Energy research Centre of the Netherlands

Development, Testing and Demonstration of a multi-fuel, integrated micro-CHP SOFC system

Fuel Cell Seminar 2009

Palm Springs

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Presented by Paul F. van den Oosterkamp (ECN)

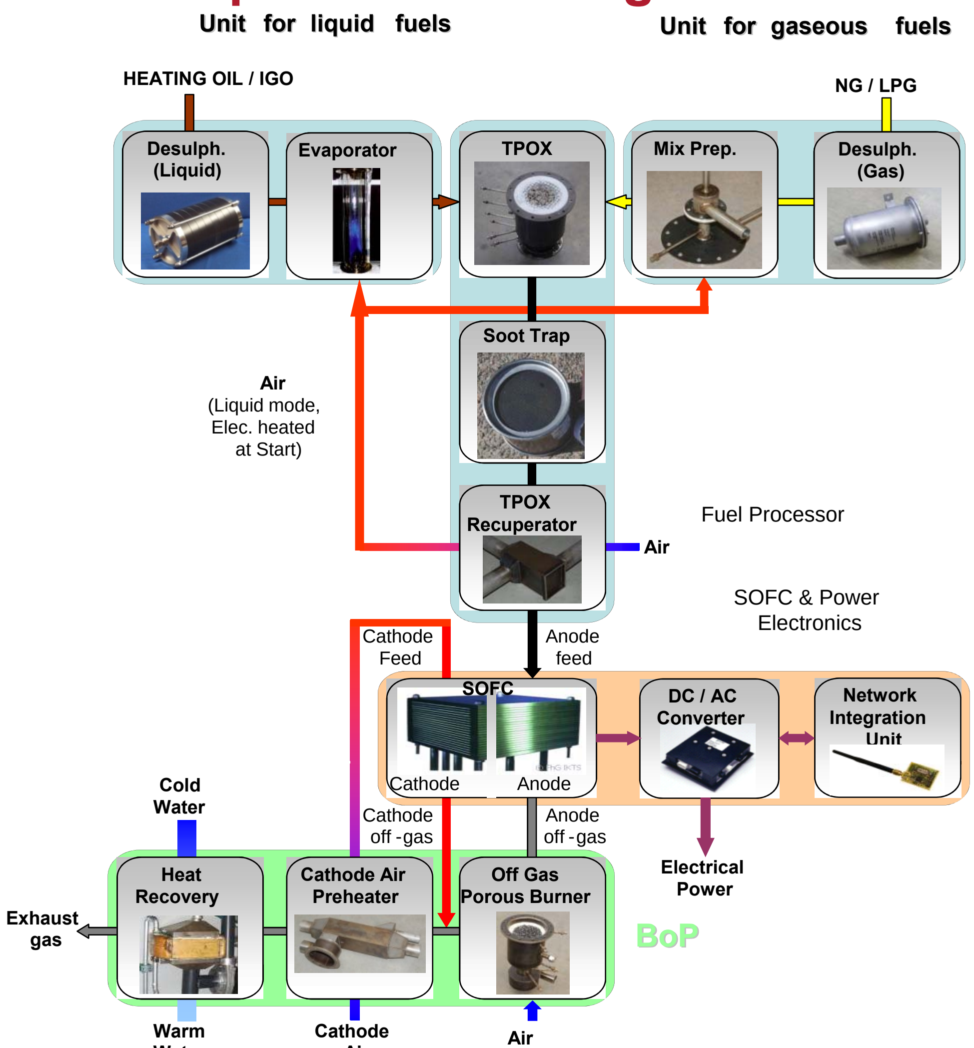
on behalf of the

Flame SOFC consortium

Introduction

- SOFC fuel cell technology is considered as a promising option for residential CHP
- Cost and robustness of SOFC technology are the key issues for commercial introduction
- The Flame SOFC project addresses costs and robustness through a number of key system characteristics :
  - No catalytic components in the fuel processing train
  - No de-ionized water management
  - Large operating window
  - Multi-fuel capability
  - Low cost and up scalable, planar SOFC technology

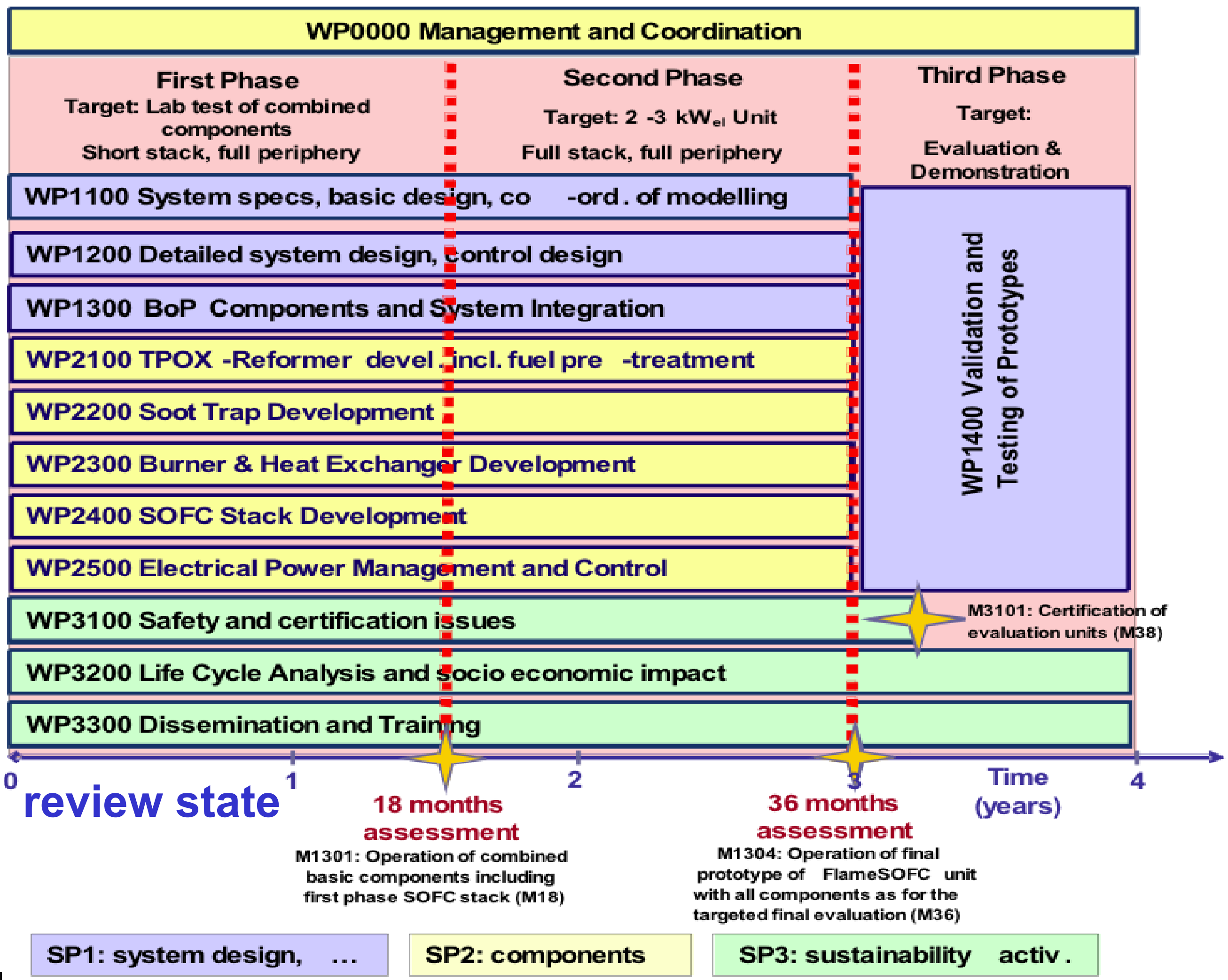
Proposed technological solution



The overall **proposed technological solution is significantly simpler and innovative** in comparison to existing practice:

- **No sensitive catalysts** are used for the fuel processing, enabling a long durability
- **No de-ionized water** management is needed
- The large operational windows of the individual components and the additional operational safety given by the soot trap yield a **robust non-sensitive design**
- **Multi-fuel feedstock** is enabled
- **Up-scalable** and **potentially low-cost SOFC** technology is applied

Project organization



Three major milestones:

1. Operation of **combined basic components** including first phase SOFC stack (M18)
2. Operation of **final prototype** of FlameSOFC unit with all components as for the targeted final evaluation (M 42)
3. Certification of **evaluation units** (M 47)

