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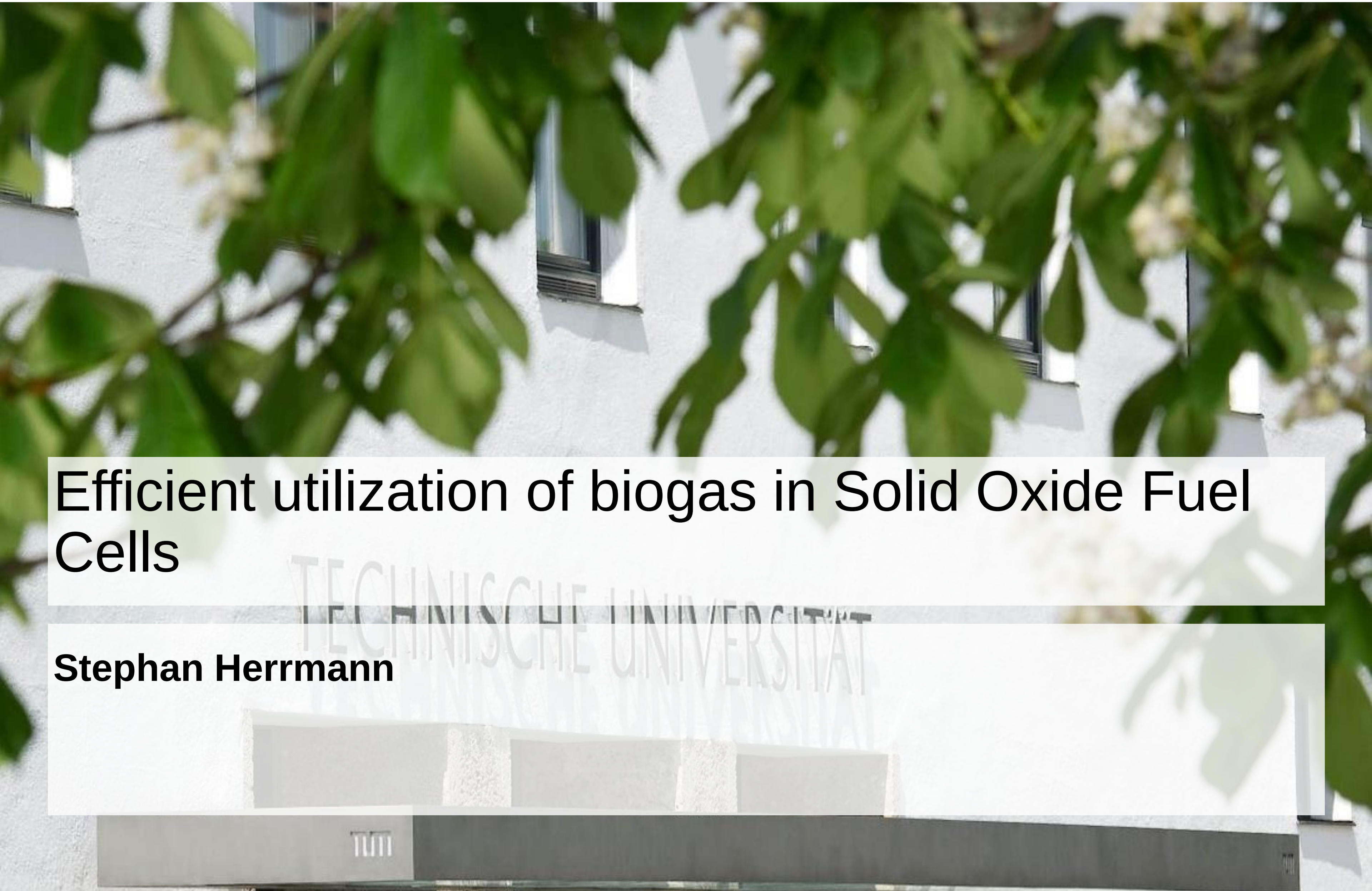


Efficient utilization of biogas in Solid Oxide Fuel Cells

Stephan Herrmann

Overview

- Motivation
- Biogas utilization
- Solid Oxide Fuel Cell - SOFC
- SOFC system design
- SOFC systems with biogas
- SOFC modelling
- Influence of steam content
- System efficiency optimization
- Summary

Motivation

- Climate contract of Paris 2015
- Energiewende
- Renewable energy supply
- If possible no fossil fuels
- However: Wind and PV are not reliable

➡ Only biomass/biogas and hydroelectric power provide large scale reliable electricty

- Both are necessary to compensate fluctuating PV und wind power
- Limited biomass/biogas resources have to be used at maximum efficiency!

