PEM Water Electrolysis - Present Status of Research and Development

Review Lecture – Session HP.3d

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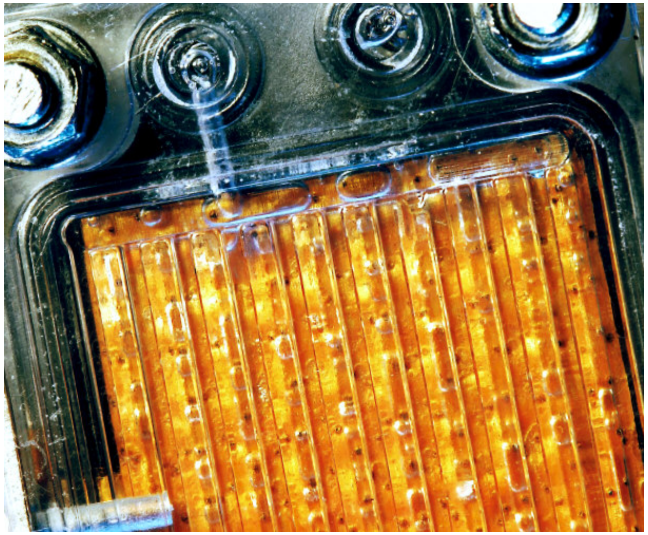
Agenda

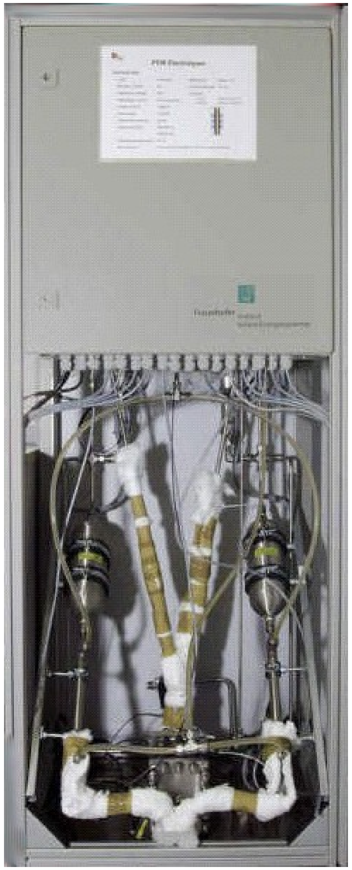


- Background of PEM water electrolysis activities at Fraunhofer ISE
- Fundamental of PEM water electrolysis
- Electrodes and Membrane Electrode Assembly
- Cell design and stack construction
- System layout and efficiencies
- Comparison to alkaline water electrolyser (Conclusion and summary)

The Self-sufficient Solar House in Freiburg …

- … begin of R&D activities in PEM electrolysis at Fraunhofer ISE
- First developments in the eighties
- Field test: 1992-1995
- Complete hydrogen storage system consisting of:
  - PEM electrolyser

    (30 bar / 2 kW_{el})
  - H_2 and O_2 pressure tanks
  - PEM fuel cell



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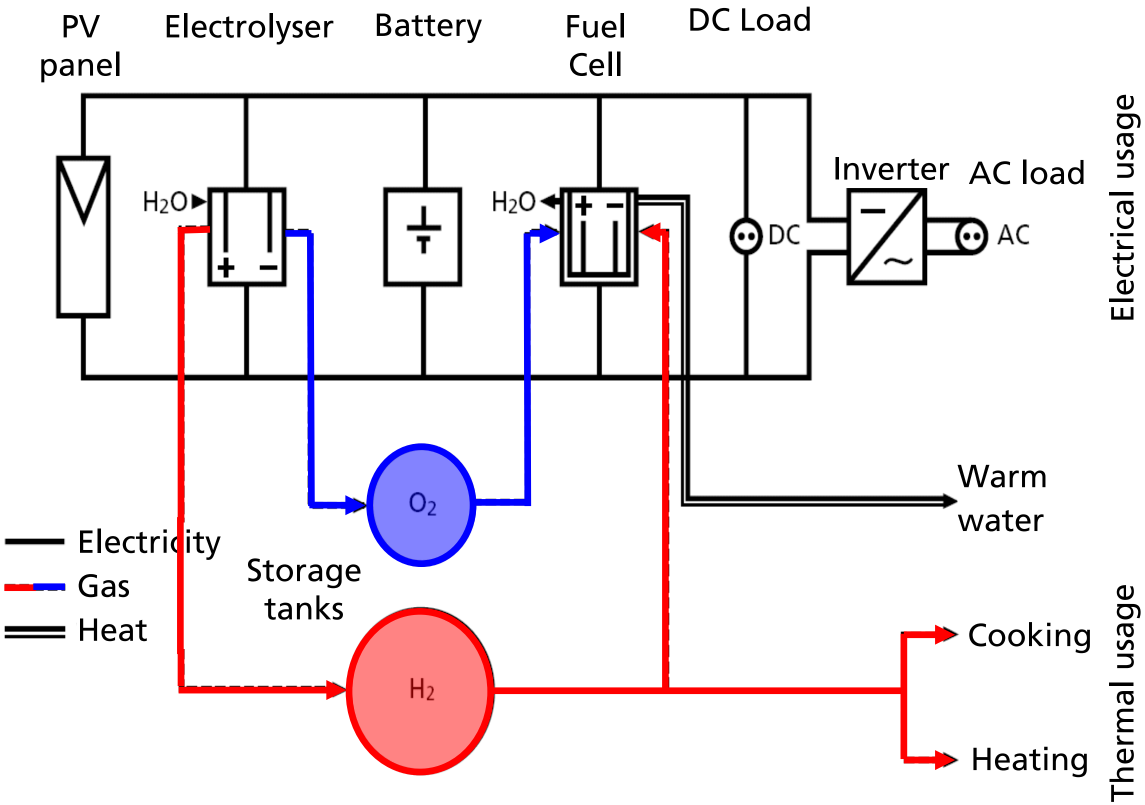
The Self-sufficient Solar House in Freiburg …

Regenerative fuel cell:

- PEM electrolysis unit (30 bar / 2 kW_{el})
- H_2/O_2 storage tanks
- PEM fuel cell
- No mech. compressor!



