Cost break down and analysis of PEM electrolysis systems for different industrial and Power to Gas applications

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World of Energy Solutions

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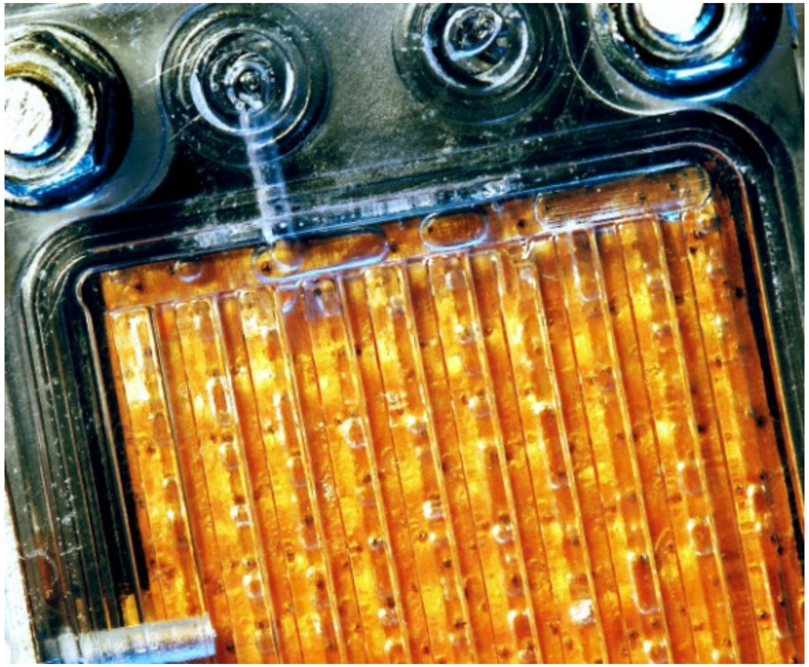
Agenda

- Hydrogen Technologies at Fraunhofer ISE
- Coupling Renewables with hydrogen
- Cost break down of a 5 MW and 100 MW electrolysis system
- Hydrogen production cost
- Summary



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Development of H_2 technologies for more than 25 years.

Hydrogen production by water electrolysis

- PEM electrolysis: cell, stack and system development
- Power to Hydrogen
- Hydrogen refuelling station

PEM fuel cell systems

- Fuel cell systems: cell, stack and system development
- Component and system charakterisation
- Accelerated aging

Thermochemical conversion of hydrocarbons & alcohols

- Residuee free evapo-ration of fuels
- Power to Liquid
- Biomass for Materials

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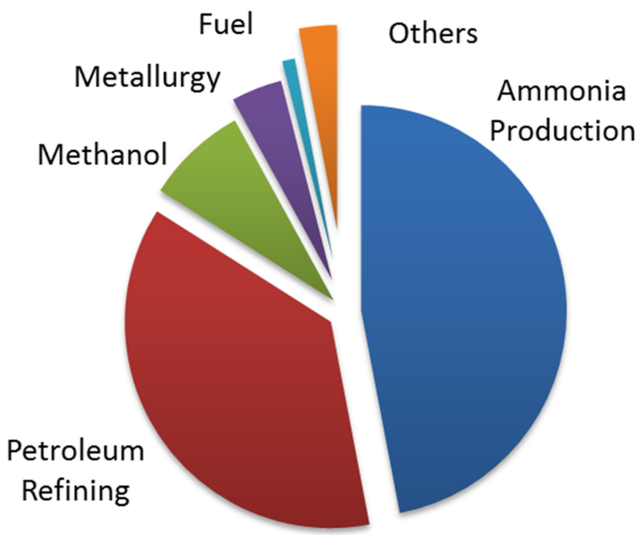
Coupling Renewable Energies and Hydrogen

Today's industrial hydrogen production.

- Global hydrogen production: 600 Bill. Nm³/yr
- Mostly steam reforming
- Less than 1 % by water electrolysis (!)



Industrial application	Typical size electrolyser
Jewellery, laboratory and medical engineering	5 - 500 Nl/h
Generator cooling in power plants	5 - 20 Nm³/h
Feed Water Inertisation (BWR water chemistry)	10 - 50 Nm³/h
Float glas production (protective atmosphere)	50 - 150 Nm³/h
Electronics industry	100 - 400 Nm³/h
Metallurgy	200 - 750 Nm³/h
Food industry (fat hardening)	100 - 900 Nm³/h
Military und aerospace	< 15 Nm³/h

Source: DWV brochure (2006)