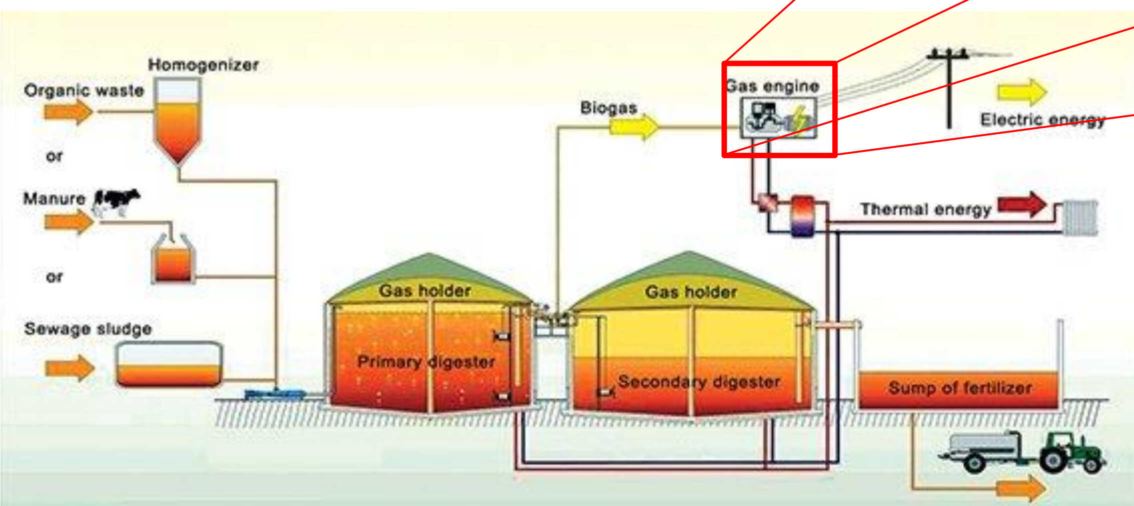
➡ SOFC is the most efficient electricity generating technology

Images: https://www.erlebnisladen.de/images/produkte/i58/5857-9908921-rindenmulch-hell--1-.JPG
http://www.verkehrsrundschau.de/sixcms/media.php/4494/Fotolia_33307528_Subscription_XXL_online.jpg

State-of-the-art biogas utilization

- Biogas generated from renewable primary resources, waste, manure
- Multi-stage digestion
- Gas cleaning (H_2S, Siloxanes)
- Heat integration (digester heating)
- CHP gas engine

- Alternative: Biogas upgrading



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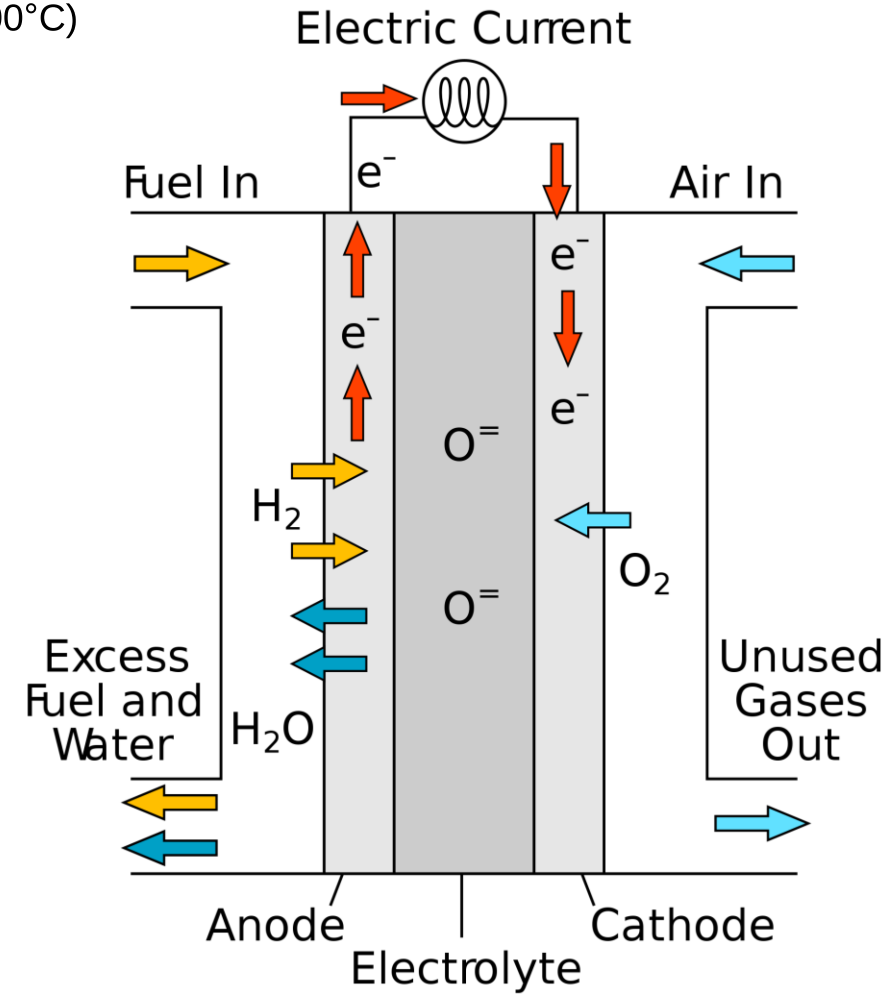
www.dieselmotornordic.com

