Reformer concepts for high efficient SOFC systems

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mCHP Reformer technology at ZBT

Reformer for PEM-FC

- More than 10 years experience
- Nominal H2 output: 2,5-12,5 kW_{th}
- Efficiency: up to 85 %
- Fuels: NG, LPG, Biogas

Features

- No electrical heaters
- Product level
- Low cost manufacture
- Patented (licence available) in EU, US, CA, JP, Korea

Related R&D

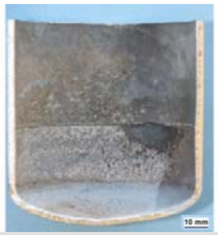
- Desulphurisation
- Long term stability
- Increase efficiency
- …

- Optimisation of heat integration
- Efficiencies > 85 %
- TÜV certificate

- Unit standardisation
- For NG
- Testing of adsorbents
- German project / coordination

- Condensing technology
- Optimisation of heat exchanger
- Optimisation of CO cleanup

- Construction modification
- Adequate materials and coating
- Joining technologies

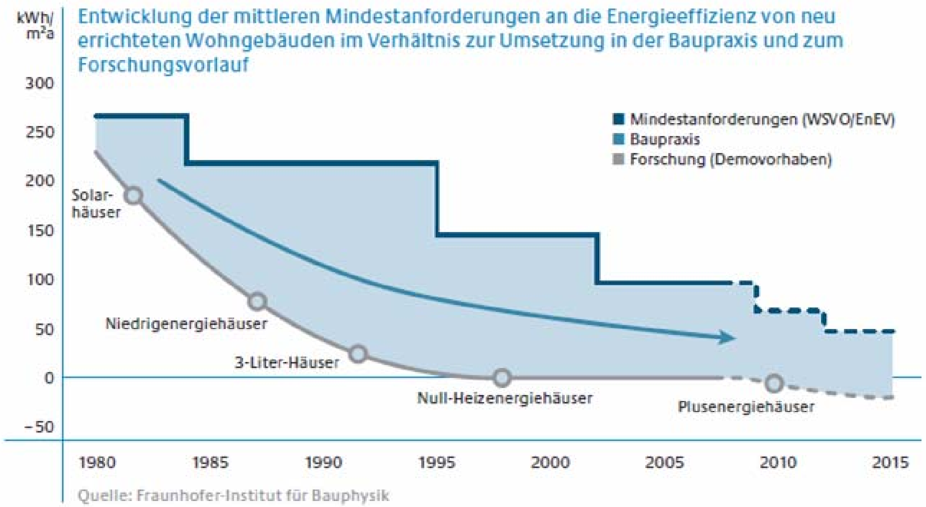


Source: DFI

Introduction

Motivation

- High efficient CHP systems play key role in future energy supply
- Possible fuels: Natural gas, LPG or Biogas
- Reducing heat demand for stationary applications
- SOFC technology has potential for high efficiencies and high CHP coefficients
  - ✓ Reduction of carbon footprint
  - ✓ System operation even at low heat demand



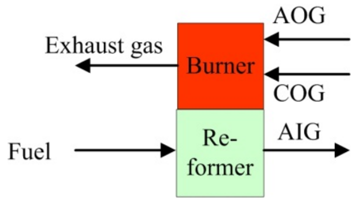
Challenges

- High el. efficiency (comparable to complete internal reforming) leading to continuous operation
- Simple and robust design

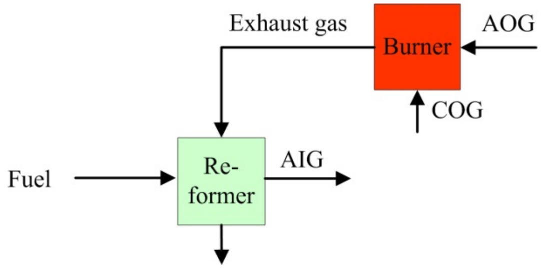
Reformer concepts at ZBT for 1 kW-class SOFC systems

External steam or combined steam and dry reforming

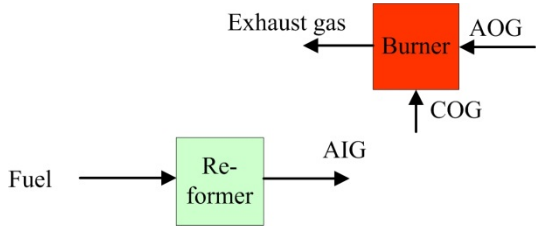
1. **Reformer/burner reactor**
   - High power density
   - Low amount of internal reforming (SOFC)
   - Single reactor



2. **Convectively heated reformer and adiabatic burner**
   - low Δp
   - Reduction of thermal stresses
   - Low amount of internal reforming (SOFC)
   - High flexibility in geometries and packaging concepts

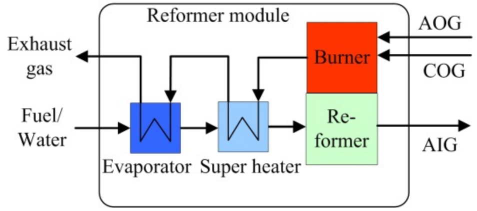


3. **Adiabatic reformer and adiabatic burner**
   - low Δp
   - Reduction of thermal stresses
   - High amount of internal reforming (SOFC)
   - High flexibility in geometries and packaging concepts