Flame-SOFC Partners: Industry

Flame-SOFC Partners: SME

Co-ordinator

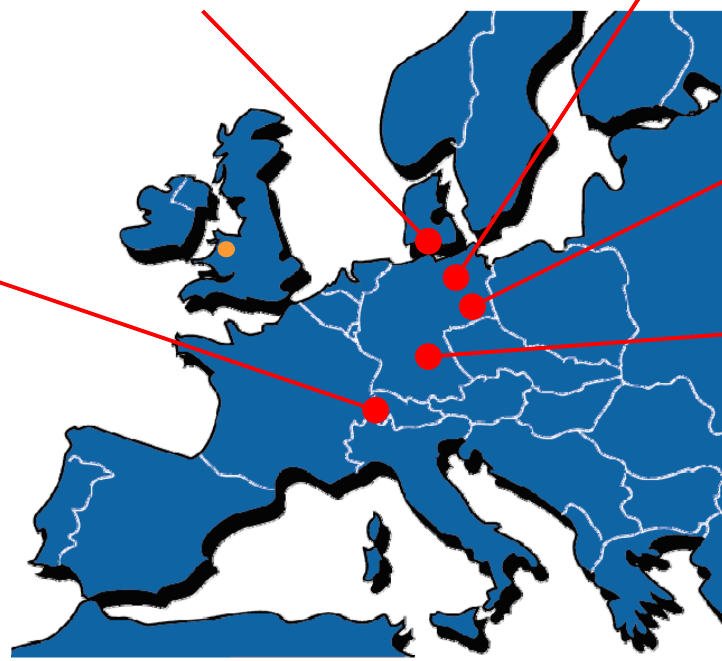
VDI|VDE|IT

Stobbe Tech Ceramics

EBZ

HTceramix From Powder to Power

promeos



Flame-SOFC Partners: Research

Main Project Objectives

Overall target: development of a robust stationary NG, LPG, IGO, or FAME fired SOFC based micro-CHP system.

Power target: 2 kW_{el} net output (expected future mainstream high volume mass market for micro-CHP's)

Power modulation target: > 1:4

Efficiency targets: min 30% (up to 35% seasonal) net electrical, > 90 % total CHP efficiency

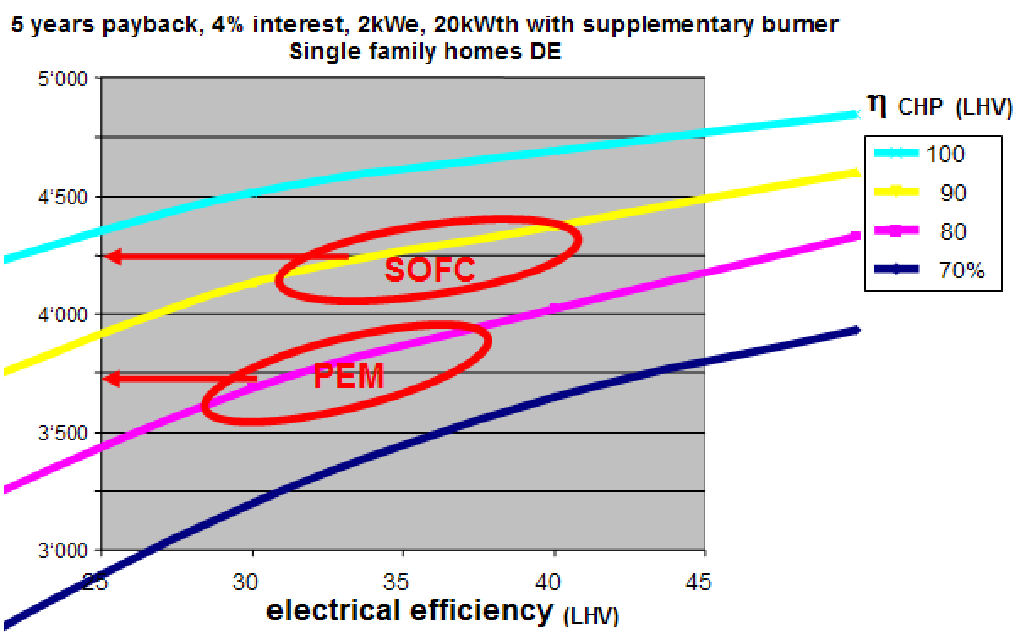
Durability target: > 30.000h (no catalytic components; limitations mainly at the SOFC stack level)

Cost targets (for series production): < 1950 € for the complete micro-CHP

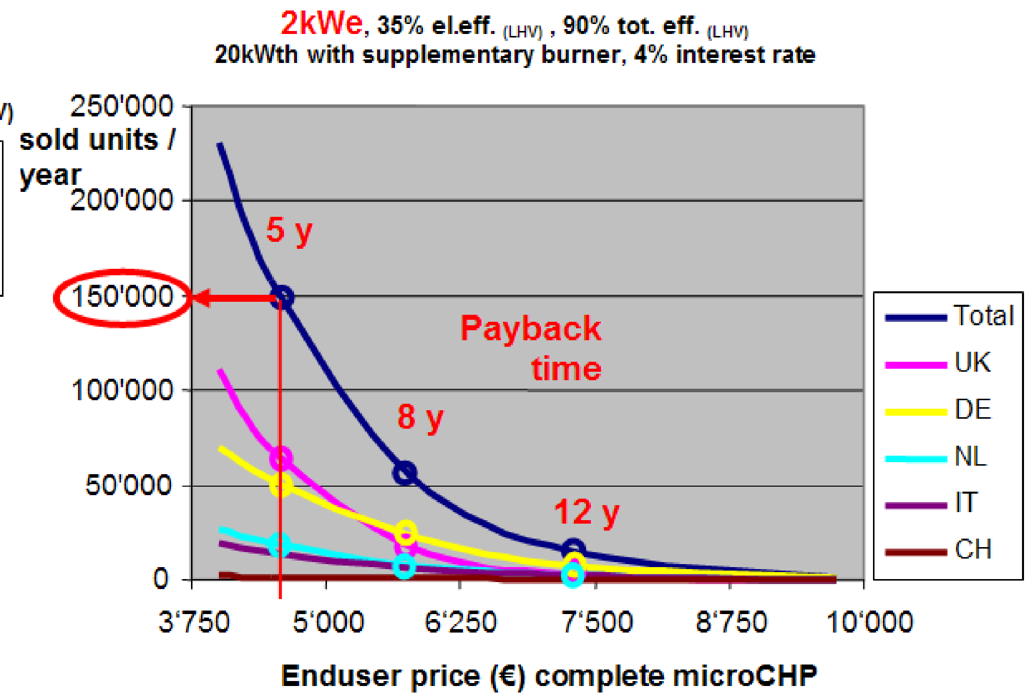
Start-up time: less than 60 minutes

Main target application: domestic micro-CHP for single or two-family homes with electrical grid connection (further potential as backup power unit, up-scaling)

Market situation
Study by MTS; 2 kW_{el} case; end-user price and market volume



*) industrial cost is ca. 45% of enduser price
(ca. 35% distributor margin, ca. 30% installer discount)



End-user price target for SOFC and PEM CHP units at 5 years payback

SOFC micro-CHP demand curve for single/two-family homes (natural gas)

Design of first phase prototype

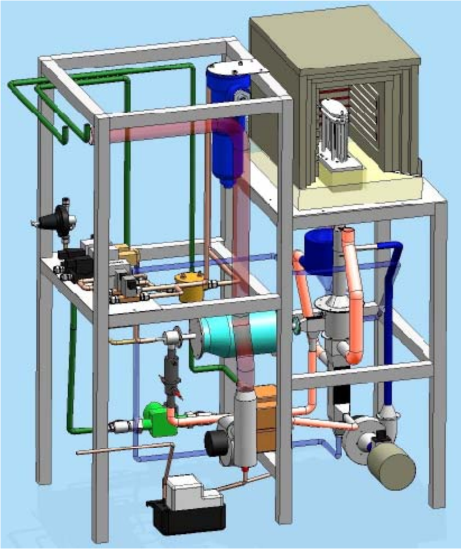
Operation in stack dummy mode

- Implementation and testing of control system
- Verification of operation modes:
  - Ignition of TPOX and afterburner
  - System heat up
  - Normal operation, load changes
  - Shut-down
- Long-term operation components
- Investigation of soot formation