Solid Oxide Fuel Cell - SOFC

- High temperature fuel cell (600-800°C)
- Solid state electrolyte (YSZ)
- Gaseous fuels (not only H_2)
- High efficiency (>60%)
- Limited fuel utilization



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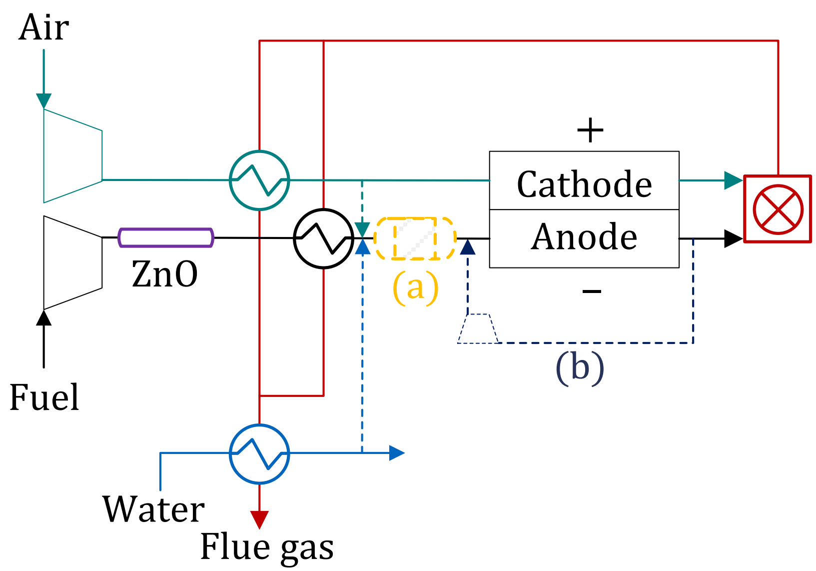
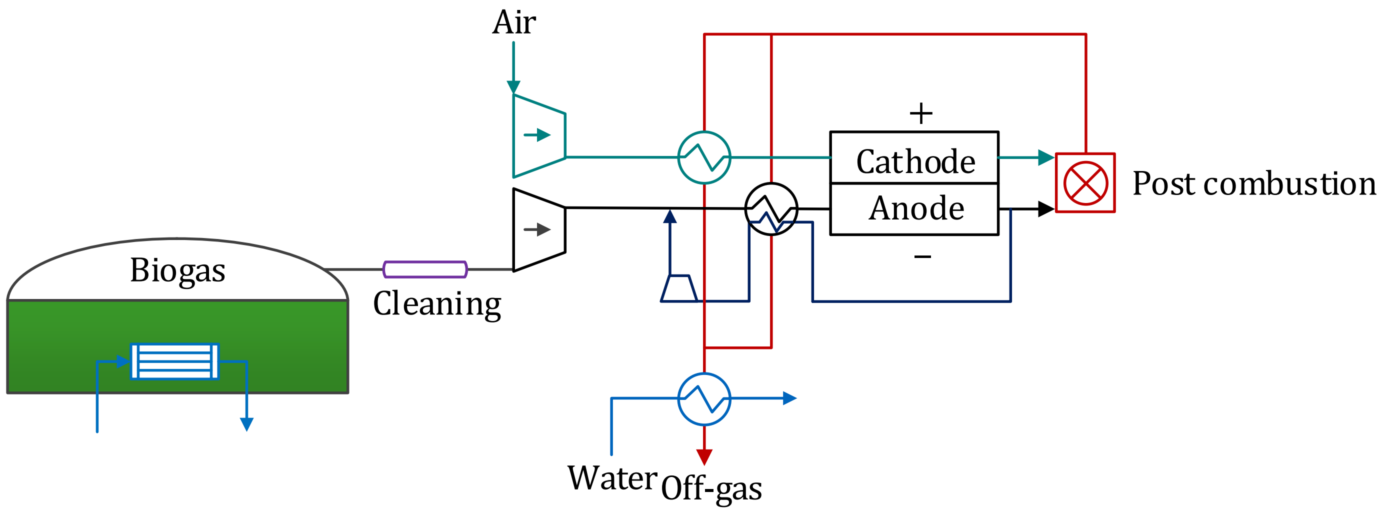
SOFC system design