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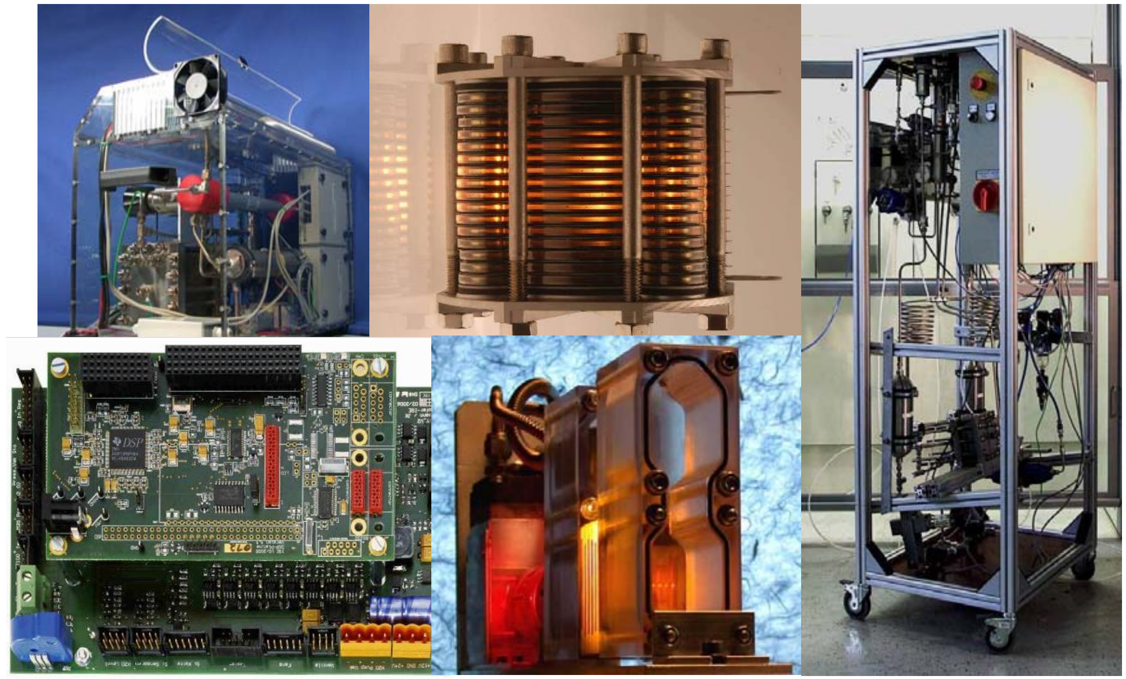
For more than 20 years experience in PEM electrolysis

- Material characterisation
- Cell and stack design
- Balance of plant
- Control strategies
- Power electronics
- Integration with RES
- System evaluation



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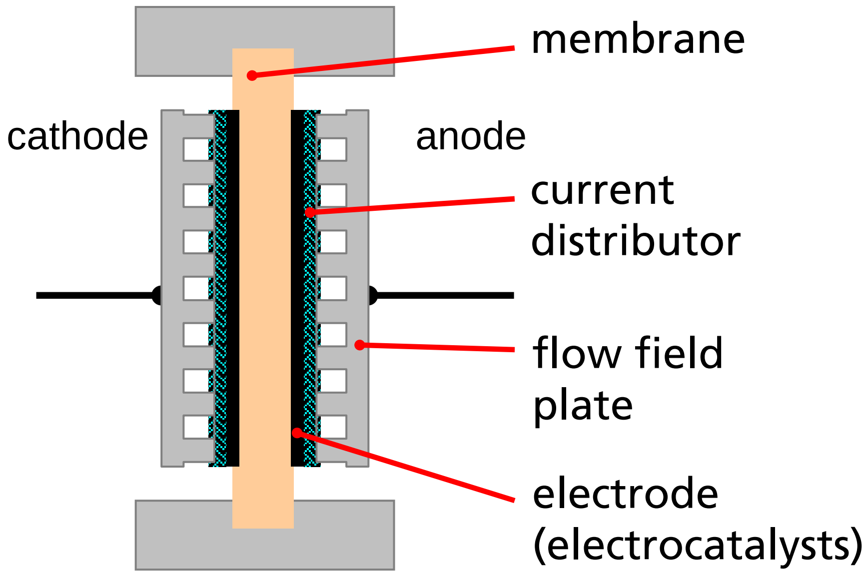
Schematic of a PEM electrolysis cell



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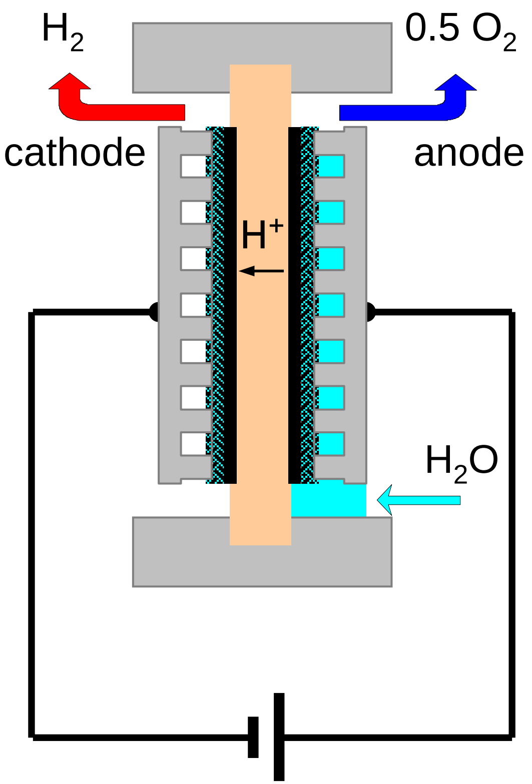
Schematic of a PEM electrolysis cell



Anode reaction:

$H_2O \rightarrow 0.5\ O_2 + 2H^+ + 2e^-$

Cathode reaction:

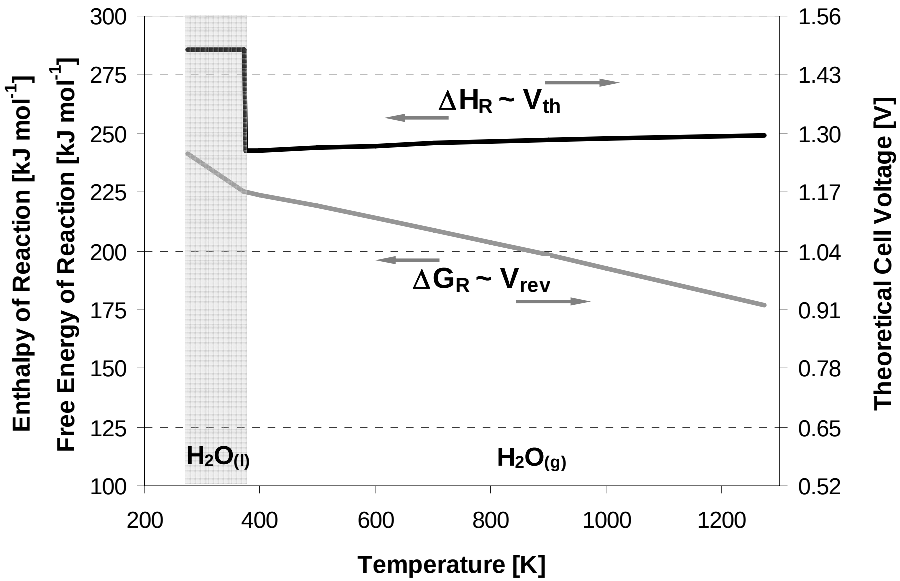
$2H^+ + 2e^- \rightarrow H_2$

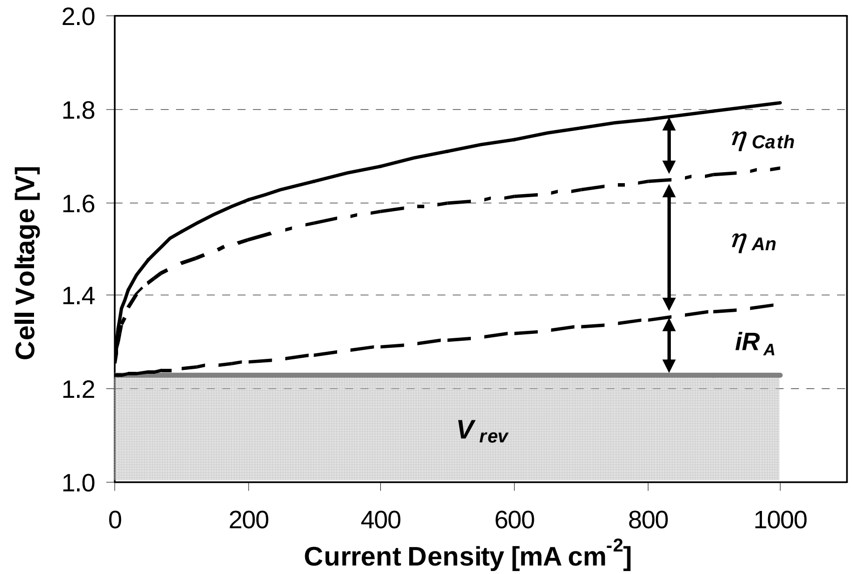
Total reaction:

$H_2O \rightarrow H_2 + 0.5\ O_2$

- V_{rev} = 1.23 V @ STP
- endothermal reaction

Decomposition of water





Thermodynamics:

- Reversible losses
- HHV: 3.54 kWh/Nm³ H_2

Reaction kinetics:

- Irreversible losses
- Overpotentials and internal resistance

➔ Cell voltage affected by temperature and pressure

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The core component: Membrane Electrode Assembly

Membrane

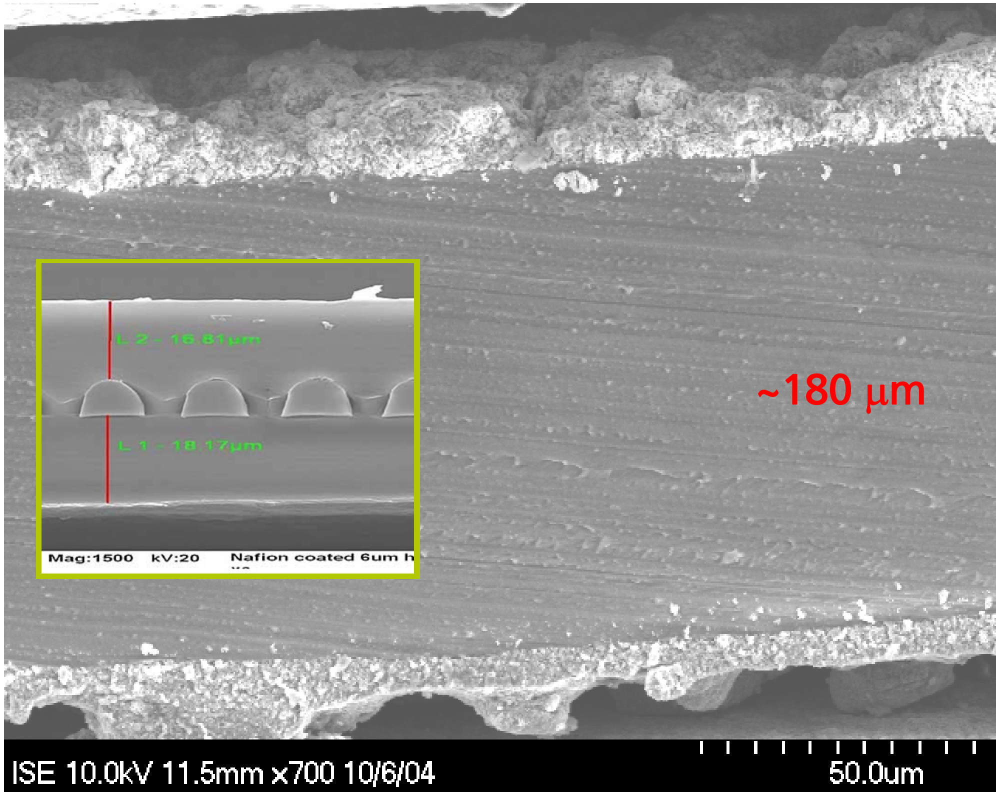
- Thickness: 100 - 300 µm (e.g. Nafion 117)
- Coated on both sides with catalysts
- Reinforcement possible

