New μ-CHP network technologies
for energy efficient and sustainable districts

Development of an SOFC based μ-CHP system in the framework of the European project FC-DISTRICT

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OUTLINE

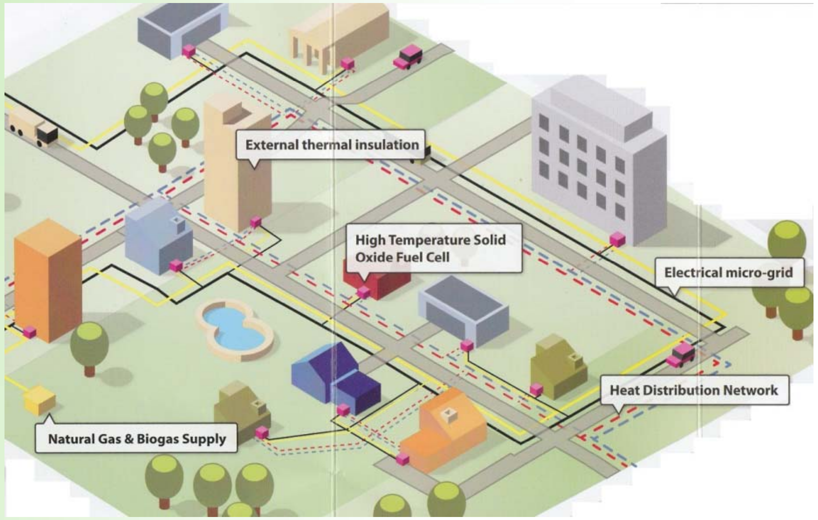
- Project FC-DISTRICT
- FC-DISTRICT Consortium
- µ-CHP System Layout
- Major System Components
  - SOFC Stack
  - CPOX Reformer
  - Anode Off-gas Burner
  - Heat Exchangers
  - Inverter
- Future Activities

CPOX based SOFC µ-CHP unit

PROJECT FC-DISTRICT I

FC-DISTRICT Key Information

- Within the 7th framework program of the European Commission
- Cooperation of 22 partners from 11 European countries
- Duration: 4 years (started: Sept. 2010)
- Total budget: 11 836 264. 6 €
- Total funding: 8 000 000 €



Overall objective:
Optimization and implementation of an innovative energy production and distribution concept for sustainable and energy efficient refurbished or new "energy autonomous" districts, exploiting decentralized co-generation coupled with optimized building and district heat storage and distribution network.

PROJECT FC-DISTRICT II

- **New concept for refurbished and new energy efficient districts**
  - µ-CHP systems (SOFC based) for energy production
  - Distribution system for electricity and heat
- **Electrical integration using the Virtual Power Plant (VPP) + Intelligent heat network at district level**
- **Study about the use of gaseous bio-fuels originating from food waste**
- **Development and demonstration of new district management business models and service models for the consumer**