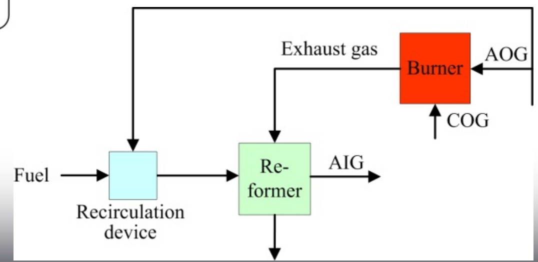


Water supply

1. **Water connection or closed water circle**
   - Evaporator and super heater needed as part of reformer module
   - Avoiding hot gas recirculation device



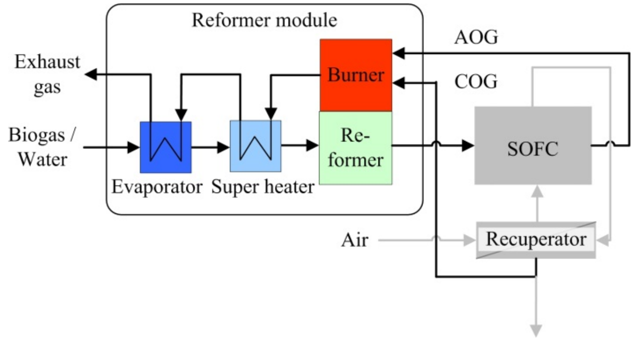
2. **Recirculation of AOG**
   - Recirculation devices needed for SOFC system
   - No external water supply



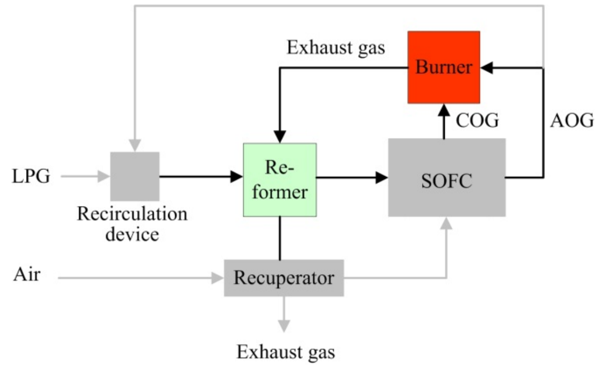
Reformer concepts at ZBT for 1 kW-class SOFC systems

***Presented reformer* configurations**

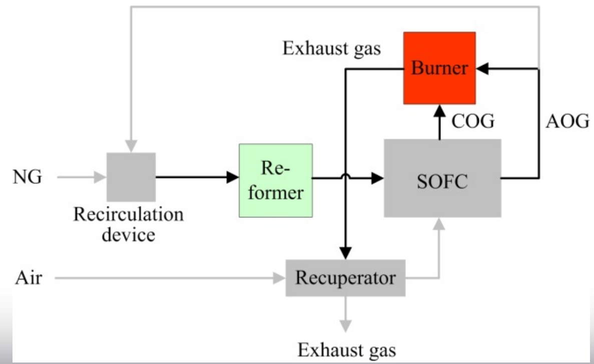
1. **Biogas reformer module**
   - Combined steam and dry reforming
   - Reformer/burner reactor
   - Water connection
   - Evaporator and super heater



2. **LPG reformer**
   - Tube bundle reformer convectively heated by the exhaust gas
   - Adiabatic burner
   - Recirculation of AOG

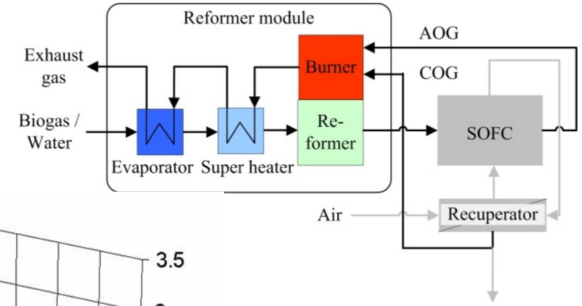


3. **NG reformer**
   - Adiabatic reformer
   - Adiabatic burner
   - Recirculation of AOG



Why water supply and combined steam and dry reforming?

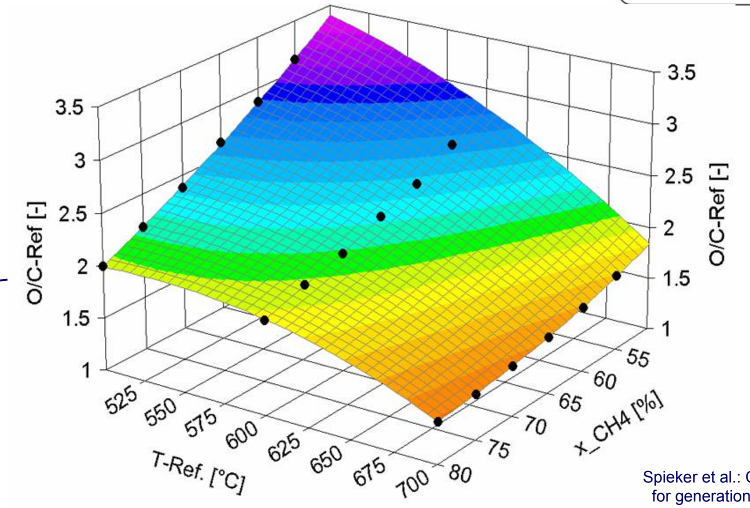
- Compensation of biogas composition fluctuations
- Temperature regulation
- Inhibition of carbon formation