Operation of 500 W stack

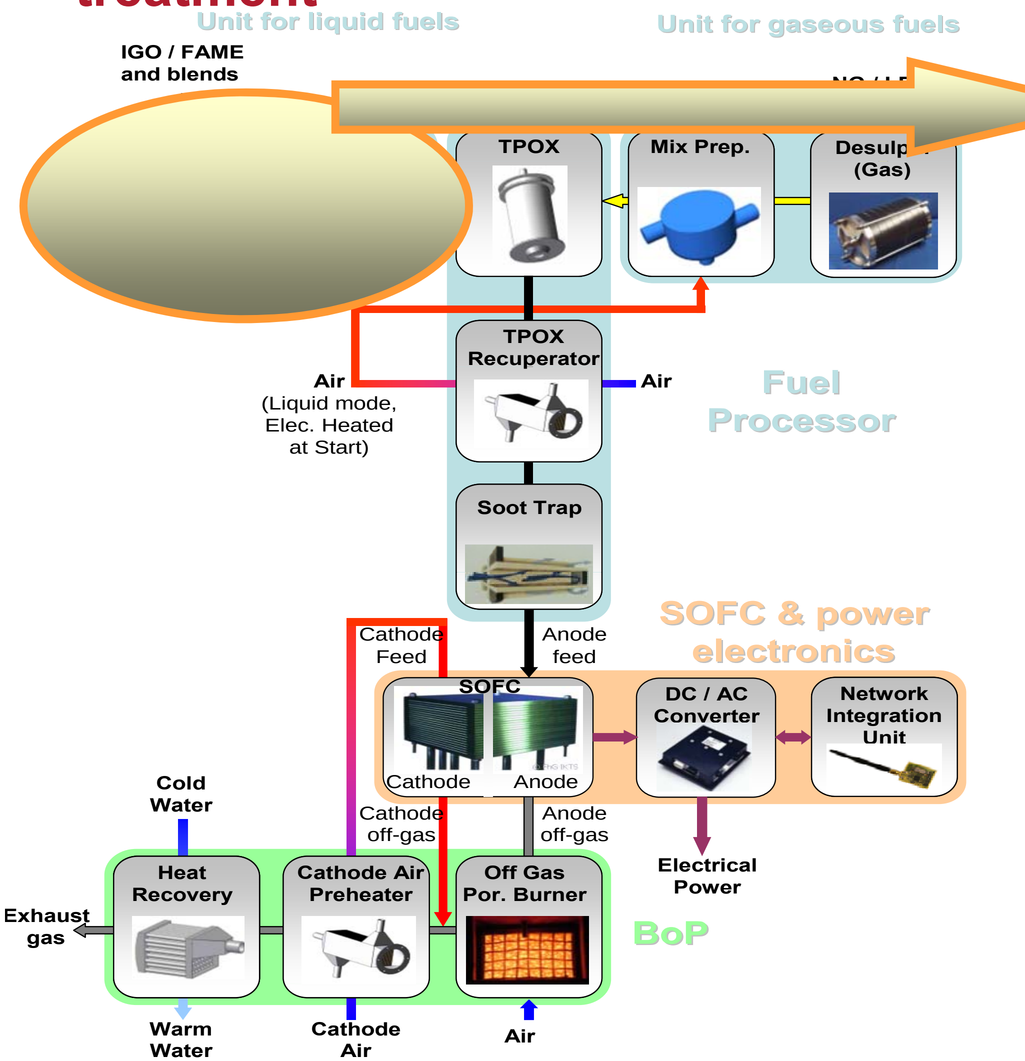
- Validation of stack performance
- Operation of system with depleted fuel

Design of 2nd phase prototype

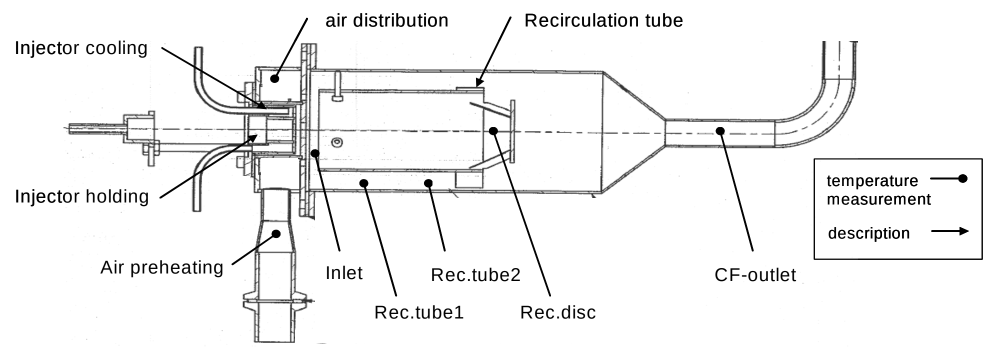


3-D schematic representation of the 1st Phase Prototype

Development state selected components: Liquid Fuel Pre-treatment



Cool flame vaporizer



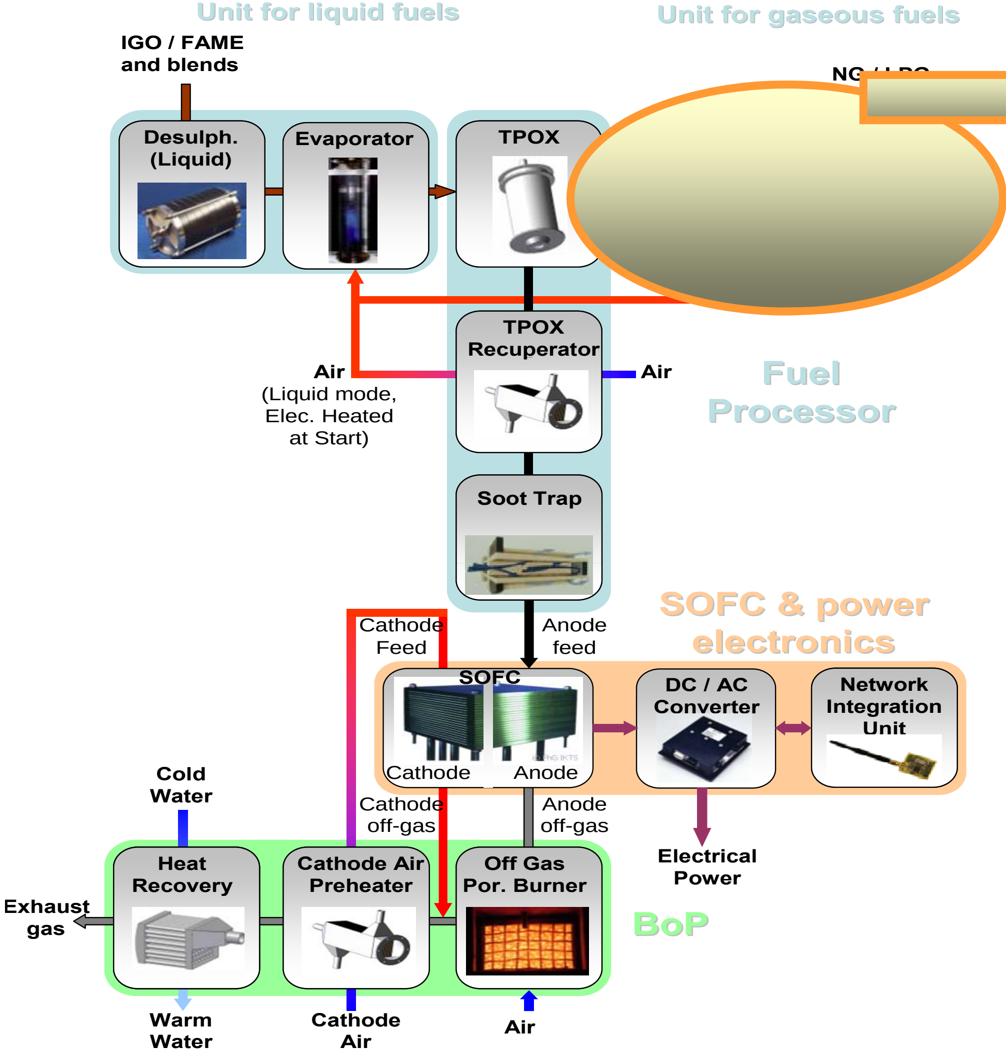
Volume: ca. 0,8 liter

low pressure injection nozzle (p=5 bar; f=5 Hz)

Stable operation for P_{th}=2 – 8 kW

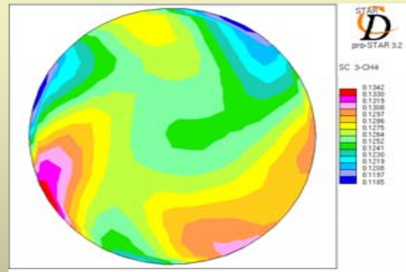
Cool flame outlet temperatures between ϑ =440 – 500°C

Development state selected components: Gaseous Fuel Pre-Treatment



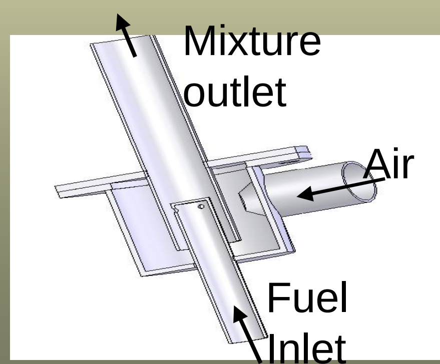
Gas/preheated air mixer

Mixing within ignition delay time (air preheating up to 700 °C)



2 development iterations with support of numerical simulation.