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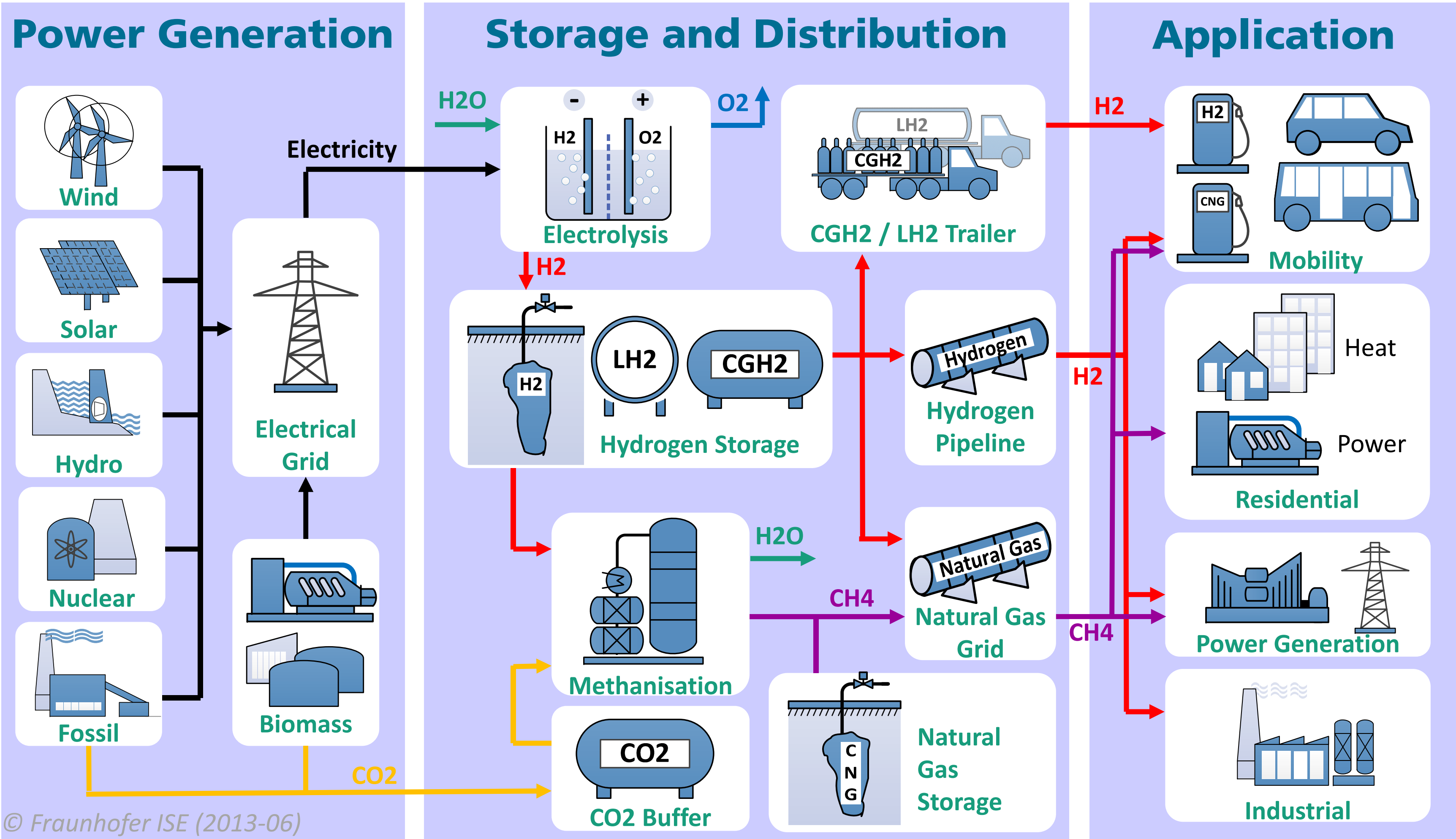
Coupling Renewable Energies and Hydrogen

New market opportunities for electrolysers



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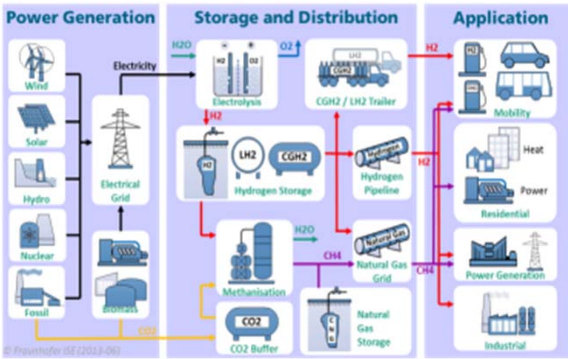
Coupling Renewable Energies and Hydrogen
New market opportunities for electrolysers



Application	Typical EL size
Industrial hydrogen	1 – 20 Nm³/h
Hydrogen for processing industry	50 – 1.000 Nm³/h
Hydrogen filling station type S / M / L	~ 60 / 160 / 360 Nm³/h
Renewable energy storage	100 – 20.000 Nm³/h

- Grid service: Operating reserve / balancing power for the electrical grid
  - demand site management, load balancing
- Power to gas: Hydrogen production (and methanisation)
  - as fuel for FCEV / for industrial applications / large-scale storage systems
- Power to liquid: Valorisation of hydrogen with carbon dioxide
  - liquid fuels for transportation / other secondary feedstocks

→ Cumulative deployment of electrolysers in GW scale is expected/demanded by 2030

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Coupling Renewable Energies and Hydrogen
Technology development and cost reduction are required!