- Natural gas is „standard“ fuel
- Gas cleaning of sulfur contaminants (activated carbon, ZnO)
- Different reforming options (CPOX, steam external, internal reforming with anode exhaust recirculation)
- 80-85% fuel utilization
- Excess air, depending on reforming concept



SOFC systems with biogas

- Biogas: 50-70% CH_4, rest CO_2 with contaminants (H_2S, siloxanes)
- Heat integration: Exhaust heat can be used for digester heating!



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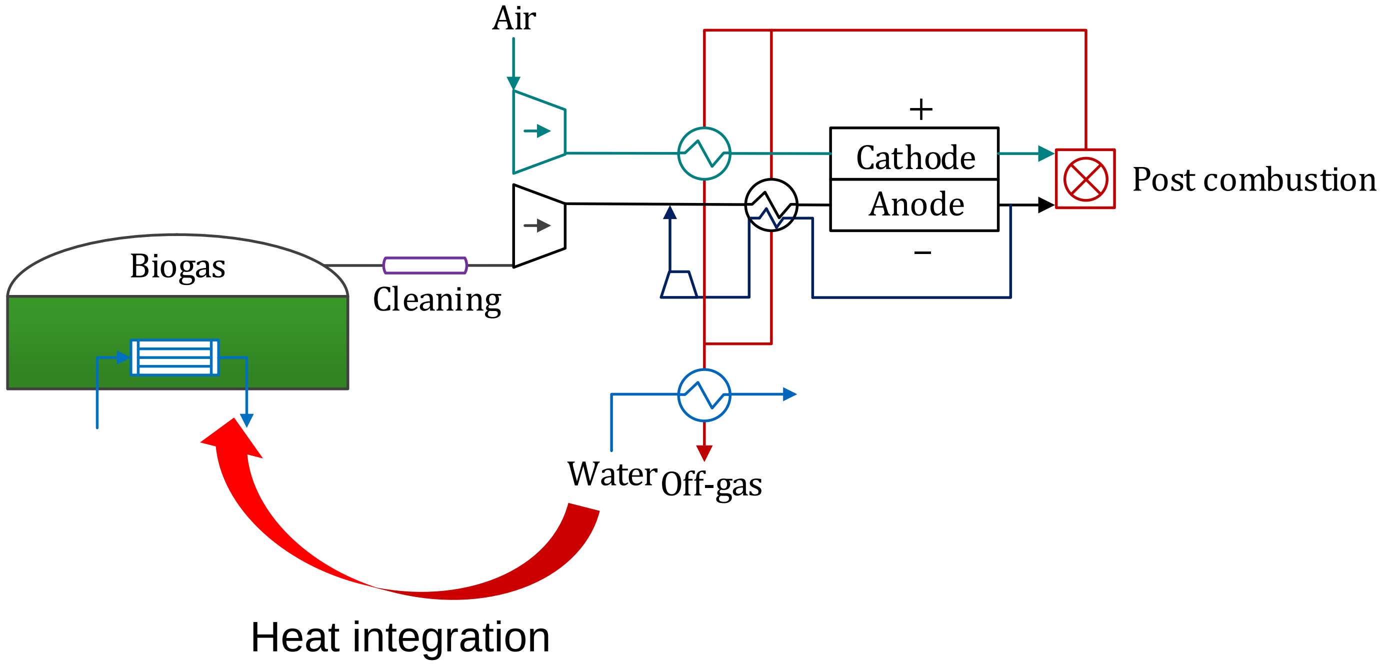
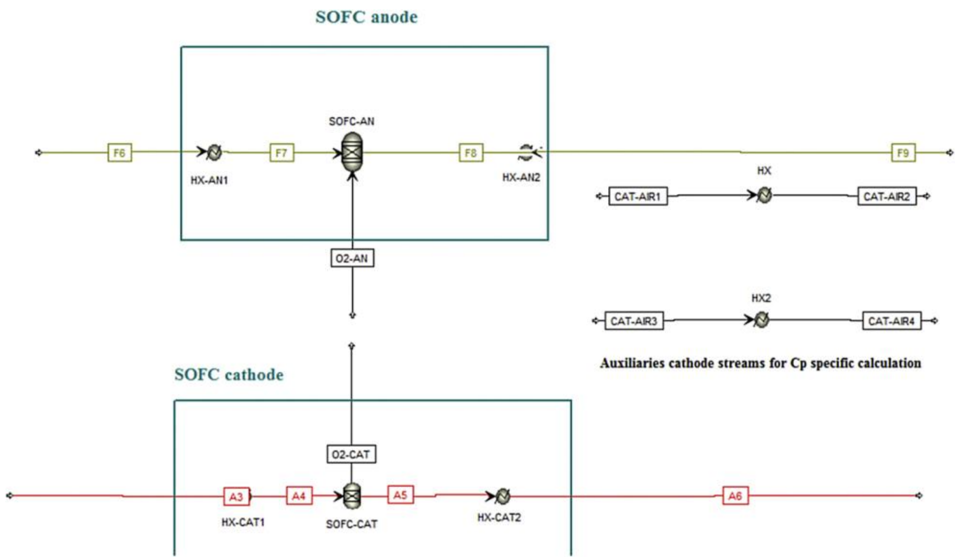


