



## Reactor development for a steam reforming fuel processor for diesel fuel in the kW range

Marius Maximini<sup>1</sup>, Philip Engelhardt<sup>1</sup>, Martin Brenner<sup>2</sup>,  
Andrea De Toni<sup>3</sup>, Hans-Georg Anfang<sup>3</sup>

<sup>1</sup>Oel-Waerme-Institut GmbH, Germany

<sup>2</sup>BEHR GmbH & Co. KG, Germany

<sup>3</sup>Süd-Chemie AG, Germany

Berlin, 12.04.2012



## Outline

- Project introduction and background
- Reactor development for mixture preparation
- Reformer development and testing
- Summary

## MÖWE 2 Project

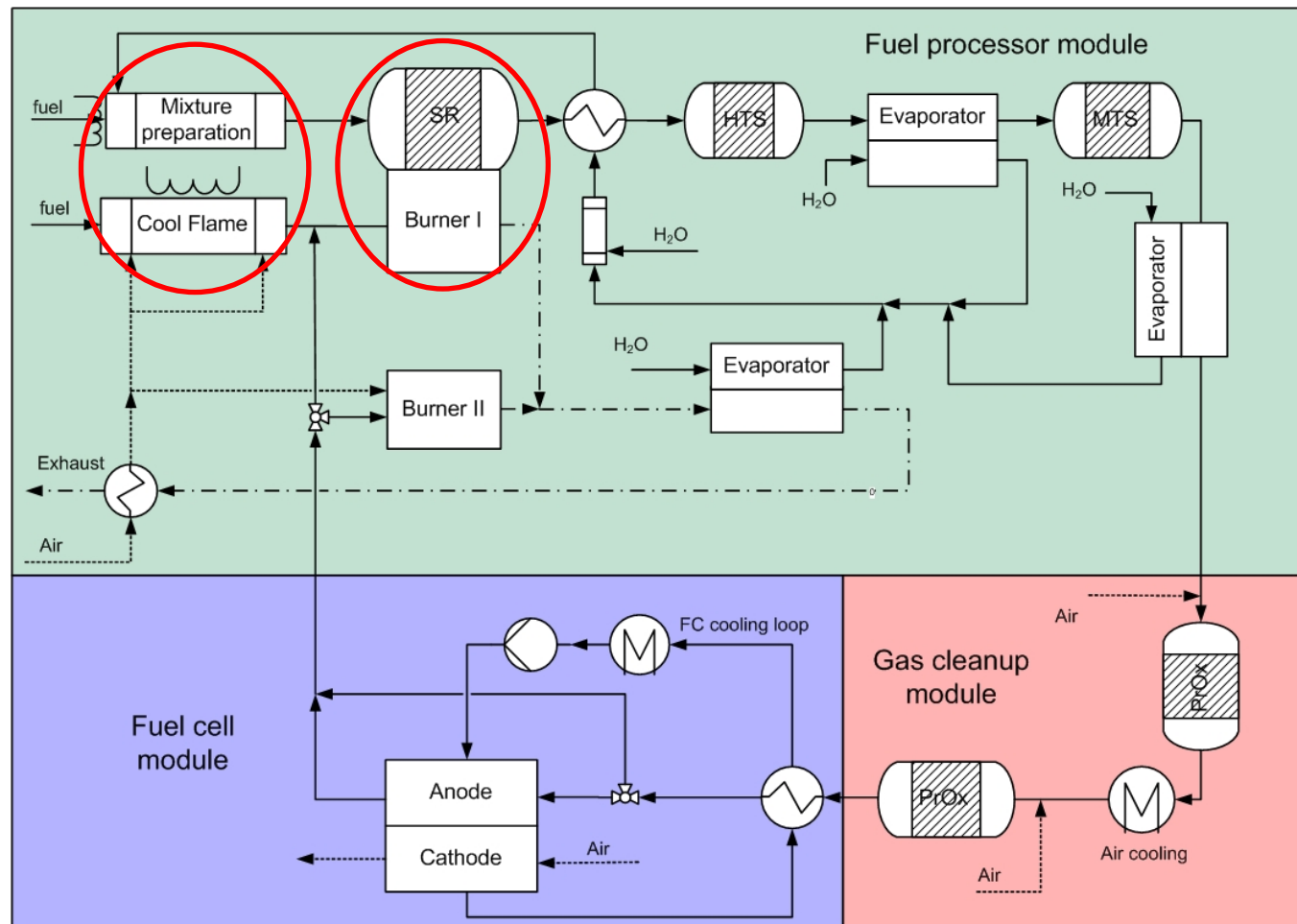
Development of an integrated fuel cell system comprising a 10 kW<sub>th</sub> diesel fuel processor and a 4 kW<sub>eI</sub> LT-PEM fuel cell

- Diesel fuel
  - High availability, existing infrastructure → easy market entry
  - High energy density → compact size
  - Easy storage
- Steam reforming
  - Highest hydrogen yield of all reforming processes
  - No dilution of reformat gas with atmospheric N<sub>2</sub>
- LT-PEM fuel cell
  - Technical maturity
  - High availability
- Market:
  - APU for recreational applications