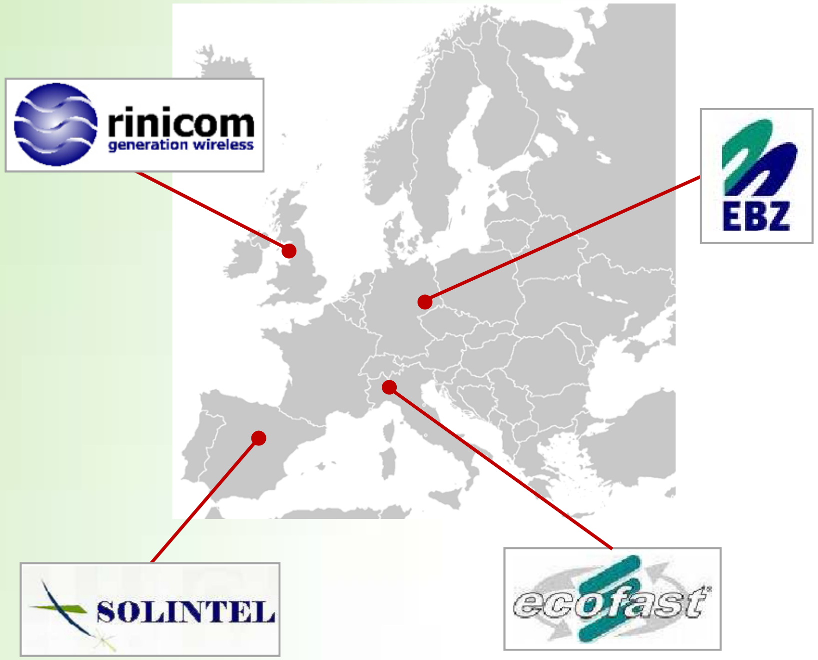
Demonstration

- *at different sites (Spain, Greece, Poland) and*
- *in three phases: unit, building, district*

FC-DISTRICT CONSORTIUM I

Large and Medium Industrial Enterprises

Technology Specialized SMEs



FC-DISTRICT CONSORTIUM II

Universities and Research Organizations

Scientific Project Coordinator

Other

Bruxelles/Belgium

µ-CHP SYSTEM DEVELOPMENT TEAM I

Bergakademie Technische Universität Freiberg	**Leader of R&D activities for micro-CHP unit** ▪ Development and adaptation of peripheral components (reformer, burner) ▪ Manufacturing and integration of first two micro-CHP SOFC based units
EBZ	**SME with expertise in the development of SOFC based systems** ▪ Close collaboration with stack supplier ▪ Development and adaptation of peripheral components (e.g. heat exchangers) ▪ Testing and verification of first lab prototype ▪ Manufacturing and installation of field test prototypes
ikerlan ik4 research alliance	**Technology research center** ▪ Development of optimized control and power electronics ▪ Development, integration and testing of control and wireless communications ▪ Installation of first system prototype

