# INNOVATIONPITCH: OPTIMIERUNG DER ELEKTROLYSE FÜR DIE WASSERSTOFFERZEUGUNG

40 YEARS
FRAUNHOFER ISE
#CreatingTheEnergyFuture

Impulsvortrag

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DVGW-Kongress „Technikforum Wasserstoff“

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www.ise.fraunhofer.de



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# The Fraunhofer Institute for Solar Energy Systems ISE

## Part of the German Fraunhofer Association for Applied Research


- 74 instituts and research units
- 28,000 employees
- €2.8 billion finance volume

Directors:
Prof. Dr. Hans-Martin Henning
Dr. Andreas Bett

Staff: approx. 1,200

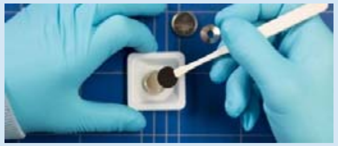
Budget 2019: €102.8 million

Established: 1981

Photovoltaics

Energy Efficient Buildings

Solar Thermal Power Plants and Industrial Processes



Hydrogen Technologies and Electrical Energy Storage

Power Electronics, Grids and Smart Systems

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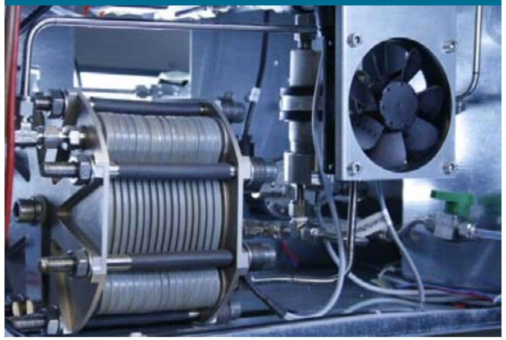
# The Fraunhofer Institute for Solar Energy Systems ISE

## Research Topic: Electrolysis and Power to Gas

### Characterisation of Materials and Components

- Elektrochemical Characterisation
- Investigation of life-time / Accelerated stress tests
- Ex-situ analysis

### Development of PEM Water Electrolysis Systems



- New Cell concepts
- Laboratory PEM stacks
- Energy-optimised balance of plant
- Control strategies

### Power to Gas

- Dynamic system modelling of PtG systems
- Development of system and plant concepts
- $H_2$ yield assessment

### Hydrogen Infrastructure


- Technology consulting
- Techno economical analysis /market survey
- Roll out $H_2$ technologies
- Life cycle assessment

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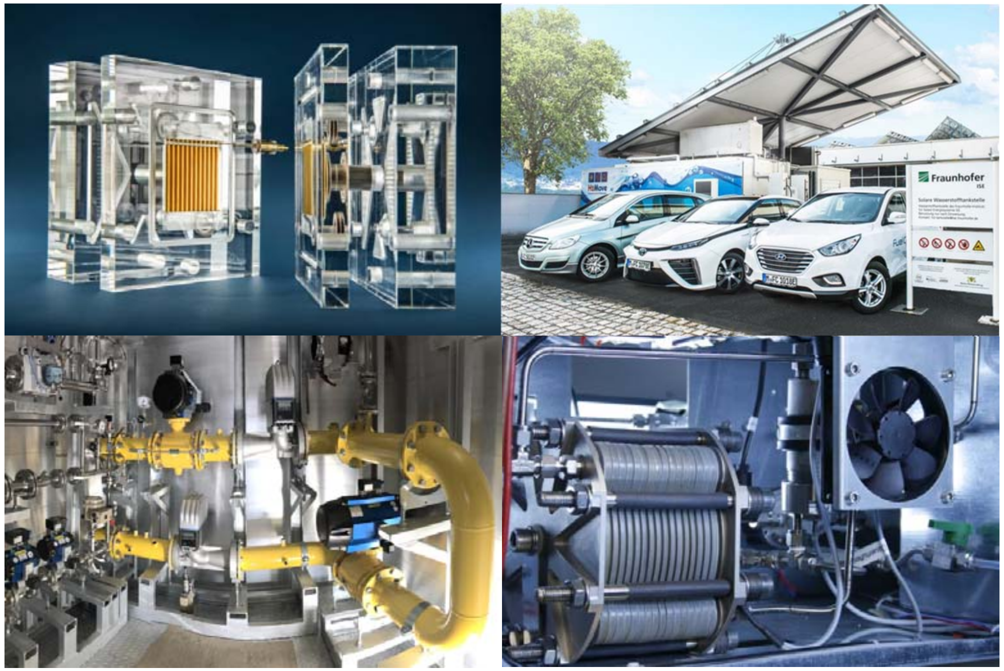
# OUTLINE OF THE TALK