## Modular fuel cell system

- fuel processor adaptable for LT-PEM and HT-PEM fuel cells



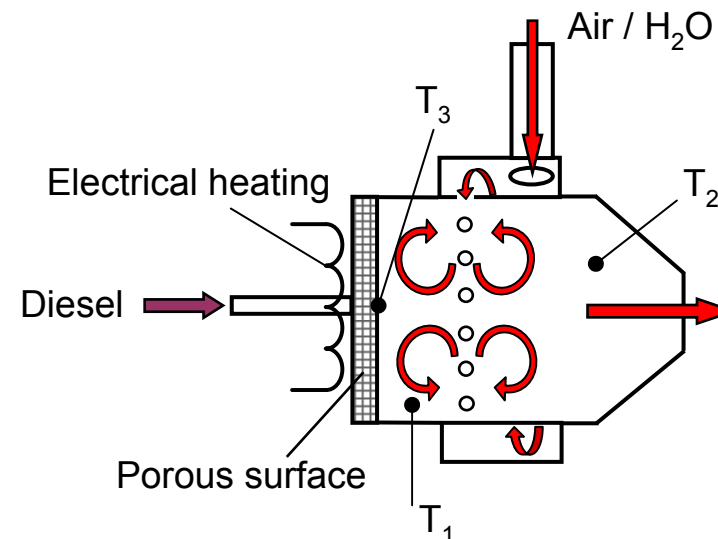
## New multifunctional reactor

(Prototype developed with J. Eberspächer GmbH & Co. KG)

- Start-up burner
- Cool Flame reactor for fuel evaporation
- Diesel / steam mixer

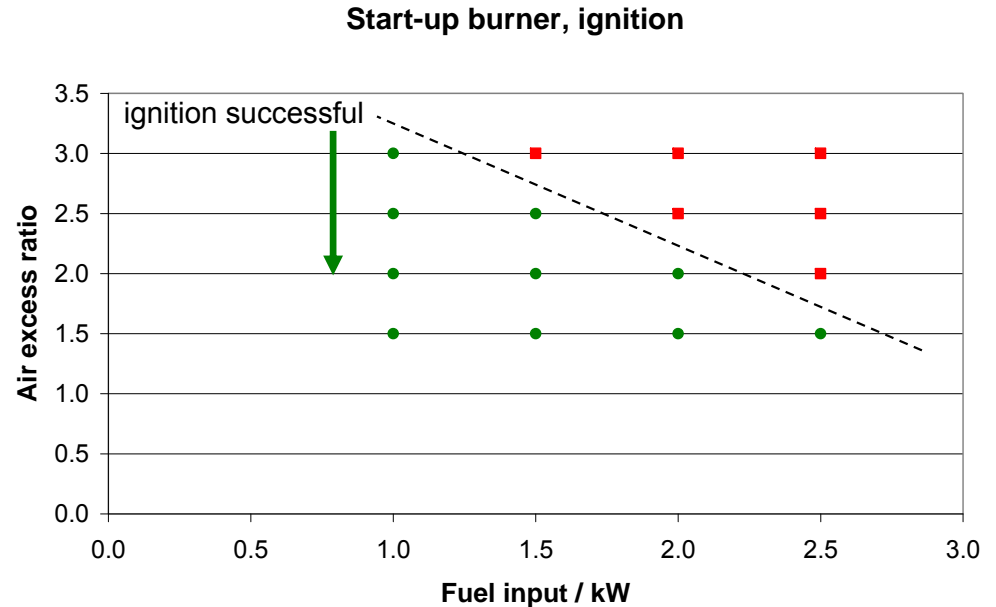
### Operation:

- Start-up burner + Diesel/steam mixer on reformer side
- Start-up burner + Cool Flame reactor on burner side
- Electrical heating for Cool Flame and mixer operation

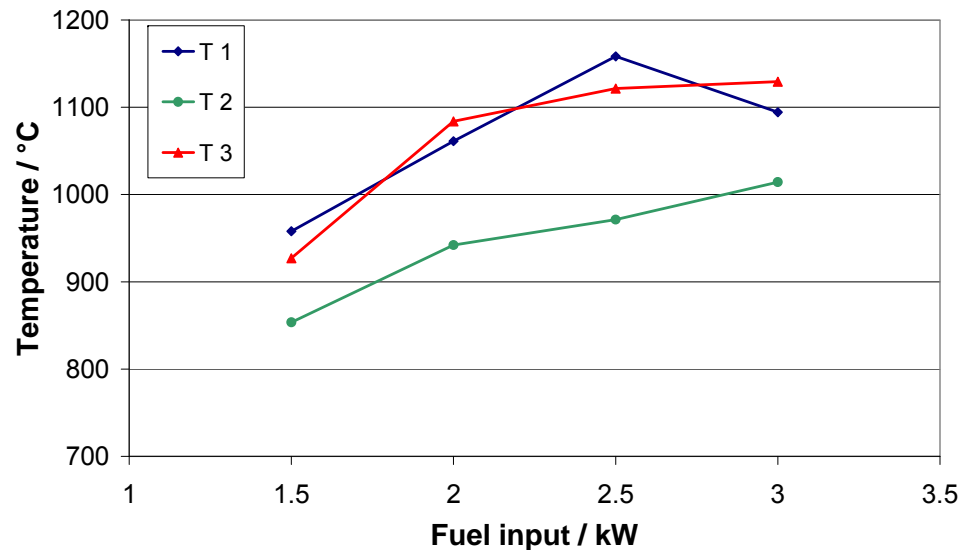


## Burner operation

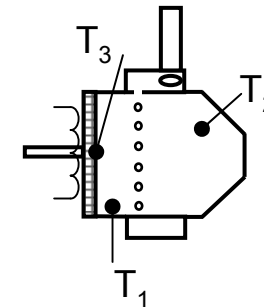
- Characteristics for safe ignition determined
- Fuel input can be increased after ignition
- Operation shown for fuel inputs up to 3 kW<sub>th</sub>