- European view: Multi-annual implemen-tation plan (MAWP) of FCH JU
- Targets defined through key performance para-meters (KPI)

➔ Analysis of cost structure is essential to identify main cost drivers and to develop cost reduction strategies

➔ Hydrogen production cost is another topic

		State-of-the-art	2017	2020	2023
KPI 1	H2 production electrolysis, energy consumption kWh/Nm³ rated power	5.40 @100kg/d	4.95 @500kg/d	4.68 @1000+kg/d	4.50 @1000+kg/d
KPI 2	H2 production electrolysis, CAPEX @ rated power including ancillary equipements and comissioning	3,200 €/kW	1,620 €/kW	920 €/kW	720 €/kW
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

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Cost break down for 5 MW & 100 MW PEM EL system
Study Plan-DelyKaD: Overall goals

- Analysis of technical and economical requirements for large-scaled „Power to Hydrogen“ systems relevant for the energy sector
  - Water electrolysis as key technology (5 → 100 MW)
    - PEM electrolysis (Fraunhofer ISE)
    - Alkaline electrolysis (DLR)
  - Caverns as large scale storage (KBB)
  - Techno-economic simulation of the integrated overall system (LBST, DLR)
  - Study of possible markets for hydrogen (DLR)


Deutsches Zentrum für Luft- und Raumfahrt e.V.

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Studie über die Planung einer Demonstrationsanlage zur Wasserstoff-Kraftstoffgewinnung durch Elektrolyse mit Zwischenspeicherung in Salzkavernen unter Druck

- Final report available (only in German):

  http://edok01.tib.uni-hannover.de/edoks/e01fb15/824812212.pdf

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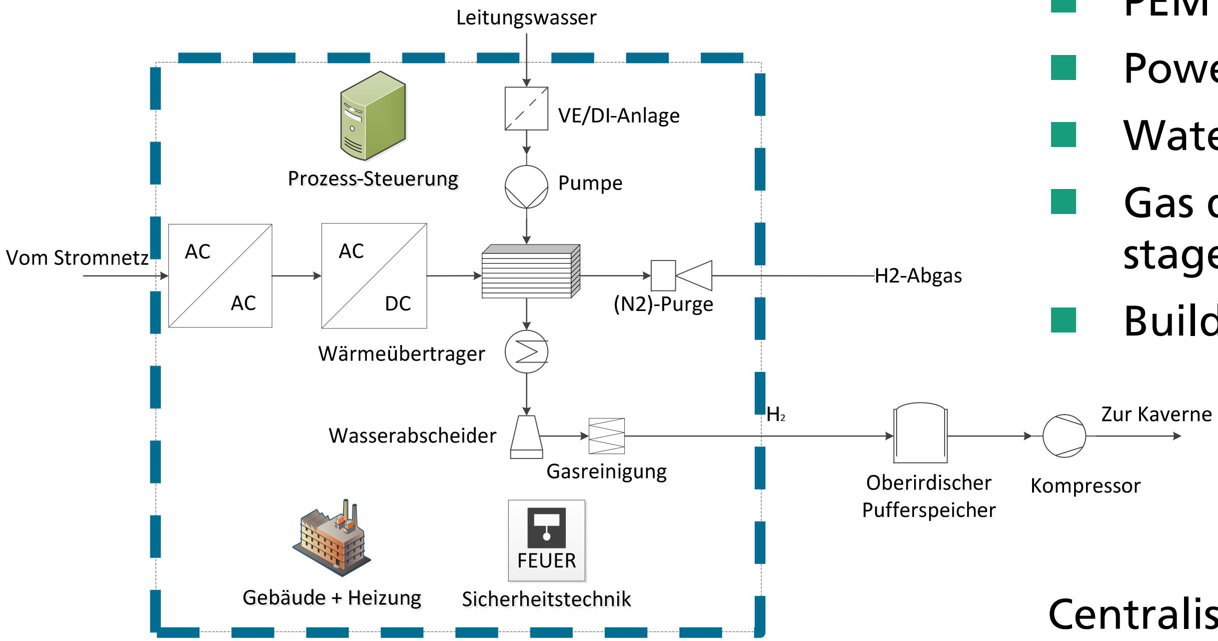
Cost break down for 5 MW & 100 MW PEM EL system

Study Plan-DelyKaD: System boundaries



Electrolysis system consists of

- PEM electrolysis stacks
- Power transformer and rectifiers
- Water purification system
- Gas drying and fine purification stages (dew point 30 °C)
- Building and safety installation

Centralised subsystems

- Gas compression / buffer
- Recooling unit

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Bundesministerium für Wirtschaft und Energie
DLR
KBB UNDERGROUND TECHNOLOGIES
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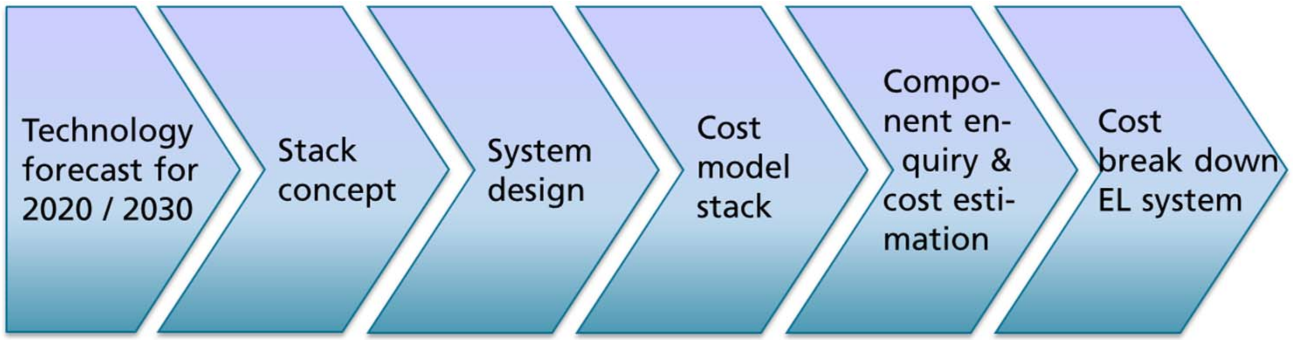
Cost break down for 5 MW & 100 MW PEM EL system
Methodology