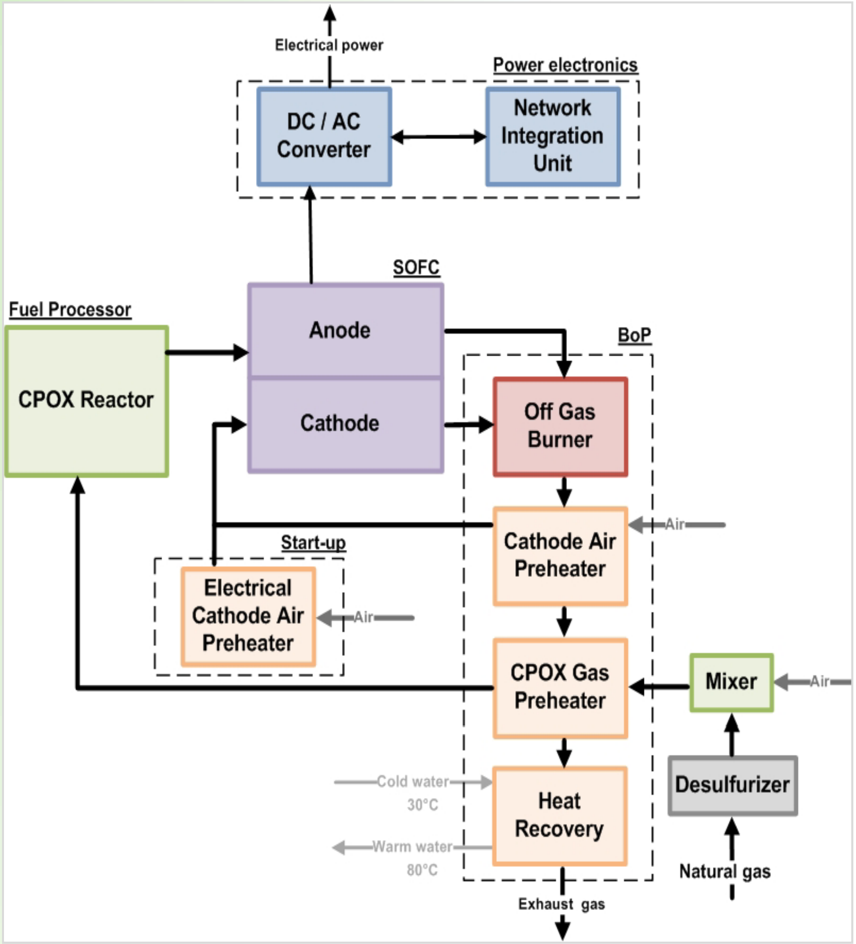
μ-CHP SYSTEM DEVELOPMENT TEAM II

ECN Energieonderzoek Centrum Nederland	**Largest Dutch R&D institute in the field of energy** ▪ Process simulations (ASPEN) ▪ Safety Analysis ▪ Certification
FAGOR	**One of the largest European household appliance manufacturer** ▪ Assembly and test demonstration unit in Spain ▪ Interfaces for unit/district integration
	Largest school of engineering in Portugal ▪ Heat management simulation under transient operational modes ▪ Numerical simulation for design optimization of anode off-gas burner, CPOX reformer and plate type heat exchangers
	Scientific project coordinator ▪ Evaluation of alternative and biofuel use in SOFCs ▪ Simulations for CPOX of biogas fuels ▪ Coordination and montitoring in Greek demonstration site

μ-CHP SYSTEM LAYOUT

Gas appliance for single-family homes and district heating environments for providing demand-flexible electricity and heat

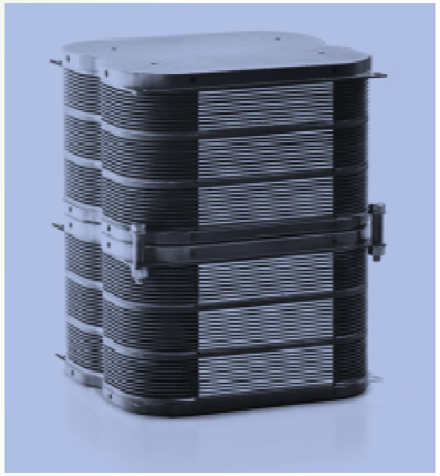
- SOFC stack from the German company STAXERA:
  - nominal max. electrical output 1.5 kW_{el}
  - nominal max. thermal output 2.75 kW_{th} on CPOX syngas
- Electrical efficiency > 30%
- Overall efficiency > 85% (targeting 90%)
- Modulation 1:3
- CPOX reforming of natural gas (biogas)
- Inter-connection with a district heat distribution system and an electrical micro-grid



SOFC STACK

Staxera 1.5 kW ISM

- STAXERA Integrated Stack Module (ISM) with ESC4 cells
- Current technology: 1.7 kW_{el} module (H_2 (40%) – N_2 (60%))
  1.5 kW_{el} with CPOX reformate
- 60 cells MK200, active area 127.8 cm²
- Fuel utilization up to 85%



STAXERA MK200 Stacks

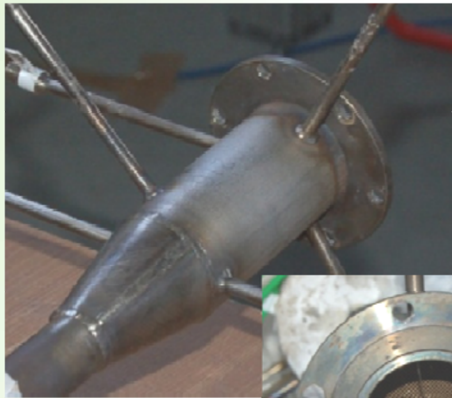
Decision criteria

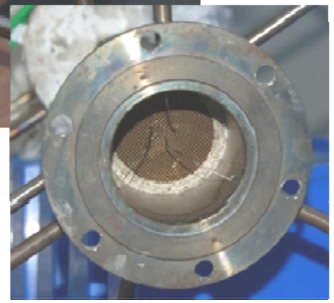
- Very robust stack
- Redox stability
- >10.000 operation hours, <0.5% / 1000 h degradation
- 150 thermal cycles without power loss proven
- Very low pressure losses due to open cathode
- Stack hotbox → easier integration

