FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

Dr.-Ing Stefan Megel, PD Dr.-Ing. Matthias Jahn

Online GLOBAL TECHNICAL CONFERENCE 2020 FUEL CELL Technology

30/06/2020

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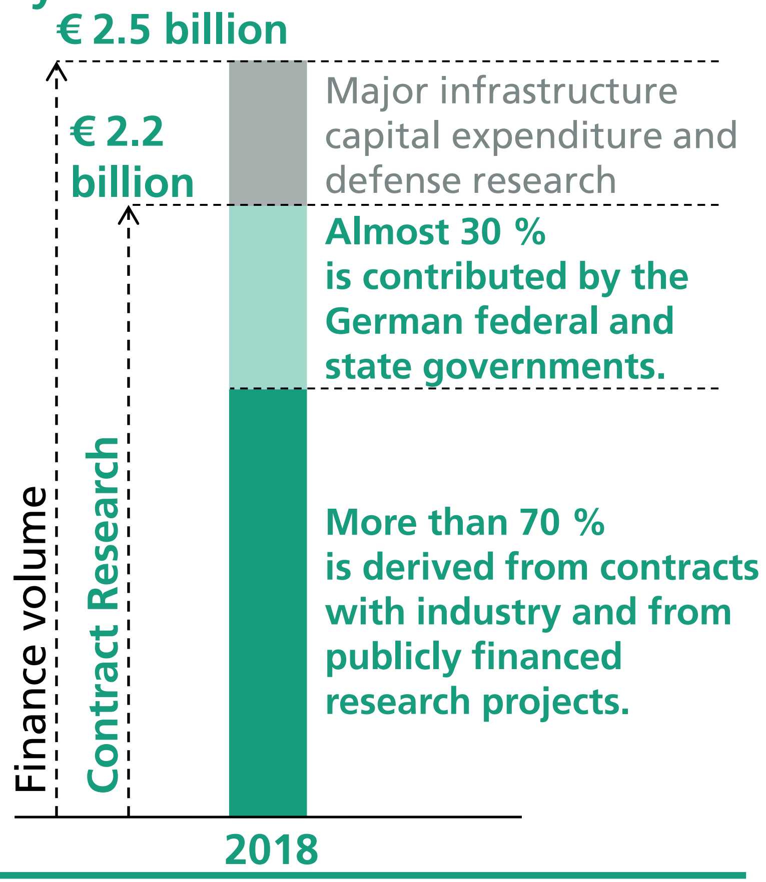
The Fraunhofer-Gesellschaft at a glance

Applied research for the immediate benefit of the economy and society

Nearly **26,600** employees

72 institutes and research units



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Fraunhofer IKTS in figures










	Total
Personnel (full-time equivalents)	**598**
Overall budget in million €	**60**
Industrial revenues in million €	**21.2**

(Latest update: December 31, 2018)

Institute Director:
Prof. Dr. Alexander Michaelis

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Fraunhofer IKTS Current research projects

Air separation O_2 generator

High-temperature oxygen separation with mixed-conducting ceramic membranes.

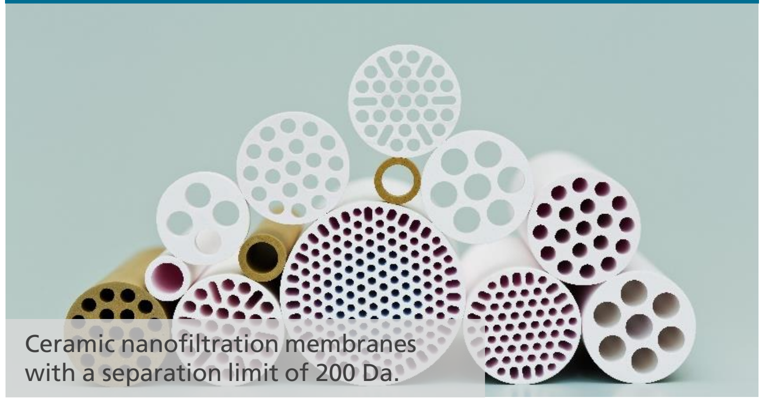
Recycling of valuables from waste water

Process chain to recycle water, energy, and fertilizer from food industry residues.

Personalized ceramic implants

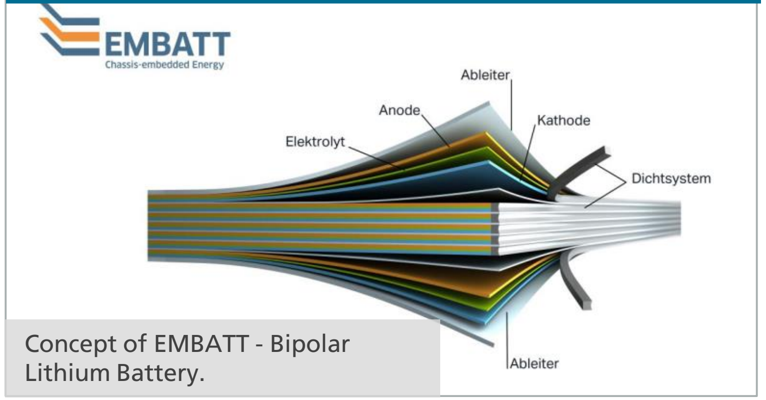
Biocompatible ceramic bone replica –
additively manufactured on the outside, freeze-foamed on the inside.

Nanofiltration



Ceramic nanofiltration membranes with a separation limit of 200 Da.

Safe driving with great range



Concept of EMBATT - Bipolar Lithium Battery.

Power and heat from biogas

Pilot SOFC plant at waste water treatment facility Dresden-Kaditz.

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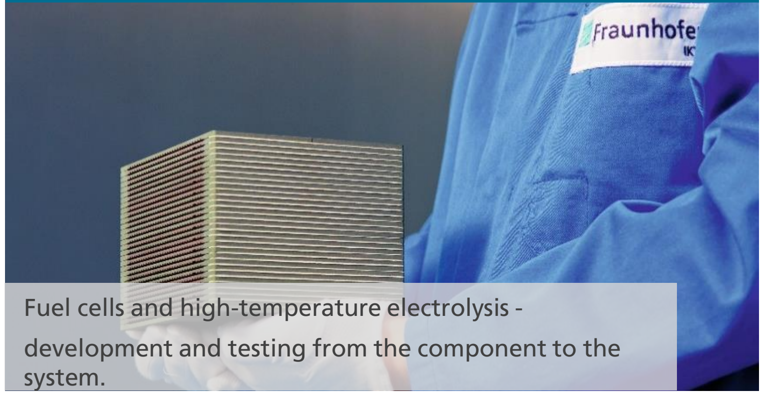
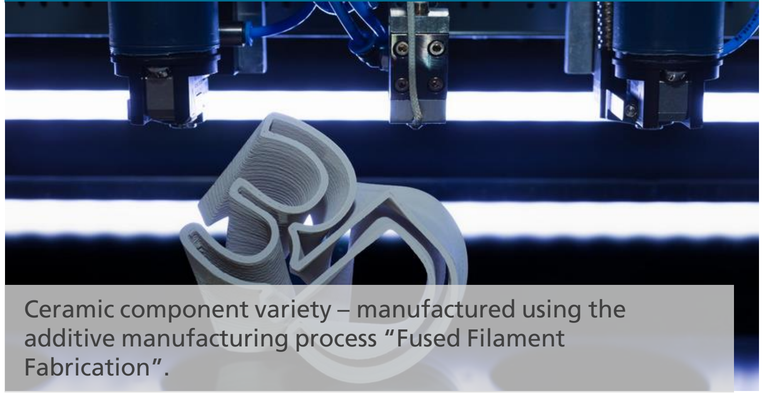
Fraunhofer IKTS Current research projects

SOC technologies



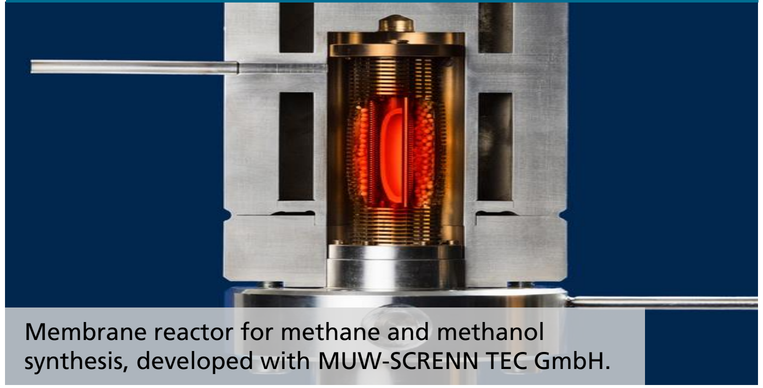
Fuel cells and high-temperature electrolysis - development and testing from the component to the system.

Additive manufacturing



Ceramic component variety – manufactured using the additive manufacturing process "Fused Filament Fabrication".

Power-to-X



Membrane reactor for methane and methanol synthesis, developed with MUW-SCRENN TEC GmbH.

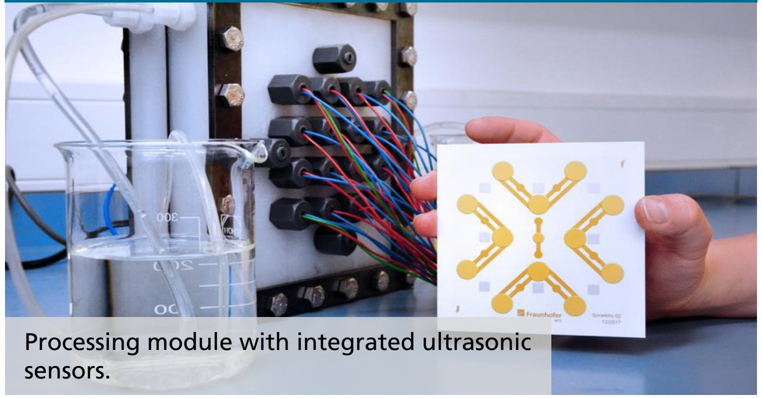
High-temperature energy storage

cerenergy® – Na/NiCl$_2$ battery system for stationary storage.

