Reforming and SOFC system concept with electrical efficiencies higher than 50 %

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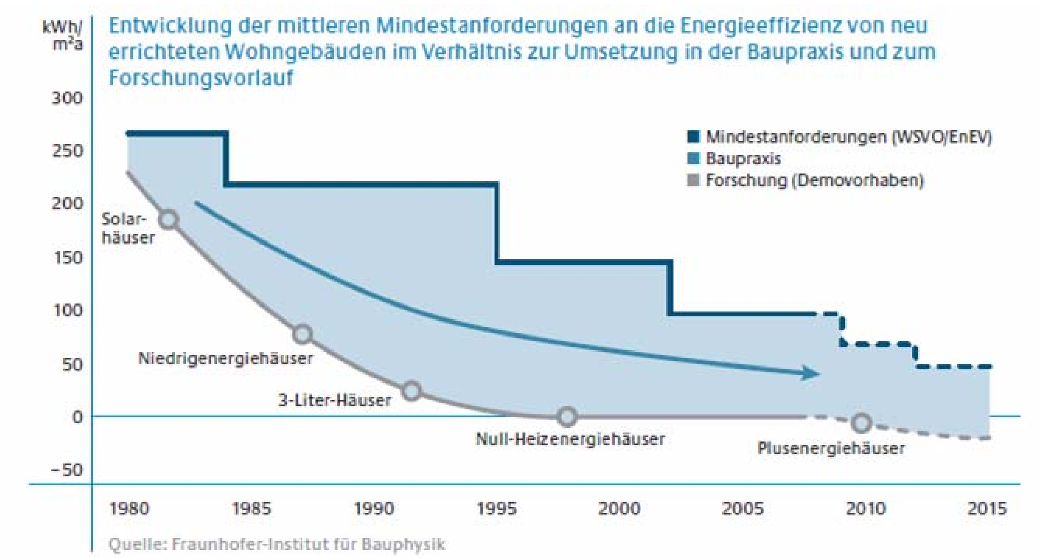
Introduction

Motivation

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



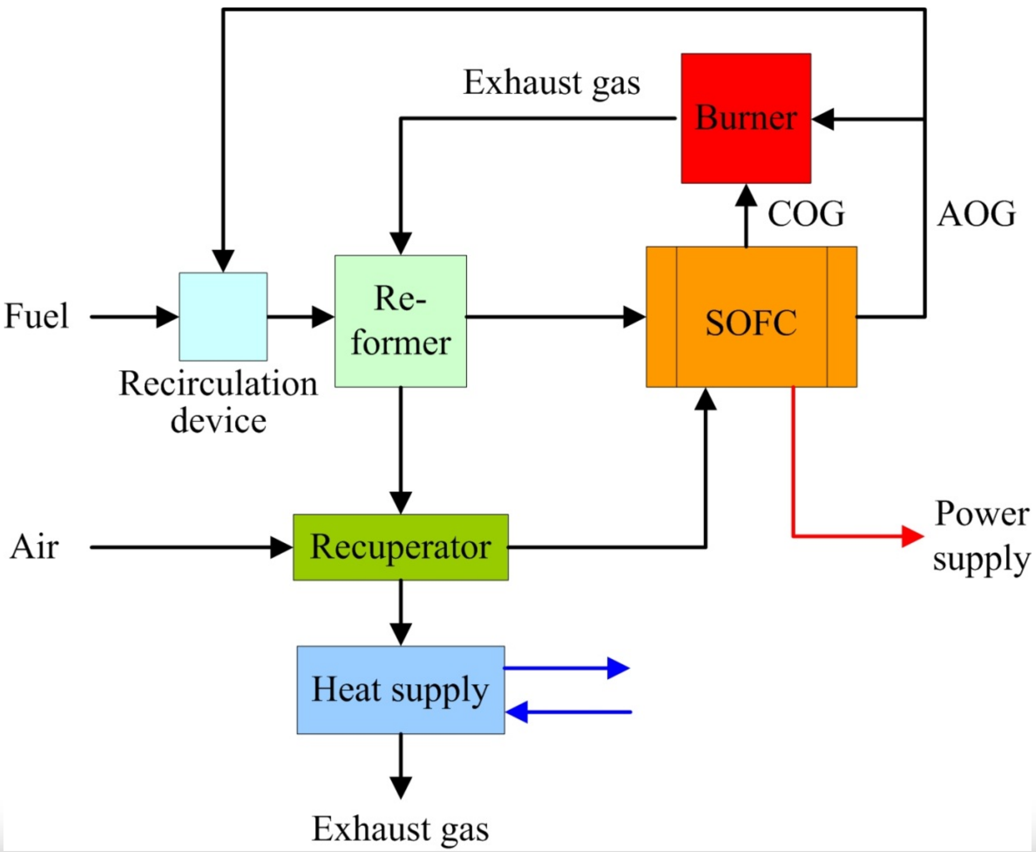
SOFC system concepts

Challenges

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

Approach

- Recuperating SOFC waste heat
- External steam reforming
- Separate reformer and adiabatic burner
- Recirculation of AOG
  (with compressor or injector)