- Stack size and performance based on technology forecast for
  - Year 2020: 5 MW system with 4x stacks à 1.25 MW → **low risk**
  - Year 2030: 100 MW system with 10x stacks à 10.3 MW → **high risk**



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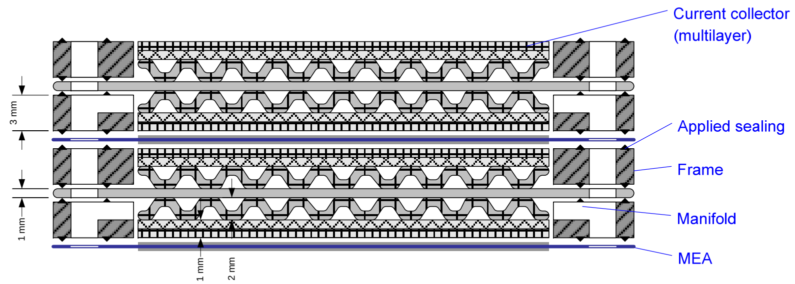
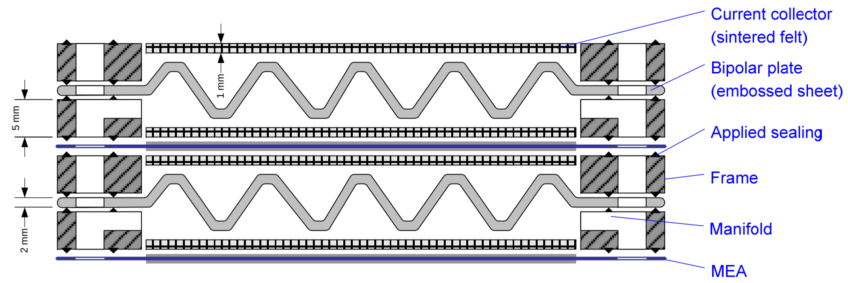
Cost break down for 5 MW & 100 MW PEM EL system
Stack designs for different systems





5 MW system		100 MW system
1.500 cm²	Cell area	10,000 cm²
1.90 V / 1.50 A/cm²	Operating point	1.65 V / 2.50 A/cm²
290	Cells per stack	250
1,240 MVA	Nominal DC power stack	10,300 MVA
265 Nm³/h H_2	Stack production capacity	2.542 Nm³/h H_2
4	Number of stacks	10
4.96 MVA	Nominal DC power system	103.0 MVA

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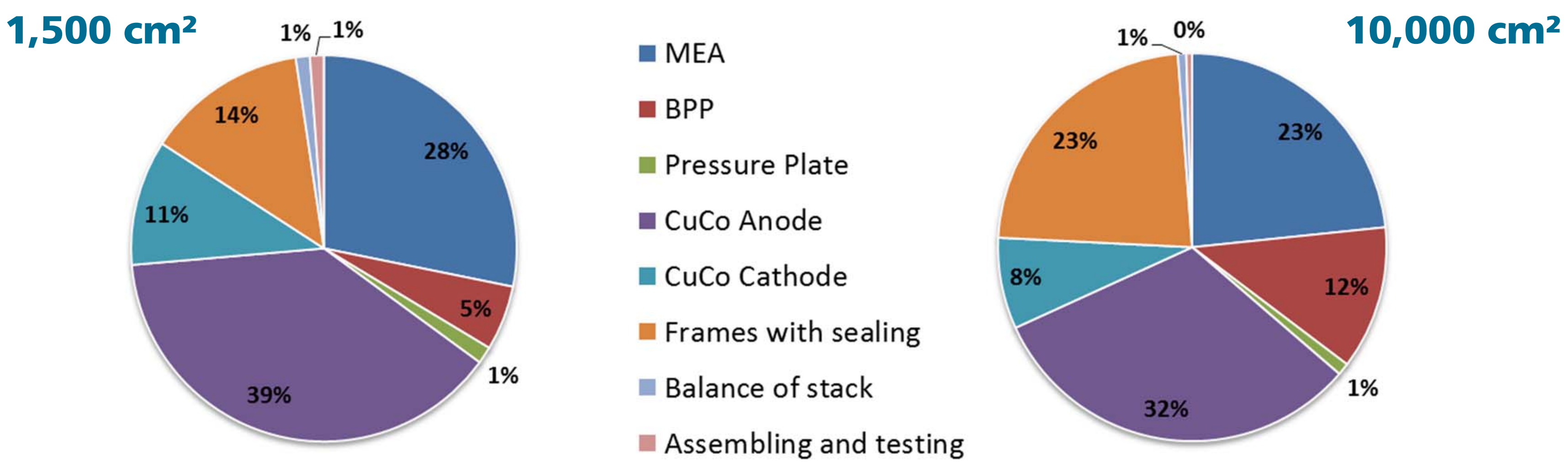
Cost break down for 5 MW & 100 MW PEM EL system