Final 2nd prototype fulfils specification (no flash-back under all operating conditions, pressure drop for each side < 4mbar)



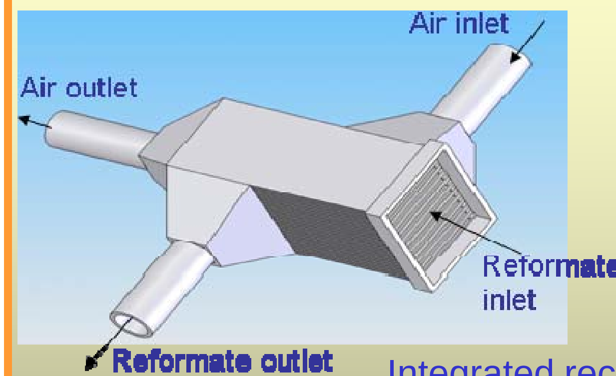
Development state of selected components: TPOX reactor and soot trap

T-POX Reformer with integrated soot trap

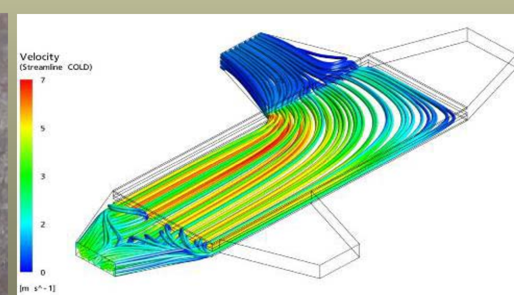


- Assembled system including Al_2O_3 porous medium based TPOX reformer (TUBAF) and soot trap (POLITO)
- Tests for "syngas" production and filtering
- Investigations for passive regeneration of the trap

T-POX air preheater

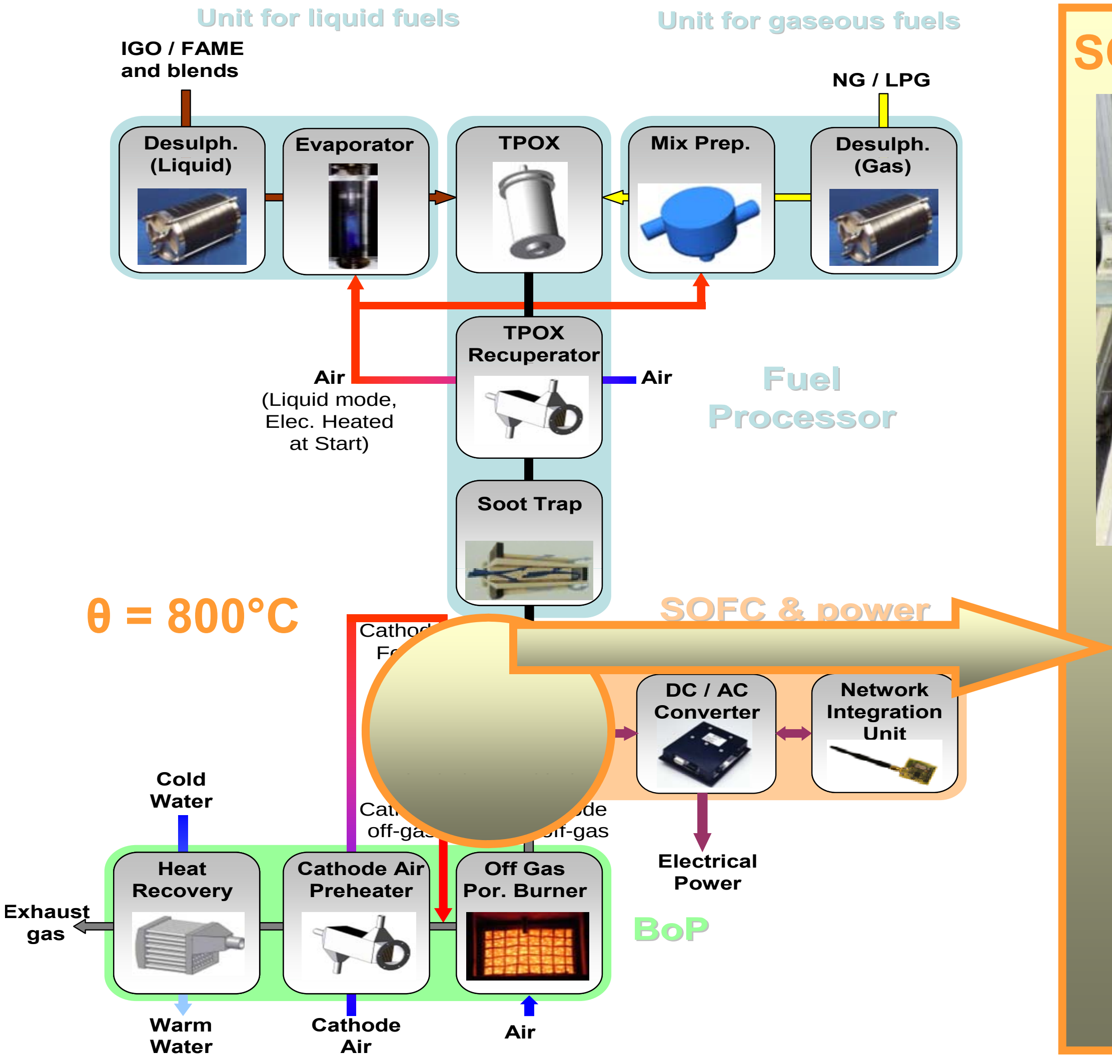


Integrated recuperator with TPOX outlet housing and TPOX ignition

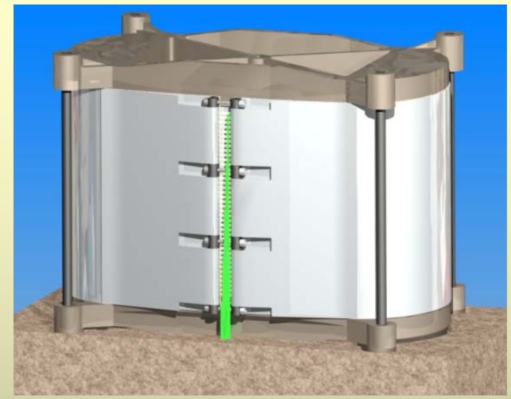



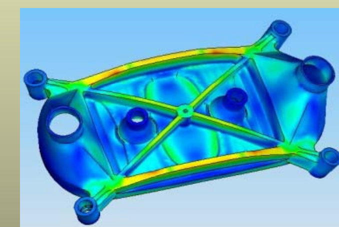
- Plate type heat exchanger from high temperature alloy
- CFD optimized design