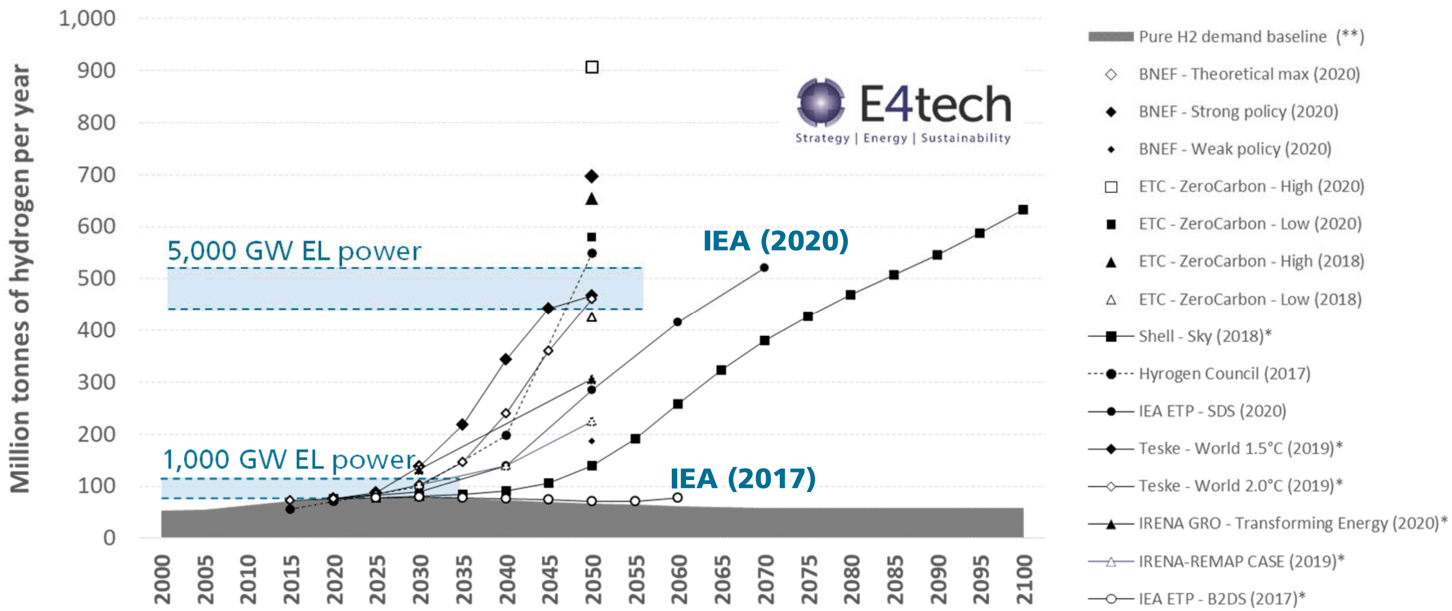
- Introduction to Fraunhofer ISE ✓
- Future Hydrogen Demand
- Current State of Water Electrolysis
- Challenges on the Way to a GW Industry
- Technology Development Outlook for PEM Water Electrolysis Cells
- Key messages



# Future Hydrogen Demand

## Global $H_2$ demand in scenarios compliant with 2015 Paris Climate Agreement

- Hydrogen demand worldwide by scenario-based studies
  - In accordance with Paris Climate Agreement (< 2°C)
  - Net zero GHG emissions by different means (e.g., RE vs. CCS)
- Demand not necessarily covered by water electrolysis
  - 2030: ~ 100 Mt $H_2$
  - 2050: < 500 Mt $H_2$
- 1 TW EL power = 100 Mt $H_2$ (1)




Source: Franz Lehner, E4tech

* Study excludes current pure hydrogen demand and values are adjusted to include baseline demand
** Baseline pure hydrogen demand estimated based on IEA 2019 "The Future Of Hydrogen" for historic demands and for future ammonia demand ("current trends"), and IEA ETP 2020 SDS for refining demand.

(1) Assumptions: Full load hours of 5,000 h and electrical energy demand of 50 kWh/kg $H_2$.