Complex hardmetal tools

3D printed tools – cost-effective and inexpensive with Fused Filament Fabrication.

Wastewater without pharmacenticals residues



Processing module with integrated ultrasonic sensors.

SOEC A KEY FOR POWER-TO-X PROCESSES

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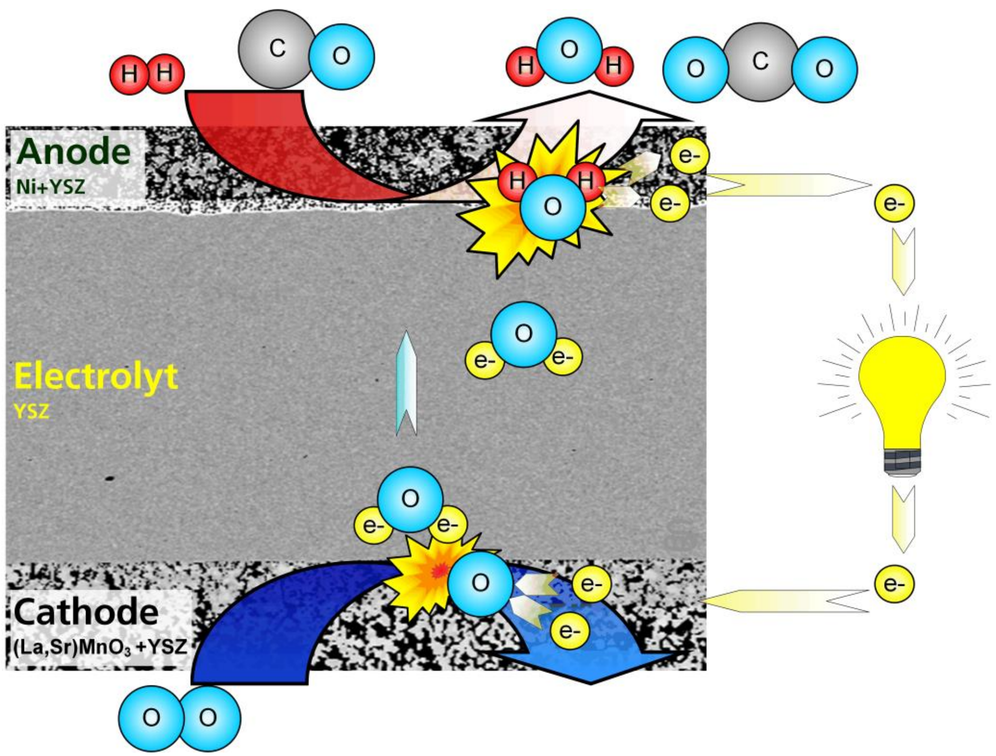
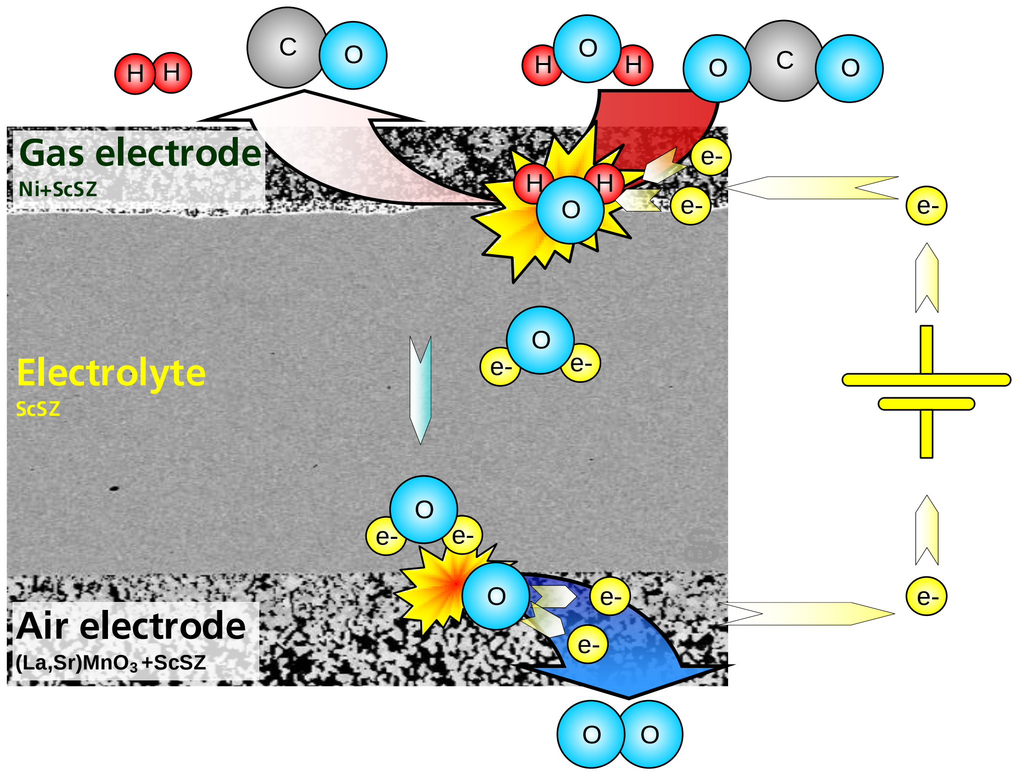
Fundamentals SOFC and SOEC

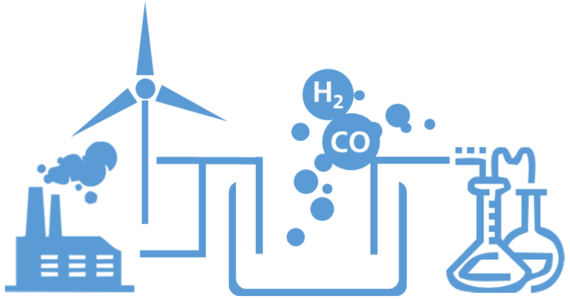
SOFC - Fuel cell

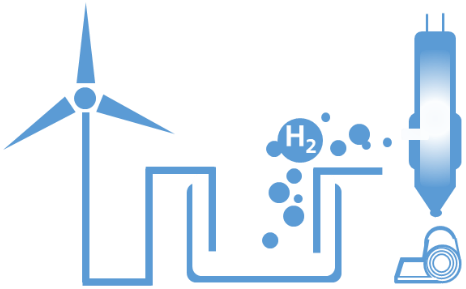


SOEC - Electrolysis



Electrolysis a key technology for the reduction of industrial CO_2-emissions

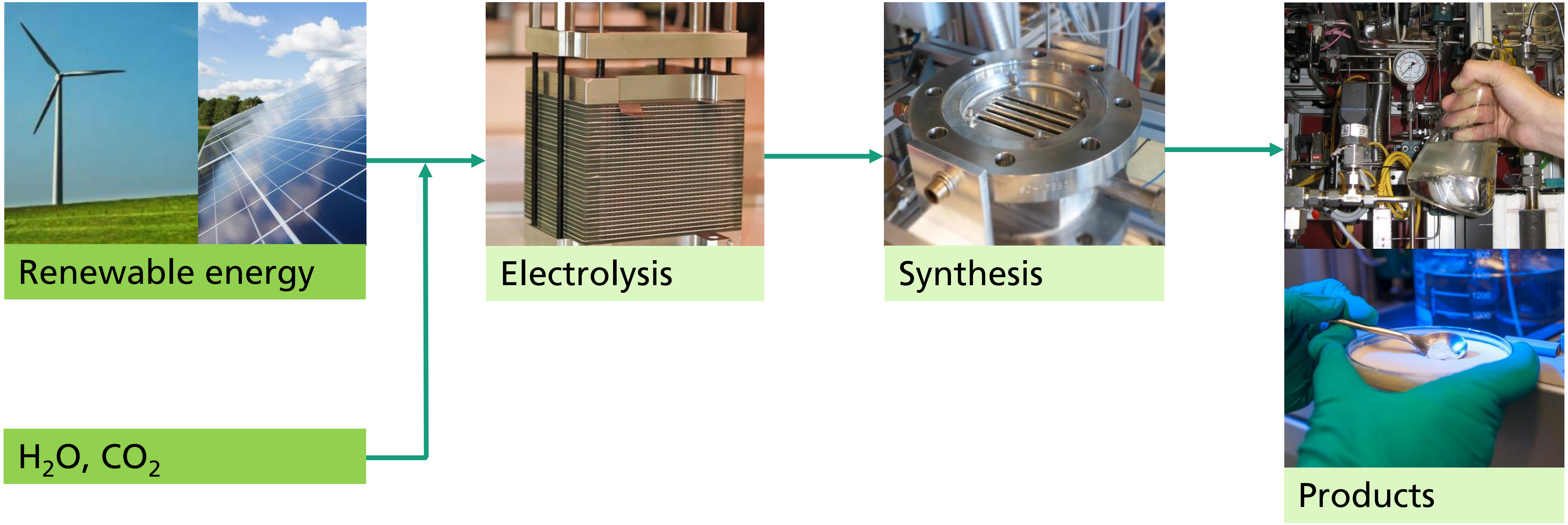




- Carbon Capture and Utilization (CCU)
  - Use of unavoidable CO_2-Emissionen
    e.g. from lime works, biomass, waste…
  - Coupling of electrolysis and synthesis
  - → High potential for e-fuels

- Carbon Direct Avoidance (CDA)
  - Substitution of coal
  - Use of renewable hydrogen
    for the reduction of iron ore in steel industry
  - → Steel production with lower CO_2 footprint

