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

FC-DISTRICT: Distributed cogeneration with a CPOX-based SOFC system network

Isabel Frenzel
Oliver Posdziech

AGENDA

- Introduction
- Project Overview
- Project Objectives
- Project Partners
- RTD Activities
- Micro-CHP system development
  - Team
  - System Layout
- Major System Components
  - SOFC Stack
  - CPOX Reformer
  - Anode Off-gas Burner
  - Inverter
- Summary - Outlook

CPOX based SOFC µ-CHP unit

INTRODUCTION I

Technische Universität Bergakademie Freiberg

- located in the Free State of Saxony, Germany
- founded in 1765
- oldest university of mining and metallurgy in the world
- actual number of students: 5500
- core topics: Geosciences, Materials, Energy and Environment

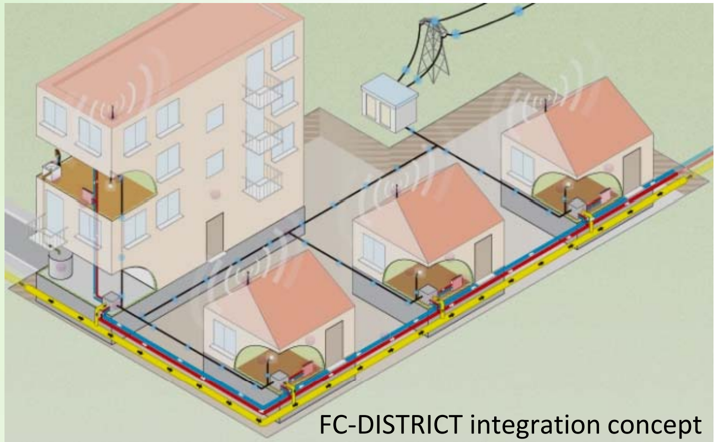
Chair of Gas and Heat Technology
Prof. Dr.-Ing. Dimosthenis Trimis

- founded in February 2006
- part of the Institute of Thermal Engineering
- thematic research areas:
  - Natural gas technologies
  - Furnaces and heat treatment
  - Combustion technologies
  - Energy

PROJECT OVERVIEW

Project FC-DISTRICT

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


FC-DISTRICT integration concept

- ***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 OBJECTIVES

- **New concept for refurbished and new energy efficient districts**
  - µ-CHP systems (SOFC) 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**