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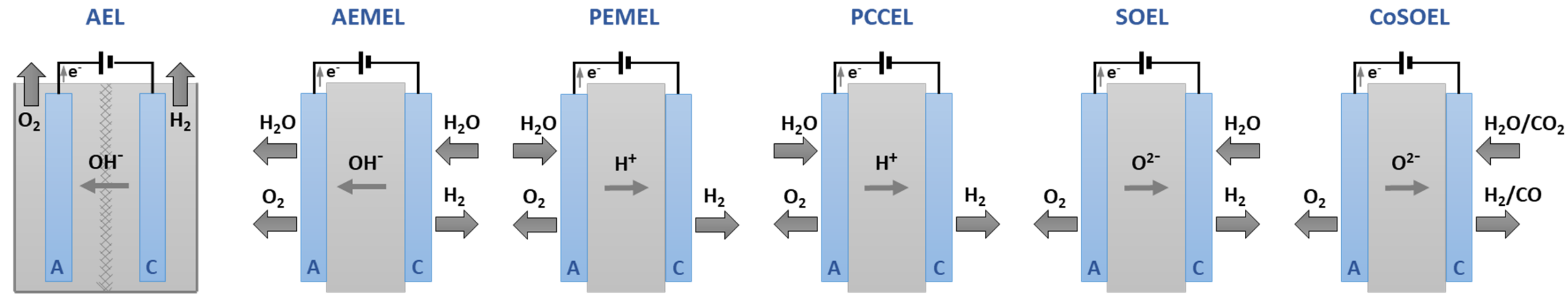
# Current State of Water Electrolysis

## Different electrolysis technologies exist but technology readiness levels vary.

| Low Temperature (Water) Electrolysis | | | High Temperature (Steam) Electrolysis | |
|---|---|---|---|---|
| Alkaline Electrolysis | | Proton Exchange Electrolysis | Oxygen Ion Electrolysis | |
| Liquid Electrolyte | Polymer Electrolyte Membrane | | Solid Oxid Membrane | |




| AEL | AEMEL | PEMEL | PCCEL | SOEL | CoSOEL |
|---|---|---|---|---|---|
| TRL: 8-9 | TRL: 5-7 | TRL 7-9 | TRL 3-4 | TRL 5-7 | TRL 4-6 |



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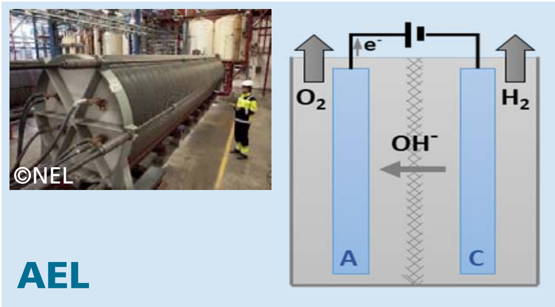
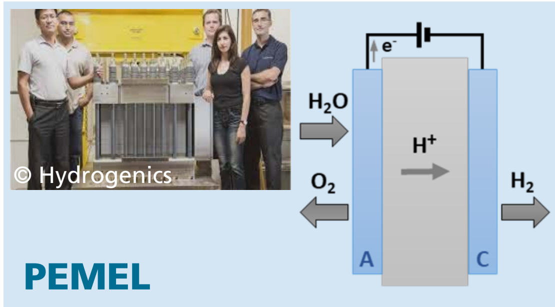
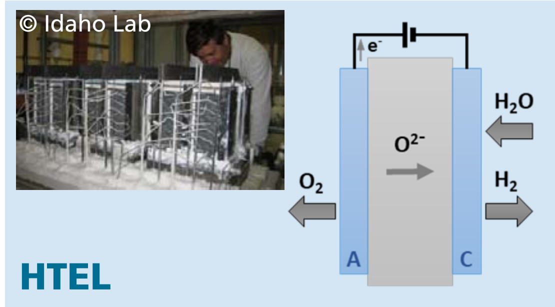
# Current State of Water Electrolysis