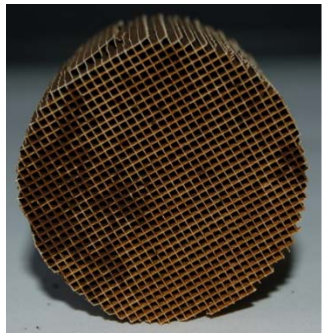
Upscaling 1.7 kW → 5 kW

CPOX REFORMER I

- Development of CPOX reformer by TUBAF/EBZ
- Operation with different qualities of natural gas and potentially biogas
- Load in the range of 1.0 kW to 4.8 kW (equivalent enthalpy input in the case of methane)
- GHSV values in the range of 15,000 h^{-1} to 100 000 h^{-1}
- Air ratios in the range of 0.24 to 0.36
- Initial preheating temperatures in the range of 20°C to 450°C
- Experimental characterization of ceramic monolith with noble metal based catalyst (D=37 mm, L=20 mm)

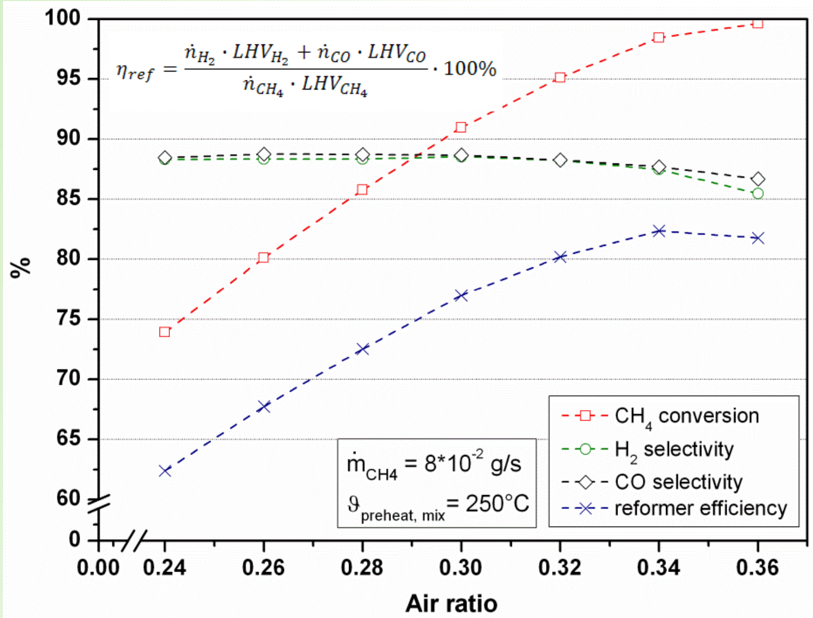






CPOX REFORMER II

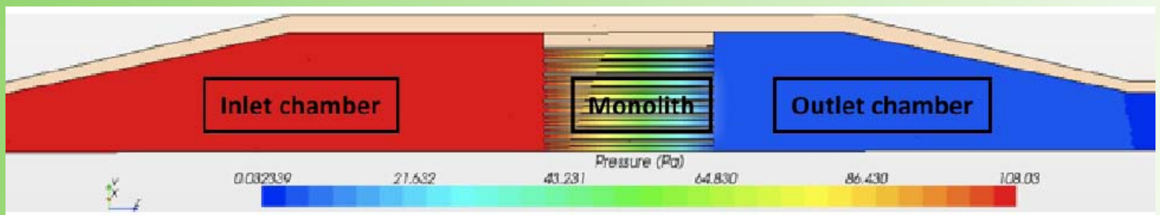
- Reformer operation with methane (P_{th}=4 kW) showed:
  - Maximum reformer efficiency of 83% for an air ratio of 0.34.
  - Maximum selectivities of 88% for air ratios < 0.31.
- For application in the µ-CHP unit an air ratio of 0.31 was chosen as compromise between performance and safety distance to overheating conditions