Burner operation, temperatures at  $\lambda = 2.5$



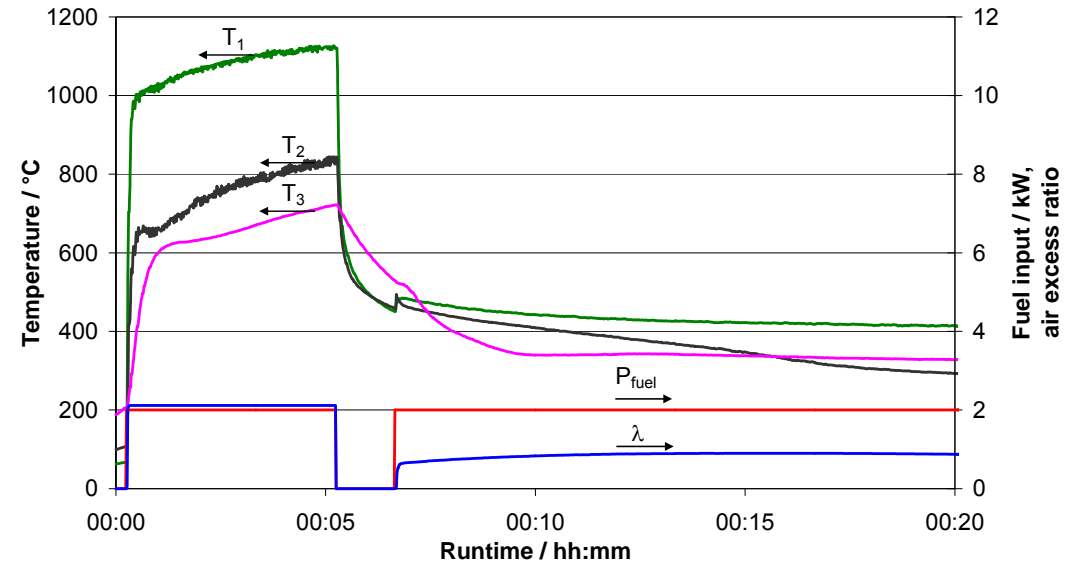
- Flame stabilizes in the reactor front
- Air excess ratio may be increased for lower outlet temperatures  
 → less thermal stress on the reformer



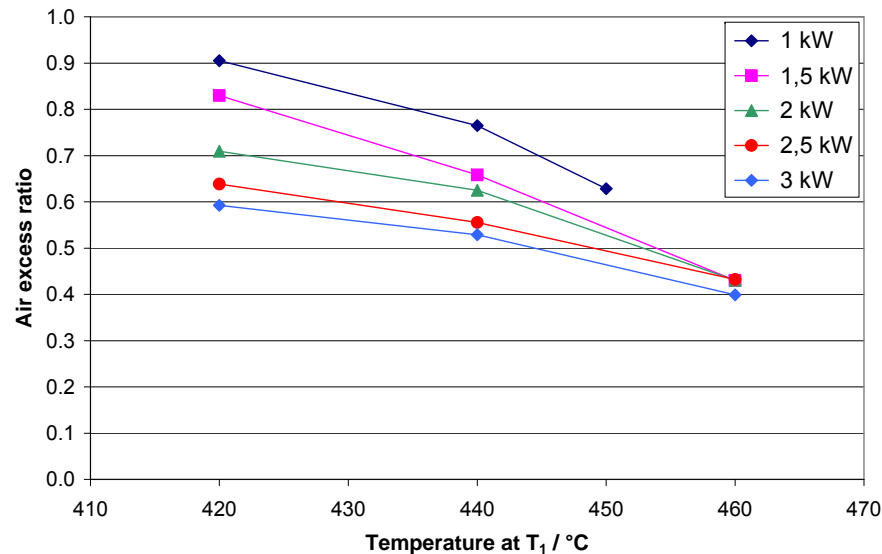
## Cool flame operation

- Preheating in burner mode
- Cooling down to cool flame temperature level
- Start of the cool flame reaction at an air excess ratio < 1

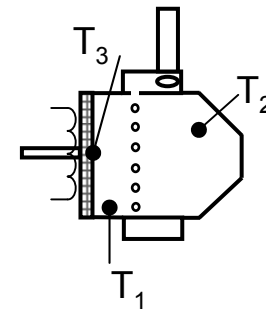
Cool flame start-up procedure, target temperature  $T_1 = 420^\circ\text{C}$