Advantages

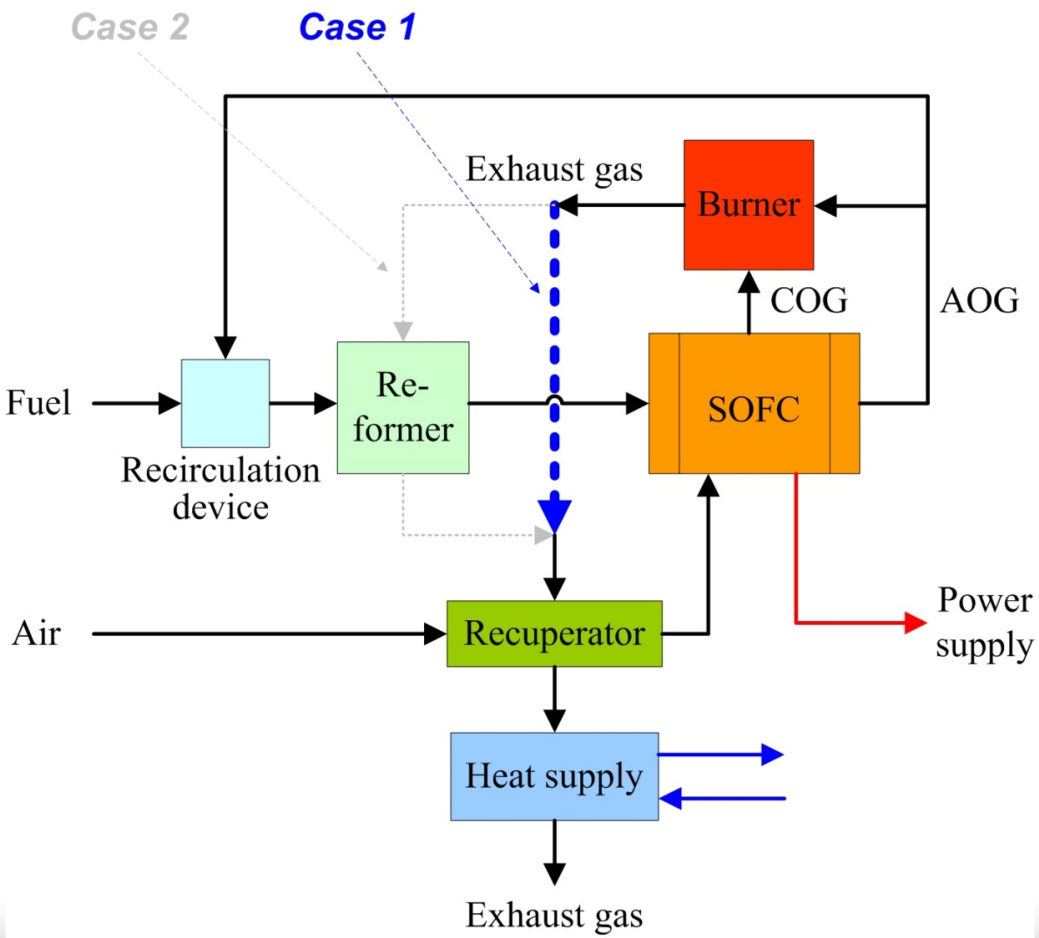
- No additional heat/fuel for reforming necessary
- High flexibility in geometries and packaging concepts
- Reduction of thermal stresses
- No external water supply

Configuration

Depending on ability of internal reforming in the SOFC

Case 1

- High internal conversion possible
- Reformer: adiabatic reactor
- Reforming temperature: 450-550 °C
- Less cathode air for cooling required