SOFC modelling

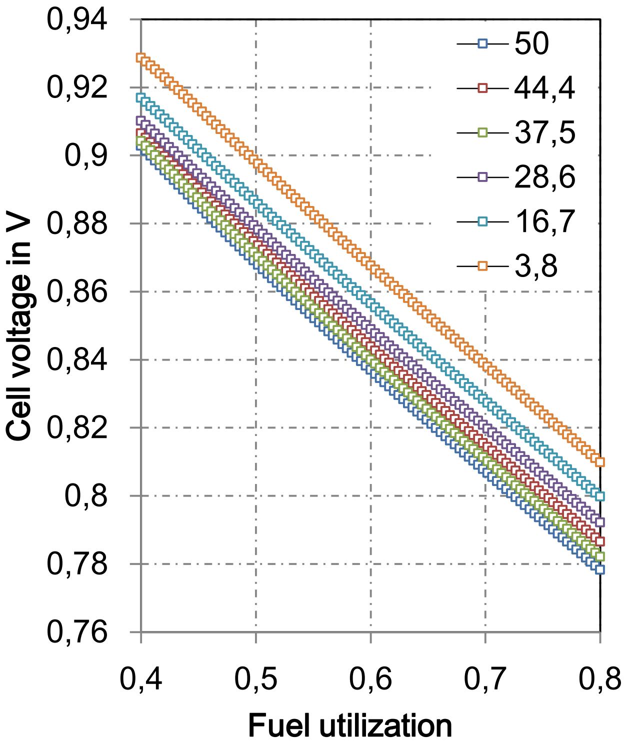
- Aspen Plus thermodynamic model
- Fortran calculator blocks