Simulation results

No carbon formation for x_{CH4} = 50-80 %

- $O/C_{Ref} \geq 2{,}5$ &
- $T_{Ref} \geq 625$ °C

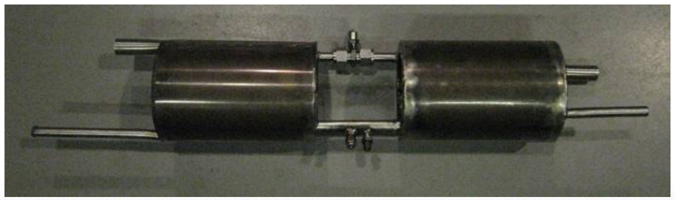


$$O/C_{\text{Ref}} = \frac{\dot{n}_{H_2O} + \dot{n}_{CO_2}}{\dot{n}_{CH_4}}$$

Spieker et al.: Combined dry and steam reforming of biogas for generation of H2 and CO rich fuel gas for SOFC, EFCF 2011, Lucerne, 2011

Design of reformer module

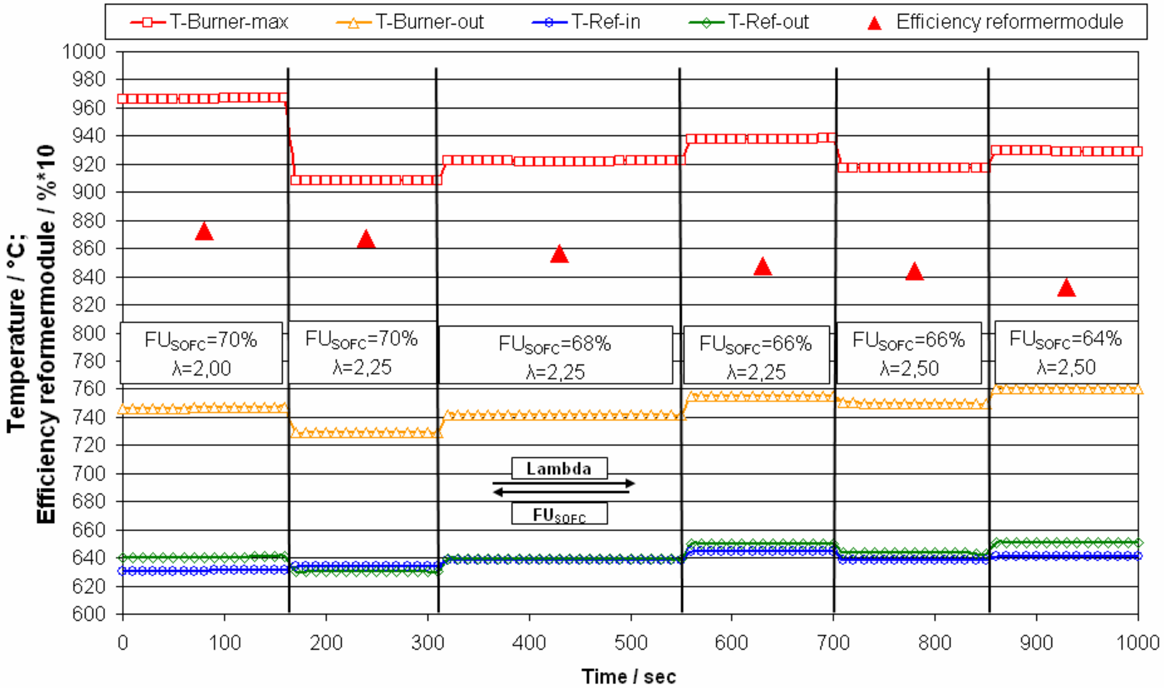
- Co-flow reformer/burner reactor as two concentric annular gaps with integrated metallic structures
- Precious metal catalysts in reformer and burner
- Counter-flow evaporator and super heater designed as spiral pipe



Experimental results

Lab characterisation of reformer module at standard operation point

- x_{CH4} = 65 %,
- O/C_{Ref} = 2,5,
- T_{Ref} > 625 °C



Spieker et al.: Combined dry and steam reforming of biogas for generation of H2 and CO rich fuel gas for SOFC, EFCF 2011, Lucerne, 2011

- ➢ Heat transfer guarantees reformer outlet temperature > 625 °C
- ➢ Adjusting of maximum burner temperature by burner air
- ➢ Efficiency reformer module > 86 %

