CO_2, independent, efficient , onsite

- Chemical synthesis (e.g. ammonia, fertilizer, methanol)
- Petrochemical processes (e.g. cracking)
- Flat glass, nonferrous metal (protective and reductive gas)
- Food & Beverages (hardening)

H_2 application: a sustainable fuel for transport concepts

- CO_2 free mobility; Renewable fuel concepts
- Sustainable and pollution-free Public Transport
- Fuel Cell based in-plant logistics (forklifts, floor conveyors)
- Reliable, safe e-mobility: “fast-to-refuel” cars with long ranges

H_2 conversion: stabilizes the power grid

- Grid balancing capability (dynamical behavior in milliseconds)
- Optimization of asset utilization in renewable energies
- Storage of medium- and long-term overcapacities (TWh)
- Power-to-hydrogen and Power-to-gas as future key concepts

PEM water electrolyzer technology – a perfect match with renewable energy requirements to convert electrical into chemical power

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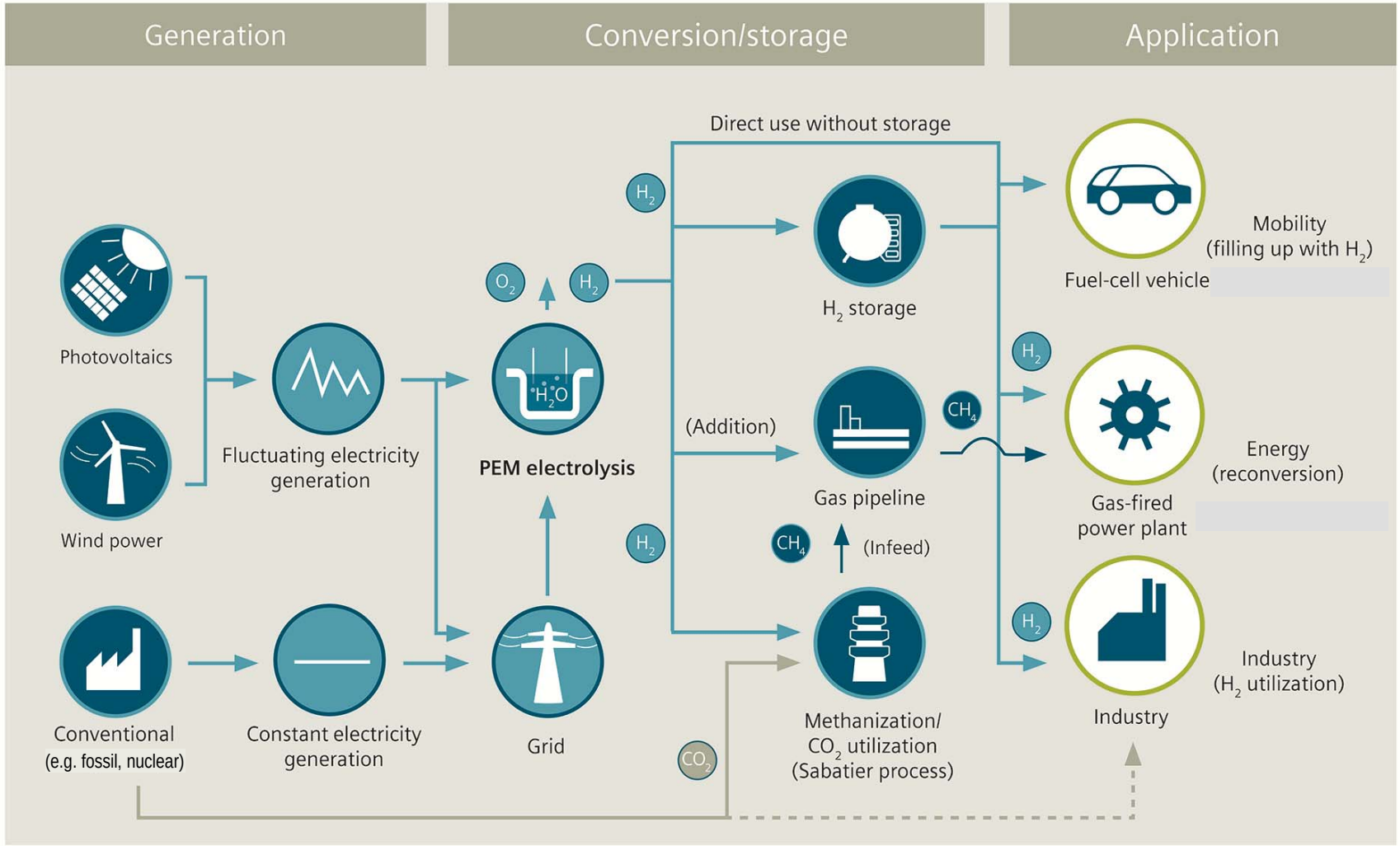
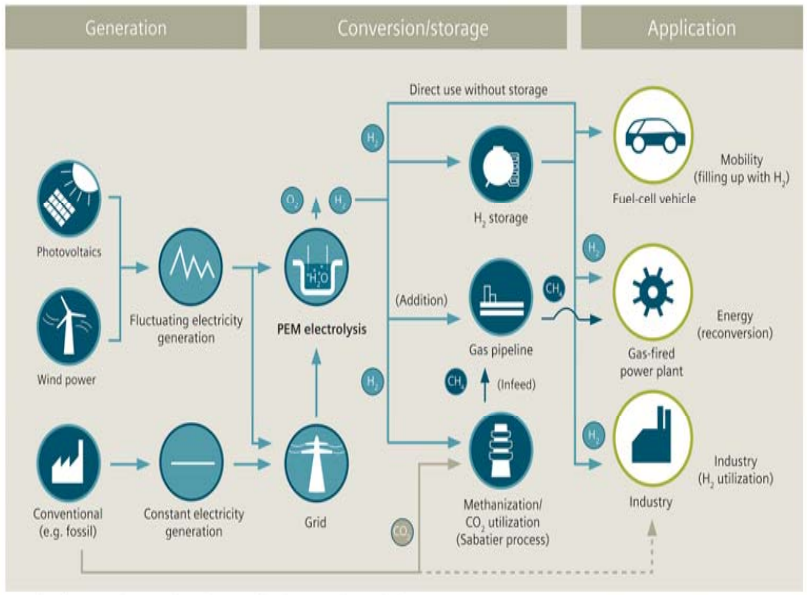