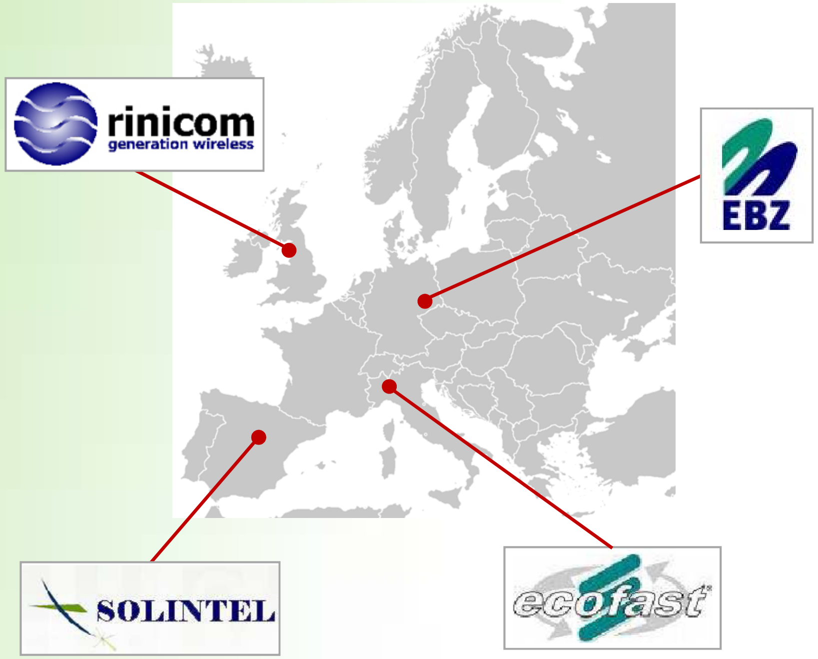
Demonstration

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

PROJECT PARTNERS I

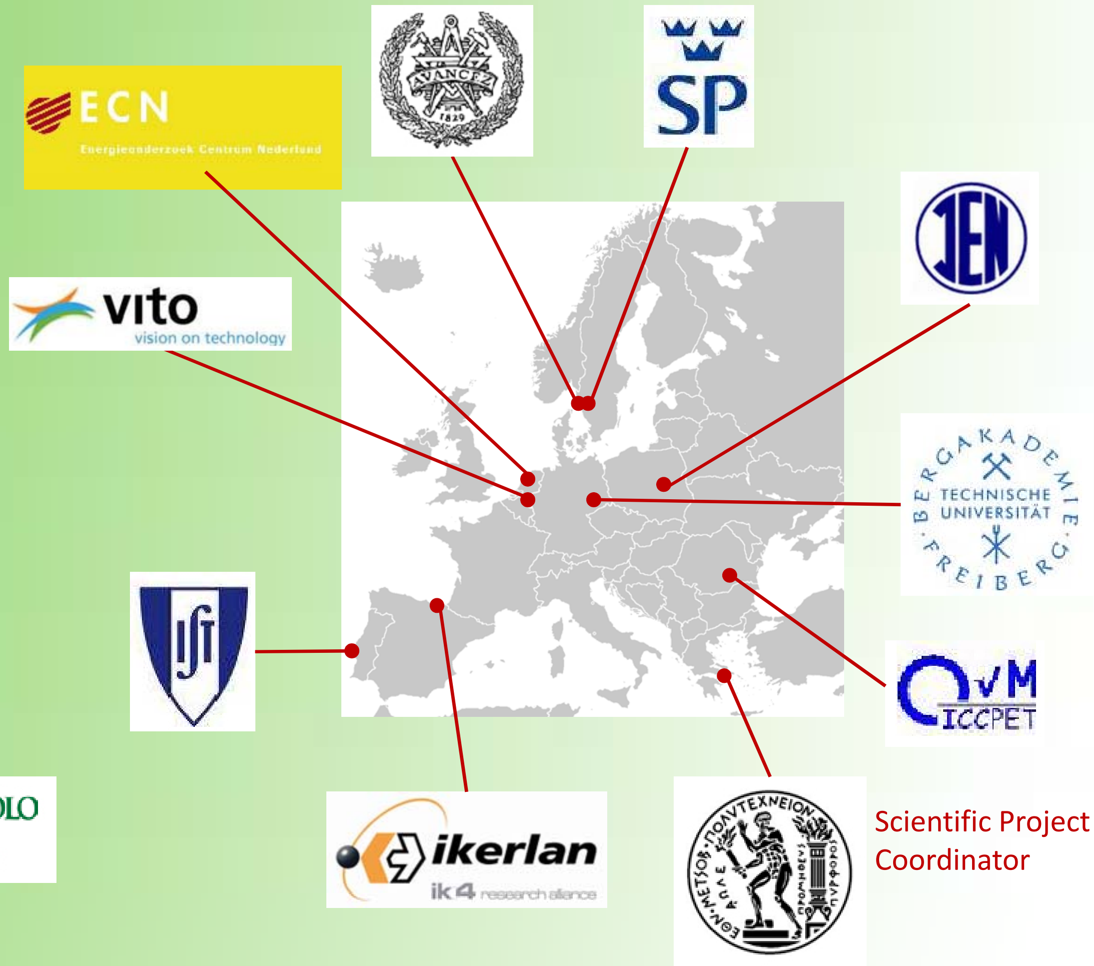
Large and Medium Industrial Enterprises

Technology Specialized SMEs



PROJECT PARTNERS II

Universities and Research Organizations



Other

INTESA SANPAOLO EURODESK

Bruxelles/Belgium

RTD ACTIVITIES

RTD topics

- µ-CHP based on high temperature SOFC
- Biogas production in waste disposer
- New solutions for thermal storage
- District wide distribution networks
- Communication needed for control of the networks

Technical work packages

- **WP2** System requirements
- **WP3** Building and district tailoring of SOFC
- **WP4** Biogas production in district waste disposers
- **WP5** Thermal storage systems for building and district
- **WP6** Efficient heat distribution network and micro-grid
- **WP7** Dynamic control and wireless communication solutions
- **WP8** System Integration – Proof of Concept
- **WP9** Demonstration in industrial settings

MICRO-CHP SYSTEM DEVELOPMENT TEAM I

	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
	SME with expertise in the development of SOFC based systems ▪ Close collaboration with stack supplier ▪ Development and adaptation of peripheral components (reformer, heat exchangers) ▪ Testing and verification of first lab prototype ▪ Manufacturing and installation of field test prototypes
	Technology research center ▪ Development of optimized control and power electronics ▪ Development, integration and testing of control and wireless communications ▪ Installation of first system prototype