Steady state cool flame operation

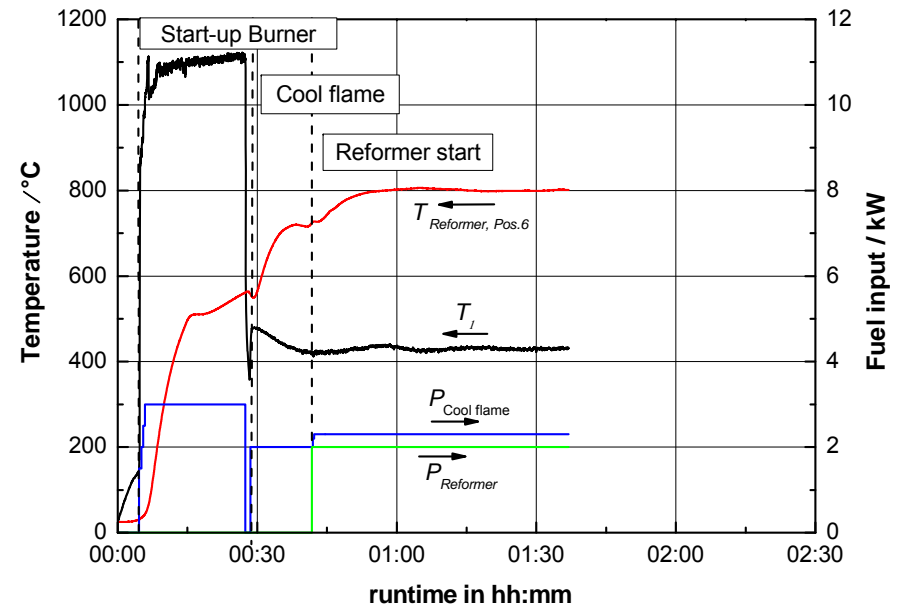
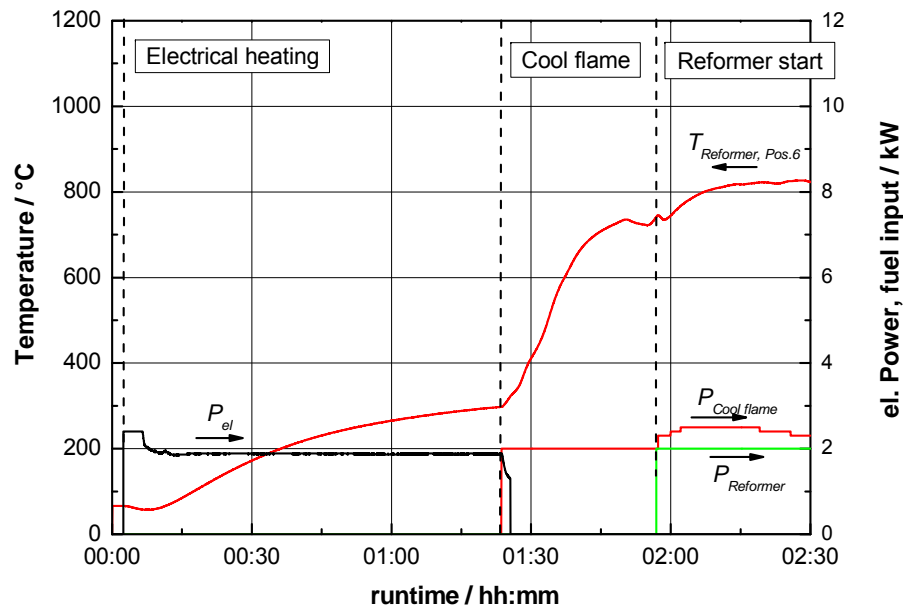


- Temperature control by air excess ratio
- Steady state operation shown at 1 – 5  $\text{kW}_{\text{th}}$



## Deployment of the reactor in the 10 kW<sub>th</sub> fuel processor

- Reduction of FP start-up time > 60 % by using one multifunctional reactor as Cool Flame reactor instead of electrical heating device
- Minimal electric power consumption
- Start-up time < 30 min expected when deploying a second reactor for diesel/steam mixing



(based on experimental data from P.Enghardt, 2012)

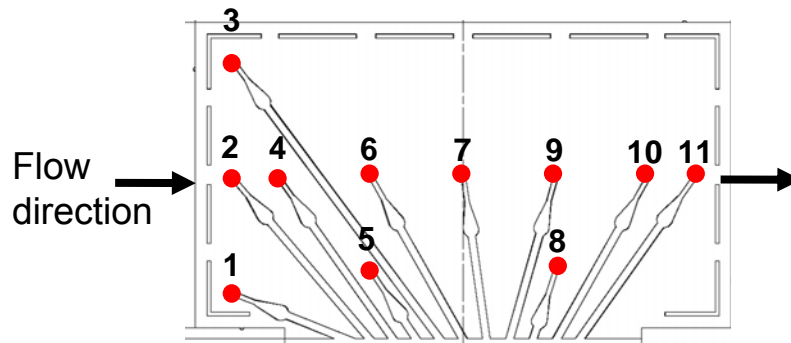


## Reformer development on downscaled steam reformers

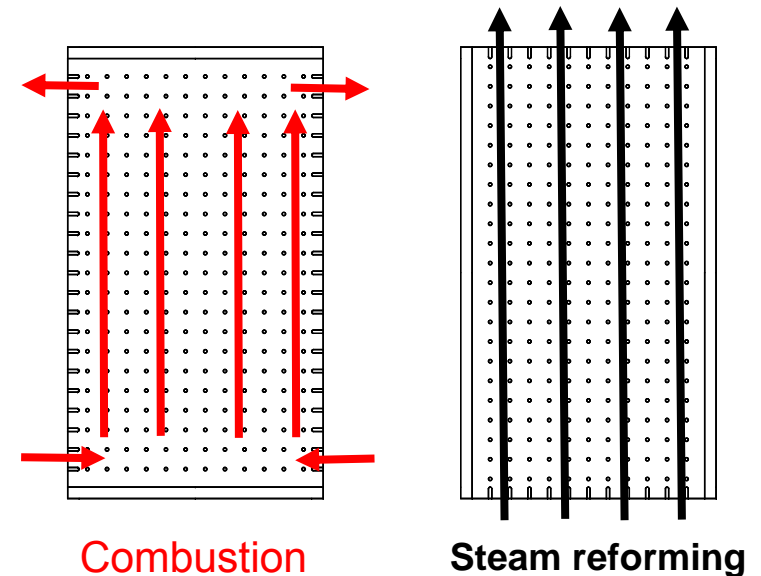
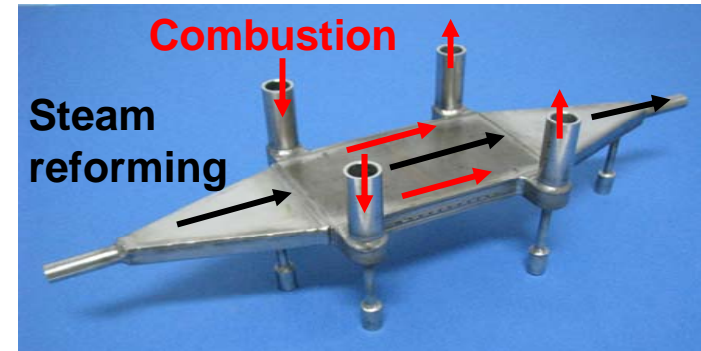
- Catalytically coated plate heat exchanger
- Microchannels with 0.6 mm channel height
- Scaling by plate number reduction, original plate size
- Design point of  $P_{th} = 1 \text{ kW}$  at  $GHSV = 25,000 \text{ h}^{-1}$