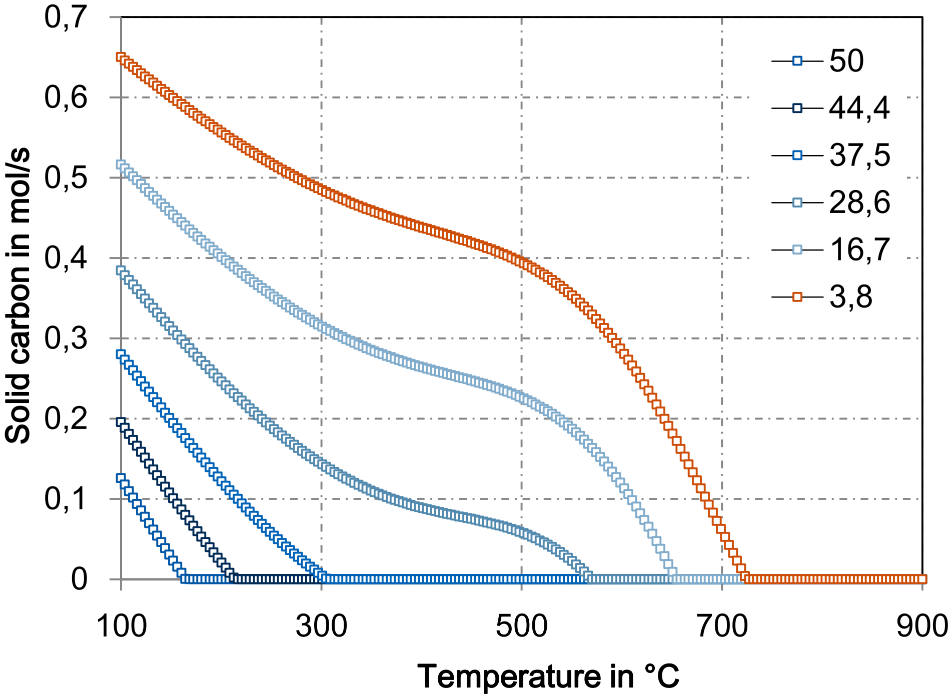


General assumptions for the system analysis.	
Parameter	Value
Fuel inlet temperature	750°C
Fuel outlet temperature	800°C
Air inlet temperature	700°C
Air outlet temperature	800°C
Average operating temperature	775°C
SOFC operating pressure	1.05 bara
SOFC active area	100 m²
Blower isentropic efficiency	0.75
Mechanical + motor efficiency	0.95
Inverter efficiency	98%
Air composition	21% O_2, 79% N_2
Oxygen utilization	≤50%
Fuel electrons input	8.0 mol/s
Single pass stack FU	≤80%
Minimum outlet fuel concentration	≥5%-mol.

Influence of steam content

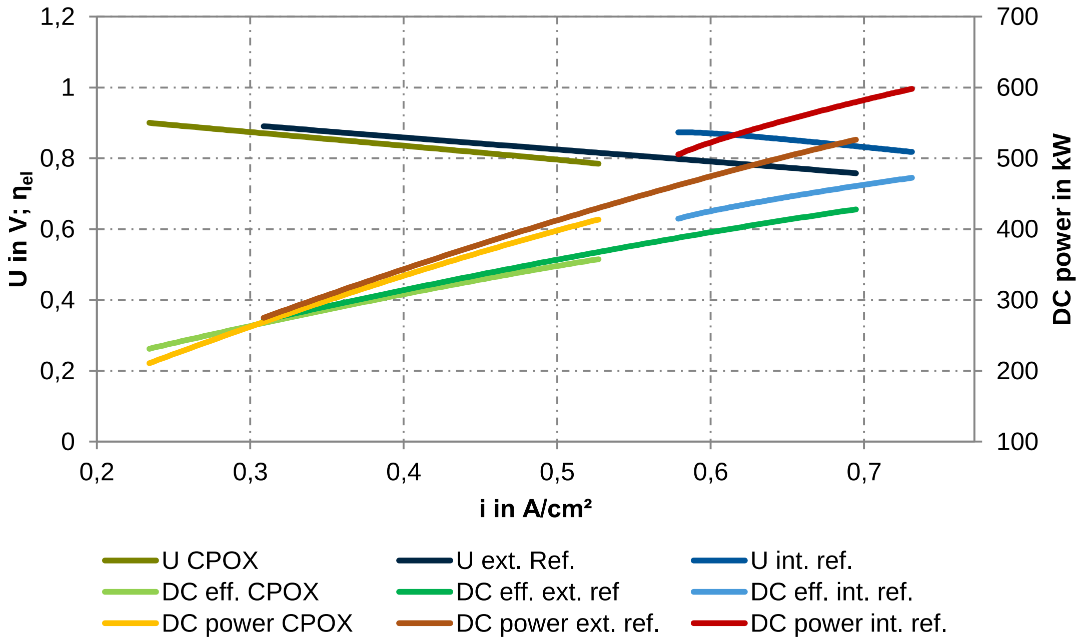
- Carbon deposition strongly dependent on steam content
- Low steam contents (below 20%) lead to carbon deposition!
- High steam contents lead to low voltage!
- Trade-off