Cathode

- Loading: 1.0 – 2.0 mg/cm²
- Pt black or Pt/C based

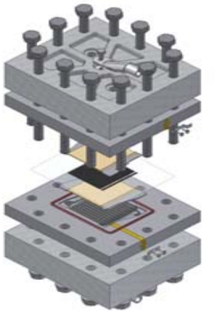
Anode

- Loading: 1.0 – 4.0 mg/cm²
- Mostly Ir, Ru, Pt, (oxide) based

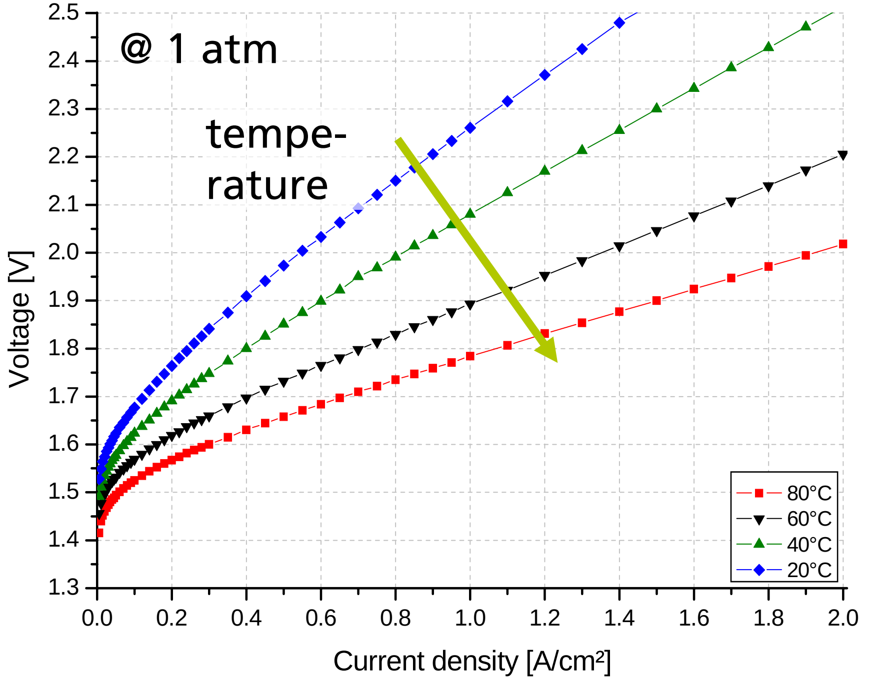


Cross Section of a MEA (Fraunhofer ISE) and reinforecd DMS membrane (Giner)

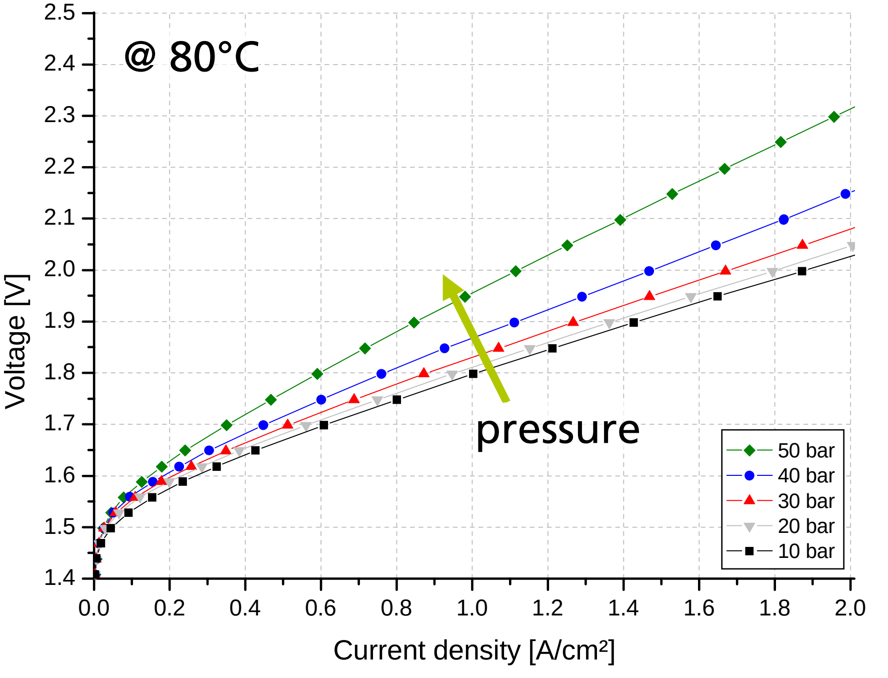
Performance of a PEM electrolysis cell



- Influence of cell temperature



- Influence of cell pressure



VII characteristics of a standard Nafion based MEA from SolviCore measured in a 25 cm² laboratory electrolysis cell (Fraunhofer ISE)

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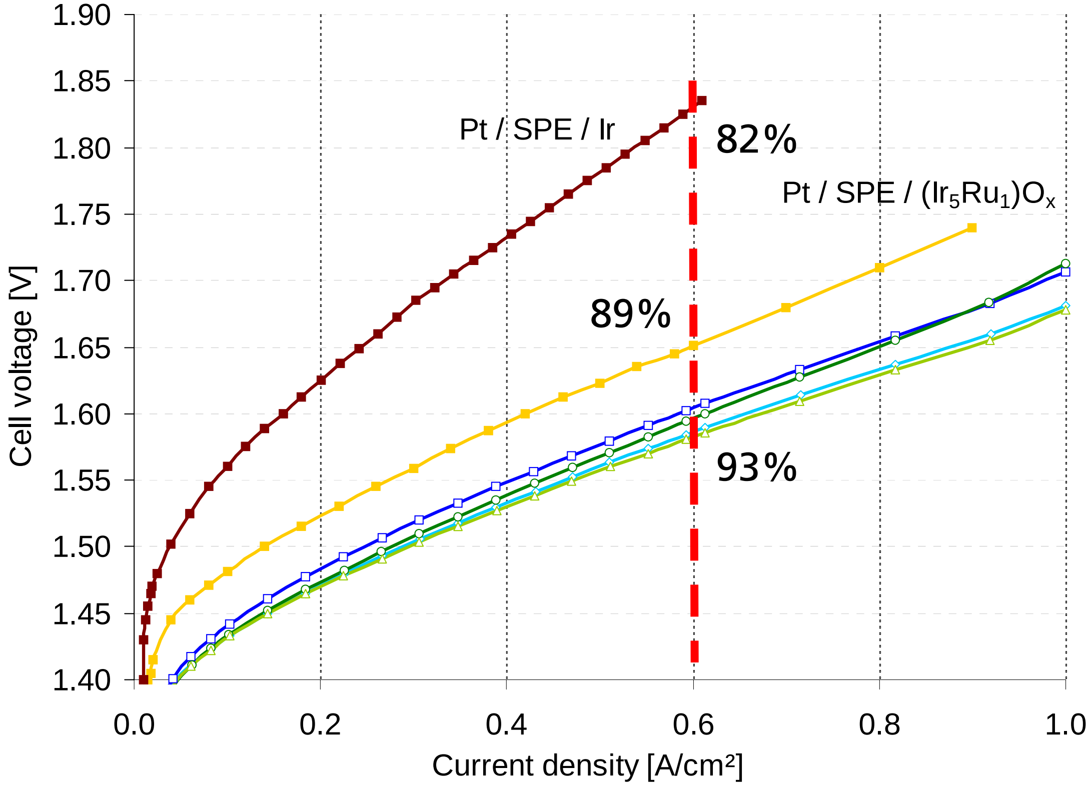
Alternative catalysts for the anode

Optimised MEAs	Metal (M)
$Ir_1Ru_2O_xM_{0.1}$ (green line)	Fe
$Ir_1Ru_2O_xM_{0.1}$ (light green line)	Ni
$Ir_1Ru_2O_xM_{0.1}$ (cyan line)	Co
$Ir_1Ru_2O_xM_{0.1}$ (blue line)	Sn