H_2 drives the convergence between energy & industry markets

The different use cases for green hydrogen follow a `merit order´ principle



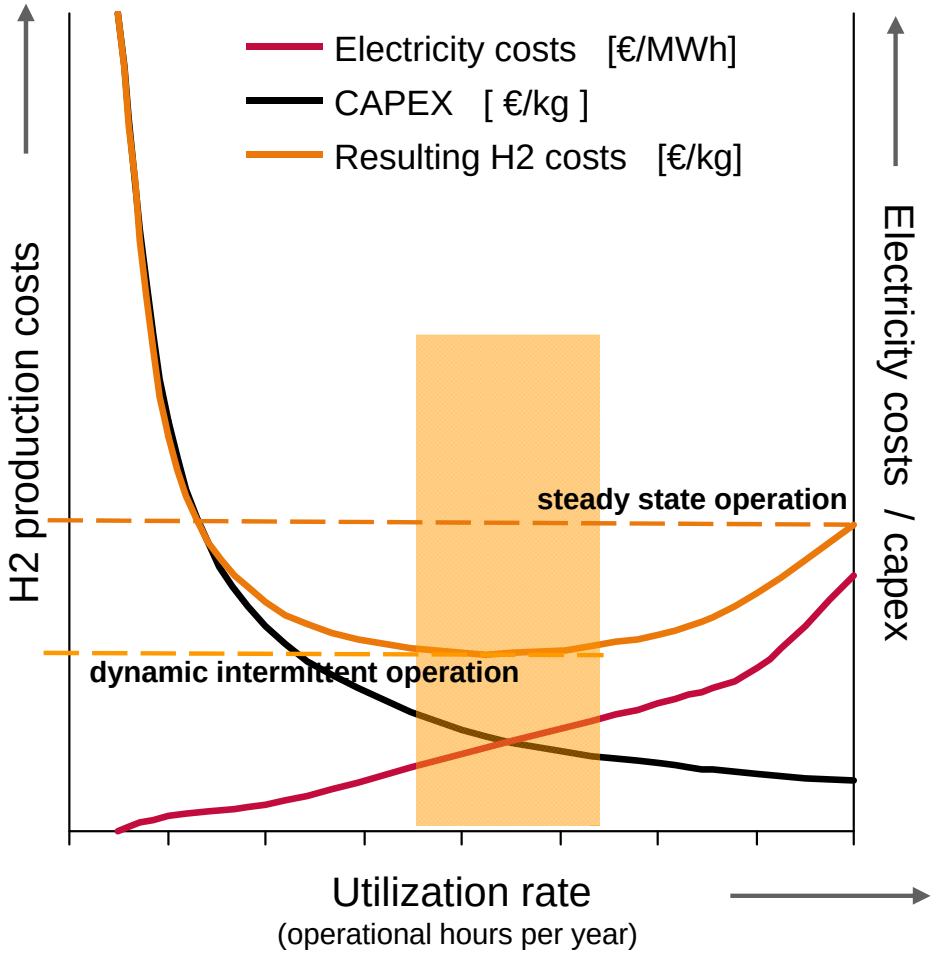
Applications and examples of use of hydrogen electrolysis

current H_2 market prices

mobility	**~ 4 – 10 €/kg**
industry	**~ 1,4 – 5 €/kg**
energy	**~ 0,7 – 1 €/kg**

- Compared to re-electrification (“power to power”) the use of hydrogen in industry or mobility leads more easily to a positive business case.
- The three use cases have different maturity, market potential and market starting points.