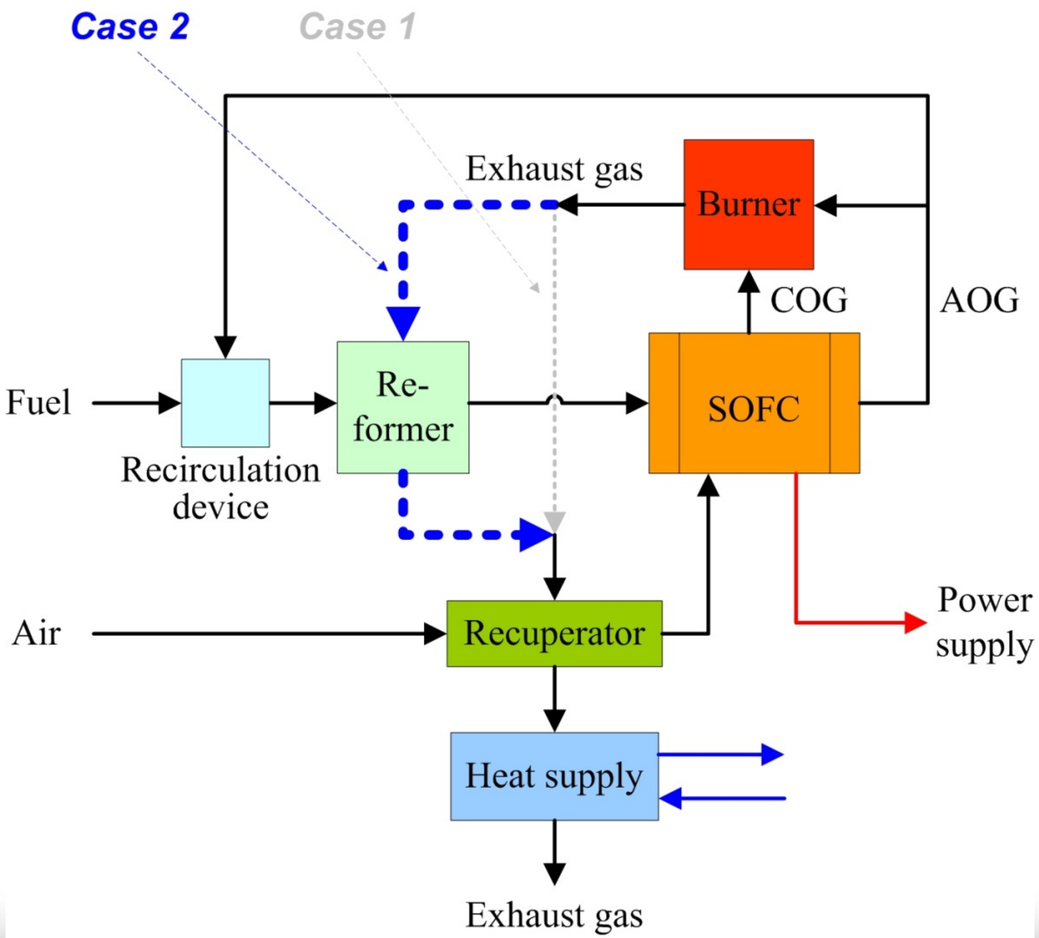


Configuration

Depending on ability of internal reforming in the SOFC

Case 2

- Low internal conversion possible
- Reformer: tube bundle reformer convectively heated by the exhaust gas
- Reforming temperature: 650-750 °C
- More cathode air for cooling required