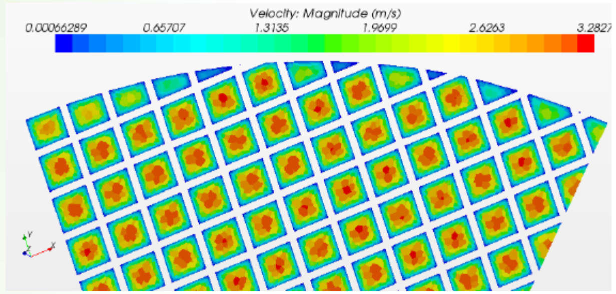


- Gas sample analysis with the SMPS (Scanning Mobility Particle Sizer) showed no soot particles in the syngas for operation with methane and λ=0.24-0.42.
- No soot accumulation was observed within the catalyst for a few hours of operation with pure methane and gas mixture of 87% methane/13% propane
- On-going experimental characterization of the reformer for operation with simulated biogas

CPOX REFORMER III

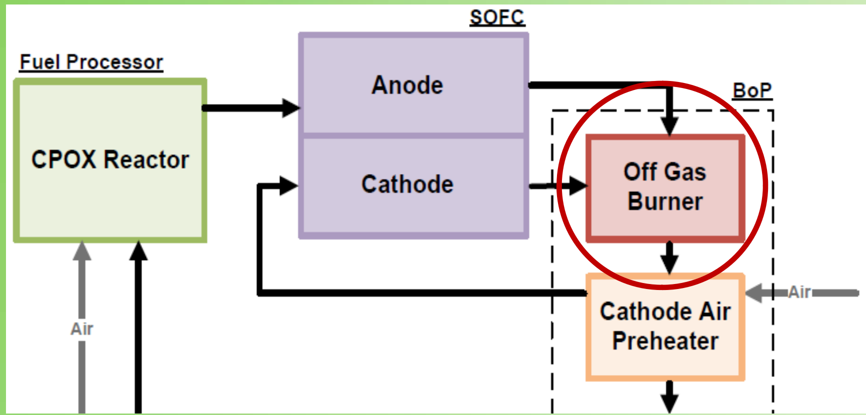
- Parametric numerical studies for reformer design and performance optimization by IST
  - Development of an 1D model with homogeneous and heterogeneous chemistry (*on the basis of CHEMKIN*) for catalytic partial oxidation of methane in a monolith single-channel geometry for prediction of heat release and species.
  - 3D flow simulation of the complete reformer geometry, using the results of the 1D chemistry simulations with software package STAR-CCM+.





- Evaluation of reaction schemes suitable for biogas reforming under POX conditions by NTUA.

ANODE OFF-GAS BURNER I



Direct combustion of the anode off-gas (stationary operation or load rejection/start-up) with the cathode exhaust for system simplification (no additional blower, control simplification etc.)

→Challenging operating conditions

		anode off-gas				reformate
electical stack power [kW]		1.5	1.5	0.5	0.5	0.5 - 1.5
stack fuel utilization [%]		70	80	75	85	-
operation mode		steady-state operation				start-up/shut-down
temperature [°C]		780°C				Ambient-830°C
gas composition	x_{H2} [Vol.-%]	10.7	7.2	8.9	5.4	34.3
	x_{CO} [Vol.-%]	4.7	3.1	3.9	2.3	16.7
	x_{CO2} [Vol.-%]	13.9	15.5	14.7	16.3	1.8
	x_{N2} [Vol.-%]	42.8	42.8	42.8	42.8	42.8
	x_{H2O} [Vol.-%]	27.4	31.0	29.2	32.7	3.8
LHV [kJ/Nm³]		1748	1168	1452	873	5808

- Cathode air flow ranging from 22 … 240 Nl/min, 830°C
- Stable conversion of gas mixtures with significantly different compositions and caloric values
- Low pressure drop