## Reformer testing

- Süd-Chemie HyProGen™ catalyst coating



Temperature measurement plate



## Test program

- Variation of
  - steam to carbon ratio (S/C),
  - operating temperature,
  - and fuel input
- Reforming of Diesel surrogate (Shellsol mixture)
- Reforming of commercial diesel (Shell petrol station)

### Diesel surrogate

Mixture of ShellSol A 100 + ShellSol D 100

Fraction	Value	Method of analysis
Paraffins	48 wt. %	GC
Naphtenes	32 wt. %	GC
Aromatics	20 wt. %	SMS 2728
Sulphur	< 2 wt.ppm	SMS 1897

### Commercial diesel (ULSD)

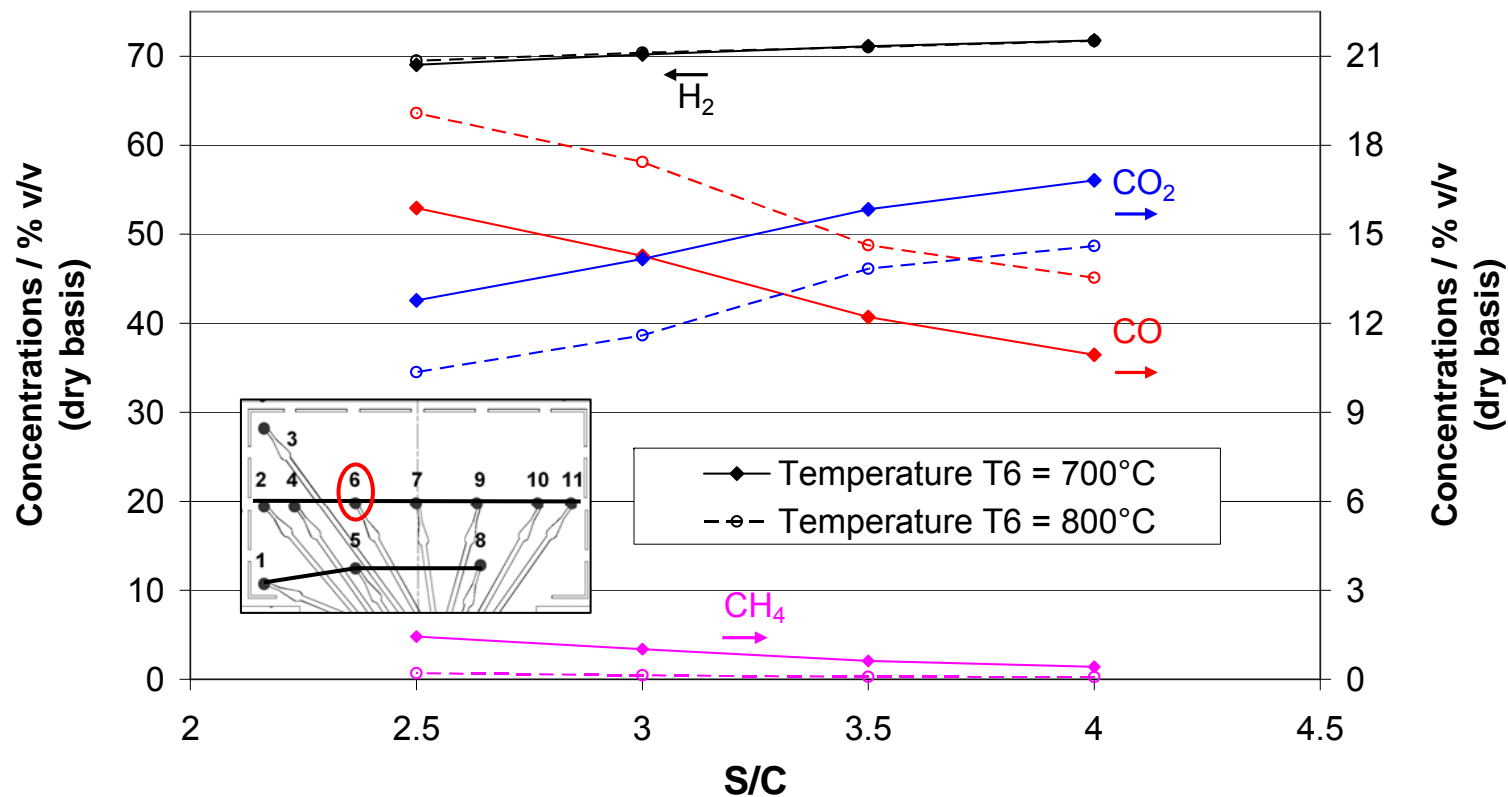
Shell

Fraction	Value	Method of analysis
Carbon	84.5 wt. %	DIN 51 732
Hydrogen	13.5 wt. %	DIN 51 732
Oxygen	1.3 wt. %	ASTM D 5291 mod.
Sulphur	6.4 wt.ppm	DIN EN ISO 20846
FAME	6.4 vol. %	DIN EN 14078
Aromatics	21.1 wt. %	DIN EN 12916

## Diesel surrogate reforming

- No diesel residues found by GC analysis ( $\text{CH}_4$  and  $\text{CO}_2$  are the only by-products found)
- Complete fuel conversion achieved over the entire parameter range