Simulation of case 1: adiabatic reformer fed with natural gas

Boundary conditions

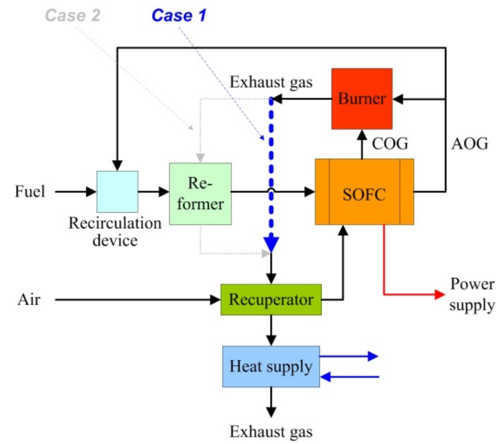
- $P_{el,gross}$ = 1 kW

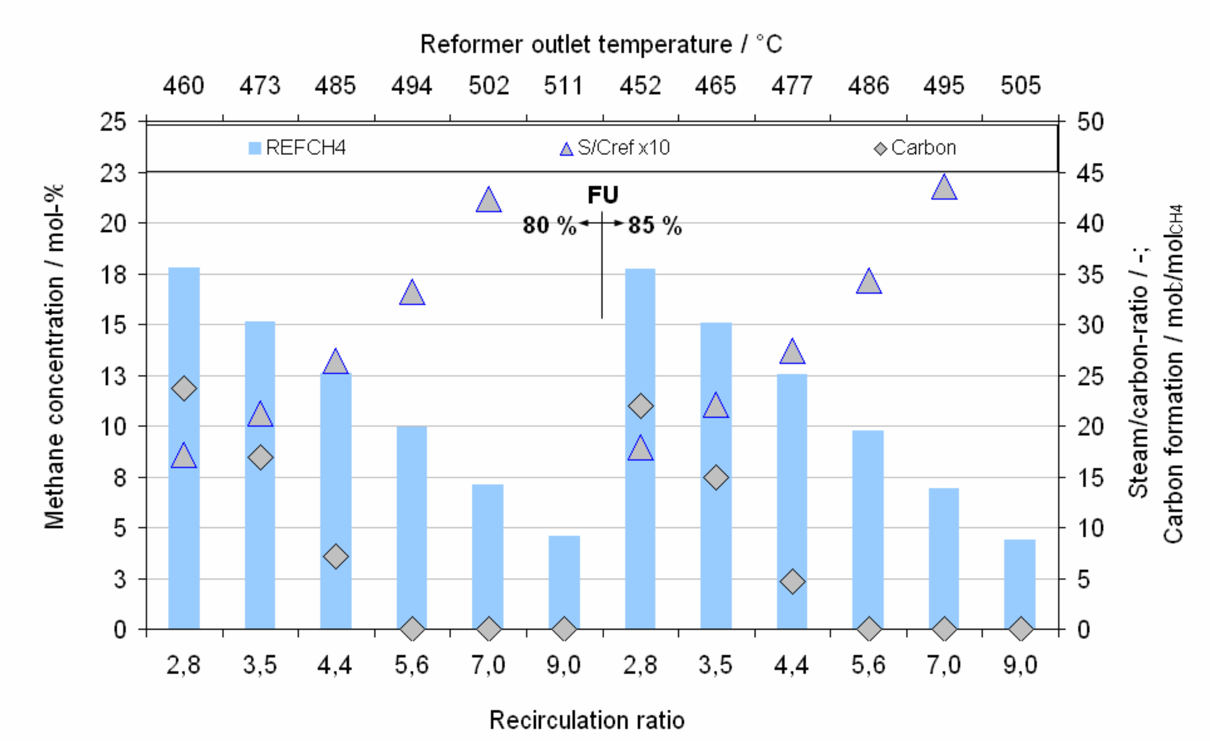
Case 1

- Fuel: Natural gas
- $\eta_{SOFC,el}$ = 50 %
- $Q_{SOFC,loss}$ = 100 W

SOFC

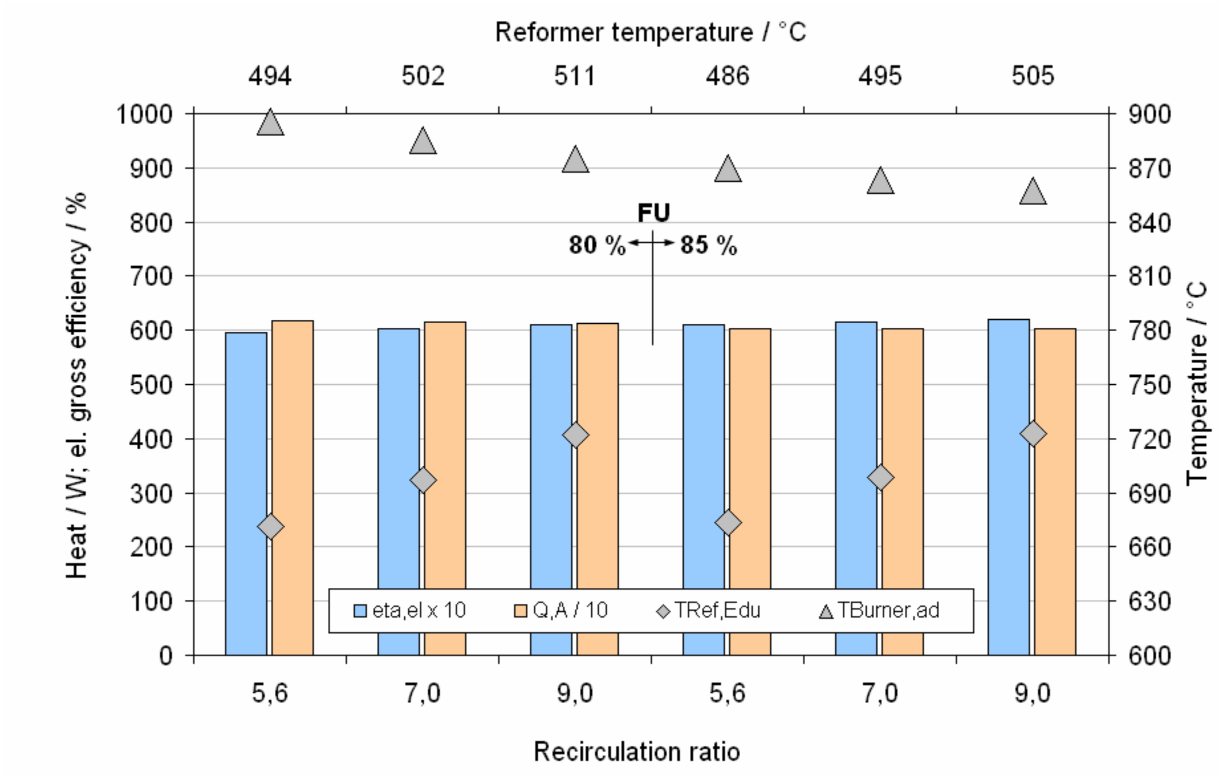
- T = 850 °C
- Methane reformed @ TSOFC
- than FU_{CH4} = 100 %
- $FU_{H2,CO}$ = 80 - 85 %
- $T_{Cat,air,in}$ = 650 °C
- $V_{Cat,air}$ depending on heat balance