## There are three main processes of water electrolysis today.




| | Alkaline Electrolysis | Membrane / PEM electrolysis | High-temperature Electrolysis |
|---|---|---|---|
| Electrolyte / ion | Liquid KOH / $OH^-$ | Solid acidic membrane / $H^+$ | Solid Zircon ceramic / $O^{2-}$ |
| Temperature/pressure | 70 - 90 °C / atm. – 30 bar | 60 - 80 °C / 15 – 50 bar | 700 - 900 °C / atm. |
| Electrodes | Nickel / Iron (Raney) | Noble metals (Pl, Ir) | Zirconia, Ni-Cermet, Perovskite |
| Typical cell voltages | 1.8 – 2.1 V | 1.7 – 2.0 V | 1.1 – 1.3 V |
| Typical current density | 0.2 – 0.8 A/cm² | 1.0 – 2.5 A/cm² | 0.5 – 1.0 A/cm² |
| Typical cell areas | 0.5 – 3.0 m² | 300 – 5,000 cm² | 50 – 150 cm² |

# Challenges on the Way to a GW Industry

## Technological development will be evolutionary, not disruptive.

- Target KPI values for water electrolysis defined by Hydrogen Europe and HE Research
  - for Horizon Europe (9th EU FP for Research and Innovation)
  - **All KPIs should be achieved at the same time**
- There are emerging technologies which will most likely not play a significant role until 2030
  - Anion Exchange Membrane Electrolysis (AEMEL)
  - Proton Conducting Ceramic Electrolysis (PCCEL)
  - Solid Oxide co-electrolysis (CoSOEL)

**KPI-1: Electricity demand (system)**

| kWh/kg | 2017 | 2020 | 2024 | 2030 |
|---|---|---|---|---|
| AEL | 51 | 50 | 49 | 48 |
| PEMEL | 58 | 55 | 52 | 48 |
| SOEL (thermal) | 41 (n/a) | 40 (+9.9) | 39 (+9.0) | 37 (+8.0) |

**KPI-2: Capital cost**

| €/(kg/d) | 2017 | 2020 | 2024 | 2030 |
|---|---|---|---|---|
| AEL | 1,600 | 1,250 | 1,000 | 800 |
| PEMEL | 2,900 | 2,100 | 1,550 | 1,000 |
| SOEL | 12,000 | 3,550 | 2,000 | 800 |

**KPI-7: Degradation**

| %/1,000hrs | 2017 | 2020 | 2024 | 2030 |
|---|---|---|---|---|
| AEL | 0.13 | 0.12 | 0.11 | 0.10 |
| PEMEL | 0.25 | 0.19 | 0.125 | 0.12 |
| SOEL | 2.8 | 1.9 | 1.0 | 0.5 |

**KPI-8: Current density**

| A/cm² | 2017 | 2020 | 2024 | 2030 |
|---|---|---|---|---|
| AEL | 0.4 | 0.6 | 0.7 | 1.0 |
| PEMEL | 2.0 | 2.2 | 2.4 | 3.5 |
| SOEL | 0.3 | 0.6 | 0.85 | 1.5 |