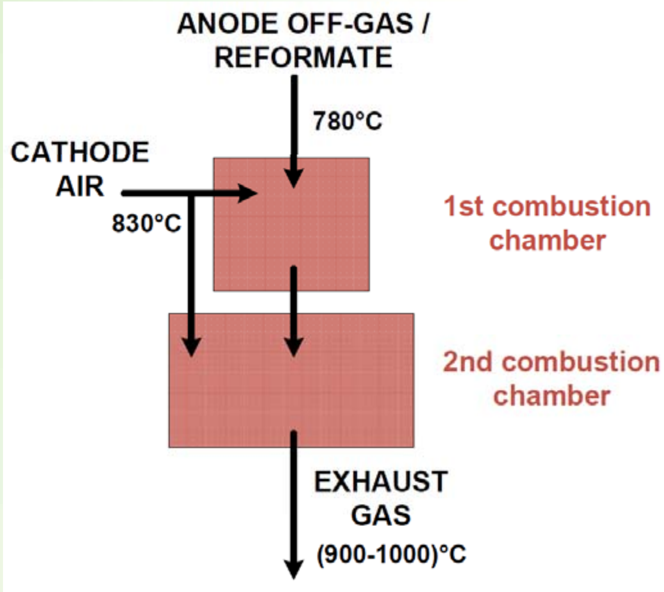
ANODE OFF-GAS BURNER II

- Development of diffusion type burner for direct combustion of the anode off-gas with the cathode exhaust
- Conversion of anode off-gas during steady state operation and reformate during start-up/ shut-down

→Two combustion chambers/stages:

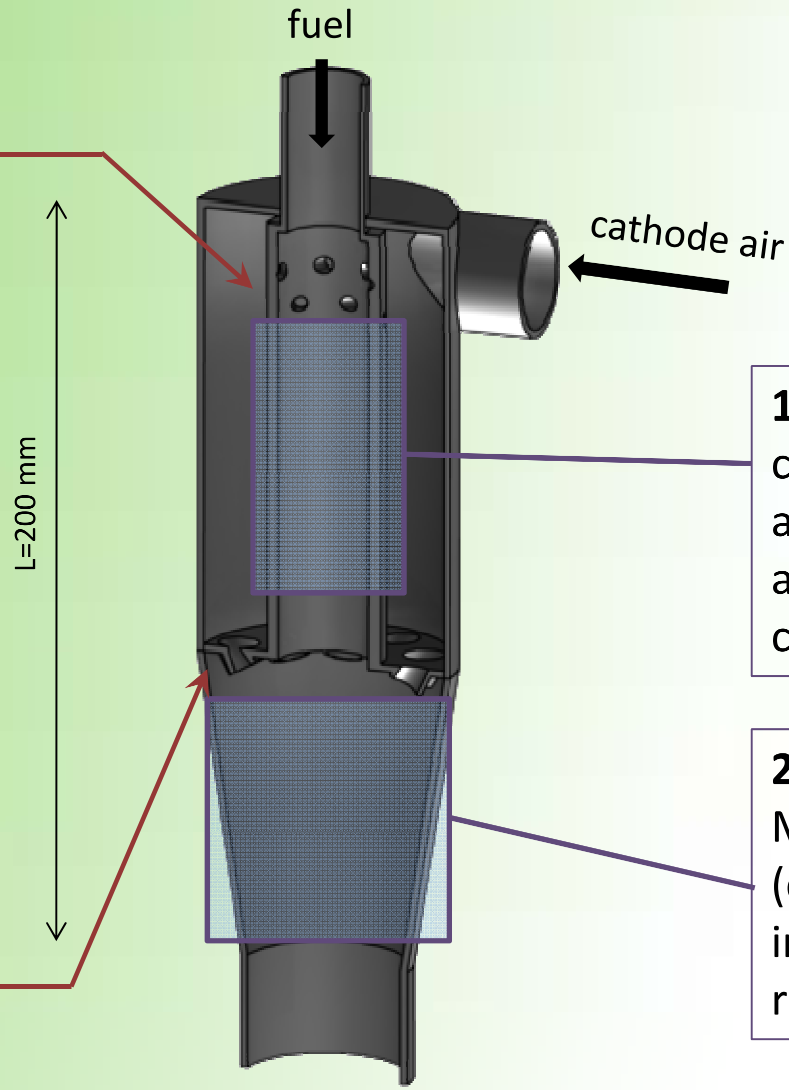
- 1st chamber: complete conversion of anode off-gas, partial conversion of reformate
- 2nd chamber: complete conversion in the case of reformate

→ Proper cathode air splitting is essential for stable operation



ANODE OFF-GAS BURNER III

Proper cathode air splitting



1st chamber:
combustion with air amount required for anode off-gas complete conversion

2nd chamber:
Mixing with rest of air (complete conversion in the case of the reformate)

ANODE OFF-GAS BURNER IV

- Maximum gas temperatures during operation with anode off-gas at 1100°C.
- For partial load operation with reformate (relevant case for reformate operation) gas temperatures do not exceed 1400°C.