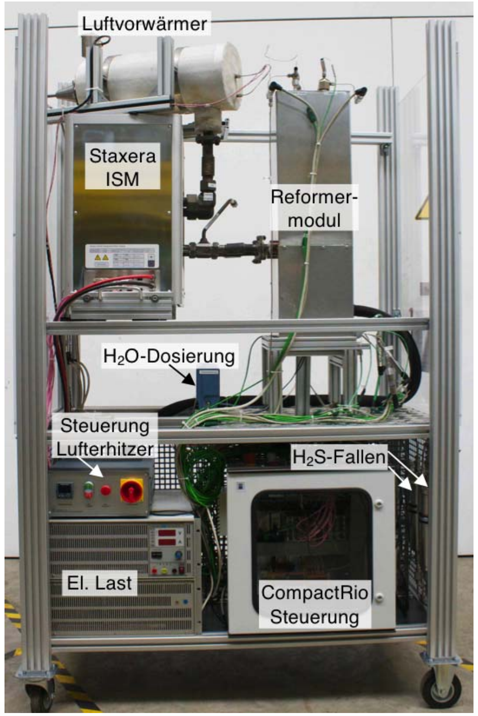
$$\eta_{\text{reformermodule}} = \frac{P_{chem,reformer,out}}{P_{chem,reformer,in} + P_{chem,burner,in}}$$

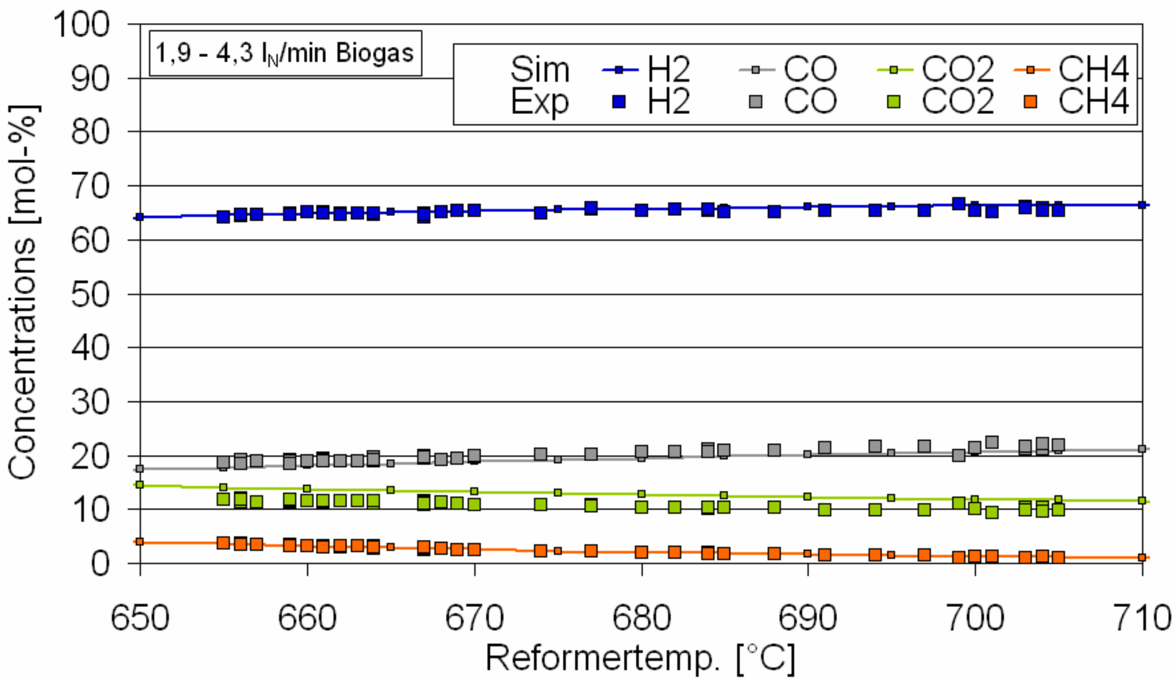
1. Biogas reformer module

Experimental results

SOFC system at biogas plant and in lab

- x_{CH4} = 68 %,
- O/C_{Ref} = 2,5,
- T_{Ref} > 625 °C



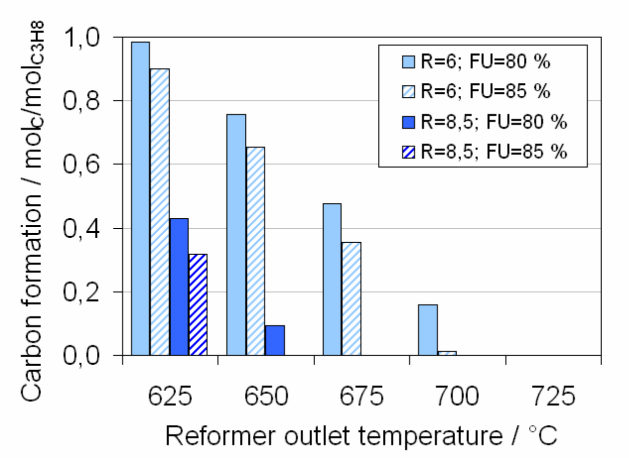


- ➢ No carbon formation detected
- ➢ Concentrations correspond very well with thermo dynamic equilibrium
- ➢ Gross electrical system efficiency 53 % (separate 500h-Lab test at Cutec)