MICRO-CHP SYSTEM DEVELOPMENT TEAM II

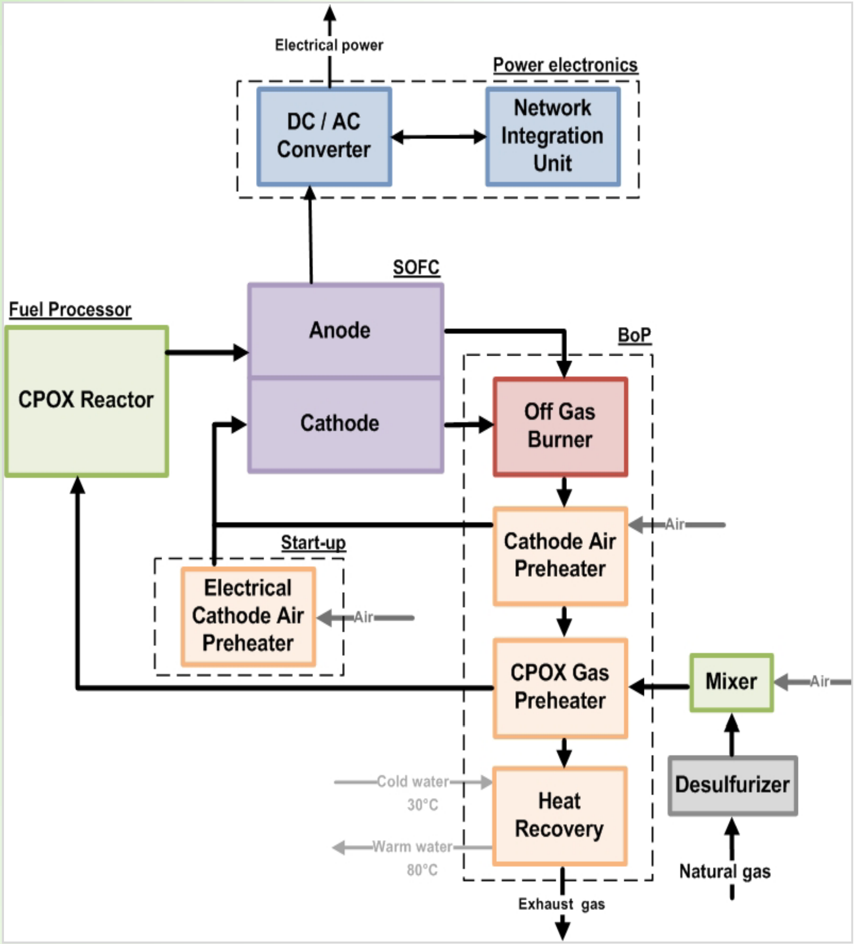
ECN Energieonderzoek Centrum Nederland	**Largest Dutch R&D institute in the field of energy** ▪ Process simulations (ASPEN) ▪ Safety Analysis ▪ Certification
FAGOR	**One of the largest European household appliance manufacturer** ▪ Assembly and test demonstration unit in Spain ▪ Interfaces for unit/district integration
IST	**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
ΕΘΝ. ΜΕΤΣΟΒ. ΠΟΛΥΤΕΧΝΕΙΟΝ	**Scientific project coordinator** ▪ Evaluation of alternative and biofuel use in SOFCs ▪ Simulations for CPOX of biogas fuels ▪ Coordination and montitoring in Greek demonstration site

MICRO-CHP SYSTEM DEVELOPMENT: SYSTEM LAYOUT I

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



PROCESS SIMULATION RESULTS WITH ASPEN PLUS (ECN)

- fuel: G20 (100% CH_4, LHV: 50.03 MJ/kg)
- CPOX air ratio: 0.31

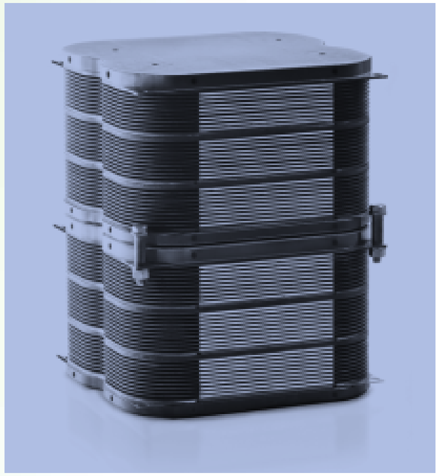
Parameter	1.5 kW electr. power 75% FU		
Heating application	Hot water storage (20 → 80°C)	Floor heating (30 → 40°C)	District heating (60 → 80°C)
Heat recovery unit duty, W	2254	2254	2107
Exhaust temperature, °C	39	39	64
Cold water flow, kg/h	32.4	194.6	90.7
Net electrical efficiency, %	**32.01**	**31.93**	**31.94**
Net system efficiency, %	**86.97**	**86.89**	**83.32**