SOFC Stack



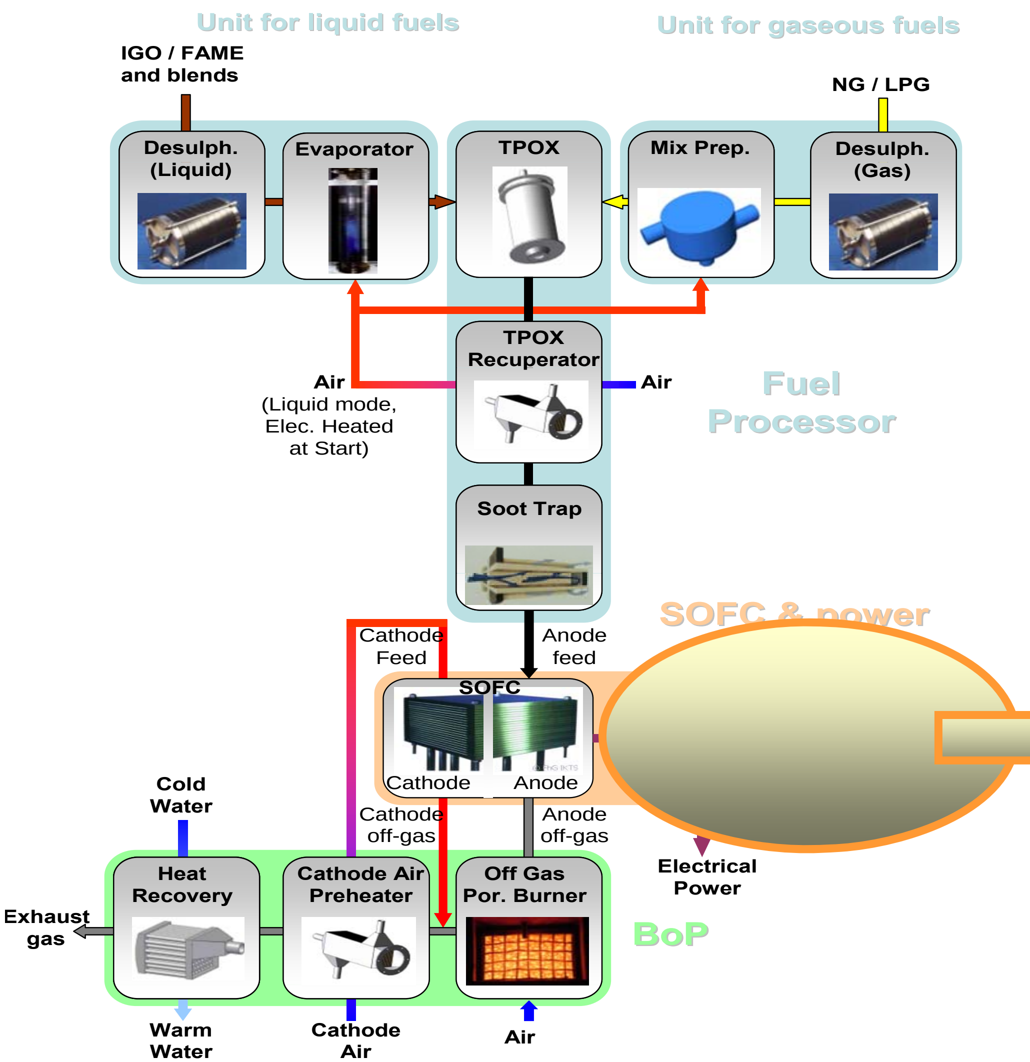
SOFC stack HT Ceramics





Stack characteristics:
Power : 1.3 kW
Fuel util. 75%
Cell voltage: 0,83V
Stack efficiency : 38 % (@ full load)
Power density : 0,32 W/cm^2
Operating temperature: ~ 750^{0}C

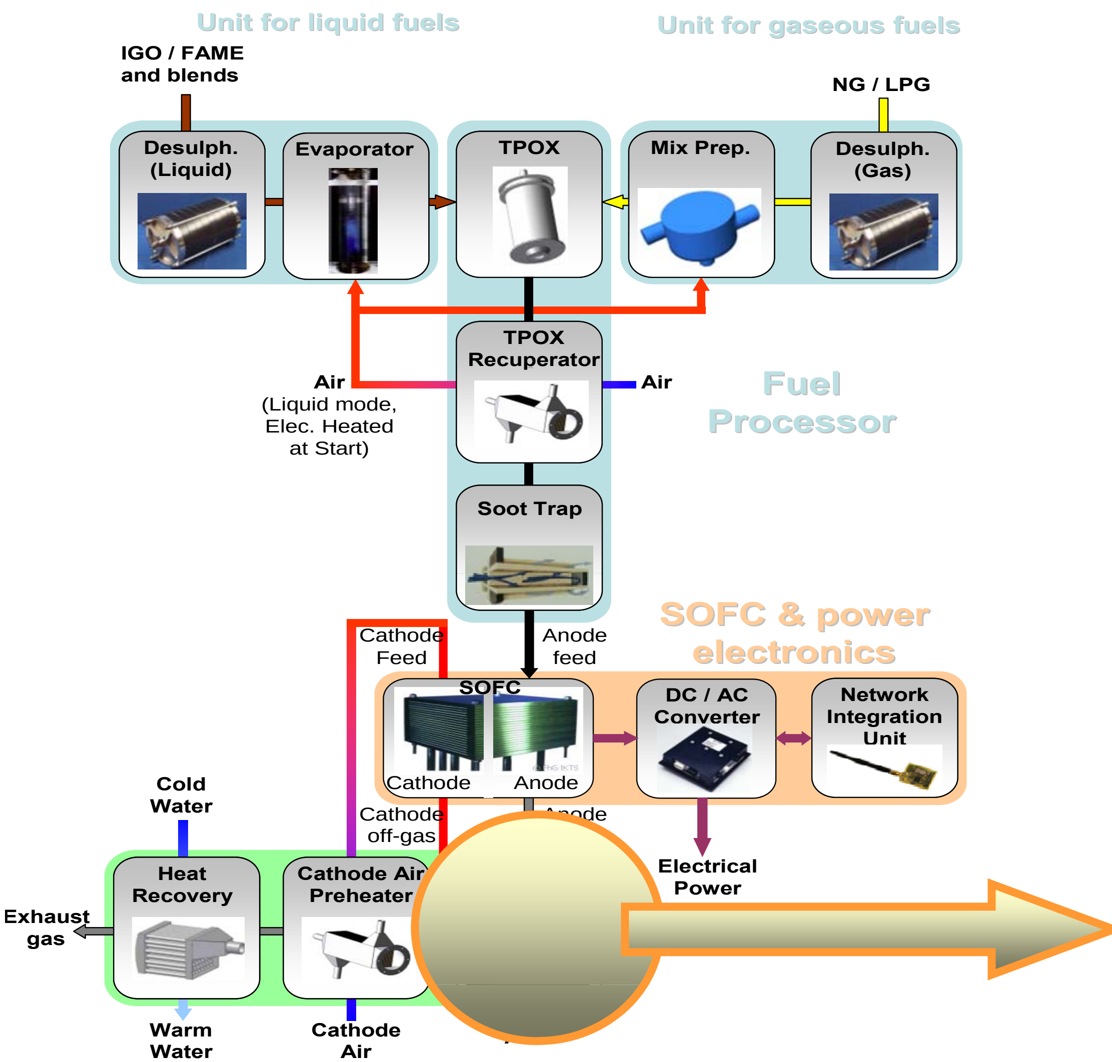
Power Electronics and Grid Connection



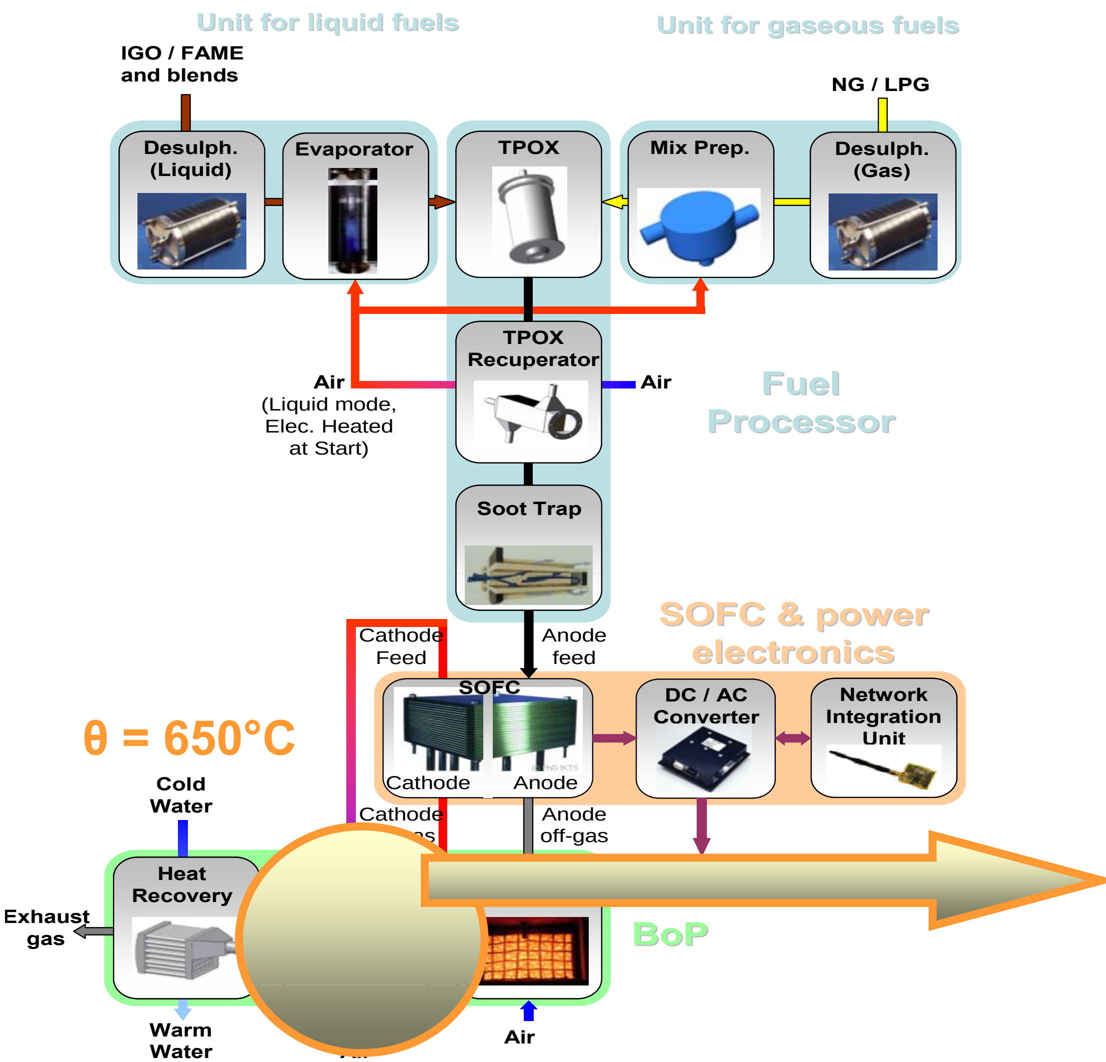
Development of electrical power management and control