Electrolysis-based synthesis processes

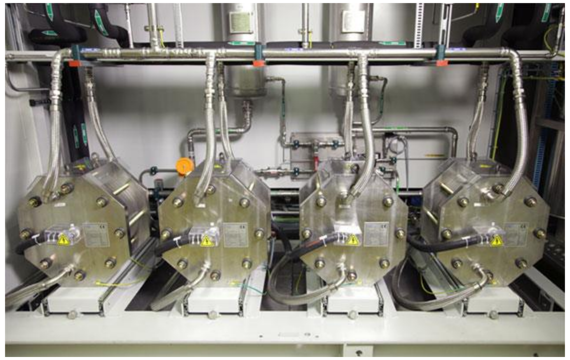


Electrolysis: Available technologies

Alkaline electrolysis

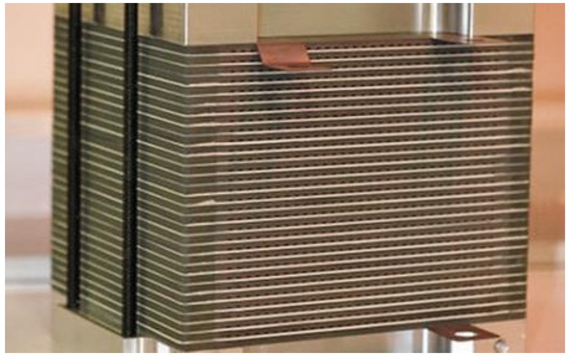
- Established in industry
- Corrosive media,
  Low current density
- 4.2–5.9 kWh/Nm³ H_2
- CAPEX: 1000-1200 €/kW
  (2030: <1000 €/kW)*

PEM electrolysis



- Demo/Industrial scale
- Lower lifetime
- 4.2–5.6 kWh/Nm³ H_2
- CAPEX: 1800-2300 €/kW
  (2030: <1000 €/kW)*

Solid oxide electrolysis



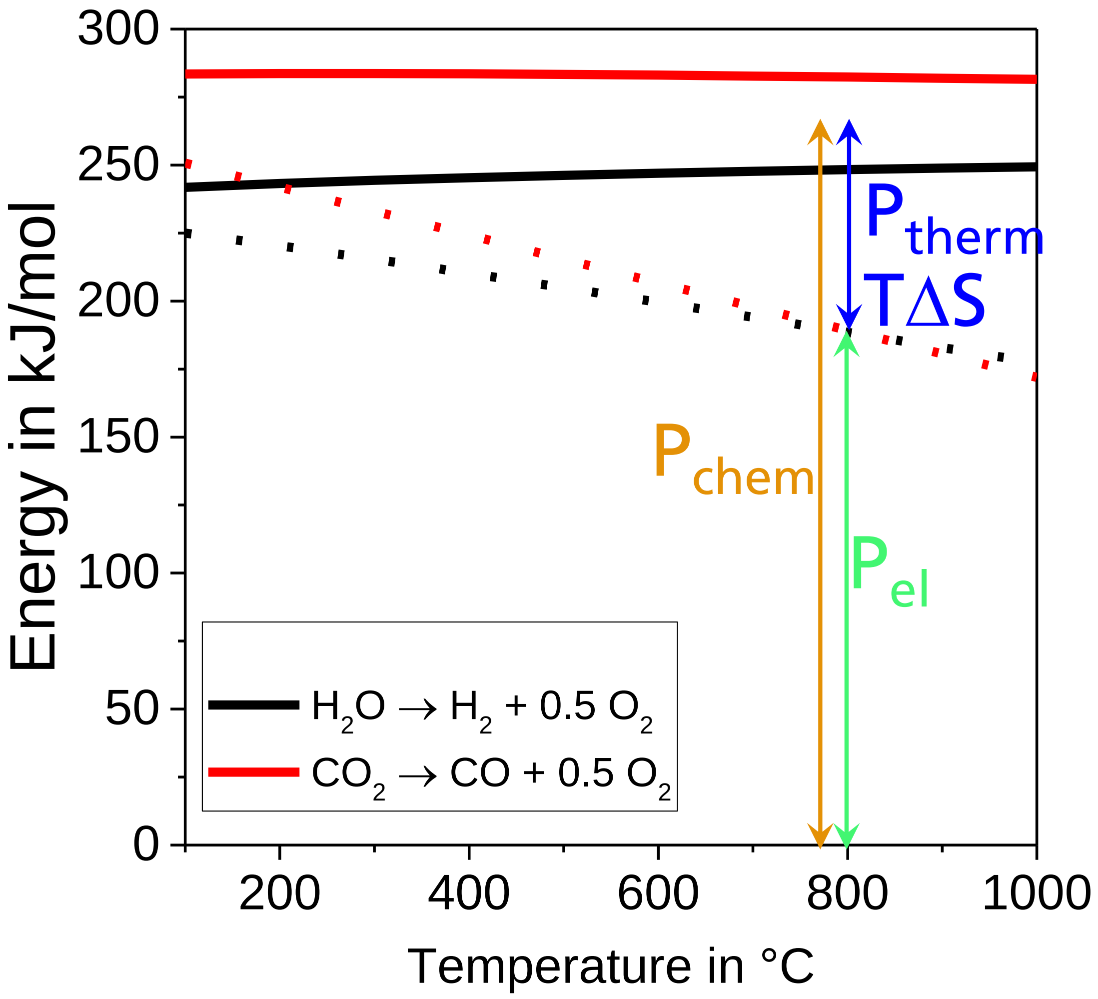
- Lab/Demo scale
- Temperature ~800 °C
- 3.0–4.5 kWh/Nm³ **H_2 + CO**
- CAPEX: >2000 €/kW
  (2030: ~1000 €/kW)*

*O. Schmidt, A. Gambhir, I. Staffell, A. Hawkes, J. Nelson, S. Few, Future cost and performance of water electrolysis: An expert elicitation study, International Journal of Hydrogen Energy 42 (2017) 30470–30492.

Electrolysis: Solid Oxide Electrolyser

- Higher efficiency in electrolysis at higher temperatures
- Electrolysis can be supported by additional heat (T*ΔS)
- Co-Electrolysis is possible
  P_{el} comparable CO_2 and steam electrolysis at 700-900°C

→ Direct production and design of syngas



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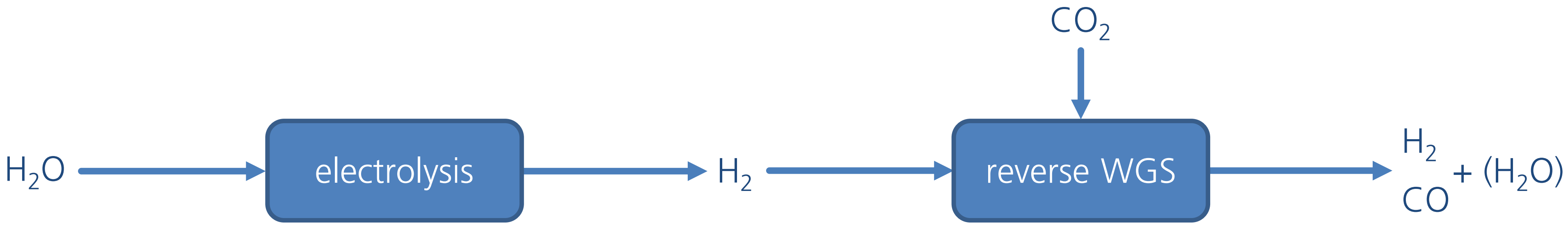
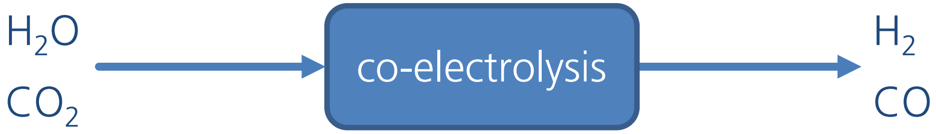
Electrolysis: Solid Oxide Electrolyser

- Why Co-Electrolysis?
  - No separate reactor for water gas shift is necessary



$$H_2O \rightarrow H_2 + 0.5\ O_2 \qquad H_2 + CO_2 \rightleftarrows H_2O + CO$$



$$CO_2 \rightarrow CO + 0.5 O_2$$
$$H_2O \rightarrow H_2 + 0.5 O_2$$

  - Syngas contents depends on inlet gas and operation parameter
  - → Generation of target syngas composition possible

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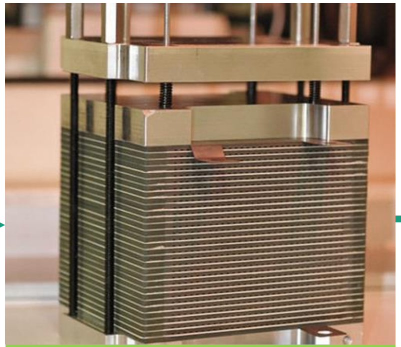
Electrolysis-based synthesis processes