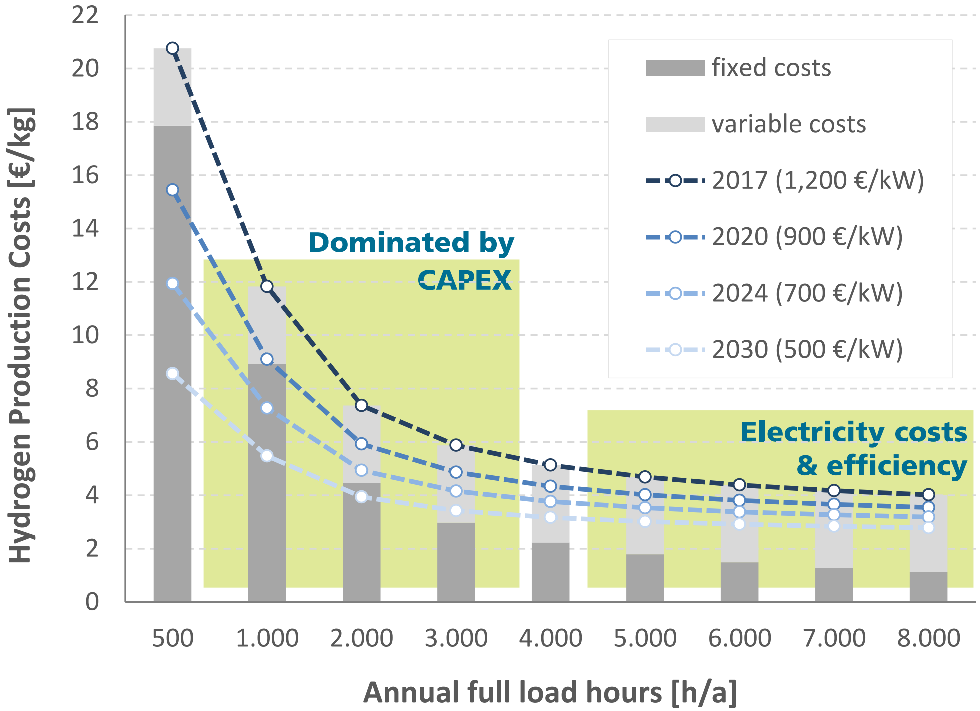



Hydrogen Europe and Hydrogen Europe Research (2020): Strategic Research and Innovation Agenda, Final Draft July 2020
https://hydrogeneurope.eu/sites/default/files/20200703%20Final%20Draft%20updated%20SRIA%20HE-HER.pdf

# Challenges on the Way to a GW Industry

## Hydrogen production costs are not only determined by investment costs.

- Optimization strategies for electrolysis must consider the intended use and application requirements.
- Levelized cost of hydrogen (LCOHy) are effected by
  - Technological cost drivers
    - Capital expenditure
    - Efficiency
    - Maintenance costs
  - Site-specific cost drivers
    - Electricity price
    - Operating hours
- Cost parity with grey hydrogen cannot be achieved alone by technological progress



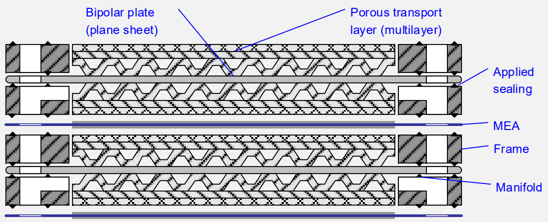

Levelized costs of hydrogen production according to Hydrogen Europe 2020

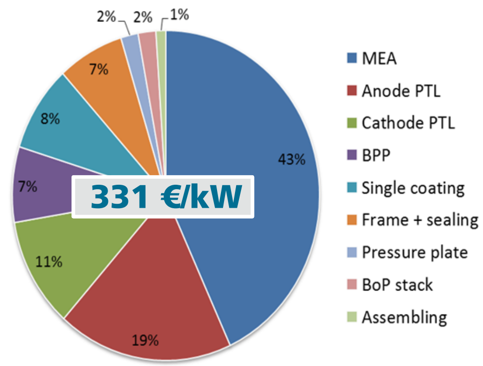
Assumptions:
- Recovery period: 20 years / interest rate: 5 %
- Electricity cost: 50 €/MWh
- plus 10% planning & 4% maintenance (incl. overhauling)

# Challenges on the Way to a GW Industry
## For modern cell designs MEA remains most expensive component in PEMEL.

- Cost break down model from Fraunhofer ISE for PEMEL stacks
- State of the art stack design and production technologies
  - @ 30 bar and 60 °C
  - Reference year **2015**
- Cost drivers
  - MEA
  - Ti based PTL and BPP
- Cost reduction by
  - Technical progress
  - Scale up
  - Automated manufacturing processes

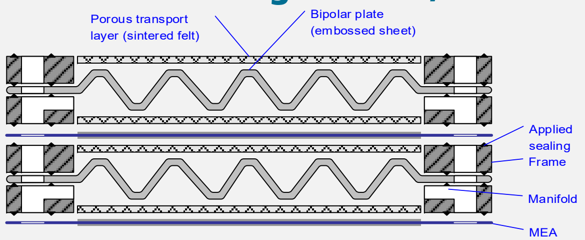
### Medium sized stack design with 1,200 cm²

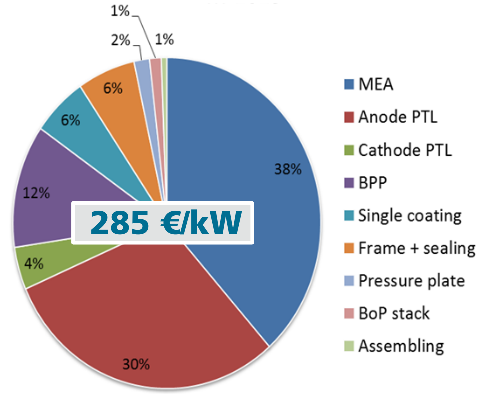



- Ti foil as bipolar plate w/o channels but with Ti spacers
- 120 cells / 1.8 V & 2.0 A/cm² / 60 °C / 30 bar → **518 kW**