Lindermeir et al.: High efficient biogas electrification by an SOFC-system with combined steam and dry reforming , EFCF 2012, Lucerne, 2012

2. Tube bundle LPG reformer

Simulations results (for Propane)

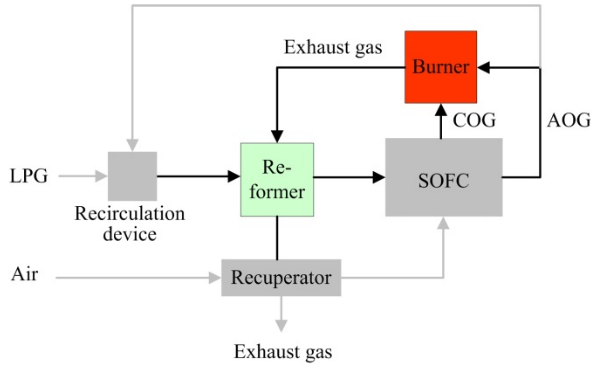


No carbon formation for

- $T_{Ref} \geq 650$ (@ R=8,5; FU=85)
- $T_{Ref} \geq 725$ (@ R=6; FU=80)

Gross el. system efficiency

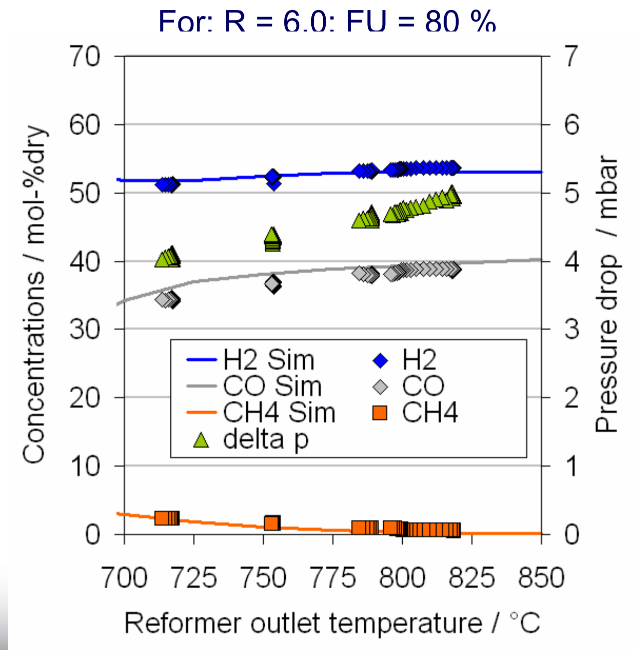
- ηel = 61 % (@ R=8,5; FU=80)
- ηel = 63 % (@ R=8,5; FU=85)



Reformer catalyst pre-tests

- Test reactor: Single tube of the tube bundle reactor (el. heated)
- Inlet temperatures 550-570 °C (according simulation)
- Test of: Fuel conversion, carbon formation & pressure drop
- Fuel: Propane

- Very well correspondence with thermo dynamic equilibrium
- H_2+CO content up to 95 mol-%$_{dry}$
- No carbon formation detected
- Pressure drop is < 5 mbar