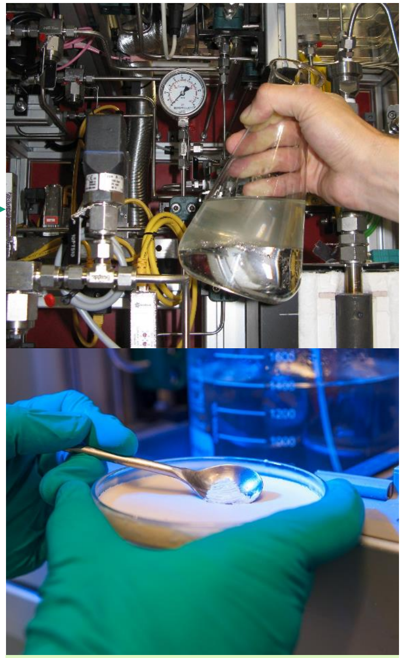
Renewable energy

H_2O, CO_2



SOEC

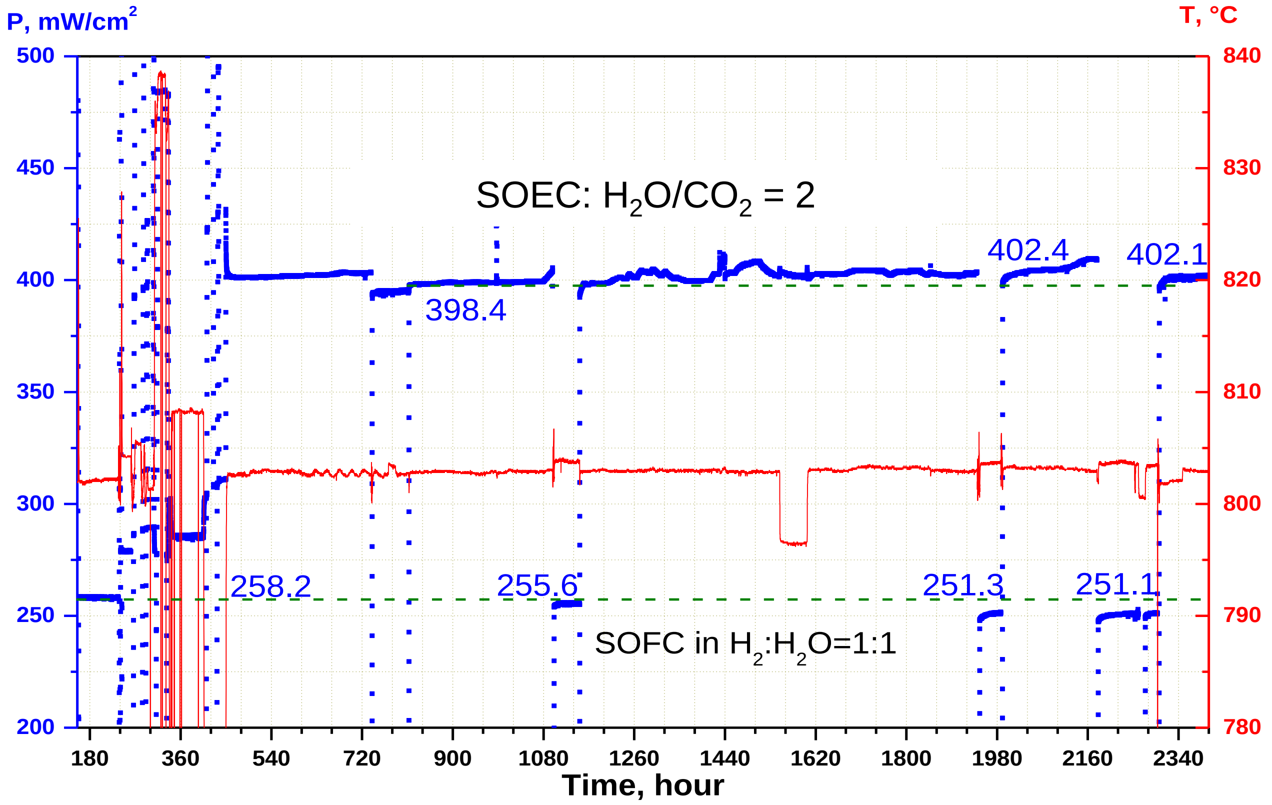
Synthesis

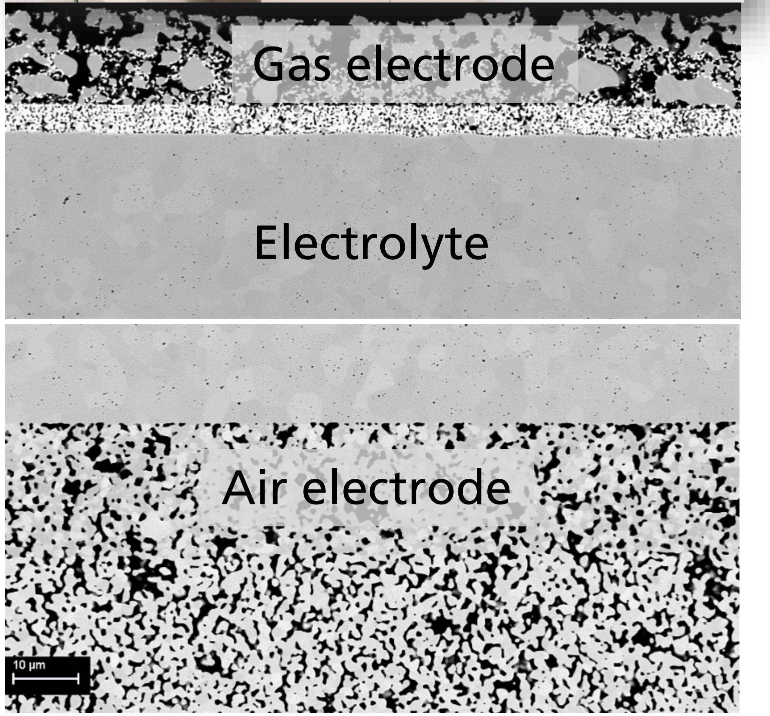


Products

Solid Oxide Electrolyser: Cell development

- Development and manufacturing of long-term stable cells
- Electrolyte supported cells





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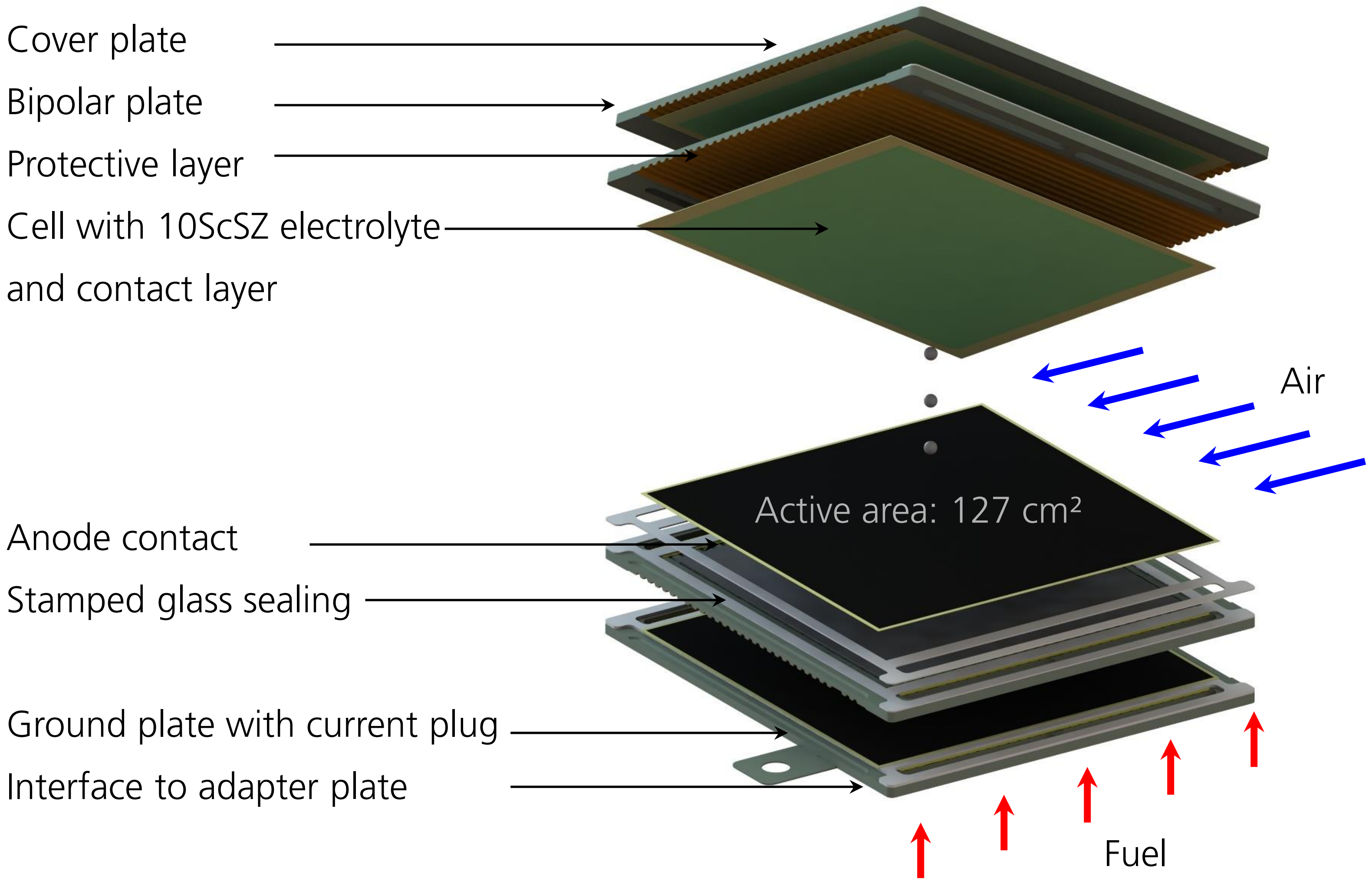
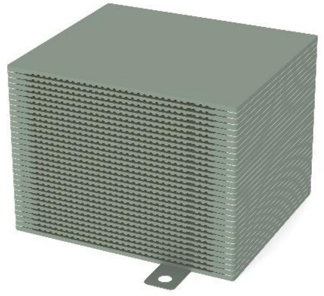
Solid Oxide Electrolyser: Stack development MK352