### Large scale stack design with 2,400 cm²




- Deep-drawn Ti sheet as bipolar plate with channels
- 150 cells / 1.8 V & 2.0 A/cm² / 60 °C / 30 bar → **1,296 kW**

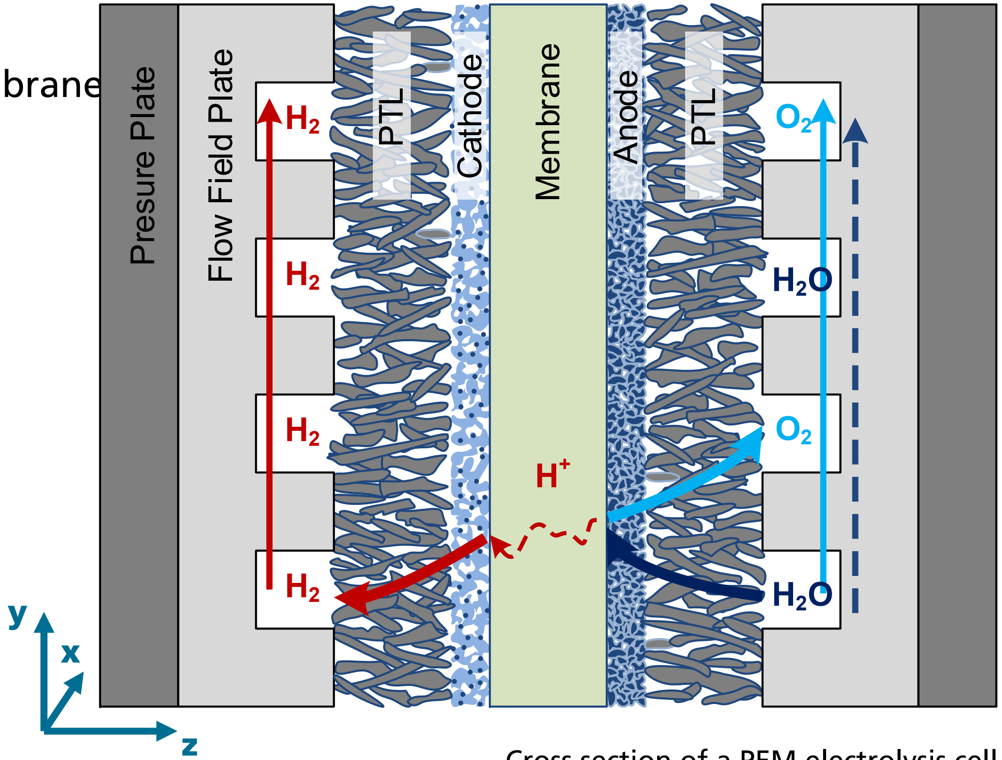



Smolinka, T.; Wiebe, N.; Thomassen, M. (2017) Cost break down and cost reduction strategies for PEM water electrolysis systems. Presentation 6th European PEFC & Electolyser Forum, Lucern, Switzerland, July 5, 2017

# Technology Development Outlook for PEM Water Electrolysis Cells

## General design features with focus on PTL and spacer/flowfield

- Design task for porous transport layer (PTL)
  - Water supply and product gas removal between membrane and flow channels (z direction)
- Design task for spacer/flowfield
  - Water distribution and product gas removal over the active area (x and y direction)
- Further tasks of the PTL and spacer/flowfield
  - Electrical contacting of surrounding components
  - Homogenisation of the contact pressure
  - Heat conduction and transfer
- Main requirements
  - Porous, electrically conductive, corrosion resistant