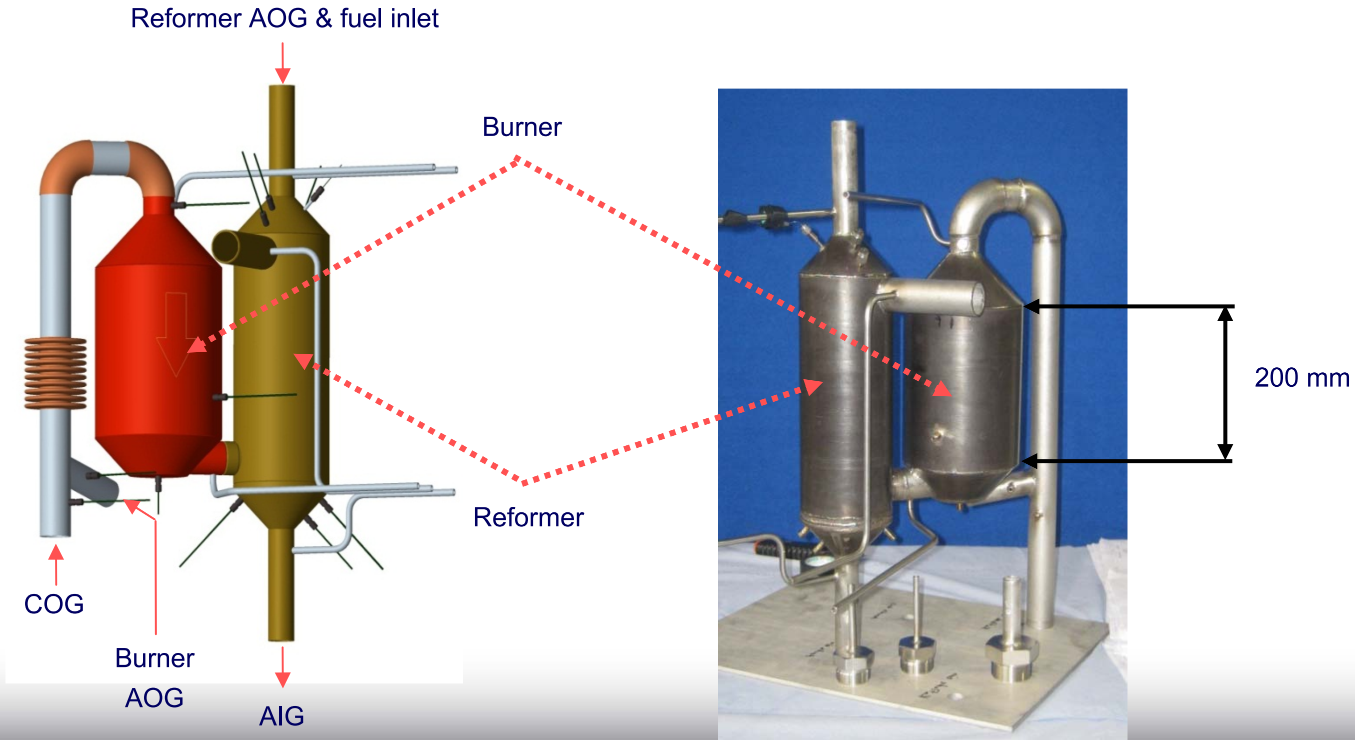


Design of reformer and burner

- Tube bundle reactor convectively heated by exhaust gas (counter-flow)
- Precious metal catalysts in reformer and burner

Restrictions

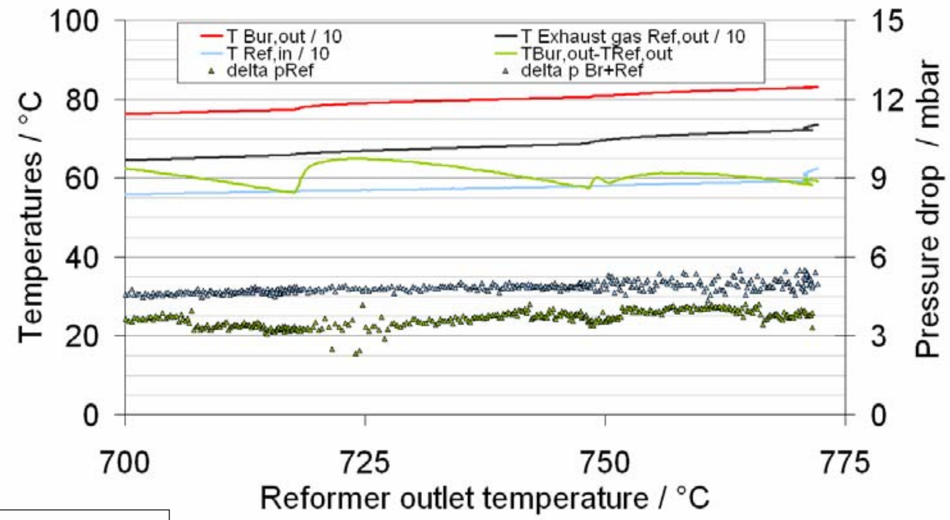
- Sufficient surfaces for heat transfer
- Big difference of flow rates of reformer reactants and exhaust gas
- Pressure drop ≤ 5 mbar (for both media)