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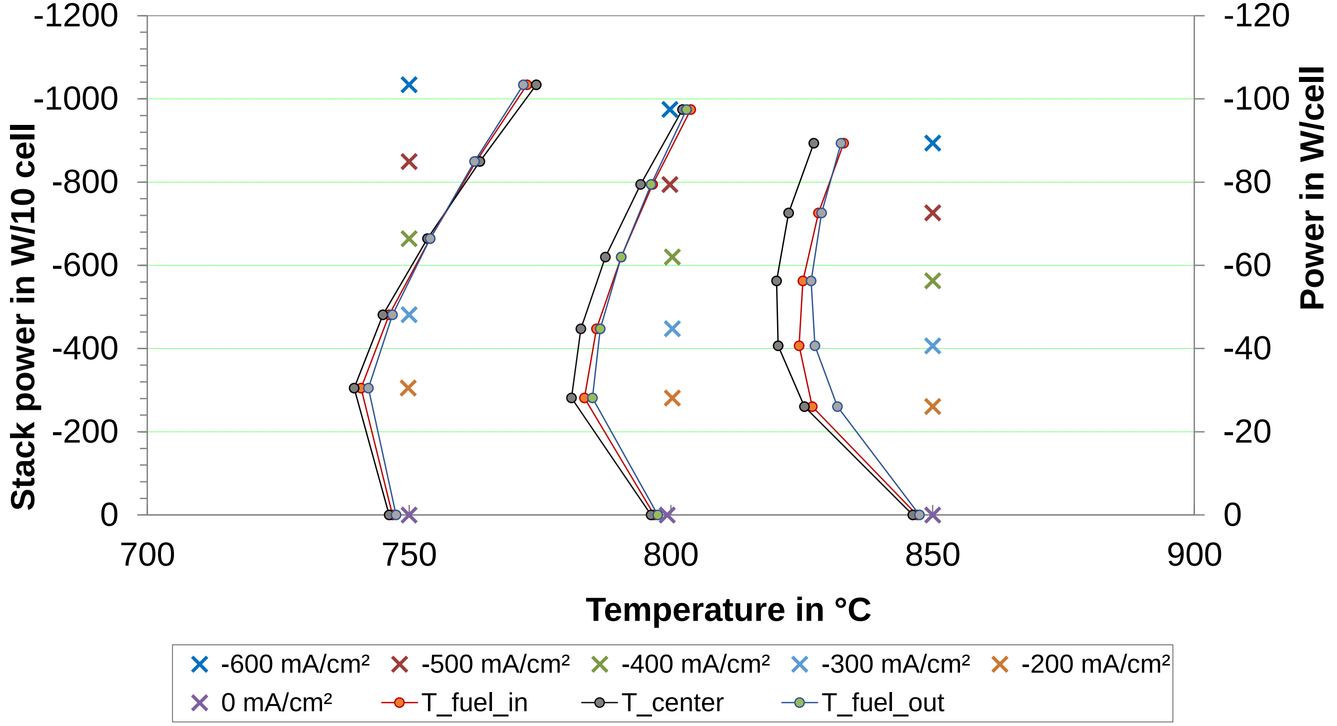
Solid Oxide Electrolyser: Stack development MK352

HydroMetha

Performance map 10 cell stack

Reformate: H_2O/CO_2=4.4; H2/CO=3.3 @75% FU



- -100 W/cell are necessary @600 mA/cm², 800°C, 75% FU
- Thermoneutral operation at
  750°C 350 mA/cm²
  800°C 600 mA/cm²

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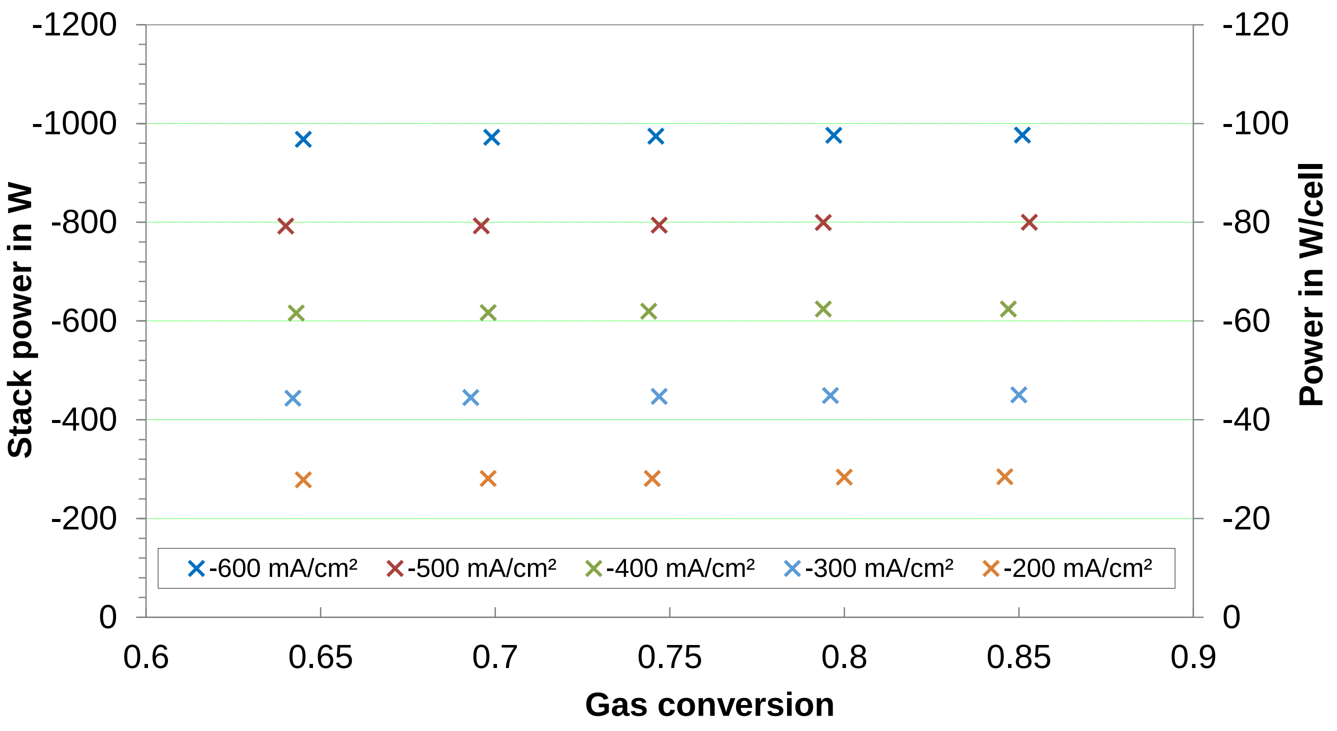
Solid Oxide Electrolyser: Stack development MK352

HydroMetha

Performance map 10 cell stack

Reformate: H_2O/CO_2=4.4; H2/CO=3.3 @800°C



- No big difference in FU variation

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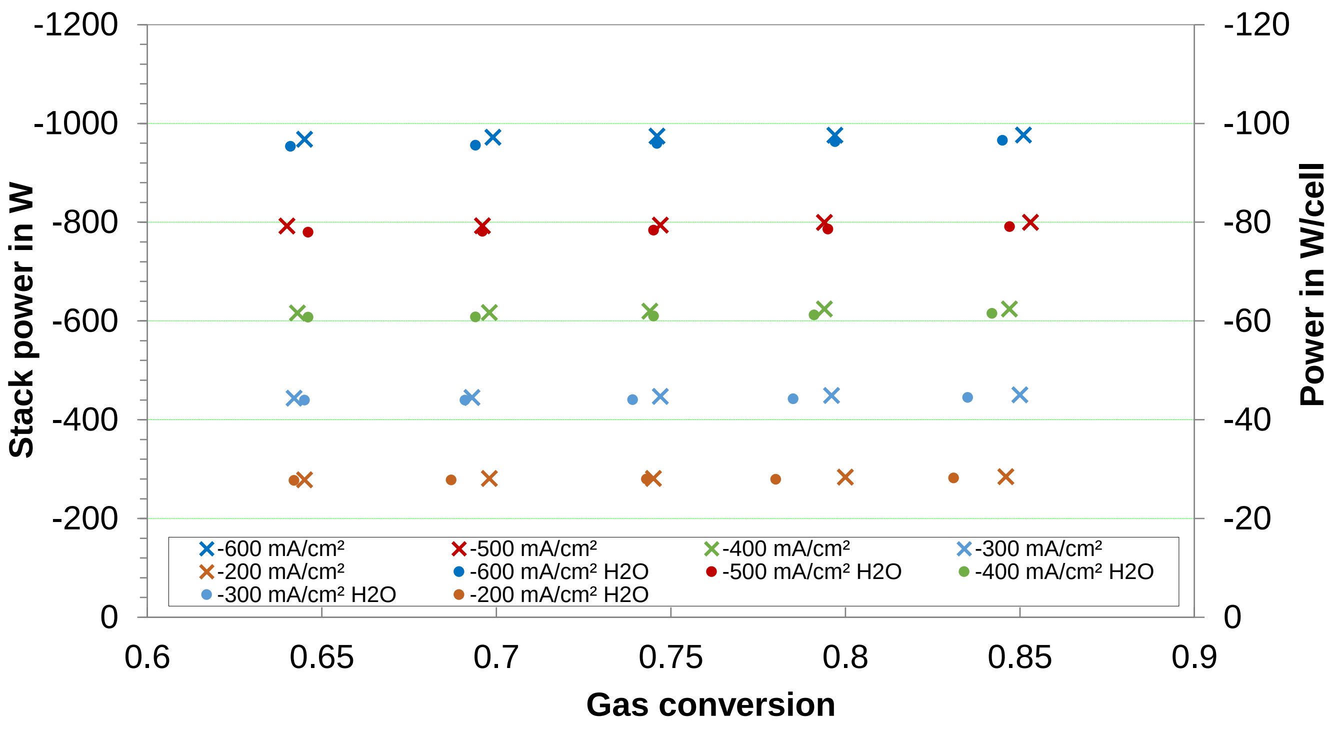
Solid Oxide Electrolyser: Stack development MK352