- Final power units have been integrated in 2nd phase system
- Power electronics (DC-DC, inverter etc.) are integrated and control and monitoring adapted to the test stand at EBZ
- Control algorithms for automatic procedure (start – stop) have been developed and integrated
- Power line communication has been selected

Off Gas Burner



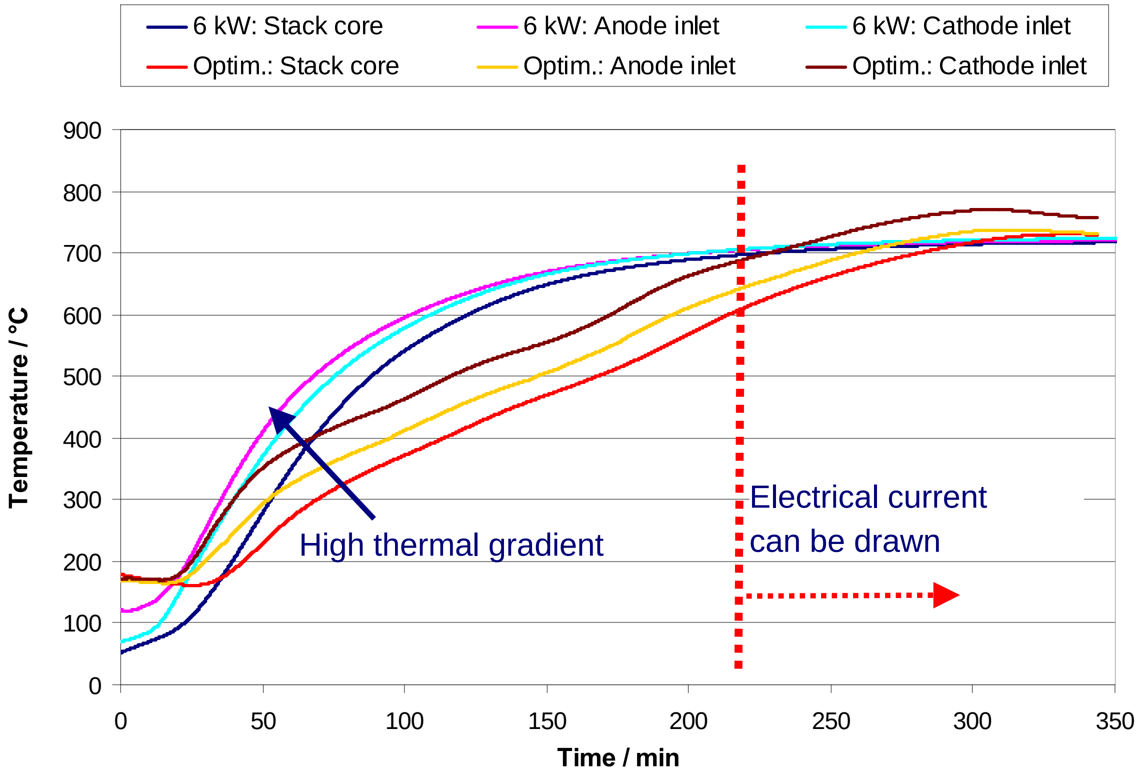
Modeling Strategy
Isothermal
Turbulent (Shear Stress Transport)
Ideal Mixture
Structured Hexahedra mesh



Cathode air preheater

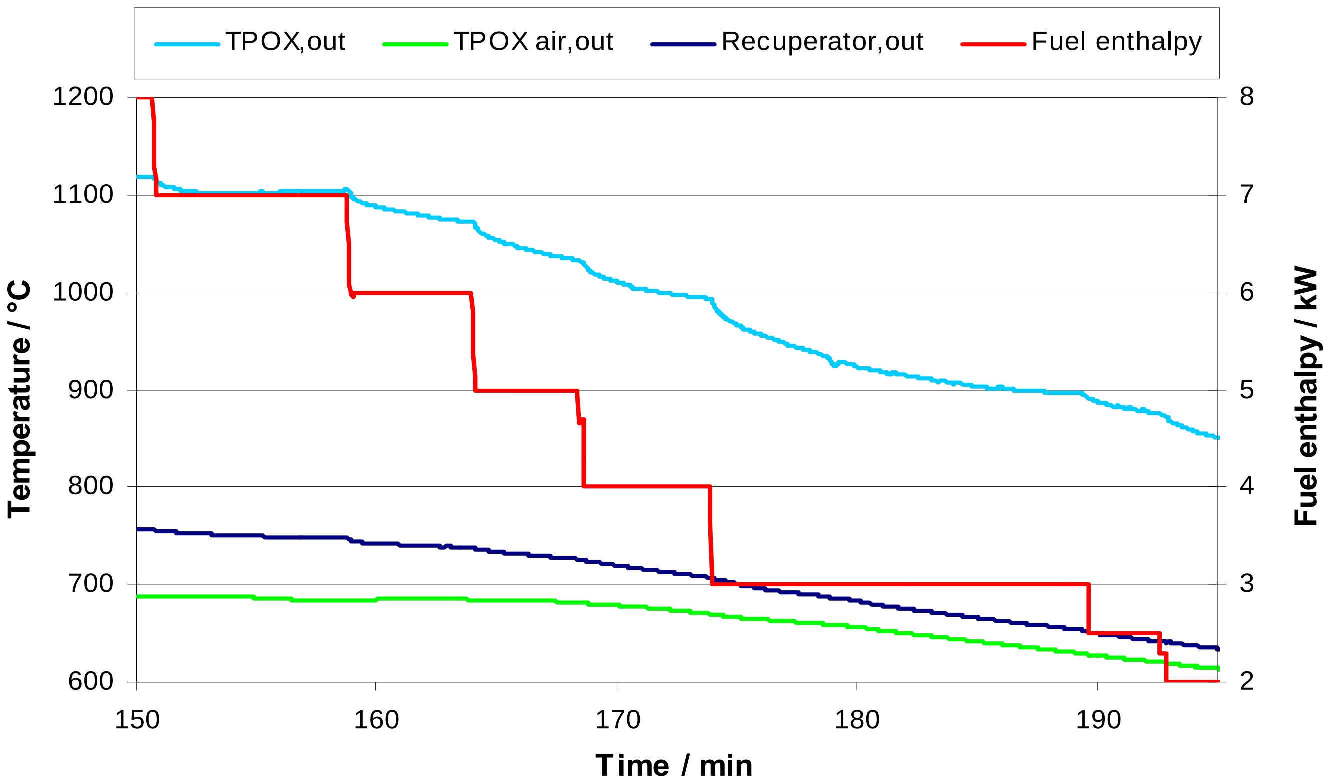
- Design adjustment for the system integration
- Counter flow L/L version
- 39 channels supported with bars (20 cold; 19 hot); channel height 1.2 mm
- Dimensions: 255 x 88 x 88 [mm]