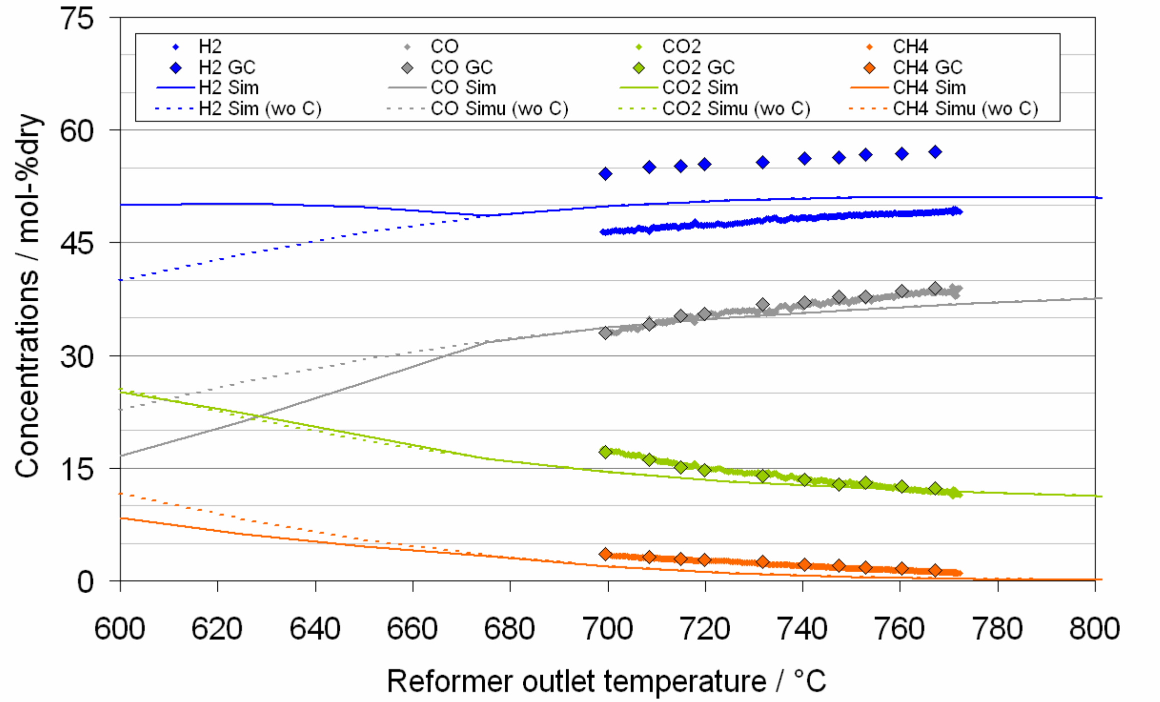


Experimental results

Lab characterisation of reformer reactor

- R = 7,0
- FU = 85 %
- Fuel: Propane

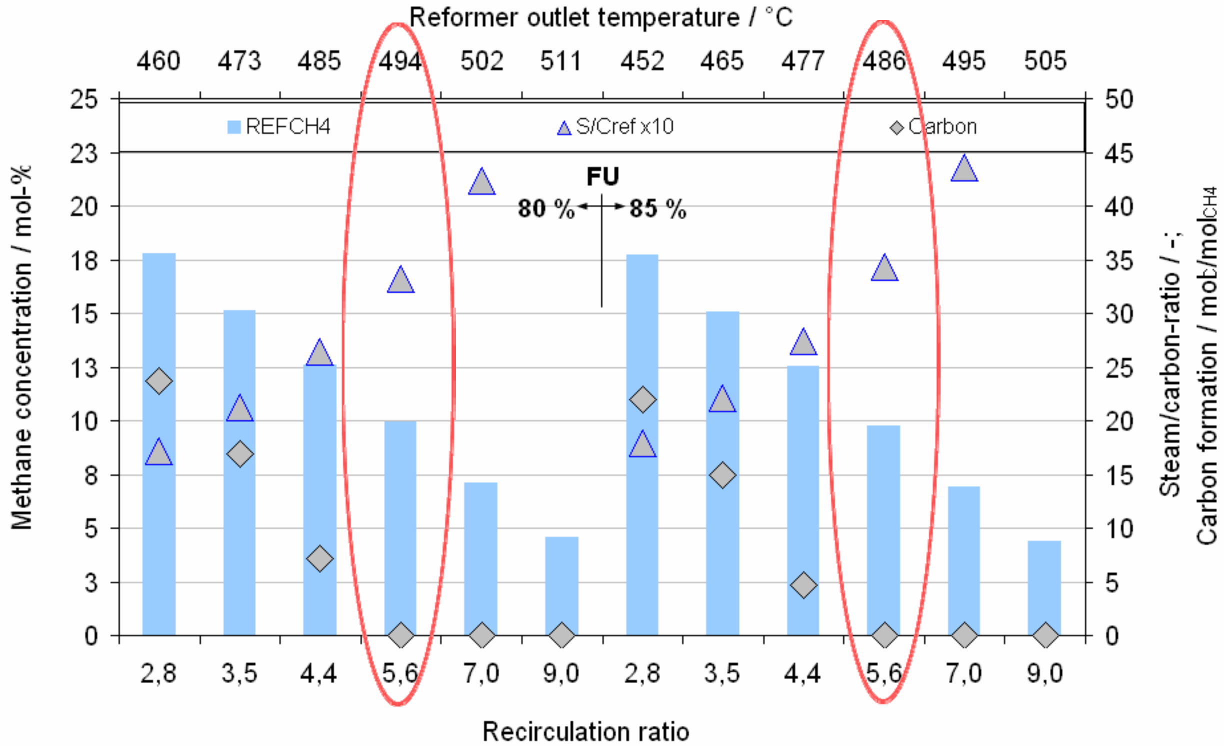


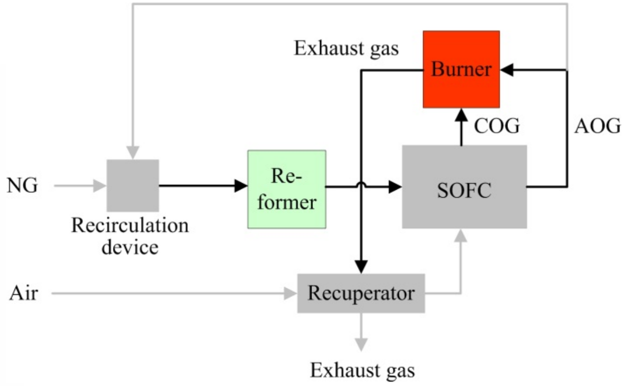


- Measured concentrations slightly deviate from thermo dynamic equilibrium
- H_2+CO content up to 90 mol-%dry
- Good heat transfer in reformer reactor
- Low pressure drops in reformer and burner reactors