HydroMetha

Performance map 10 cell stack

Reformate: H_2O/CO_2=4.4; H2/CO=3.3 @800°C vs H_2O_SOEC



- <2% power difference between steam and Co-Electrolysis

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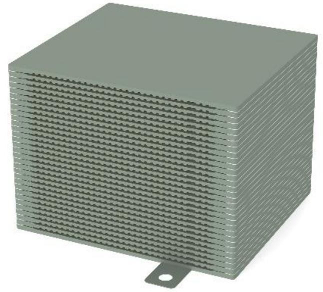
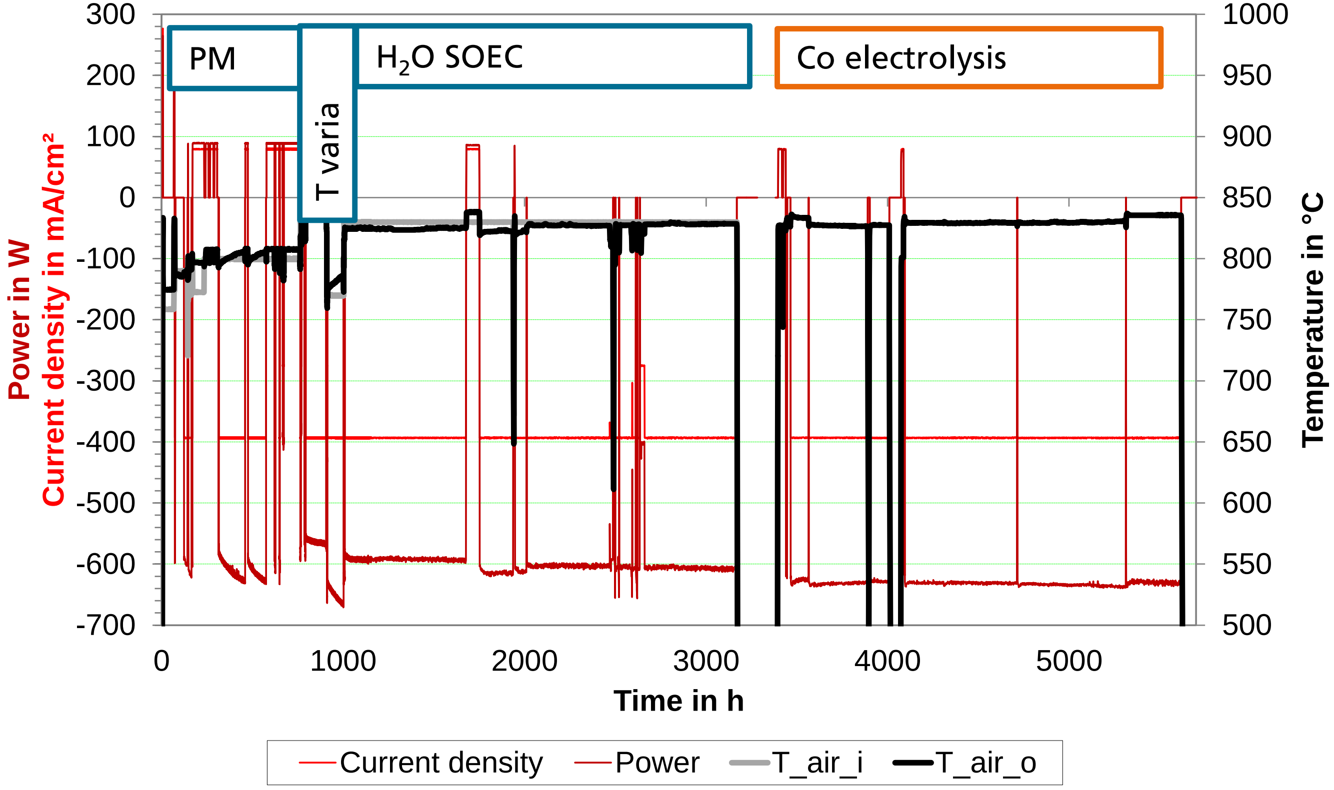
Solid Oxide Electrolyser: Stack development MK352

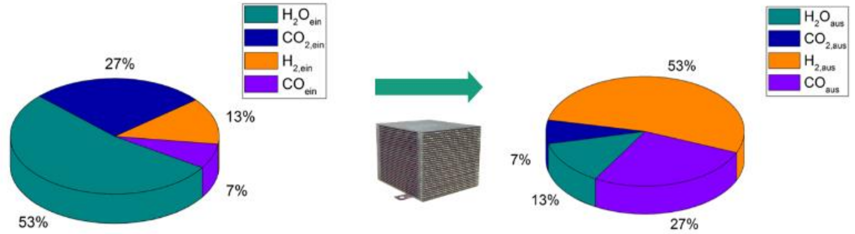


Long term test 10-cell stack:

Gas: 20 % H_2 in 80 % H_2O + Co-electrolysis H/C=2 η_{FU}=75 %

Air: 30 Nl/min $T_{\_An\_i}=T_{\_Cat\_i}=T_{furnace}$=830°C





STROM
ALS ROHSTOFF

HydroMetha

→ $\Delta P/P_0$=-0,5 %/1000 h (>5000 h)   ΔASR=17 mΩcm²/1000 h   degradation in steam and co-electrolysis comparable

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SOC-stack technology - MK35x

mPower GmbH, Winterbergstrasse 28, 01279 Dresden

Product: MK35x CFY Stacks

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Exclusive product licensing

- Covering market in Europe
- Expand to India

Technology Transfer to mPower GmbH

- Upscaling production
- Efficient processes

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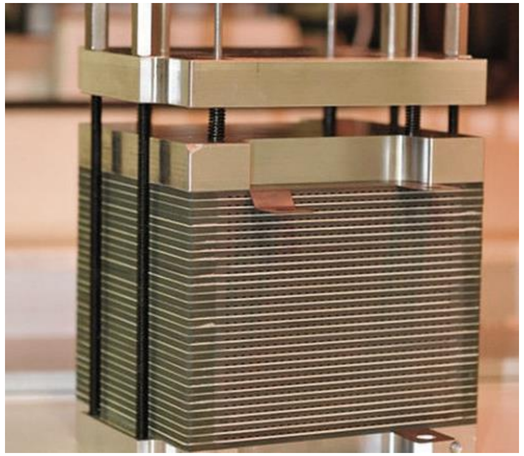
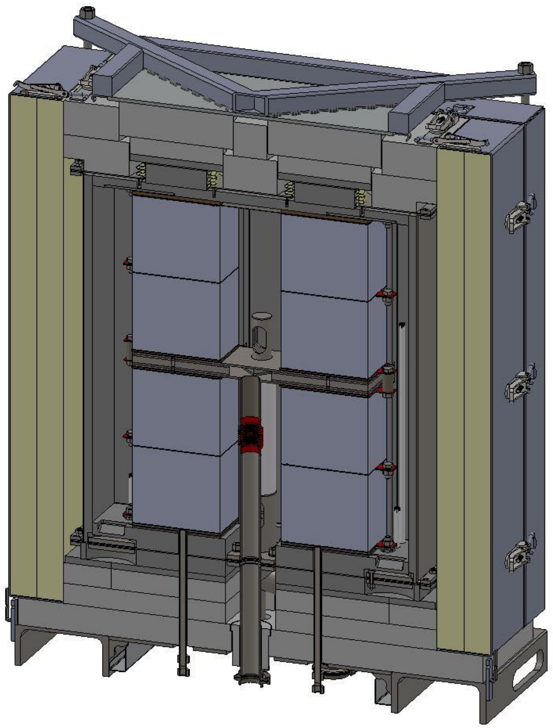
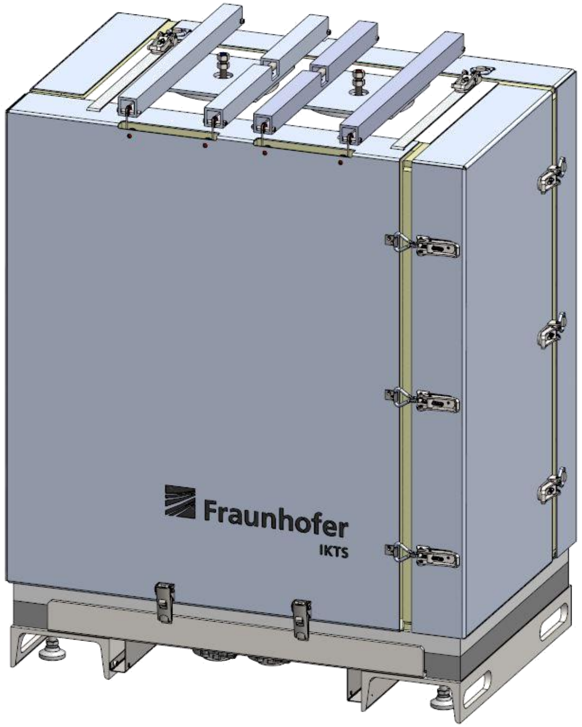
Solid Oxide Electrolyser: Stack modules

- Stacks with 10-40 cells are validated
- Stack modules for higher power available







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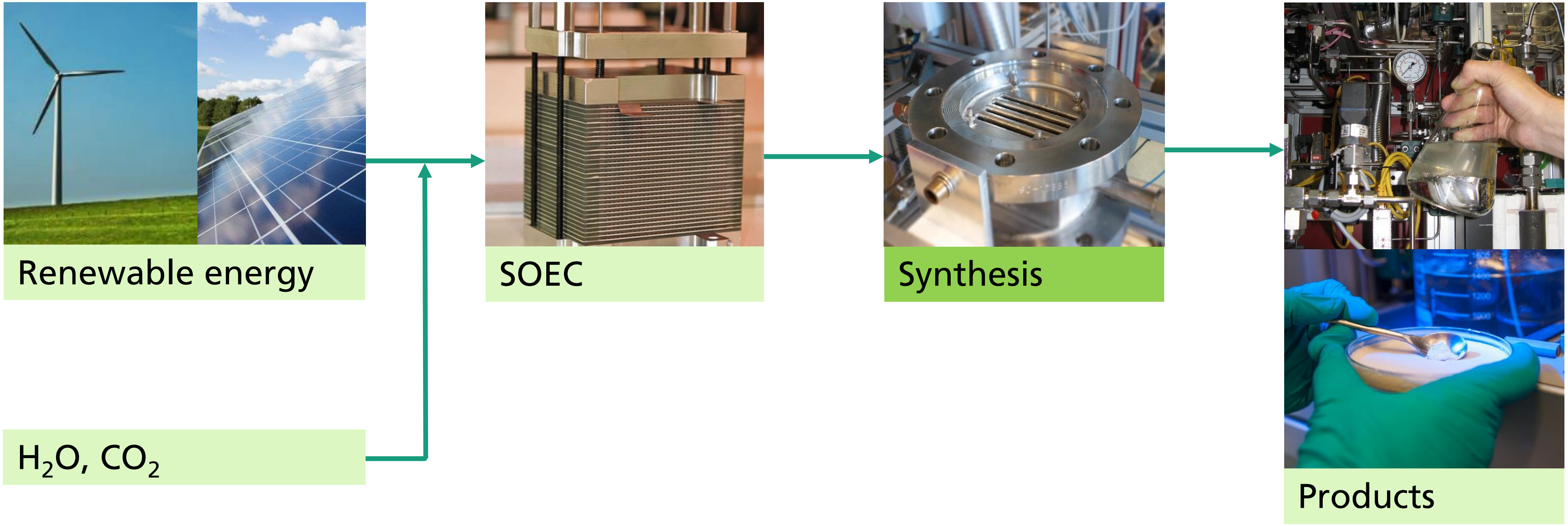
Electrolysis-based synthesis processes