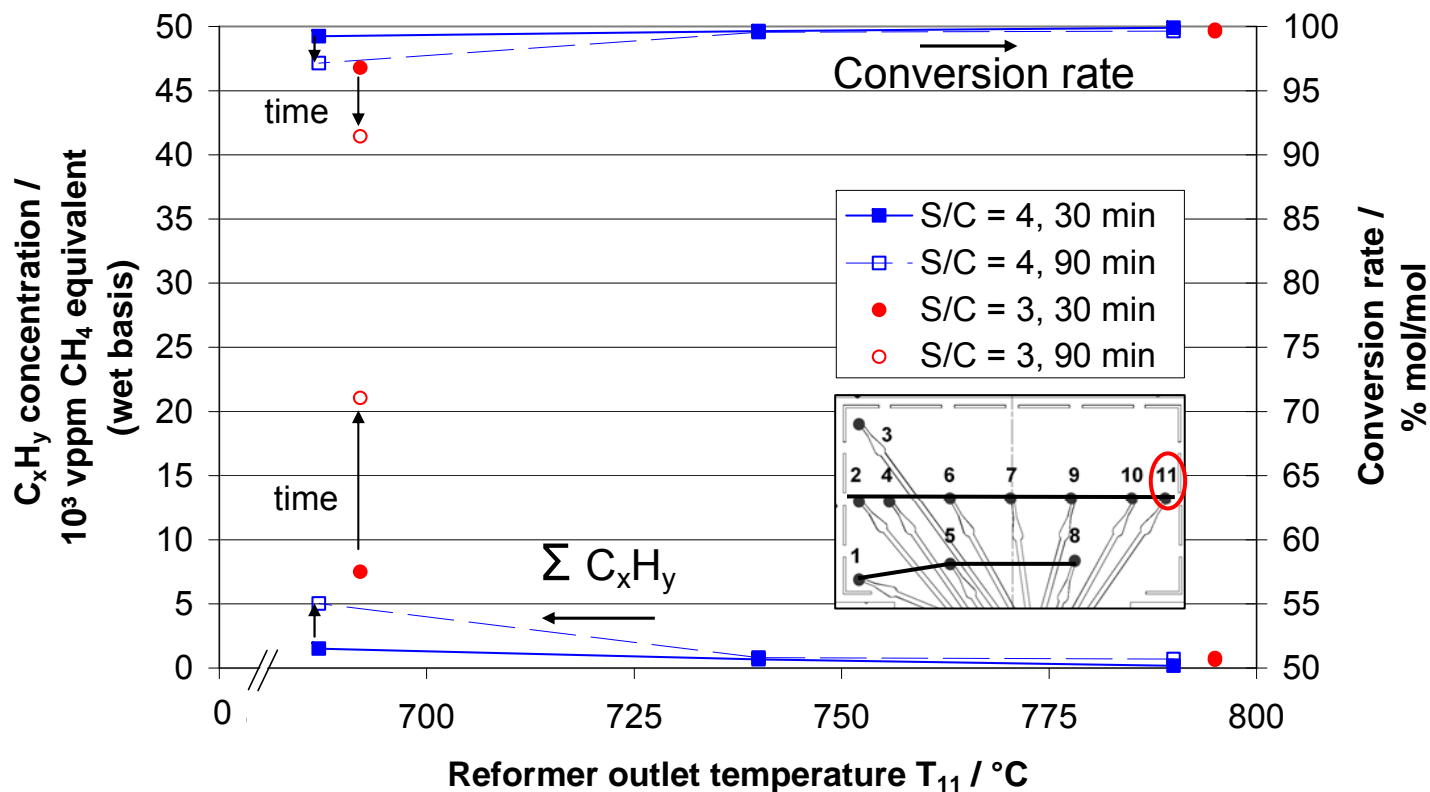
Gas concentrations, diesel surrogate,  $P_{\text{th}} = 1.25 \text{ kW}$



## Commercial diesel reforming

- Complete fuel conversion at outlet temperatures > 740°C, slight degradation after 90 min
- Rapid catalyst deactivation at low temperatures, but reversible