Testing results: Heat-up procedure of the 1st phase prototype



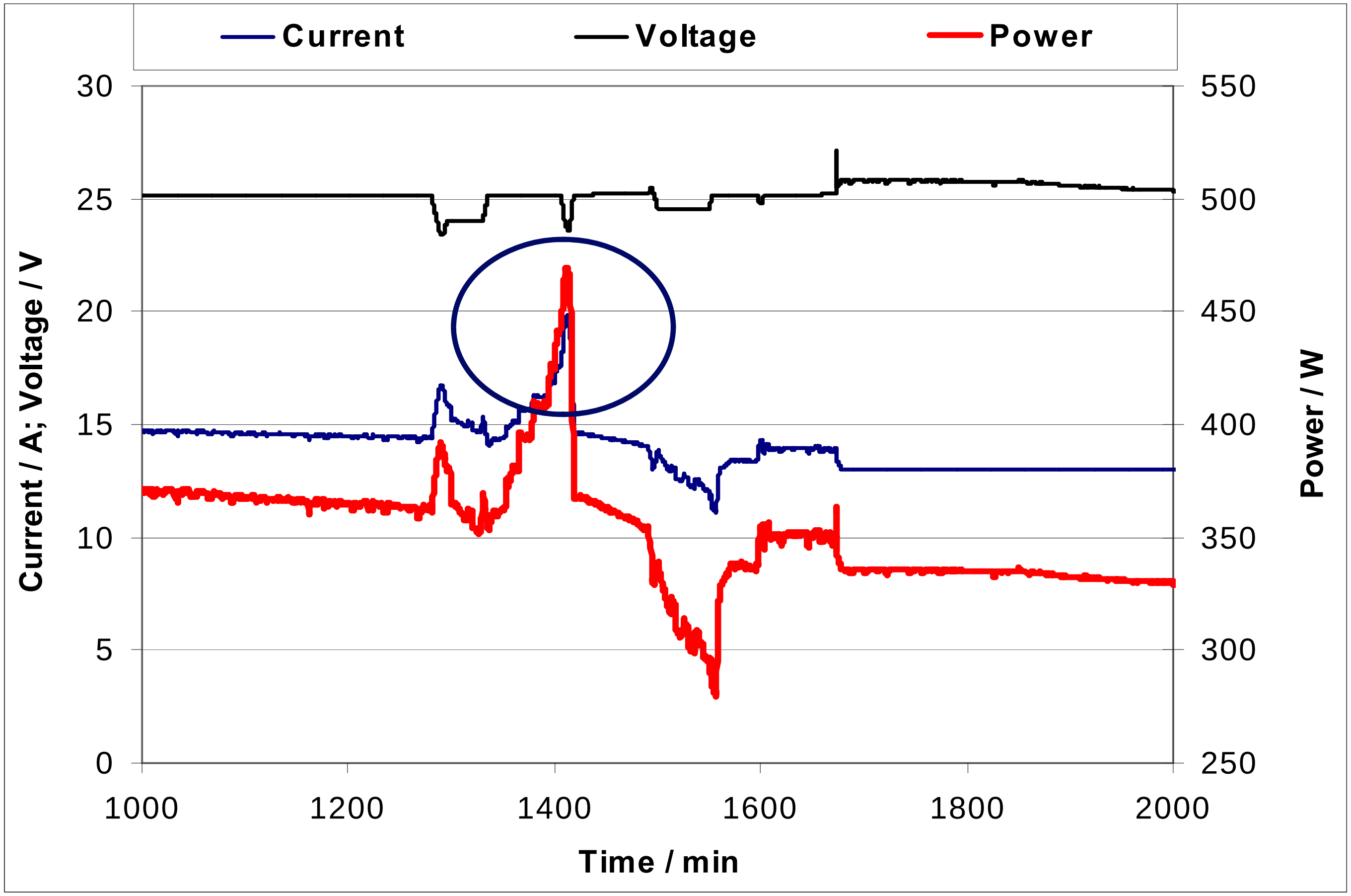
- A load variation during heat-up was applied to optimize thermal gradients
- The load was initially set to 3 kW until the thermal gradients decreased and then to 8 kW
- The target of 700°C achieved
- Heating time 4 hours due to stack constraints

Normal operation mode - Load Variation



- Load variation from
  2 kW to 8 kW successfully proven
- Afterburner in dummy stack mode
  had to convert the reformate gas
- Heat losses of TPOX reactor to be
  minimized by improving system
  integration

Normal operation mode - Stack Performance



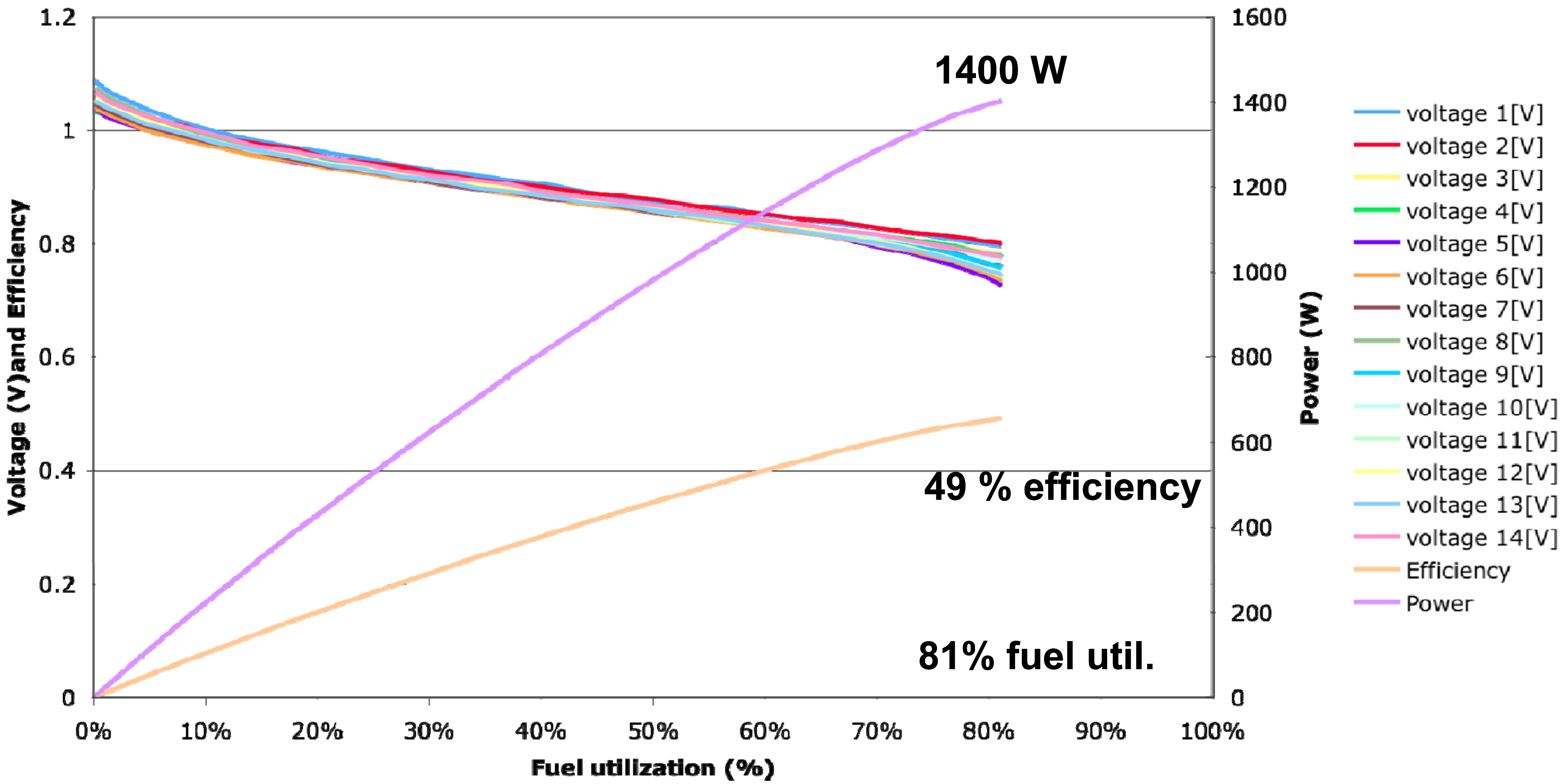
- Operation of 500 W class “S-Design” stack (HTceramix)
- Maximal power 485 W achieved
- Performance limited by one block of cells
- Fuel utilization up to 40 %

Stack performance
(Stack design 2nd prototype system)