System efficiency

- CPOX consumes electrons → less fuel available!
- External steam reforming requires high temperature heat integration
- Internal reforming with anode exhaust recirculation is most efficient option



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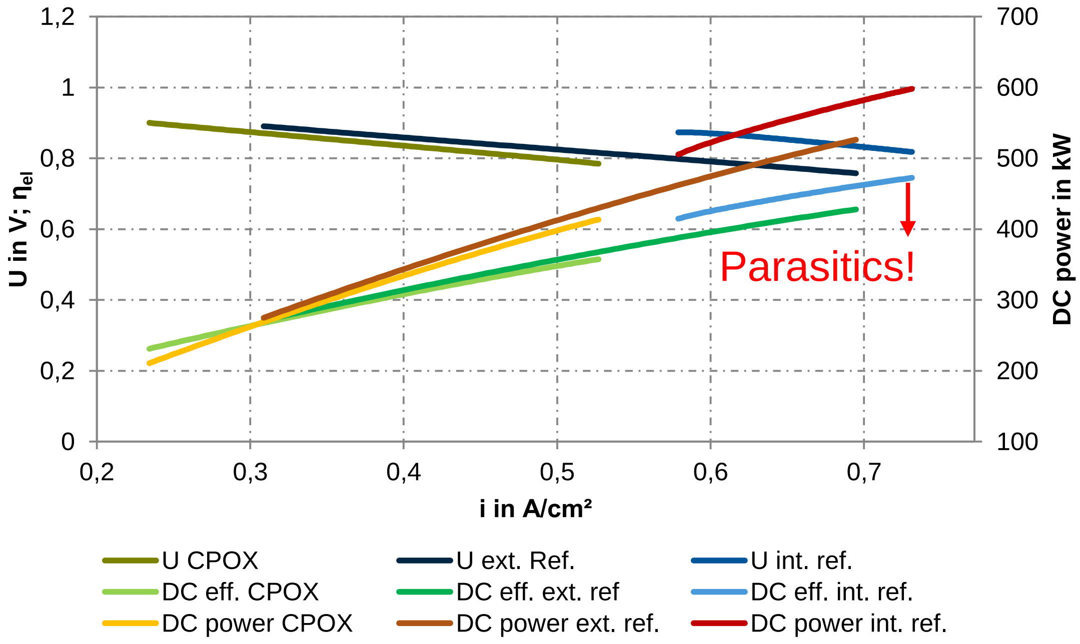

System efficiency - Auxiliary consumption

- Air blower consumes a lot of power!
- High total efficiency due to low digester temperature

Parameter	Value
SOFC- Stack (700°C)	
Voltage	0.827 V
Current density	0.438 A/cm²
DC power	543.6 kW
Balance-of-Plant (BoP)	
Inverter losses (2%)	-10.9 kW
Digester electricity	-20.0 kW
Recirculation blower	-6.5 kW
Air blower	-31.6 kW
Biogas blower	-1.3 kW
Total BoP	-70.3 kW
Net output	
Net power (AC)	473.2 kW
Digester heating (33°C)	133.0 kW
District heating (134/85°C)	140.3 kW
Electrical efficiency	
LHV (HHV)	59.0% (53.1%)
Total efficiency (incl. digester and district heating)	
LHV (HHV)	93.0% (83.7%)

Summary

- PV and wind are intermittent generation technologies
- Renewable balancing power potential is only available from hydro and biomass/biogas
- Biogas is a limited resource – high efficiency utilization is required
- SOFC is the most efficient gas-to-electricity technology
- SOFC system design (reforming option!) determines efficiency
- Heat integration SOFC-digester is possible and reasonable
- Optimization has to take thermodynamic constraints into account (carbon deposition)
- Optimized state-of-the-art systems can reach up to 60% electrical net efficiency

Thank you very much for your attention!

Stephan Herrmann