Fischer-Tropsch synthesis: Fundamentals

- Highly exothermic reaction
  - $2n\ H_2 + n\ CO \rightarrow \cdots (CH_2)_n \cdots + n\ H_2O \quad \Delta_R H^0 = -158{,}5 \frac{kJ}{mol}$
- Chemical reactions:
  - Paraffins $(2n+1)\ H_2 + n\ CO \rightarrow C_nH_{2n+2} + n\ H_2O$ — Cobalt
  - Olefines $2n\ H_2 + n\ CO \rightarrow C_nH_{2n} + n\ H_2O$ — Iron
    Alcohols $2n\ H_2 + n\ CO \rightarrow C_nH_{2n+1}OH + (n-1)\ H_2O$

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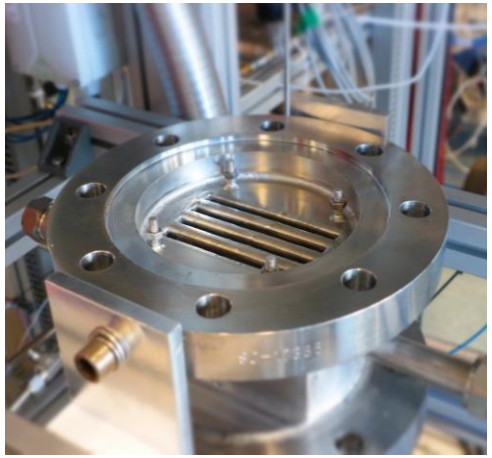
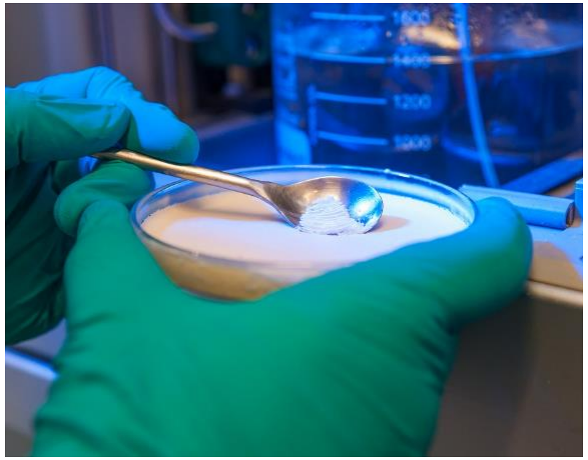
Fischer-Tropsch synthesis: Fundamentals

- State-of-the-art Fischer-Tropsch synthesis
  - Large plants using coal or natural gas as feedstock
  - Preferred products: gasoline, diesel, naphta

- Modified Fischer-Tropsch synthesis
  - Scalable, modular catalyst and reactor design
  - Valuable products: waxes, higher alcohols, jet fuels

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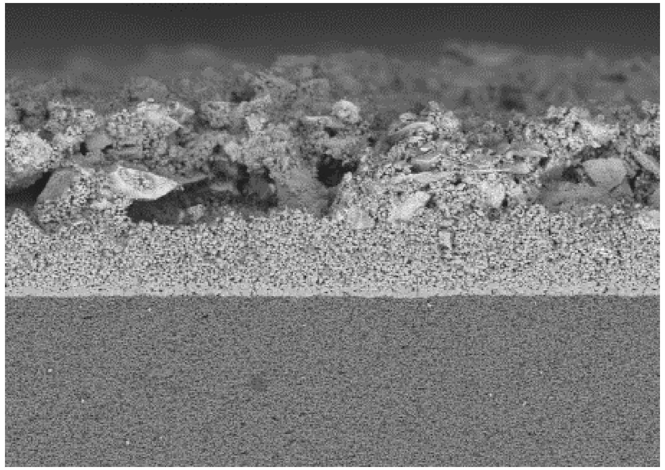
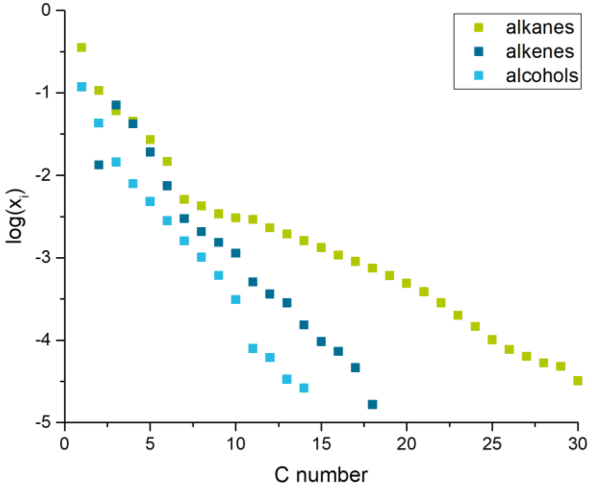
Fischer-Tropsch synthesis: Development at IKTS

- Preparation of iron- and cobalt-based Fischer-Tropsch catalysts
- Testing in terms of catalytic activity as well as stability
- Analysis of all product phases (gaseous, aqueous, oily and wax phase)



- Challenges:
  - Highly exothermic
  - Diverse product spectrum
  - Limited conversion



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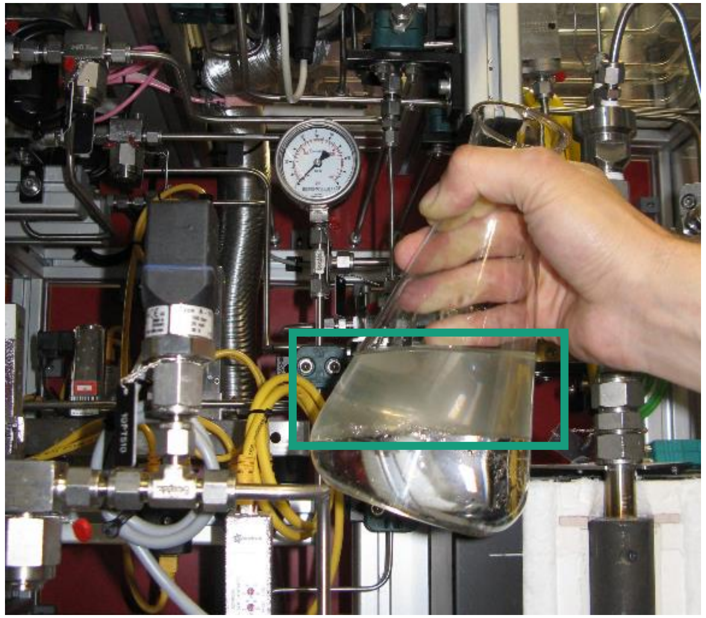
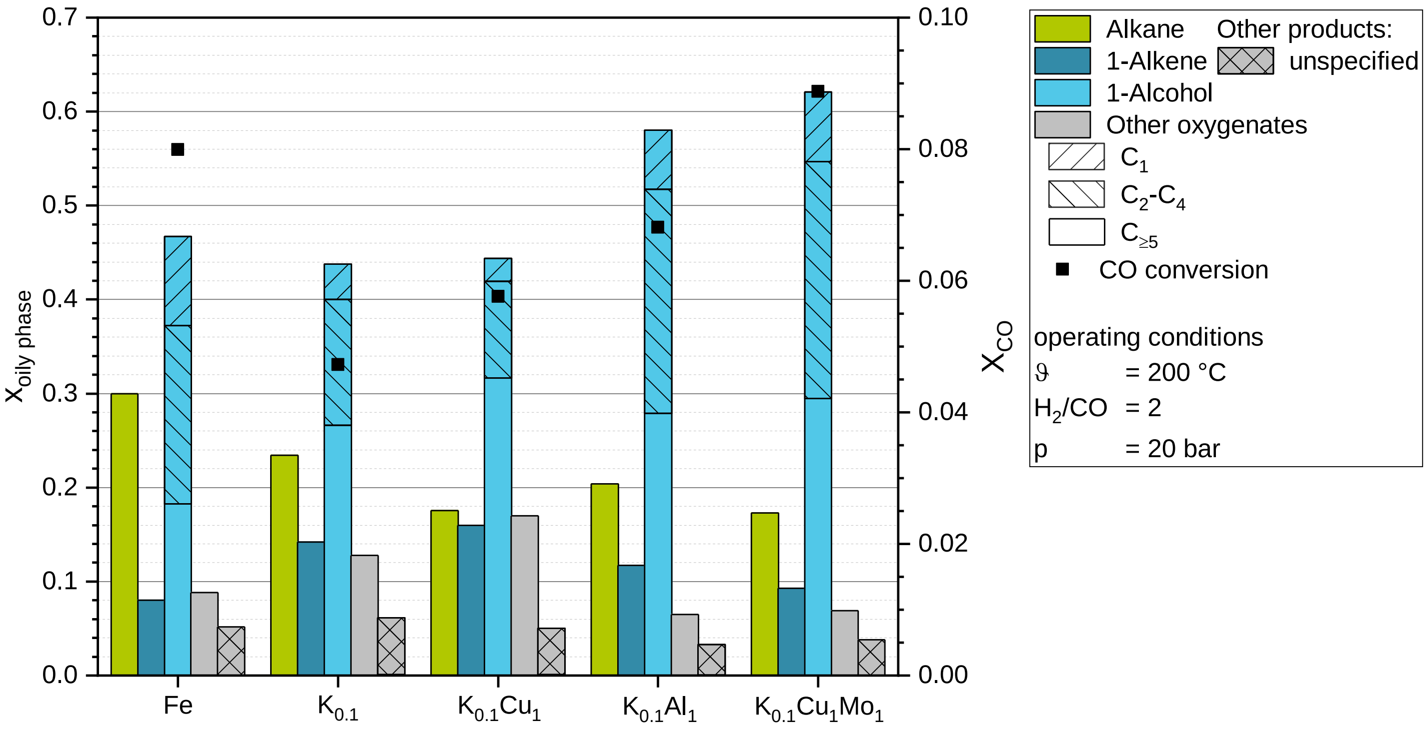
Fischer-Tropsch synthesis: Higher alcohols on iron-based catalysts