Cross section of a PEM electrolysis cell

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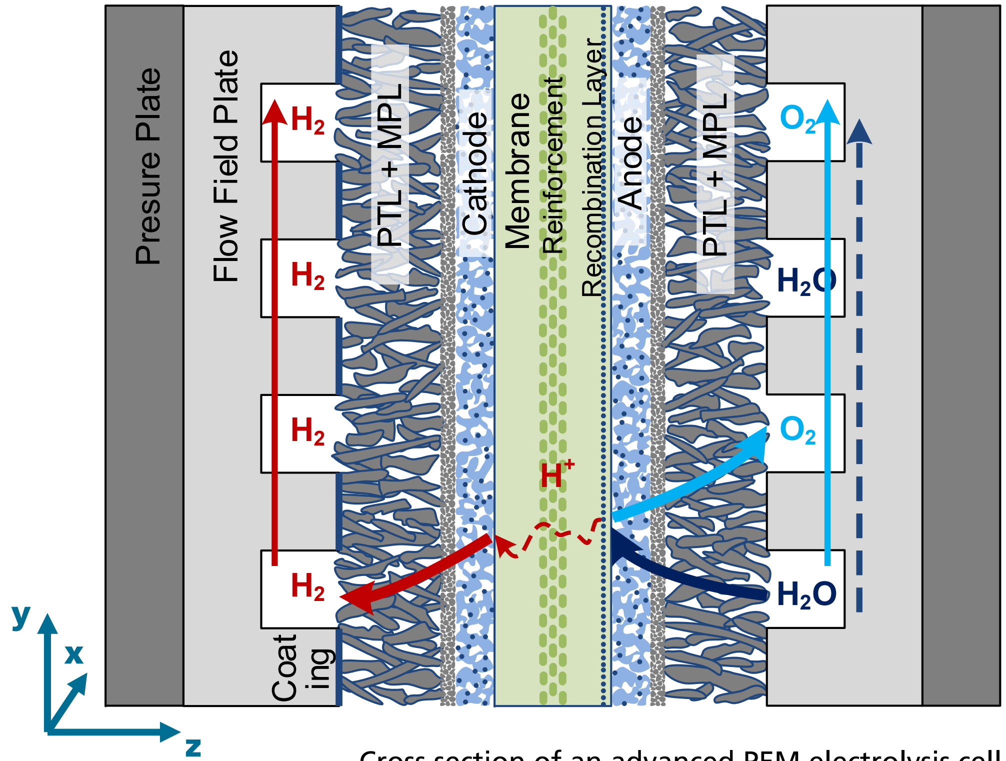
# Technology Development Outlook for PEM Water Electrolysis Cells

## To achieve target values in 2030 several cell design modifications are required.

- Thinner membrane (80 – 100 μm) with
  - Internal reinforcement (PTFE fabric)
  - Recombination layer @ anode (Platinum)
- Supported Ir or $IrO_2$ catalyst at anode
  - Reduction in material usage (g/W) by factor 10 - 15
  - Support must be highly conductive (doped TiOx)
- Titanium PTL at anode
  - Reduction in thickness (mechanical trade-off)
  - with microporous layer (MPL) made from Ti
- Carbon PTL at cathode with carbon MPL
- Protective coating (at least) at cathode for interface Ti BBP // Carbon PTL




Cross section of an advanced PEM electrolysis cell



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# Zusammenfassung und Kernaussagen

## Optimierung der Wasserelektrolyse für die Wasserstofferzeugung

- Die Rolle von Wasserstoff und der Wasserelektrolyse in der Transformation des Energiesystems ist allg. anerkannt
  - Prognosen/Szenarien zum zukünftige Wasserstoffbedarf variieren jedoch stark
  - Ehrgeizige Ausbauziele: Bis zum Jahr 2030 soll eine GW-Industrie aufgebaut werden
- Die verschiedenen Arten der Wasserelektrolyse befinden sich auf unterschiedlichen Entwicklungsstand
  - Die NT-Verfahren AEL und PEMEL werden in den nächsten Jahren den Markt dominieren, AEL bleibt Zugpferd
  - Die SOEL erzielt derzeit erhebliche Fortschritte, wesentliche Marktanteile vor 2030 nicht zu erwarten
- Die Weiterentwicklung der Elektrolyse ist ein evolutionärer Prozess, disruptive Technologien nicht sichtbar
  - KPI-Ziele 2030 sind einzeln erreichbar, Herausforderung liegt in der Summe aller Zielwerte
- Wettbewerbsfähigkeit ist nicht alleine durch technologischen Fortschritt zu erreichen
  - Wasserstoffgestehungskosten sind entscheidend, nicht CAPEX → Strombezug, Regularien, Marktdesign
- Ausbaupotenzial der PEM-Elektrolyse:
  - Einziges KO-Kriterium könnte die Verfügbarkeit von Iridium werden
  - Aus rein technischer Sicht ist die Membran entscheidend für die Wettbewerbsfähigkeit → hohes FuE-Potenzial




Bildnachweis: Fraunhofer ISE

# Vielen Dank für Ihre Aufmerksamkeit!

Dr. Tom Smolinka

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