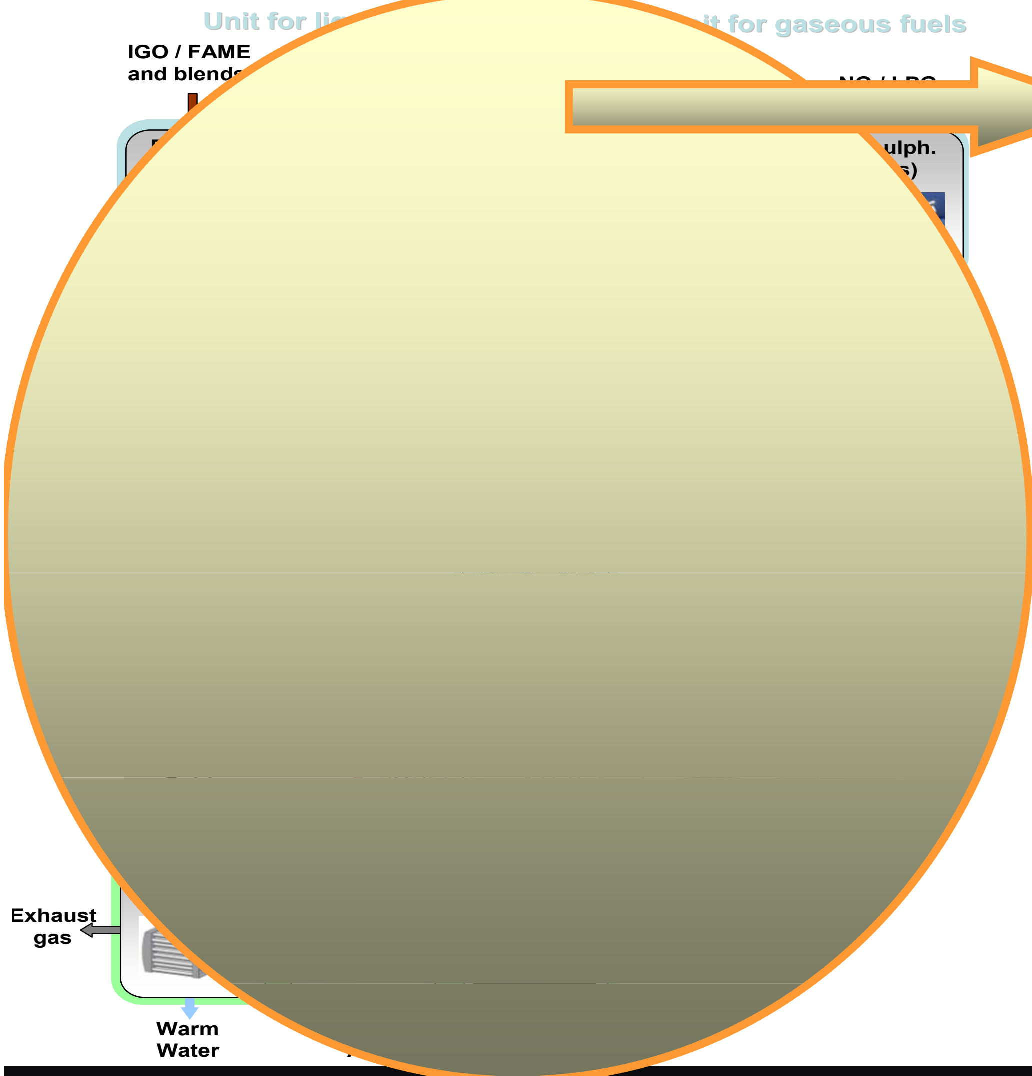
CONFIDENTIAL - Proprietary Information SOFCPower/HTceramix

F-09 : 40% H_2 and 60% L/min N_2

4 mL/min/cm^2 H2 ; 20 cells



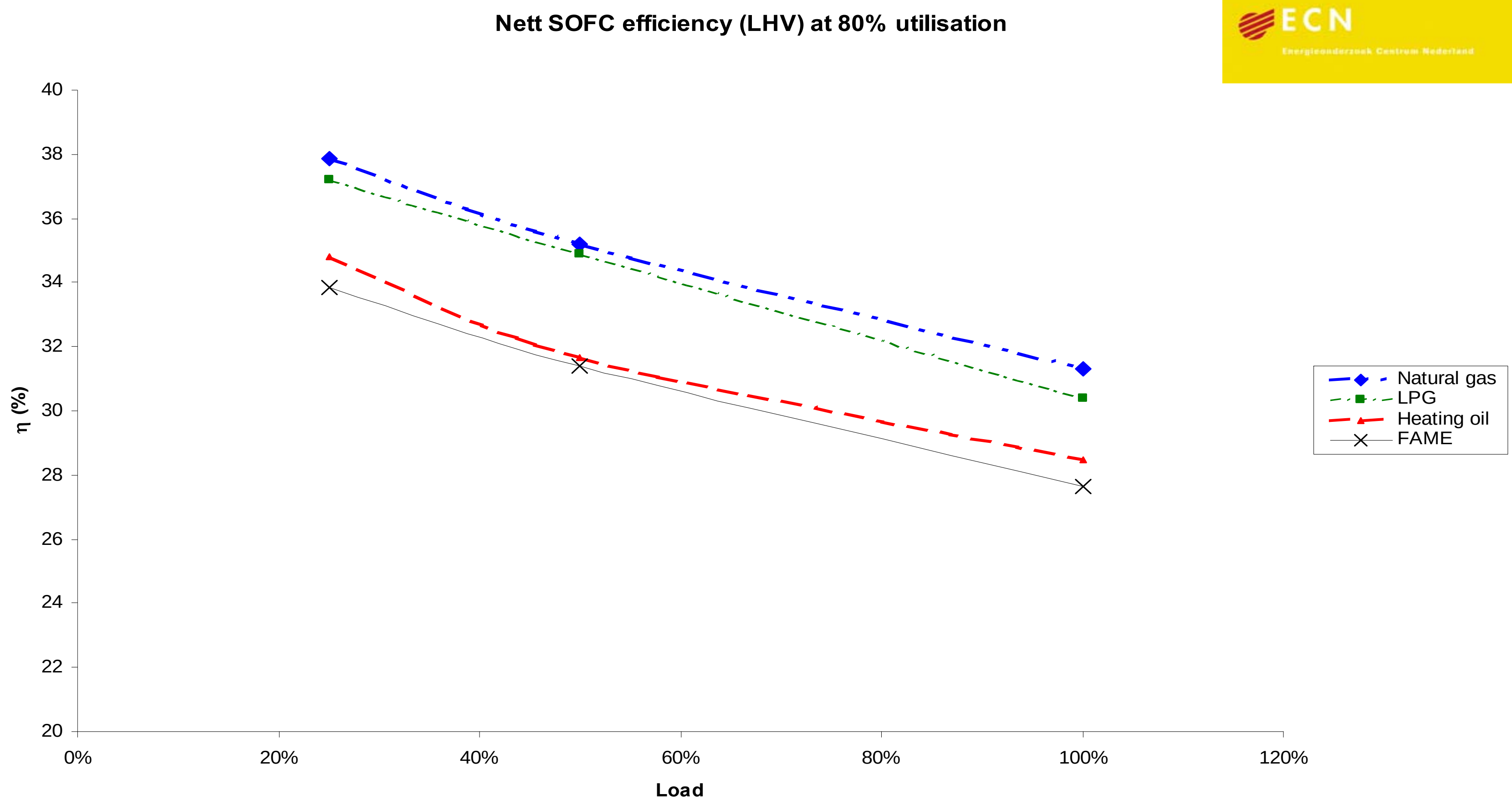
Overall System Design (Housing)



System design of 2nd prototype

- Complete SOFC micro-CHP system in 19" rack
- Separation between hot and cold part
- Hot parts are bundled in FlameHotBox
- Enhanced heat management, due to better packaging

Expected net efficiency



The process simulation (AspenOne Ver.12), considering all peripheral components and the currently available characteristics, indicates that the FlameSOFC unit will reach a net el. efficiency of ca. 30% at full load (up to 37 % at min power and NG fuel)

Outlook

- Results of prototype development is integrated in design for two validator units:
  - One unit in Spain (gaseous fuel based)
  - One unit in Germany (liquid fuel based)
  - Both units will be operated for about 6 months
- CE certification test will be conducted for validator unit in Germany
  - CE certification by notified body in progress and includes:
    - Gas technical testing (emission, functional testing)
    - Safety Electronics testing
    - Electrical Safety testing
    - Electromagnetic compatibility (EMC) testing

Lessons learned

- Problems related with connections, thermal expansion, corrosion etc. in the high temperature section are underestimated and no standard solutions exist.
- Tailored Bop components are essential in order to reach the efficiency.
- Quality management and control are needed already in the prototype development stage
- Development costs and time are always underestimated
- Optimism, cooperation, management and a reasonable work pressure is needed for finally achieving functioning prototypes with a consortium of 20 partners.

Acknowledgements

• The authors would like to thank in the name of all participating organizations the European Commission for the financial support of this work within the 6th framework programme, project FlameSOFC, contract no. 019875 (SES6).

•The following partners are within the FlameSOFC consortium and contributed to the present work:

1.TU Bergakademie Freiberg, Germany, 2.VDI/VDE Innovation + Technik GmbH, Germany, 3.MTS GROUP (Merloni TermoSanitari SpA), Italy, 4.Fagor Electrodomesticos S. Coop, Spain, 5.EBZ GmbH, Germany, 6.HTceramix SA, Switzerland, 7.PROMEOS GmbH, Germany, 8.Stobbe Tech Ceramics A/S, Denmark, 9.Ikerlan S. Coop., Spain, 10.ECN, Netherlands, 11.OWI gGmbH, Germany, 12.University of Erlangen-Nuremberg, Germany, 13.Ecole Polytechnique Fédérale de Lausanne, Switzerland, 14.Politecnico di Torino, Italy, 15.National Technical University of Athens, Greece, 16.Instituto Superior Tecnico, Portugal, 17.Imperial College of Science Technology and Medicin, UK, 18.Budapest University of Technology and Economics, Hungary, 19.EC BREC Instytut Energetyki Odnawialnej, Poland, 20.ELCO/ELCO Shared Services GmbH, Germany

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Thank you for your attention!