Cost drivers in a stack: Ti current collectors and MEAs

- Required quantities and specific costs of materials/components in a stack provide data input for cost break down model developed at Fraunhofer ISE



Production volume: 40 stacks (10 systems)

Production volume: 10 stacks (1 system)

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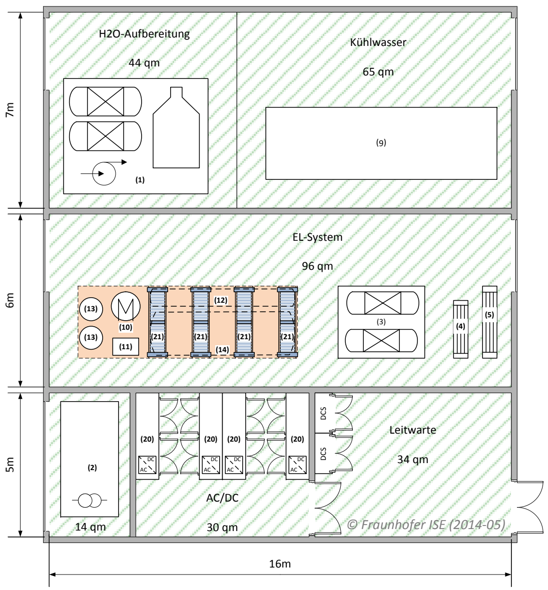
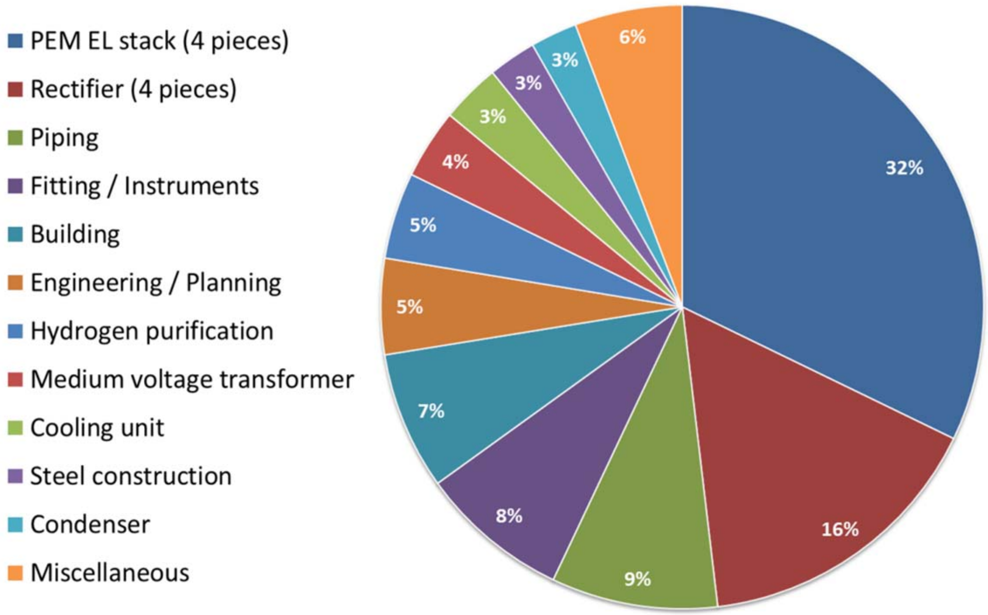
Cost break down for 5 MW PEM EL system

On system level power electronics and stacks are dominant.



~ 285 m²



- Cost model of system based on plant layout with energy and mass balances and cost input from manufactures of main subsystems
- Cost estimation for planning, piping, construction etc. by Diamond Lite SA (CH)