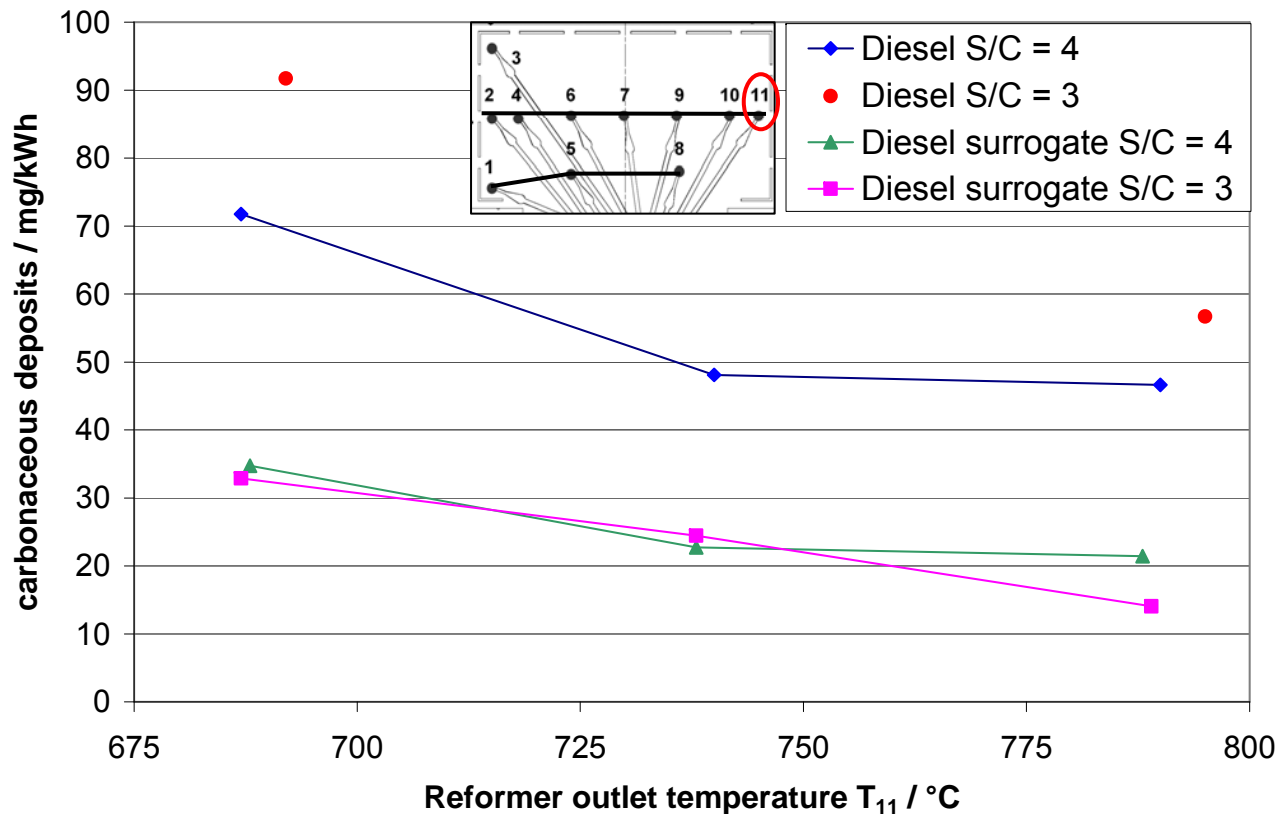
Residual hydrocarbons and fuel conversion,  $P_{th} = 1.25$  kW



## Commercial diesel reforming

- Coke / carbon formation increased using commercial diesel compared to diesel surrogate
- Low temperatures and low S/C increase the effect

Coke / carbon formation,  $P_{th} = 1.25 \text{ kW}$

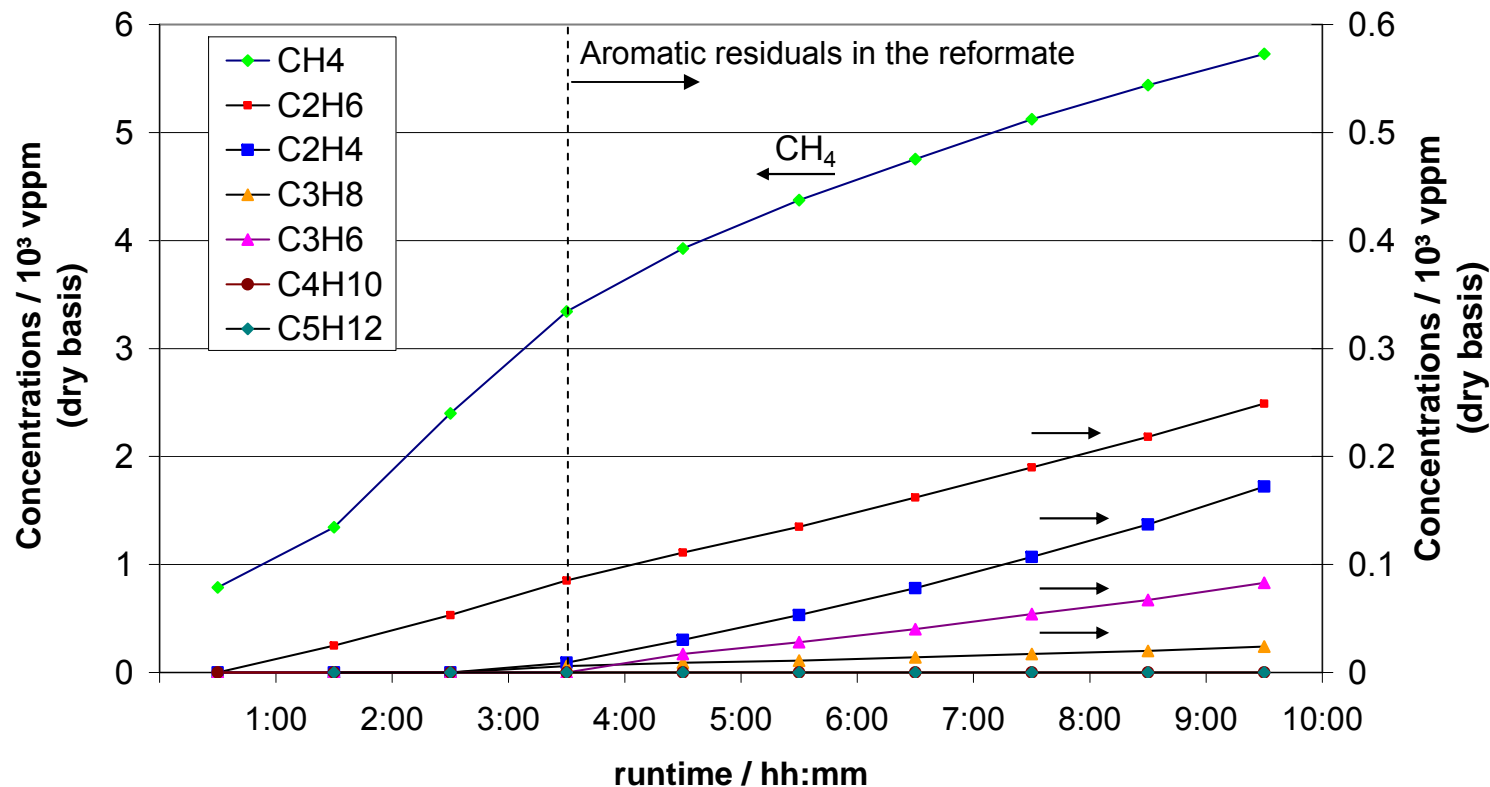


## Commercial diesel reforming

- Selectivity suffers from catalyst deactivation
- Hydrocarbon concentrations increase due to progressing catalyst deactivation