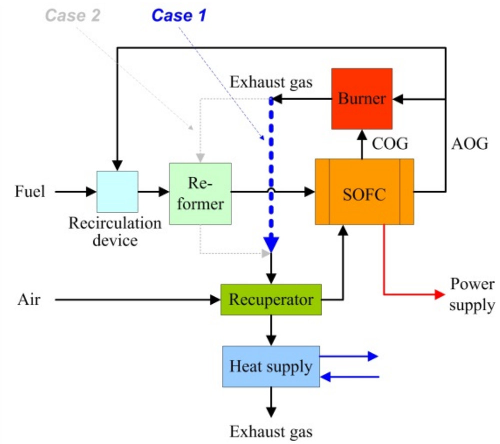




- No carbon formation for recirculation ratios > 5,6
- Corresponding to
  - $T_{Ref} \geq$ 494 / 486 °C
  - S/C $\geq$ 3,3 / 3,4
  - $x_{CH4} \leq$ 9,9 / 9,7 %

Simulation of case 1: adiabatic reformer fed with natural gas





- 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 %

Simulation of case 2: convectively heated reformer fed with LPG

Boundary conditions

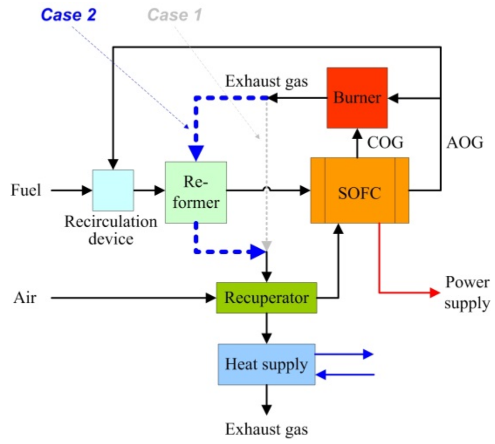
- $P_{el,gross}$ = 1 kW

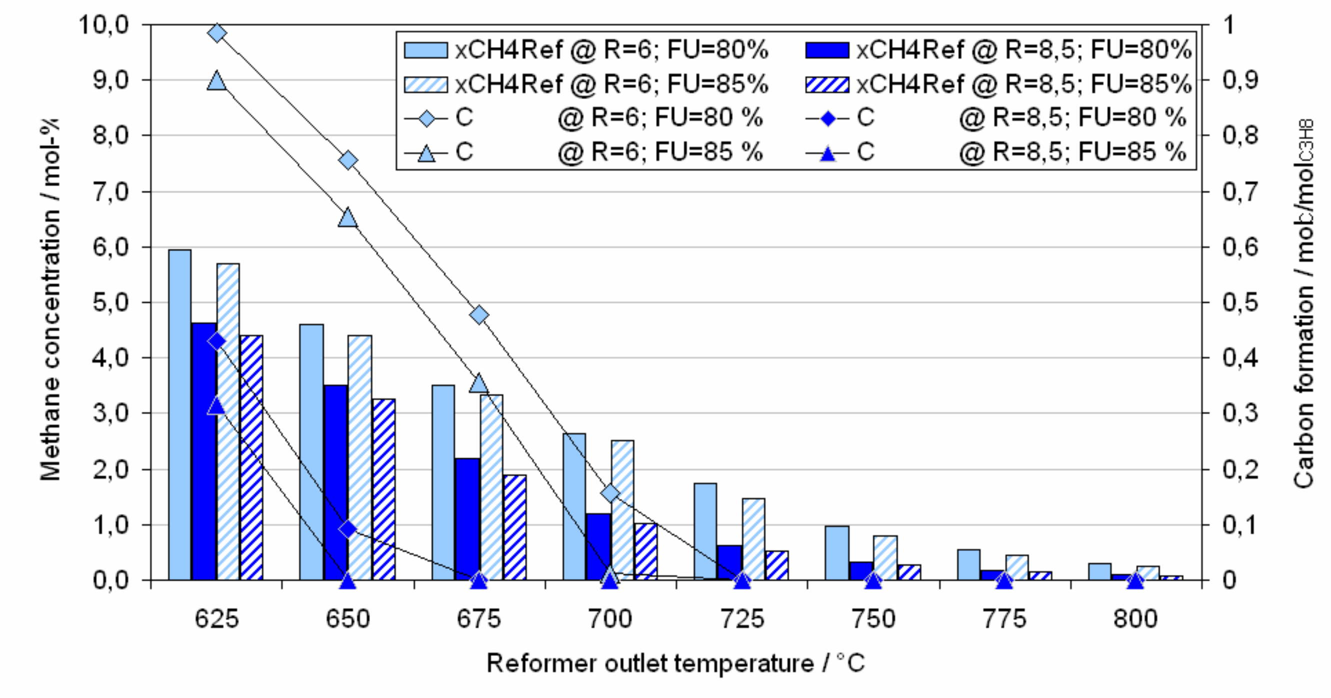
Case 2

- Fuel: Propane
- $\eta_{SOFC,el}$ = 53 %
- $Q_{SOFC,loss}$ = 220 W

SOFC