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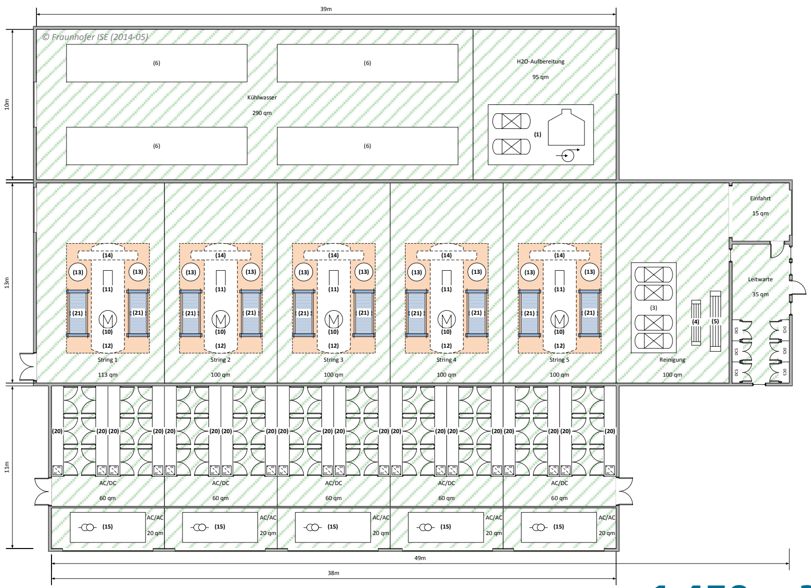
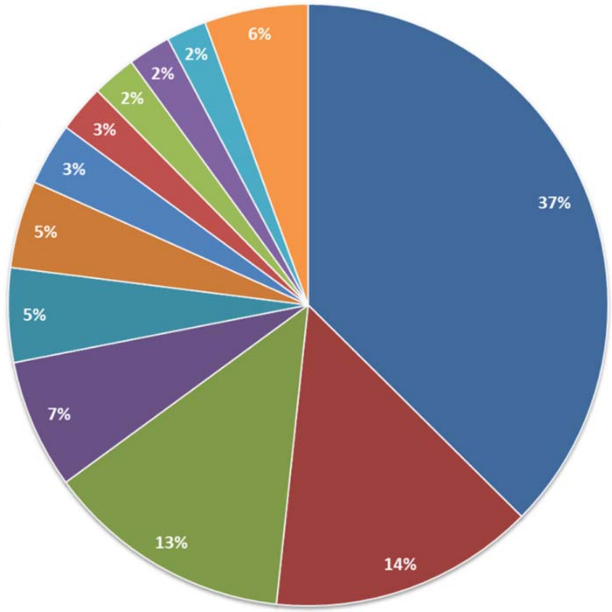
Cost break down for 100 MW PEM EL system

On system level power electronics and stacks are essential.





- Comparison with 5 MW system
  - Cost share of stacks increases with larger systems
  - Power electronics has a similar share as stacks

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Cost break down for 5 MW & 100 MW PEM EL system

Summary of key performance indicators

	5 MW system	100 MW system
Power BoP	390 + 20 kW	2,300 + 110 kW
Power Stand by	77 kW	1,667 kW
Efficiency @ nominal power	69 $\%_{(HHV)}$	84 $\%_{(HHV)}$
Efficiency @ overload	64 $\%_{(HHV)}$	77 $\%_{(HHV)}$
CAPEX stack	370 k€ (1.24 MW)	1,310 k€ (10.3 MW)
Stack overhault	186 k€	581 k€
CAPEX system	4.8 Mio. €	35.7 Mio. €
with overload capacity (30 min)	5.2 Mio. €	40.7 Mio. €
Spec. CAPEX system	960 €/kW	350 €/kW
with overload capacity (30 min)	1,030 €/kW	400 €/kW

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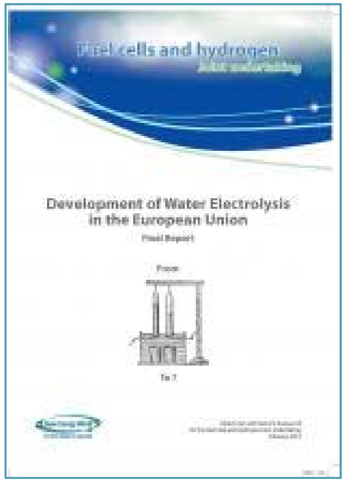
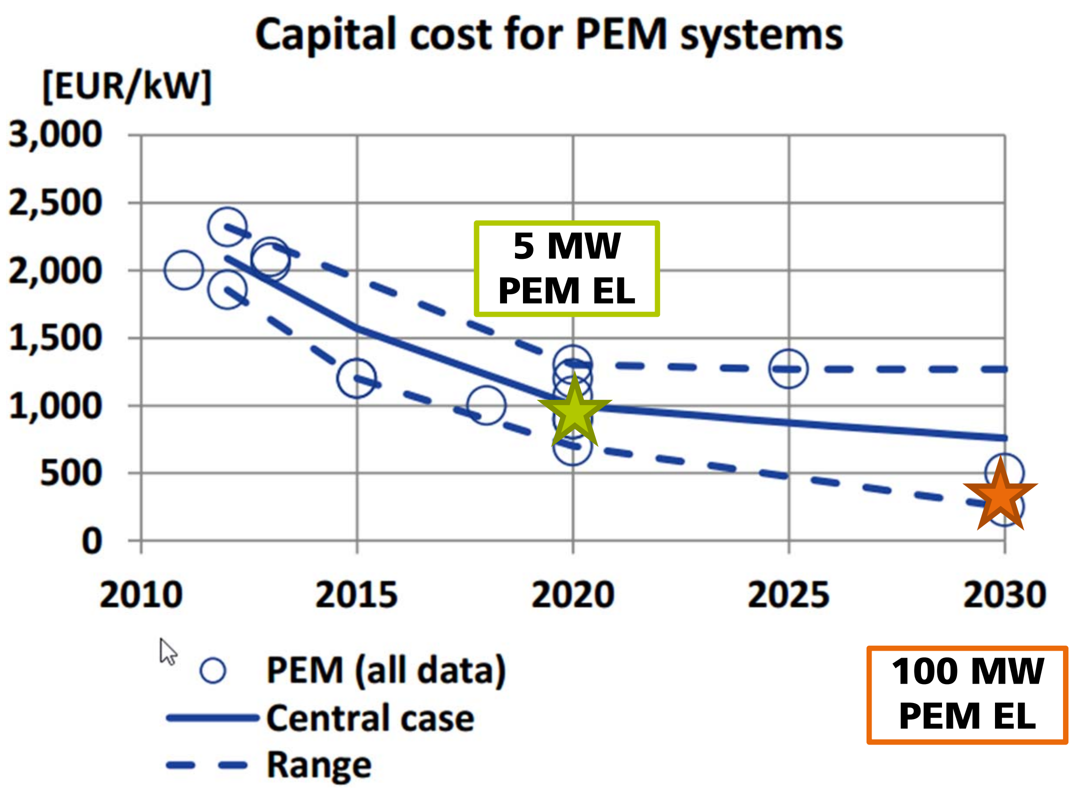
Cost break down for 5 MW & 100 MW PEM EL system
Comparison with data from literature