- Cell efficiency:

$$\varepsilon = \frac{V_{HHV}(T,p)}{V_{OP}(T,p)}$$

- Efficiencies > 95% at 1000 mA/cm² reported in literature



V/i characteristic @ 80°C / 1 atm, cathode: Pt black (Fraunhofer ISE)

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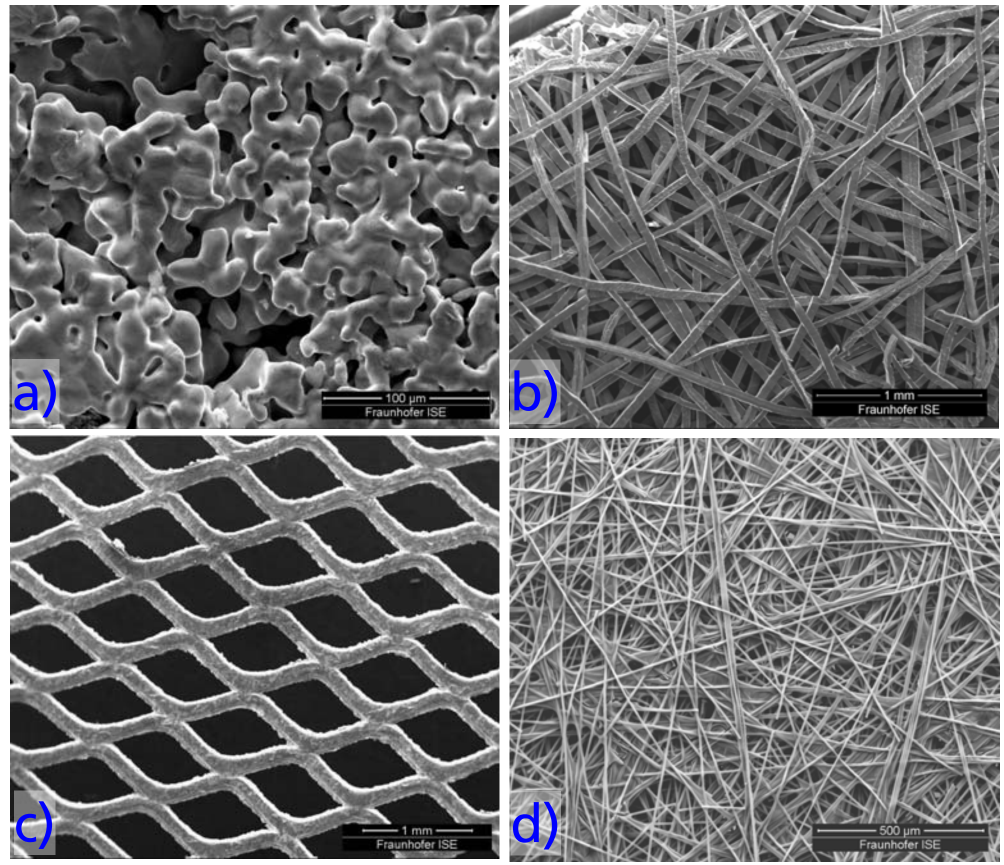
Current collectors/distributors

Challenge:

- Porous, electrically conductive and corrosion-resistant material

Solution:

- Sintered Ti powder (a)
- Sintered Ti felt (b)
- Expanded Ti mesh (c)
- Carbon-based paper (d)



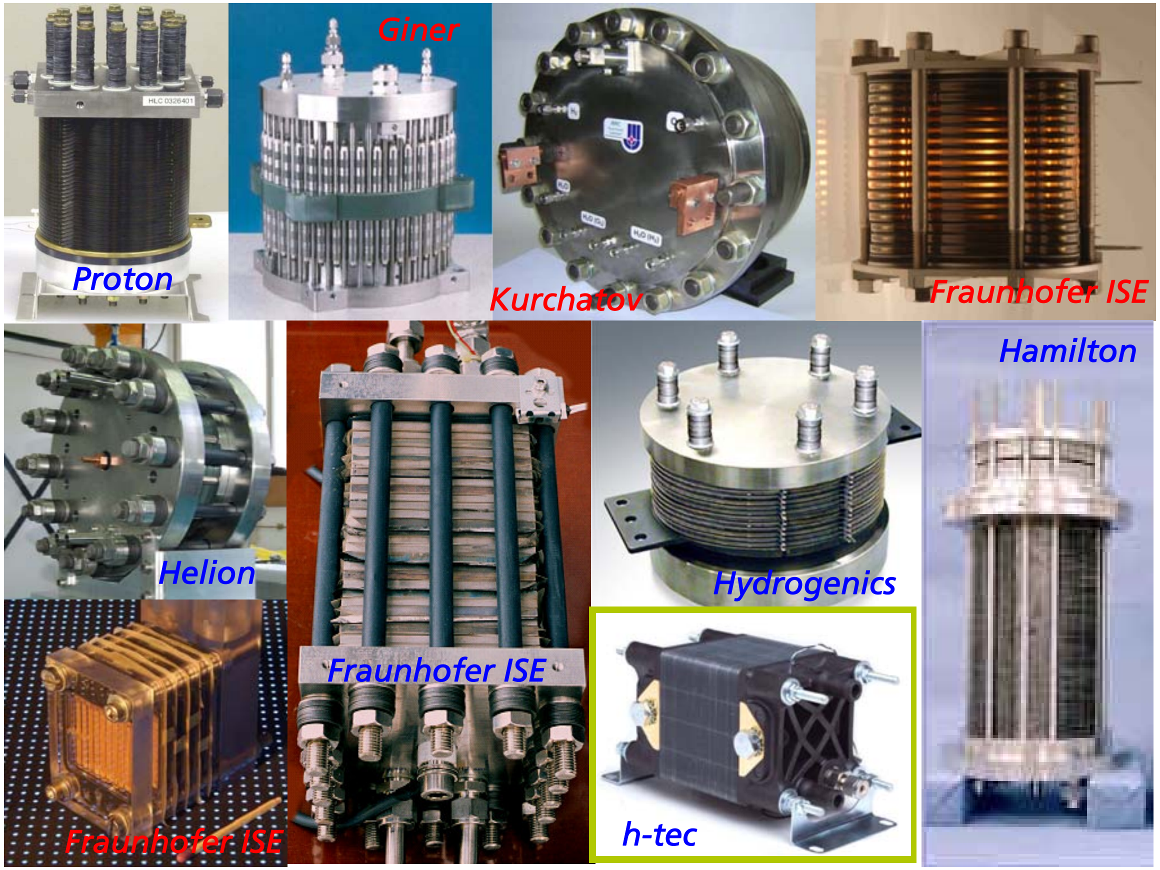
From cell design …

- Corrosion-resistant materials
  - Titanium
  - Coated metals
  - Plastic-composite
- Pressure-resistant cell design
  - Metal-cutting production
  - Frame construction
    - Die cutting
    - Metal-laminate
    - injection molded
  - Structured plates with applied gaskets