Parameter	1.5 kW electr. power		0.5 kW electr. power	
	70% FU	80% FU	80% FU	85% FU
Heating appication	Hot water storage (20 → 80°C)			
Heat recovery unit duty, W	2505	2066	336	283
Exhaust temperature, °C	39.5	37.5	50.5	49.0
Cold water flow, kg/h	36.0	29.7	4.8	4.1
Net electrical efficiency, %	**30.14**	**33.63**	**38.62**	**40.61**
Net system efficiency, %	**87.61**	**86.63**	**69.05**	**67.59**

SOFC STACK

Staxera 1.5 kW ISM

- STAXERA Integrated Stack Module (ISM) with ESC4 cells (H.C. Starck GmbH)
- 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 cm^2
- Fuel utilization up to 85%



STAXERA MK200 Stacks

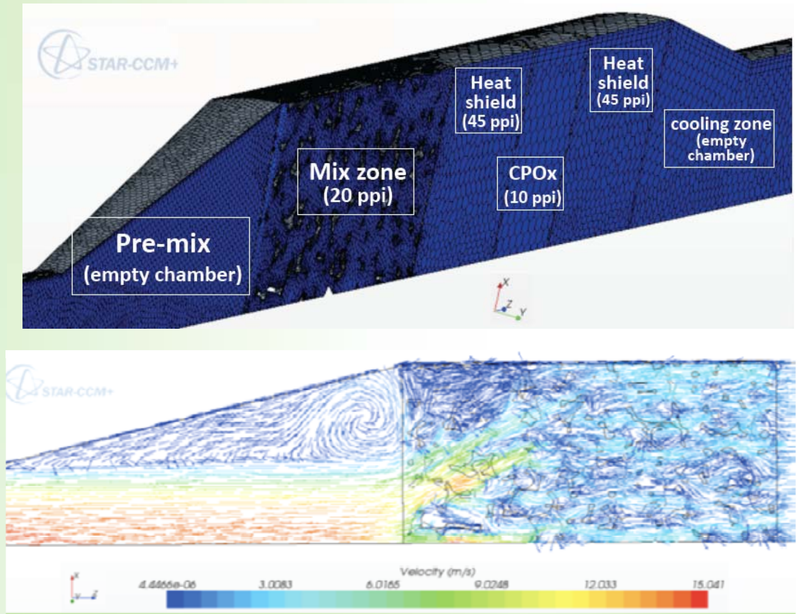
Decision criteria

- 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

- Fuels: Different qualities of natural gas and potentially biogas
- Load range: 1.0 kW … 4.4 kW (equivalent enthalpy input in the case of methane)
- Experimental characterization of available commercial catalysts (noble metal based)
- Parametric numerical studies for reformer design/ performance optimization



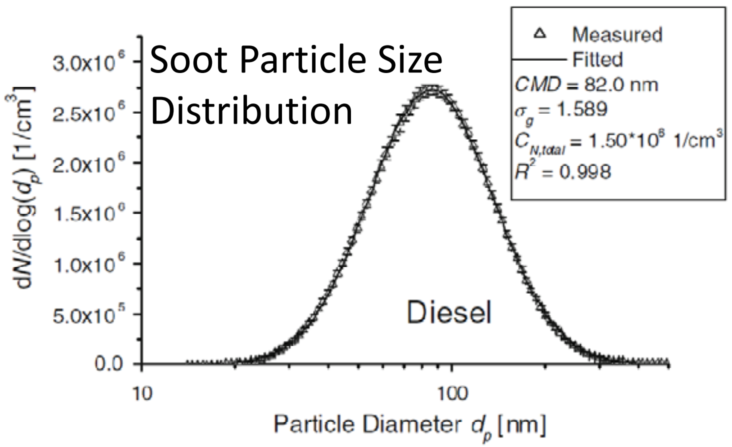
CPOX REFORMER

Further steps for CPOX reformer development:

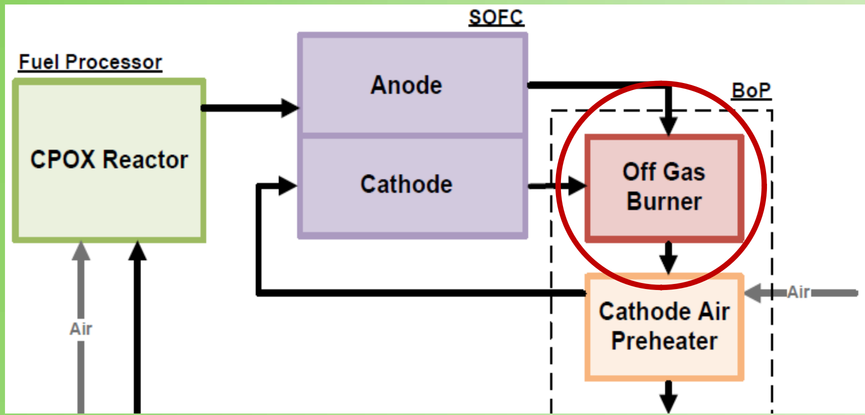
- Long-term testing for catalyst performance and lifetime
- Detailed characterization of reformer with different fuels:
  - limit gas G21: 87% CH_4, 13% C_3H_8
  - limit gas G231: 85% CH_4, 15% N_2
  - biogas: 60% CH_4, 40% CO_2
- Investigation of soot formation in CPOX and influence of catalyst degradation
  - Gas sample analysis with an SMPS (Scanning Mobility Particle Sizer)
  - Measurement of soot particle size distributions in the range of 3 nm to 1000 nm with an accuracy of ±10%

Scanning Mobility Particle Sizer

Soot Particle Size Distribution



ANODE OFF-GAS BURNER I



Direct combustion of the anode off-gas with the cathode exhaust for system simplification (no additional blower, control simplification etc.)

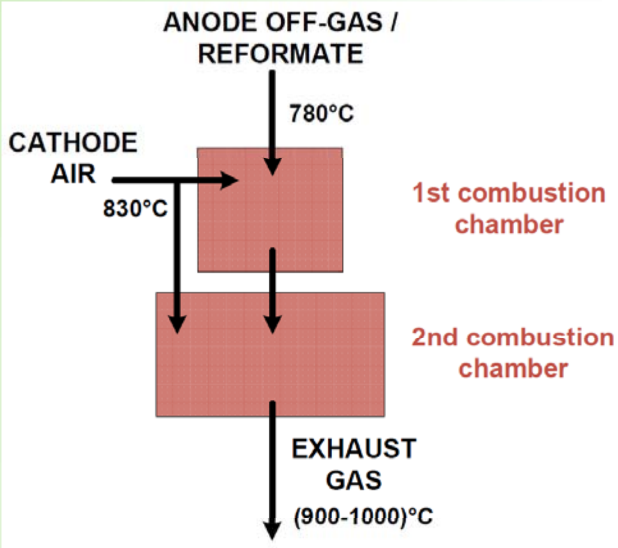
→**Challenging operating conditions**

	anode off-gas (85% stack fuel utilization)	**reformate**
operation mode	steady-state operation	start-up/shut-down
temperature	780°C	830°C
gas composition	x_{H2} = 5.4 Vol.-% x_{CO} = 2.3 Vol.-% x_{CO2} = 16.3 Vol.-% x_{N2} = 42.8 Vol.-% x_{H2O} = 32.7 Vol.-%	x_{H2} = 34.3 Vol.-% x_{CO} = 16.7 Vol.-% x_{CO2} = 16.3 Vol.-% x_{N2} = 42.8 Vol.-% x_{H2O} = 3.8 Vol.-%
LHV	873 kJ/Nm³	5808 kJ/Nm³

- Cathode air flow ranging from 15 … 200 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
- Two combustion chambers/stages:
  - 1st chamber: complete conversion of anode off-gas
  - 2nd chamber: complete conversion in the case of reformate
- Proper cathode air splitting is essential for stable operation



INVERTER

- 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

SUMMARY - OUTLOOK

- Currently the FC-DISTRICT project is in the 9th month and the development of the major components of the SOFC based micro-CHP system is on-going.

- The 1st prototype complete system is going to be ready for laboratory operation in six months.

- The evaluation of the project concept will start after the second year with demonstration operation in building level of two complete micro-CHP systems, at two different demo sites (Spain and Greece).

- The overall project concept will be evaluated during the fourth year 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!

The FC-DISTRICT Consortium would like to acknowledge the financial support of the European Commission under the Seventh Framework Program.