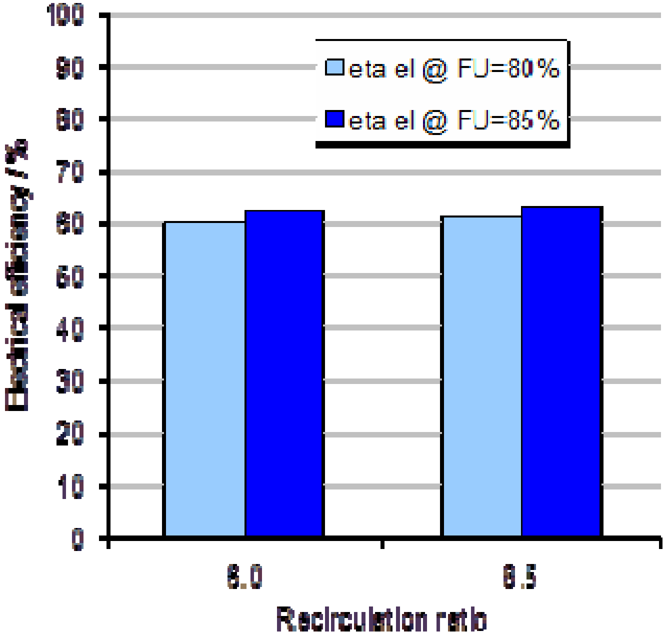
- T = 850 °C
- Methane reformed @ TSOFC
- than FU_{CH4} = 100 %
- $FU_{H2,CO}$ = 80 - 85 %
- $T_{Cat,air,in}$ = 650 °C
- $V_{Cat,air}$ depending on heat balance

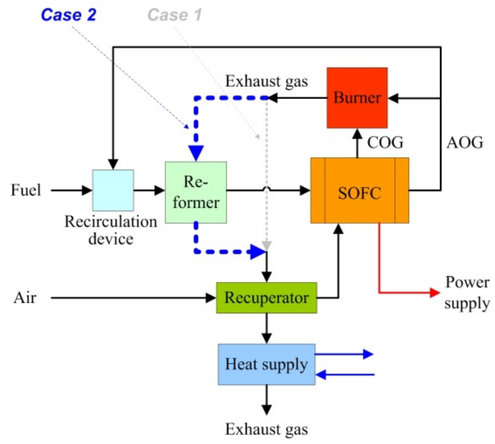




- No carbon formation for recirculation ratios > 6 **and** $T_{Ref} \geq 725$
- Corresponding to $x_{CH4} \leq 1{,}7$ / 1,5 %

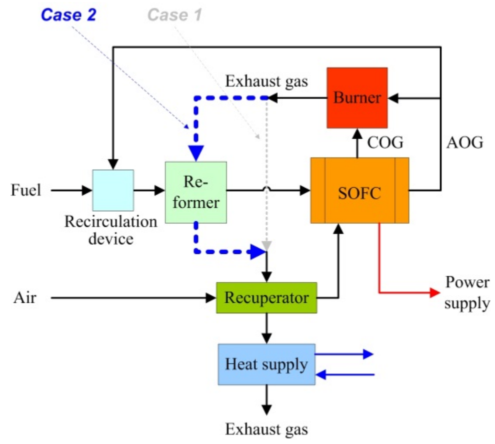
Simulation of case 2: convectively heated reformer fed with LPG





- With increasing recirculation ratio $\eta_{el,gross}$ increases up to 61 / 63 %
- Adiabatic burner temperature is < 900 °C

Reactor design (case 2)