(Hamilton Sunderstrand, Fraunhofer ISE)

… to stack construction for PEM water electrolyser

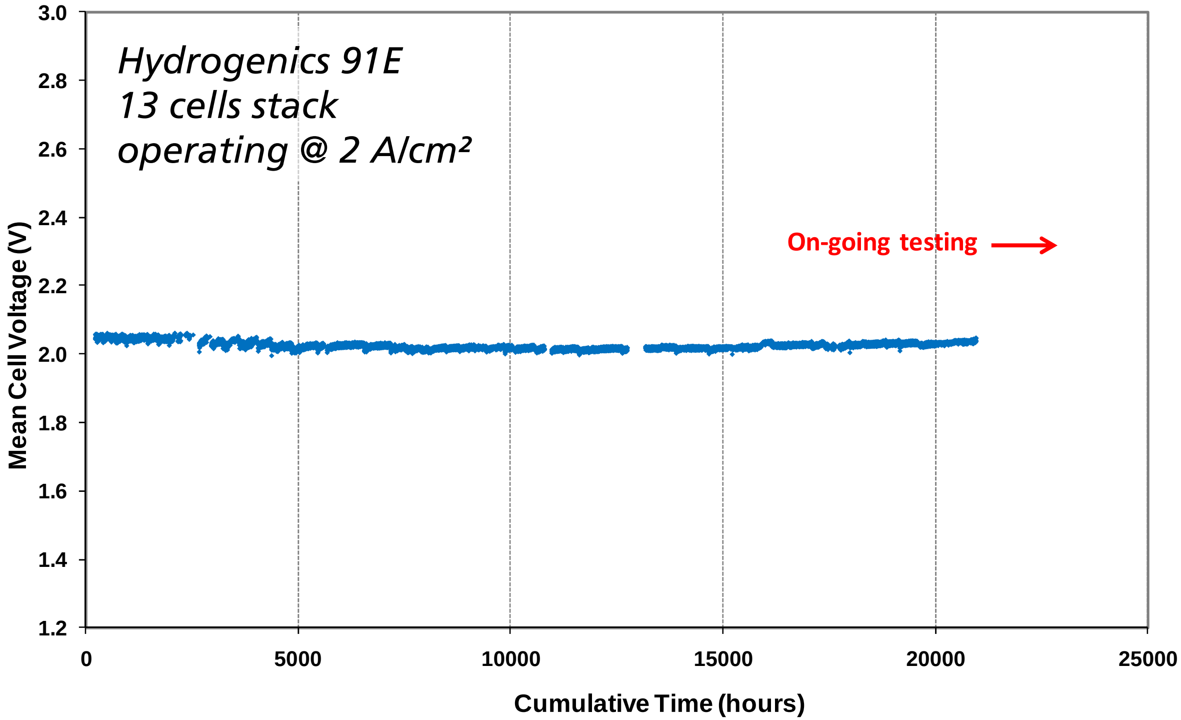
- Filter press configuration
- Pressure resistance:
  up to 207 bar
- Active area:
  10 – 750 cm²
- Current density:
  up to 2.5 A/cm²
- Cell voltage: max. 2.2 V
- Number of cells: < 120
- H_2 production rate:
  2 Nl/h – 30 Nm³/h
- Power input per stack:
  up to 160 kW_{el} (estimated)



Long-term performance of PEM electrolysis stacks

Typical stack life time

- 5,000 - 20,000 h in a system
- Stack replacement: every 5 - 9 years
- In military applications up to 100,000 h reported



Hydrogenics 91E stack

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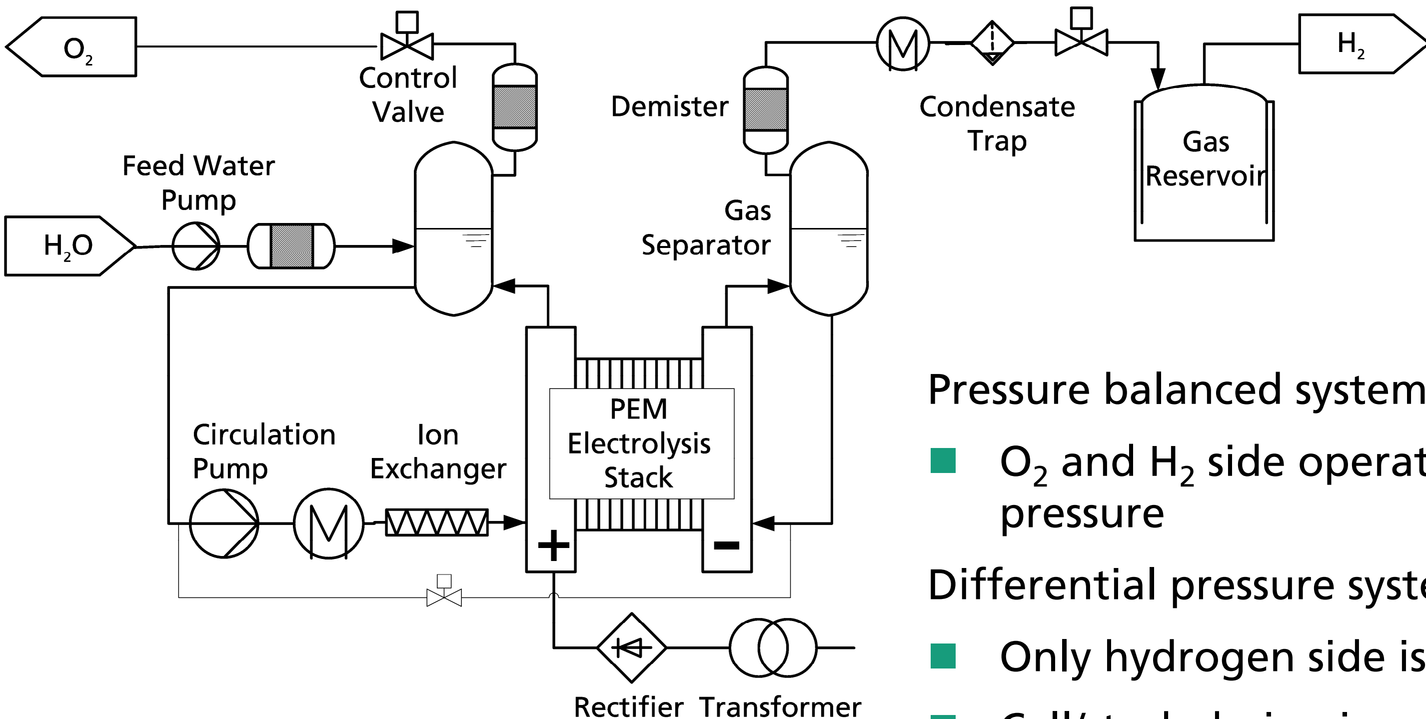
PEM electrolysis system = stack + balance of plant