- Study on development of water electrolysis in the EU
  - published in 2014-02-07
  - E4tech / element energy
- Data sources included literature and interviews with stakeholders





http://www.fch.europa.eu/sites/default/files/study%20electrolyser_0-Logos_0_0.pdf

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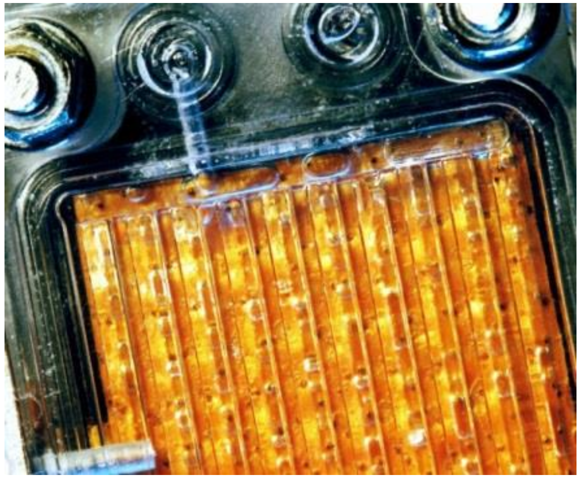
Hydrogen production cost
Focus only on CAPEX is not enough!



- Main shares in hydrogen production cost:
  - investment cost / capital expenditure (CAPEX)
  - electricity cost to run the electrolysis process
  - remaining operational expenditure (OPEX)
    - Water and operating resources
    - Service and maintenance
    - overhaul, rental charges etc.
- Storage, transportation and distribution are NOT included

→ economical evaluation against other hydrogen production technologies (e.g. steam reforming)

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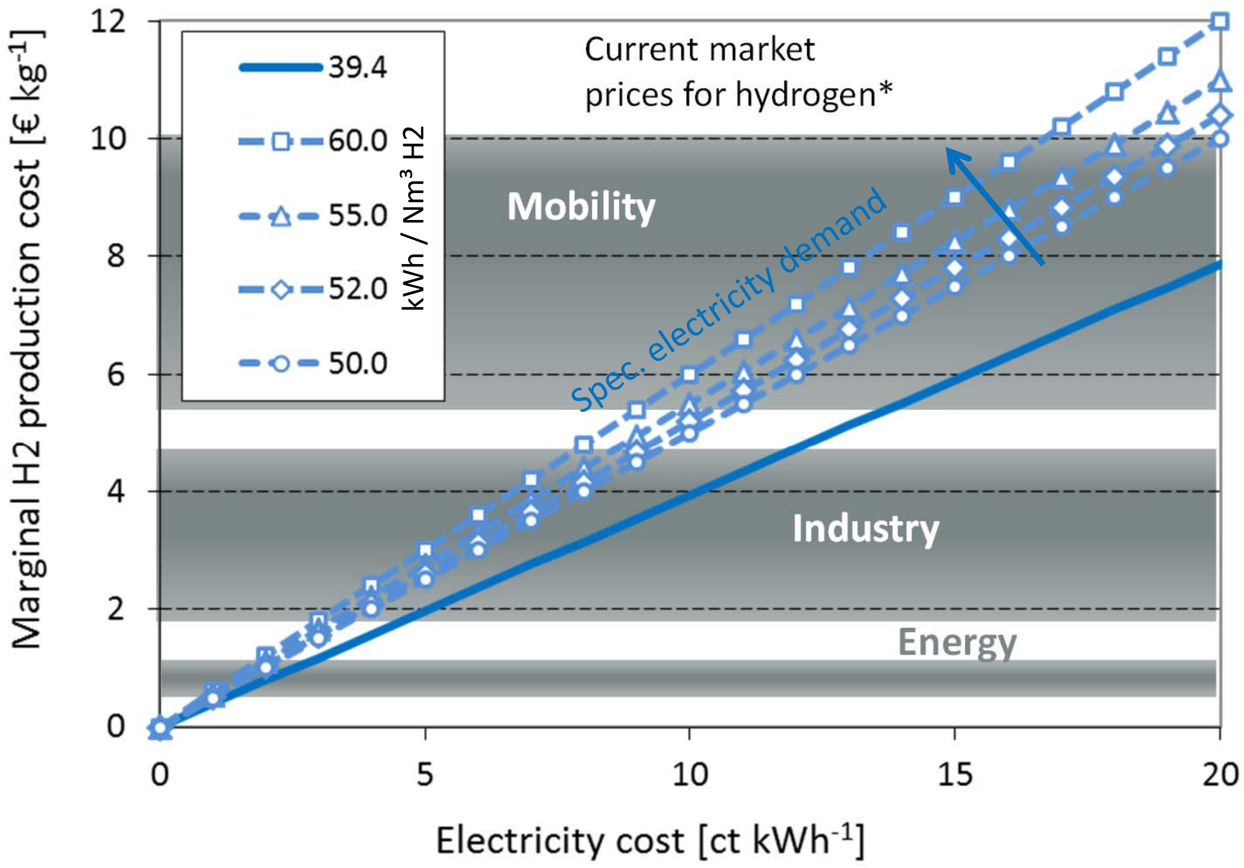
Hydrogen production cost