Utilization rate, CAPEX and Electricity Costs Impact on the H_2 Costs



Key statements

- The H_2 production costs are mainly dependent from electricity costs, operational hours and capex.
- dynamic operation can yield incentives from “Regelenergie” and further select attractive low price periods for intermittent operation. This leads to lower H_2 production costs
- In order to benchmark different technologies a comparison of capex costs only is misleading.

H_2 production via electrolysis
Economy of operation

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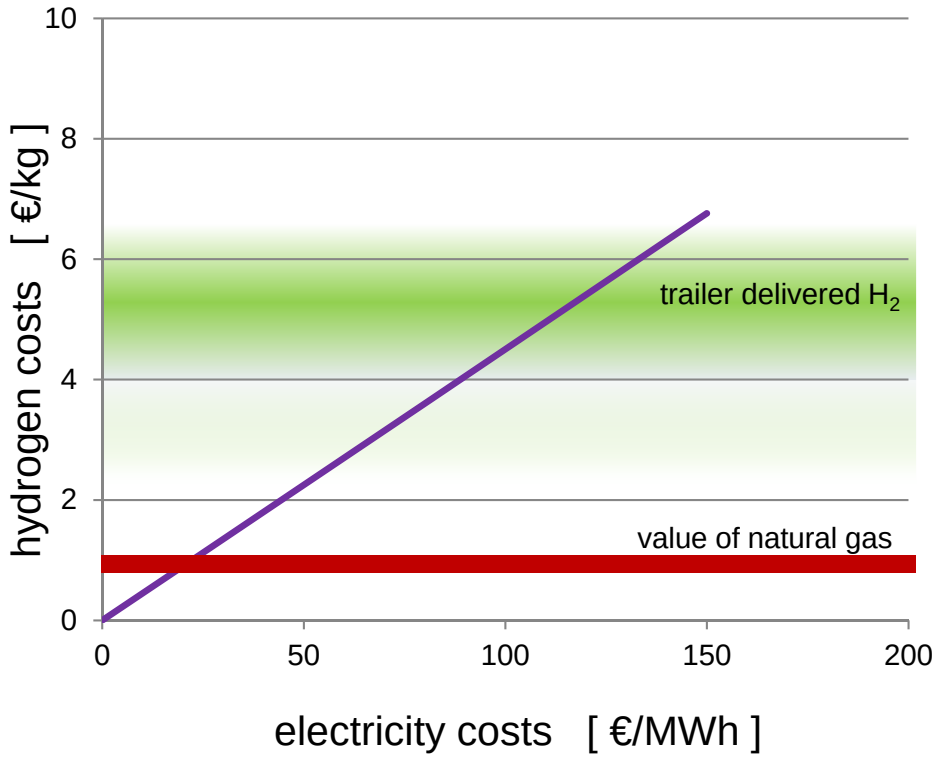
Theoretical threshold considerations

invest costs = 0 ! 1)

hours of operation: 8760 h/y



further assumptions:

1) maintenance costs = 0; efficiency electrolyzer system = 70 % vs HHV;

The publically available cost targets of electrolyzer technology 1/2

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KPI for water electrolysis

		State-of-the-art	2017	2020	2023
KPI 1	H2 production electrolysis, energy consumption (kWh/kg) @ rated power	57-60 @100kg/d	55 @500kg/d	52 @1000+kg/d	50 @1000+kg/d
KPI 2	H2 production electrolysis, CAPEX @ rated power including ancillary equipements and comissioning	8.0 M€/(t/d)	3,7 M€/(t/d)	2.0 M€/(t/d)	1.5 M€/(t/d)
KPI 3	H2 production electrolysis, efficiency degradation @ rated power and considering 8000 H operations / year	2% - 4% / year	2% / year	1,5% / year	<1% / year
KPI 4	H2 production electrolysis, flexibility with a degradation < 2% year (refer to KPI 3)	5% - 100% of nominal power	5% - 150% of nominal power	0% - 200% of nominal power	0% - 300% of nominal power
KPI 5	H2 production electrolysis, hot start from min to max power (refer to KPI 4)	1 minute	10 sec	2 sec	< 1 sec
	H2 production electrolysis, cold start	5 minutes	2 minutes	30 sec	10 sec

source: FCH JU

Before defining cost targets for electrolyzer technology we have to clearly define the following:

- what belongs to the electrolyzer system?
  proposal:
  - stack(s)
  - BOP (water separation cycle including pumps, sensors, heat exchangers, water and gas purification)
  - rectifiers, transformers (incl. housing)
  - control system including safety supervision
  - commissioning
- “costs” means sales price

The publically available cost targets of electrolyzer technology 2/2

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source NOW (Germany) - draft:

2018:	1000 €/kW	corresponds to 2,32 Mio €/t*d
2021:	800 €/kW	corresponds to 1,85 Mio €/t*d
2025:	600 €/kW	corresponds to 1,39 Mio €/t*d

source FCH-JU (EU):

2014:	corresponds to 3450 €/kW	8,0 Mio €/t*d
2017:	corresponds to 1600 €/kW	3,7 Mio €/t*d
2020:	corresponds to 860 €/kW	2,0 Mio €/t*d
2023:	corresponds to 650 €/kW	1,5 Mio €/t*d