Pressure balanced system:

- O_2 and H_2 side operates at same pressure

Differential pressure system:

- Only hydrogen side is pressurised
- Cell/stack design is more sophisticated
- BoP more simple and less expansive

Commercial PEM electrolyser

- Compared to alkaline systems low H_2 production rates:
  - 100 Nml/min – 15 Nm³/h today
  - Up to 30 Nm³/h in the near future
- H_2 output at 6 – 30 bar and purified up to 6.0
- Applications:
  - Laboratory equipment (e.g. gas chromatography)
  - Generator cooling in power plants
  - Float glas manufacturing and further industrial processes (food industry)
  - Military (submarines) and space

Schmidlin Proton FuMA-Tech ITM Power Hydrogenics Proton Claind Proton Statoil Treadwell

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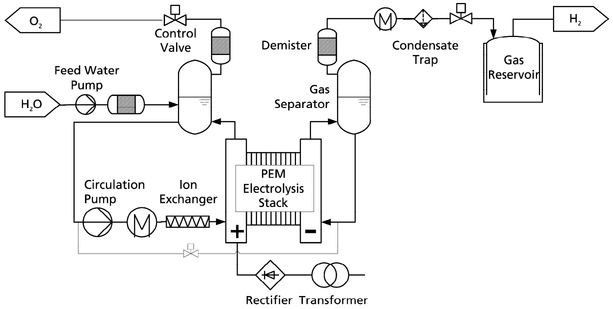
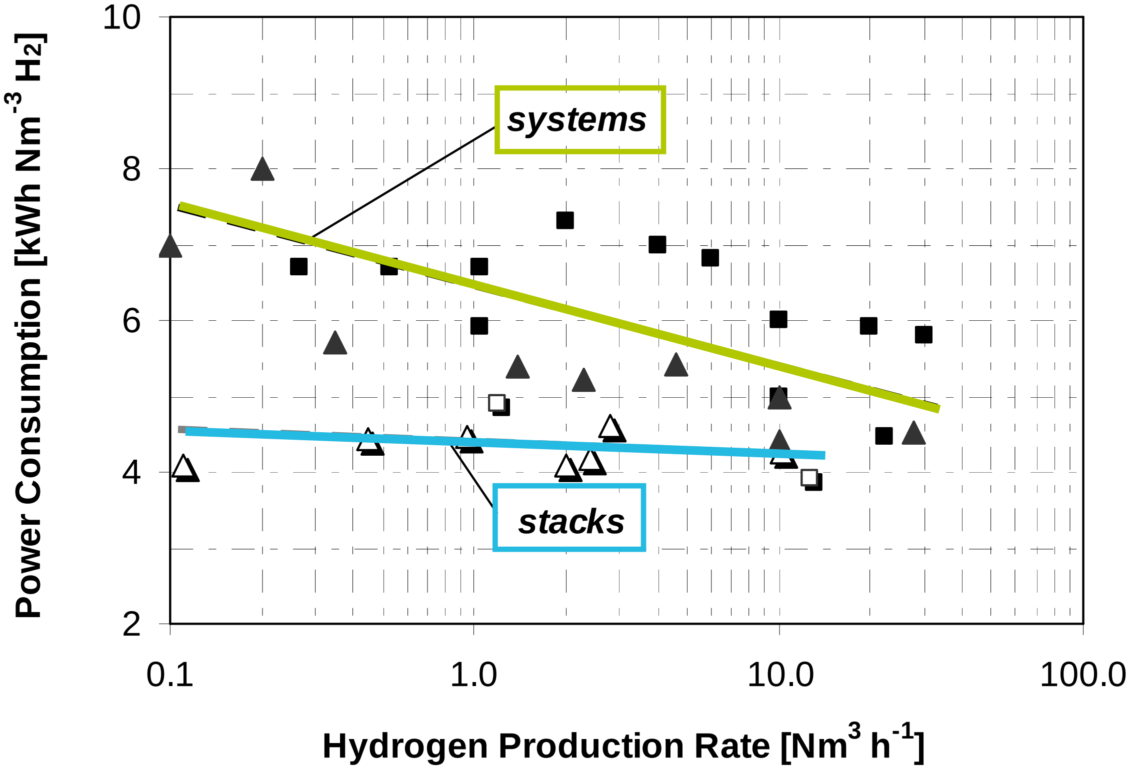
How efficent are PEM electrolysers?

- Prefered measure: specific power consumption in kWh/Nm³ H_2
- High efficiencies on stack level
- Moderate efficiencies on system level (low H_2 production rates)





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Comparison of alkaline and PEM electrolysers

- Comparable young technology, still high potential for further improvement
- Principle advantages:
  - Simple system configuration
  - Very high current and power densities
  - High efficiencies on cell level
  - Very fast response time, suitable for coupling with RES