  → preliminary tests with reformate indicated that there is no degradation of the material

- Full load with reformate shows critical gas phase temperatures (1600°C) but this operational mode is not foreseen and could only take place under malfunction of the complete system.
- Pressure drop for cathode air side does not exceed 3 mbar.
- Pressure drop for fuel side does not exceed 0.5 mbar.

ANODE OFF-GAS BURNER V

Operation with anode off-gas/ Stationary mode for the complete SOFC system				
Stack Loads [kW]	**Burner load [kW]**	**Total air ratio (λ)**	**CO [mg/kWh]**	**NOx [mg/kWh]**
1,5	1,0-0,6	13-24	50	0
0,75	0,4-0,2	10-21	10	0
0,5	0,2-0,1	4-11	10	0

- Complete conversion of major species is achieved.
- Emitted CO concentrations are on the level of the accuracy limits of gas analyzers (measured value <10 ppm).
- The CO emissions comply with the DIN EN 50465 (CO < 1000ppm @ 0% O_2).
- The CO emissions comply also with the Blue Angel Standard (RAL-ZU 61) which requires CO < 50 mg/kWh (calculated on the basis of the CH_4 input to the µ-CHP system.

ANODE OFF-GAS BURNER VI

Operation with reformate/
Transient modes (start-up/ load rejection)
for the complete SOFC system

Stack Loads [kW]	Burner load [kW]	Total air ratio (λ)	CO [mg/kWh]	NOx [mg/kWh]
1,5	3,5-3,1	5-6	0	210
0,75	1,5-1,4	3-5	0	205
0,5	1,0-0,8	2-2,5	0	200

- Major species are converted and safe burner operation is achieved.
- The high NOx emissions are not critical, since they are only present for short time at low load during start-up or load rejection. Characterization applies for all stationary operation modes.
- The NOx emissions could be further reduced and this is expected for the next improved prototype of the component which is going to be tested.

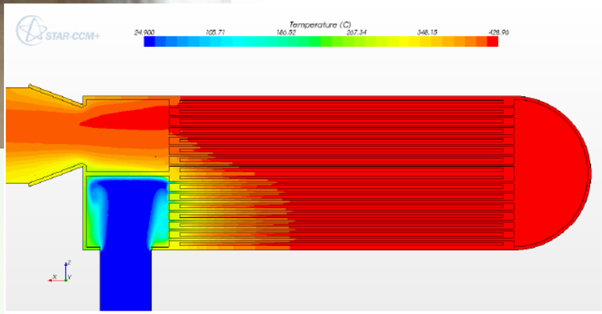
HEAT EXCHANGERS

Cathode air preheater

- Plate type heat exchanger
- Development by EBZ
- Pressure loss target < 10 mbar
- Electrical preheater for system start

CPOX air preheater

- Plate type heat exchanger
- Development by EBZ



INVERTER

- Development by IKERLAN for efficient operation at low voltages and high currents
- Targeted efficiency: 94 %
- Voltage level: 35 … 72 V
- Nominal voltage: 42 V
- Electrical current: 0 … 35 A
- Connection to control and safety system

FUTURE ACTIVITIES

- The 1st prototype complete system is going to be ready for laboratory operation in February 2012.
- The µ-CHP unit will go through CE certification, performed by a certifying body within 2012.
- Field testing of two µ-CHP units will be performed in 2012/2013: one unit is going to be tested in demo site in Spain and another one in demo site in Greece.
- The overall project concept will be evaluated in 2013/2014 with large-scale demonstration of all the targeted technical developments combined in district level (demo site in Poland); three micro-CHP systems will be installed for this purpose.

THANK YOU FOR YOUR ATTENTION!

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