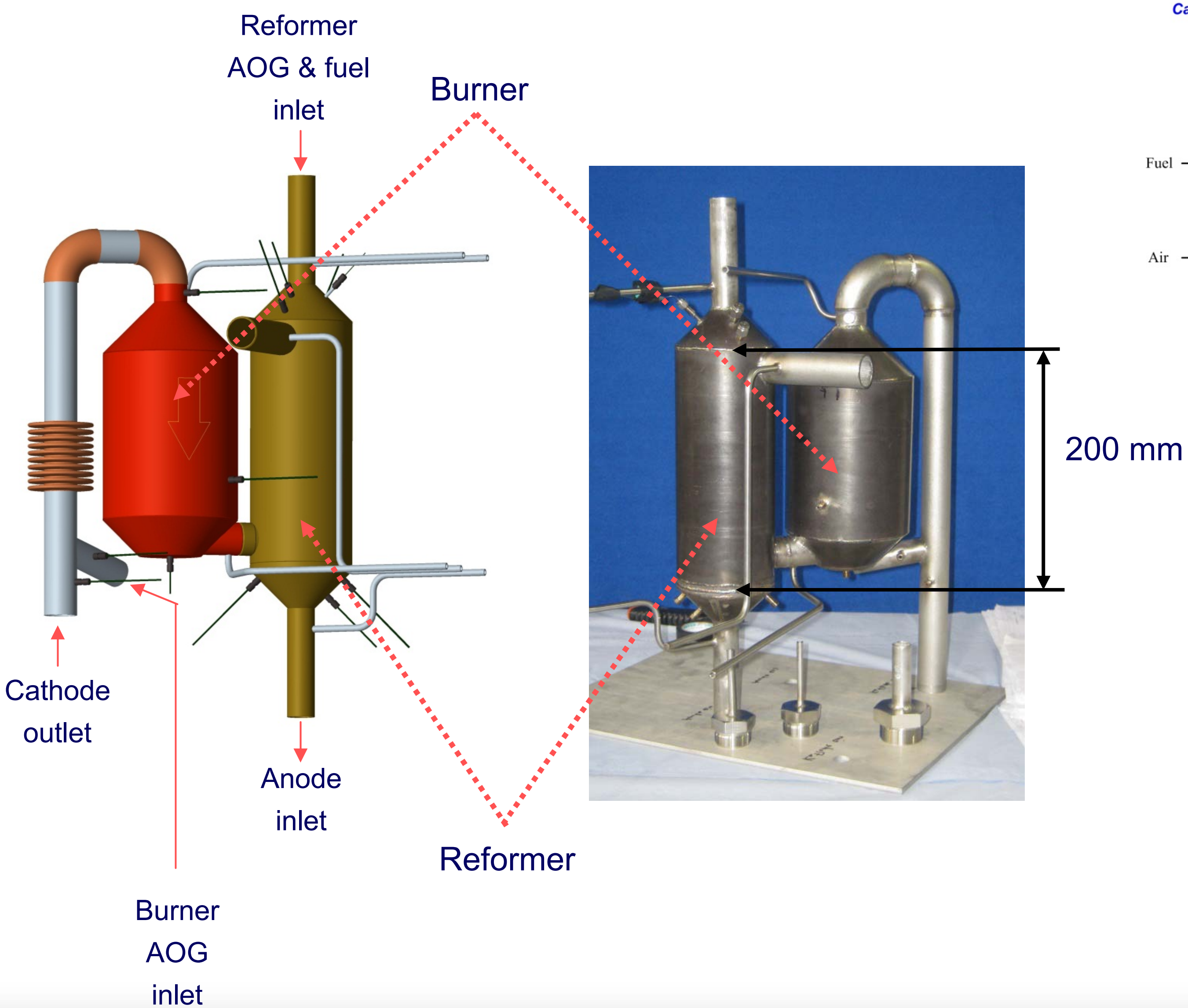
Restrictions

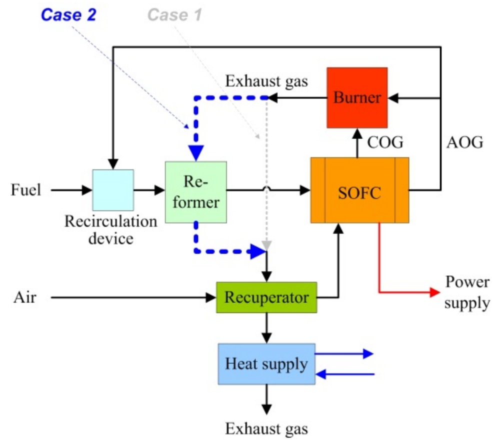
- Simple construction
- Low thermal stresses
- Sufficient surfaces for heat transfer: exhaust gas => reforming zone
- Big difference of flow rates of reformer reactants and exhaust gas
- Pressure drop ≤ 5 mbar (for both media)
- Catalysts geometries and GHSV
- Short connections to SOFC

- Separate reactors
  - Reformer: tube bundle reactor
  - Burner: adiabatic reactor