- Selectivity towards higher alcohols can be improved by catalyst promotion
- Alcohols as main products in the oily phase
- Product conditioning necessary





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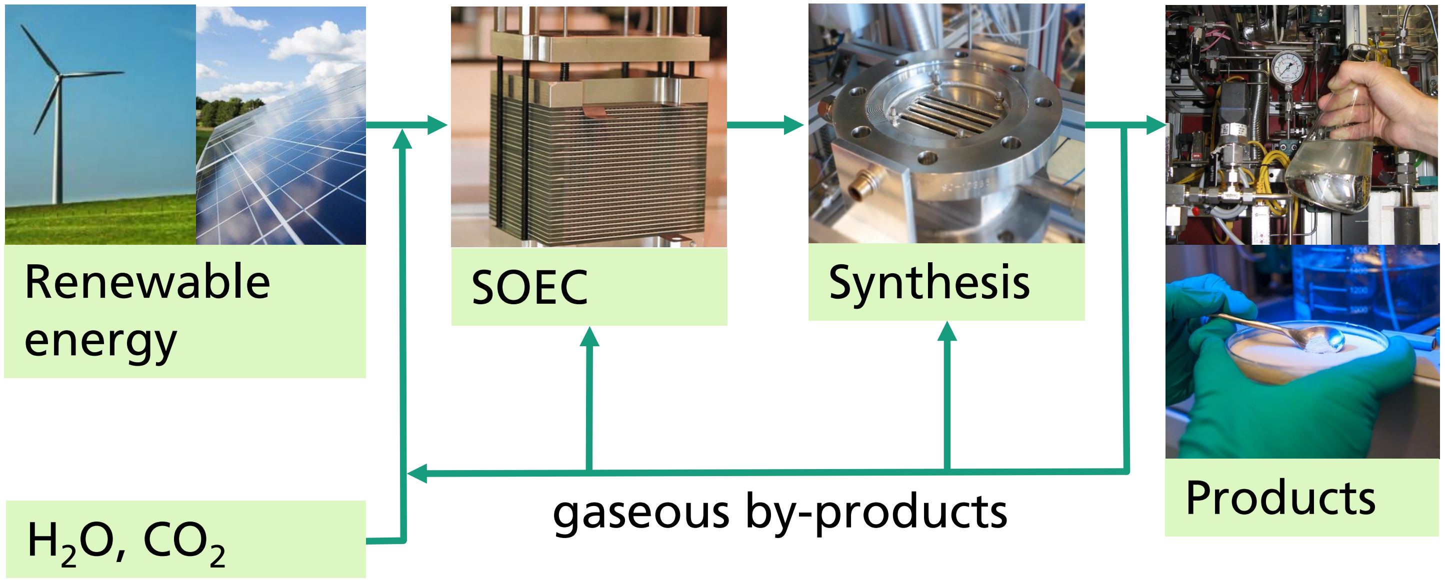
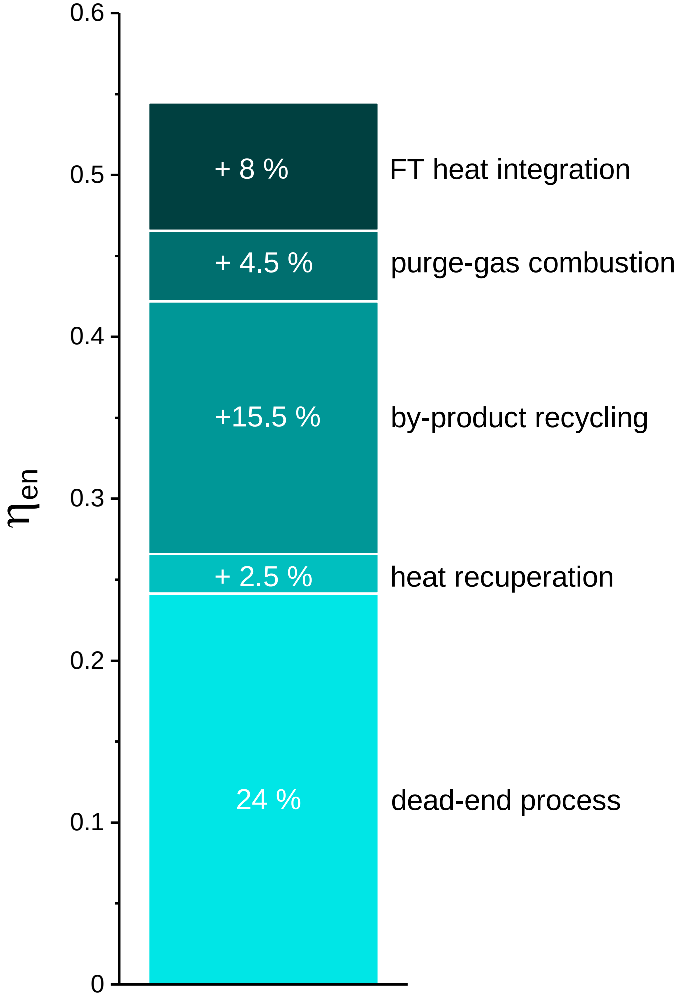
Carbon Capture and Utilization: Analysis

- Heat and by-product utilization crucial for process efficiency
- Waxes and liquid hydrocarbons considered as products



→ 55% efficiency for production of alcohols

$$\eta_{en} = \frac{chemical\ power\ output}{electric\ power\ input}$$



Carbon Capture and Utilization: Demonstrator

Lab-scale Power-to-Liquid plant

- Successful realization of a co-electrolysis based synthesis process on lab scale (1 kW_{el})
- Currently testing the influence of internal reforming

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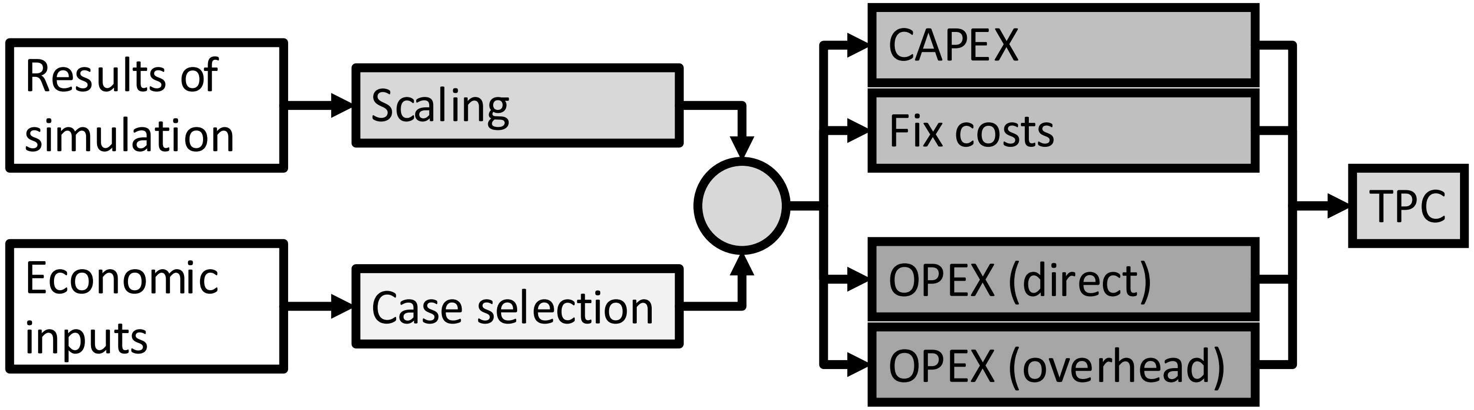
Carbon Capture and Utilization: Demonstrator

- Lime works
  - BMBF 2020-Project (HYPOS)
  - CO_2 -separation with membranes
  - Coupling of SOEC and FT-Process

Carbon Capture and Utilization: Economic evaluation

- Based on experimental and theoretical data economic feasibility was evaluated
- Calculation of capital expenditures (CAPEX) based on total cost of investment
- Operational expenditures are comprised of raw materials, electricity, materials, labor and maintenance



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Conclusion

- Proofed stack technology MK35x for SOFC and SOEC
  - Available robust stacks
  - Wide temperature range 750°C-900°C
- Assembling to modules >2 kW_{el}
- Highly-efficient electrolysis-based synthesis processes
  - Methanation (not mentioned here)
  - Fischer-Tropsch catalysts with high selectivity developed
  - Lab plant of 1 kW_{el} SOEC coupled with Fischer-Tropsch reactor realized

→ Higher valued hydrocarbons as products from excess power and CO_2 is economic feasible

→ Problems of Hydrogen can be avoided by e-fuels

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THANK YOU FOR YOUR ATTENTION

SOFC Testing and Laboratory Infrastructure at IKTS

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