Cost on purchased electricity and efficiency are dominantly



* Scope of application adapted from Waidhas / Siemens 2015

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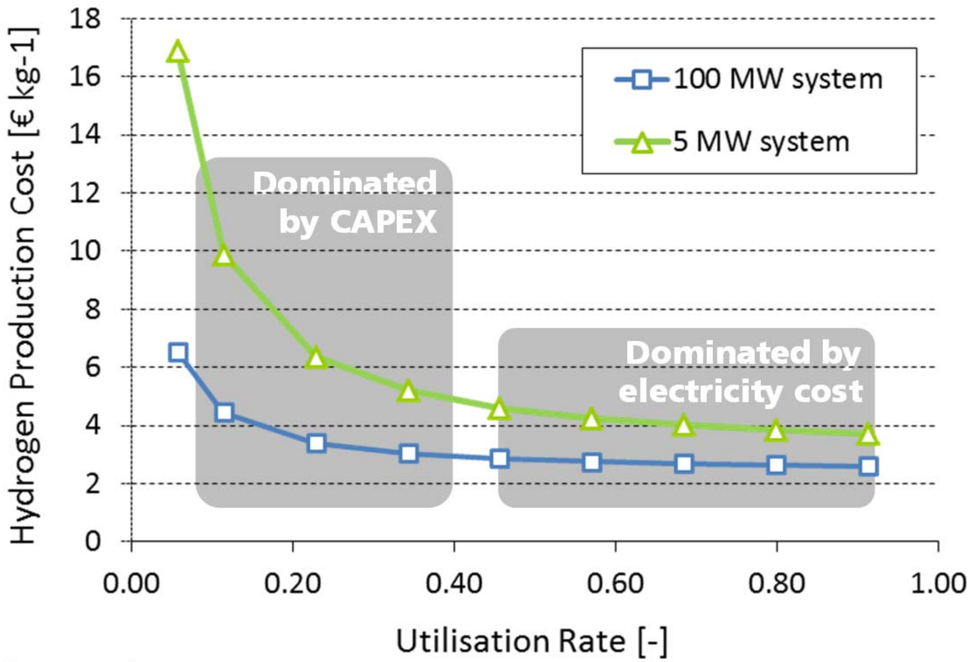
Hydrogen production cost

Utilisation rate defines the importance of CAPEX

- Hydrogen production cost mainly depends on electricity cost, operational hours and CAPEX
- Low utilisation rate
  - CAPEX important
  - Rather larger systems
- High utilisation rate
  - Electricity cost and efficiency important
  - Rather smaller systems



Assumption

- Recovery period: 20 years / interest rate: 5 %
- Electricity cost: 50 €/MWh
- 5 MW: 69 $\%_{HHV}$ / 960 €/kWh
- 100 MW: 84 $\%_{HHV}$ / 350 €/kWh
- plus 10% planing & 4% maintenance (incl. overhauling)

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Summary and Results

Cost break down

- Substantial cost reduction for PEM electrolysis stacks is possible by
  - Scaling up of PEM cells
  - Technical progress for cell components
  - Economy of scale
- Investment cost < 500 €/kW for PEM electrolysis systems are possible if specifications of technology forecast can be met in the future

Hydrogen production cost

- CAPEX is sufficiently high that high utilisation rate is required for cost-effective deployment of EL systems
- Hydrogen production cost is dominated by cost of electricity (for business cases with high utilisation rate)

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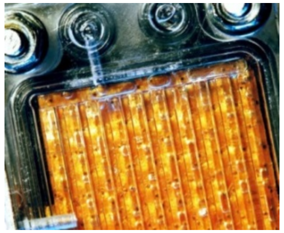
Acknowlegdment



- Hans Vock / Diamond Lite SA
- Christopher Voglstätter / Fraunhofer ISE

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  http://forschung-energiespeicher.info/wind-zu-wasserstoff/projektliste/projekt-einzelansicht/74/Wasserstoff_Kraftstoff_aus_Elektrolyse

- Fuel Cell and Hydrogen Joint Undertaking
  (Project Megastack - grant agreement n°621233)
  http://www.fch.europa.eu/project/megastack

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Thanks a lot for your kind attention!

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