} Small footprint

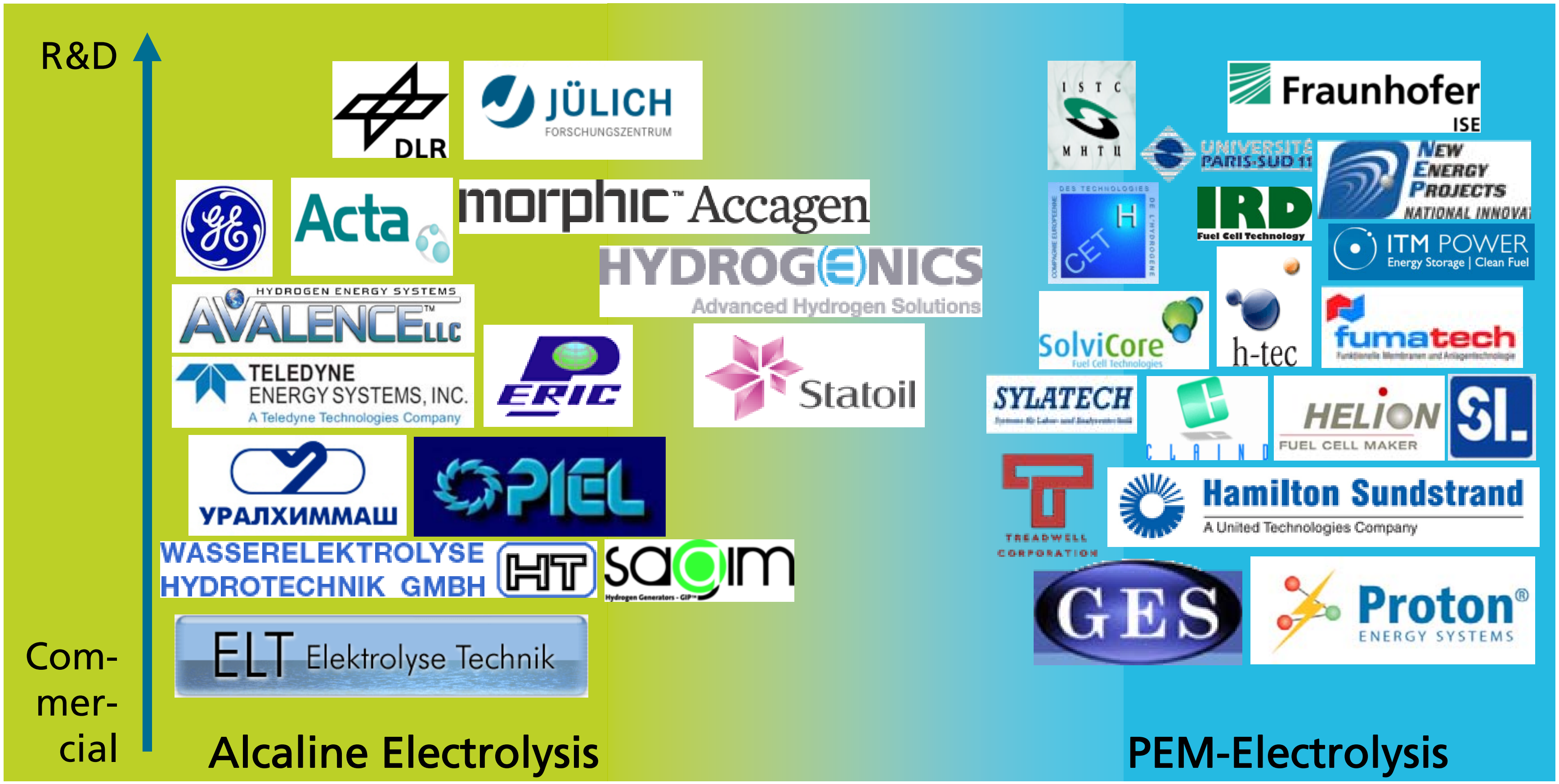
- Usage of expensive materials (membrane, electrodes, bipolar plates)
- Attractive competitive position for small electrolysis units << 100 Nm^3/h
  - How large will PEM electrolysers become in the next 10 years??

Comparison of alkaline and PEM electrolysers

	today		in the future	
	AEL	PEMEL	AEL	PEMEL
Current density	-	+	o	++
Power density	--	+	-	++
Efficiency (system)	+	o	+	+
System complexity	-	o	-	o
Durability / Life cycle	++	o	++	+
Investment costs	o	-	o	o

Manufacturer of water electrolysers - Who is on the road?

This figure does not claim to be exhaustive!



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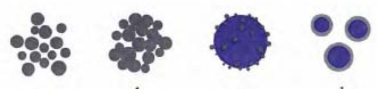
NEXPEL main objective:

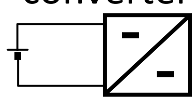
Develop and demonstrate a PEM water electrolyser integrated with RES:

75% Efficiency (LHV), H_2 production cost ~ €5,000 / Nm^3h^{-1}, target lifetime of 40,000 h

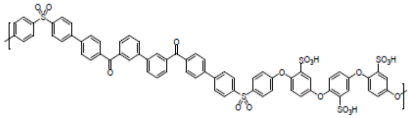
New catalysts

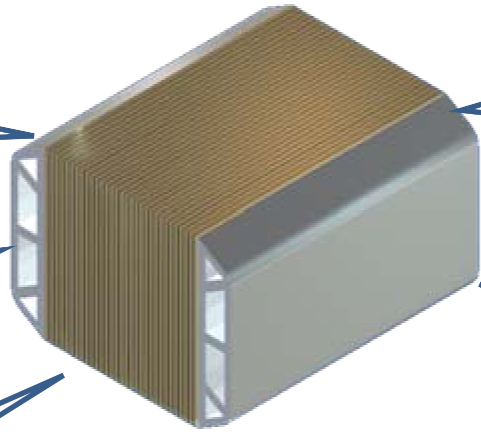


Improved DC-DC converter

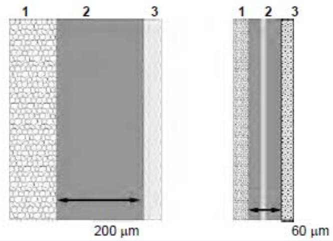


New membrane materials

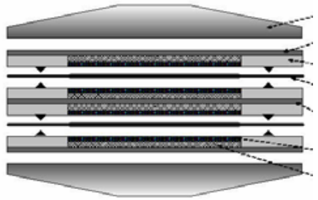




Improved MEAs



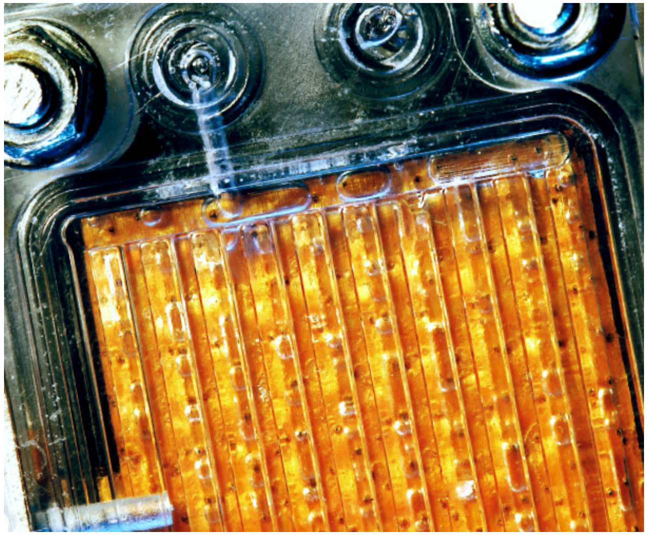
Novel stack design and new construction materials



Jan 2010 - Dec 2012
Co-ordination: SINTEF
Funding: Fuel Cells and Hydrogen JU
Total Budget: € 3,353,549
www.nexpel.eu

SINTEF University of Reading Statoil cea HELION HYDROGEN POWER fumatech Funktionelle Membranen und Anlagentechnologie Fraunhofer ISE

Thank you for your kind attention!



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Questions?

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