3. Adiabatic NG reformer (Study)

Simulations results

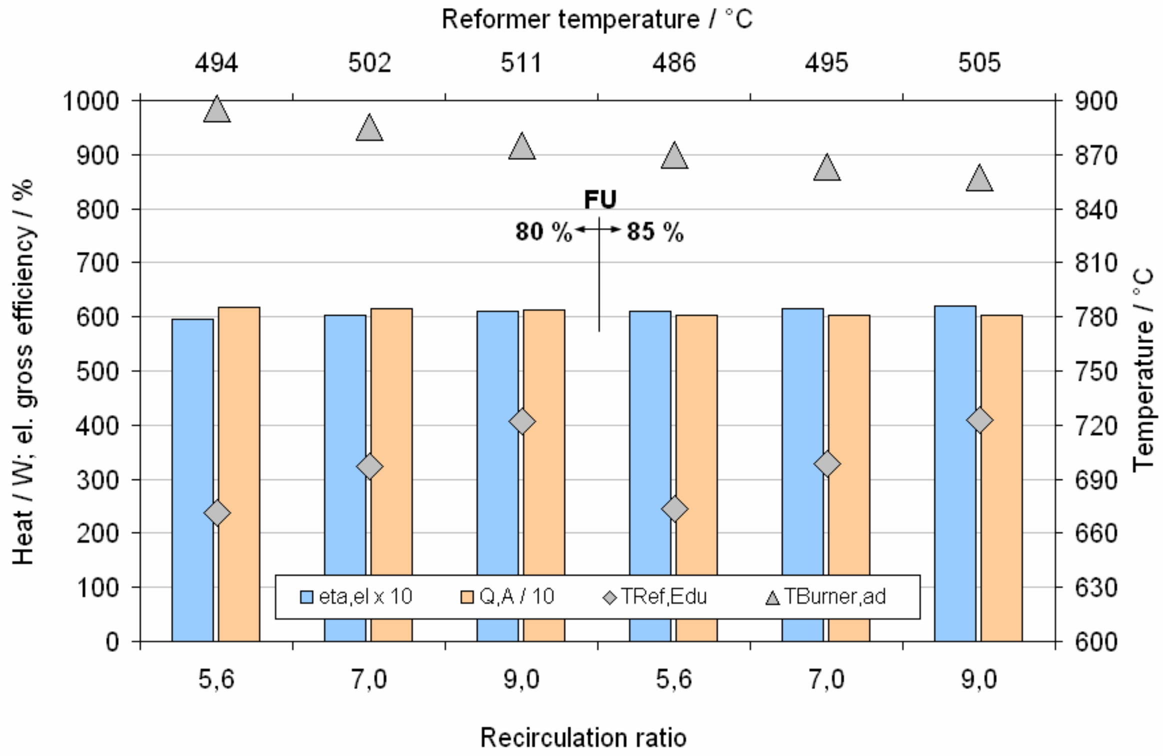


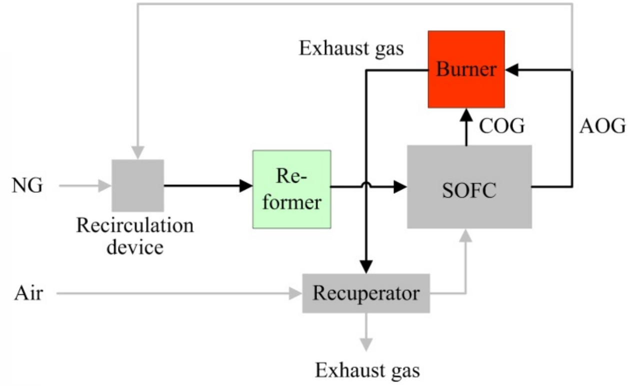


No carbon formation for

- R > 5,6
- Corresponding to
  - $T_{Ref} \geq 494 / 486$ °C
  - $S/C \geq 3,3 / 3,4$
  - $x_{CH4} \leq 9,9 / 9,7$ %

Simulations results





- Heat for reforming & preheating of anode inlet gas in SOFC ≈ const.
- ➢ λ_{cat} ≈ const. ≈ 2,5 / 2,7 (referred to supplied reformate gas)
- With increasing recirculation ratio
  - $T_{Ref,inlet}$ increases up to 722 °C
  - $T_{Burner,ad}$ decreases down to 875 / 857 °C
  - $\eta_{el,gross}$ increases up to 61 / 62 %

Conclusion and outlook

Conclusion

- Presentation of 3 reformer and water supply configurations for 1 kW-class SOFC system
- Simulation for all configurations showed
  - Gross electrical system efficiencies > 50 %
- Tests of biogas reformer module demonstrated
  - Biogas composition fluctuations could be compensated by steam and dry reforming
  - Concentrations correspond very well with thermo dynamic equilibrium
  - High reformer and system efficiencies in Lab and at biogas plant
- Tests of tube bundle LPG reformer showed
  - Good heat transfer from exhaust gas to reformer
  - Low pressure drop in reformer and burner
  - H2+CO content up to 90 mol-%dry

Outlook

- Further proves of concept of biogas SOFC system reformer module at other biogas plants
- Test results on system level with the tube bundle LPG reformer
- Combinations of reformer and water supply concepts
- Scale-up of tube bundle reformer

Acknowledgements

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Thank you for your attention!

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