**GC analysis, 10 h steam reforming of commercial diesel at**

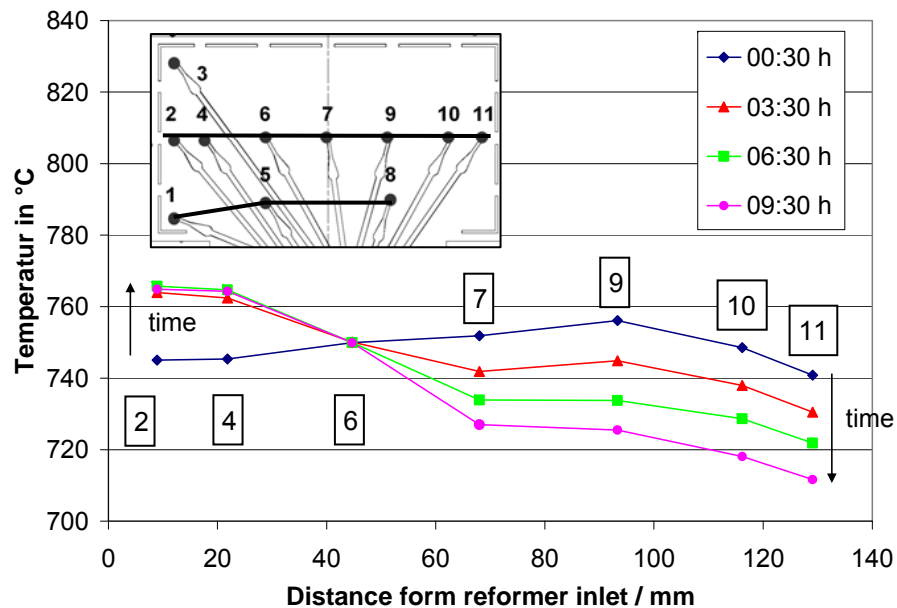
**$T_6 = 750^\circ\text{C}$  ,  $S/C = 4$ ,  $P_{th} = 1.25 \text{ kW}$ ,  $GHSV = 31,000 \text{ h}^{-1}$**



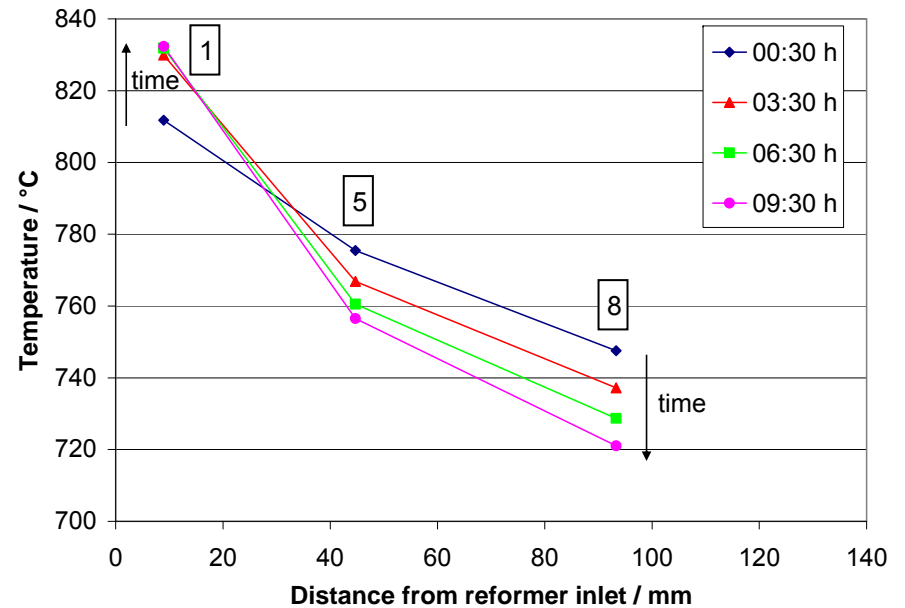
## Commercial diesel reforming

- Progression of temperature profiles in the reformer
- Shift of the main reaction zone through the reformer due to catalyst deactivation

Temperature profile reformer center



Temperature profile reformer periphery



## Summary

### Reactor development

- Multifunctional reactor for mixture preparation has been developed and characterised
- Deployment of one reactor leads to FP start-up time < 45 min,
- Potential start-up time < 30 min when using a second reactor

### Catalyst testing

- Süd-Chemie HyProGen™ shows complete fuel conversion in reforming diesel surrogate
- Complete fuel conversion achieved in reforming commercial diesel at outlet temperatures > 740 °C
- Increased catalyst deactivation from carbon/coke formation and sulfur poisoning in reforming commercial diesel, deactivation is reversible
- Catalyst deactivation leads to a progression of the temperature profile inside the reformer



Thank you for your  
attention!

Contact:

Dipl.-Ing. Marius Maximini  
OWI Oel-Waerme-Institut GmbH  
Affiliated Institute of RWTH-Aachen  
Kaiserstrasse 100  
52134 Herzogenrath  
Tel: +49 (0) 2407 / 9518-176  
Mail: m.maximini@owi-aachen.de

Acknowledgement:



Funding by the

German Federal Ministry of  
Economics and Technology (BMW<sub>i</sub>)  
Project **MÖWE II**, FZK: 0327724