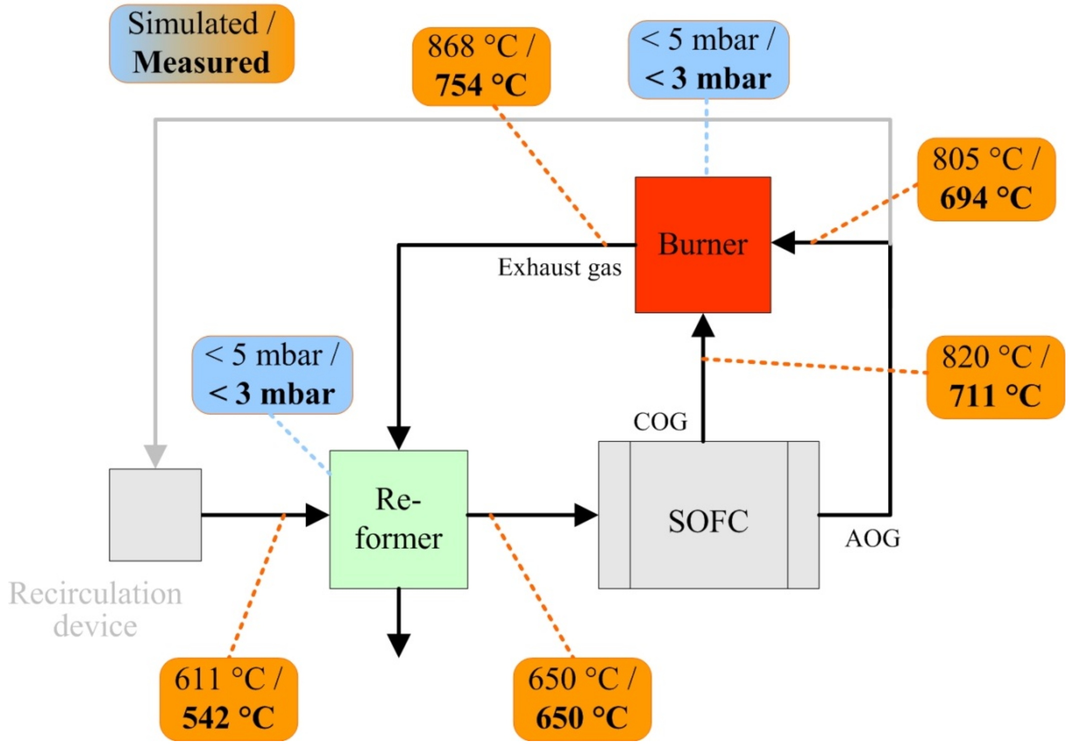
- The geometries were designed based on the vdi method for pressure drop und heat transfer calculations.

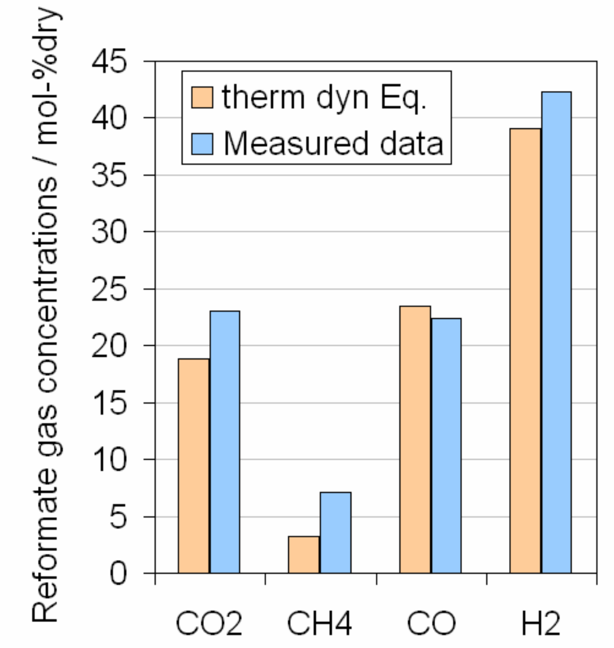
Reactor design (case 2)





Experimental results (case 2)





Test parameters

- Recirculation ratio = 8,5
- FU = 85 %
- T_{Ref} = 650 °C
- Add. H2/CO fed to burner

Results

- Burner in- and outlet temperatures 100 K to low
- ΔT_{Burner} ≈ 50 K reached due to add. H2/CO
- Good heat transfer in tube bundle reactor
- Measured concentrations deviate from th. dyn. equilibrium
- Low pressure drops in reformer and burner

Conclusion and outlook

Conclusion

- Presentation of 2 reformer and SOFC system configurations with el. power output of 1 kW
  - Case 1: adiabatic reformer (fuel: natural gas)
  - Case 2: tube bundle reformer reactor convectively heated by the exhaust gas (fuel: propane)
- Simulation show for both configurations
  - Gross electrical system efficiencies > 60 %
  - Carbon formation free reforming @ recirculation ratio ≥ 6,0
    - Depending on FU (≥ 80 %)
    - And for case 2 depending reformer temperature (≥ 725 °C)
- Reactor was designed based on the vdi method for pressure drop und heat transfer calculations
- Tests of tube bundle reformer reactor with adiabatic burner (case 2, fuel: propane) show
  - Need for improved insulation of connections and reactors
  - Good heat transfer from exhaust gas to reformer
  - Low pressure drop in reformer and burner

Outlook

- Further detailed measurement data will be presented in the near future

Acknowledgements

Ideen eine Zukunft geben

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- IWBT (dynamic process simulations)
- IEE (Control)

Thank you for your attention

and

what about collaboration?

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