Advanced Multi-Fuel Reformer for Fuel CELL CHP Systems

ReforCELL (278997)

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Fundación Tecnalia Research & Innovation

This project is supported by the European Union's Seventh Framework Programme (FP7/2007-2013) for the Fuel Cells and Hydrogen Joint Technology Initiative under grant agreement nº 278997

General Overview

- Project full title: Advanced Multi-Fuel Reformer for Fuel CELL CHP Systems
- Duration: 3 years, 01 February 2012 up to 31 January 2015
- Budget: 5,546,194 Euros
- FCH contribution: 2,857,211 Euros
- Partnership/consortium description:

11 European organisations from 6 countries:

6 Research Institutes and Universities

5 top industries (4 SMEs) in different sectors (from hydrogen production to catalyst developments to boilers etc.)

1 TECNALIA, Spain
2 TU/e, Netherlands
3 CEA, France
4 POLIMI, Italy
5 SINTEF, Norway
6 ICI, Italy
7 HYGEAR, Netherlands
8 SOPRANO, France
9 HYBRID, Netherlands
10 QUANTIS, Switzerland
11 JRC, Netherlands

1. Project achievements in relation to the AIP/MAIP: Project objectives and targets

To **improve the efficiency** of the **PEM fuel cell micro-CHP system** with an **innovative multi-fuel processor** (5 Nm^3/h of hydrogen) while **reducing the system cost** from the state of the art to achieve cost bellow 5000 €/kWel by 2020.

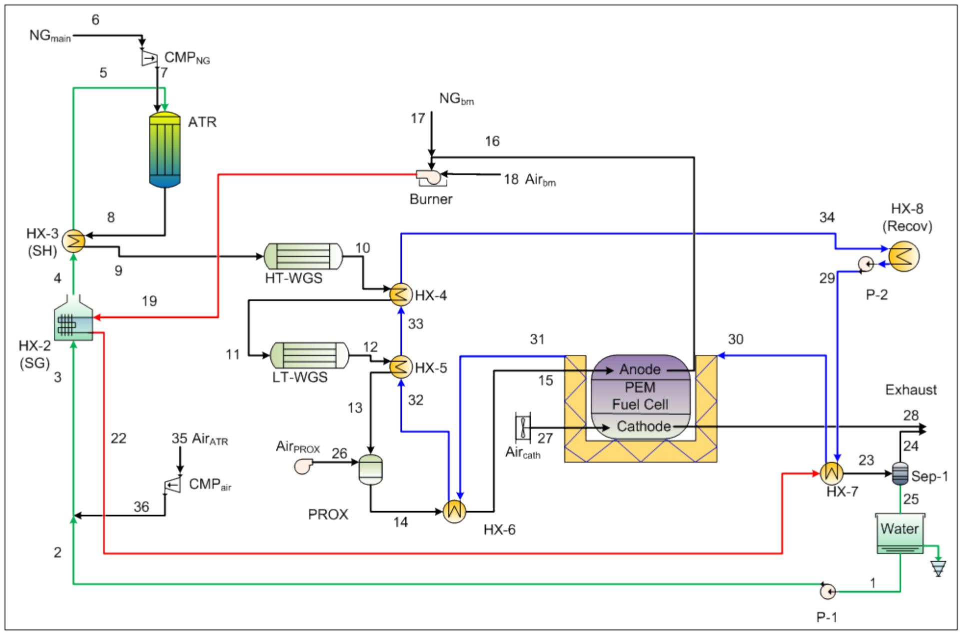
The **target** is a net electric efficiency higher than **42%** using natural gas and an overall efficiency higher than **90 %**.

HOW?: By the **development of a novel catalytic membrane reactor (CMR) for hydrogen production** with:

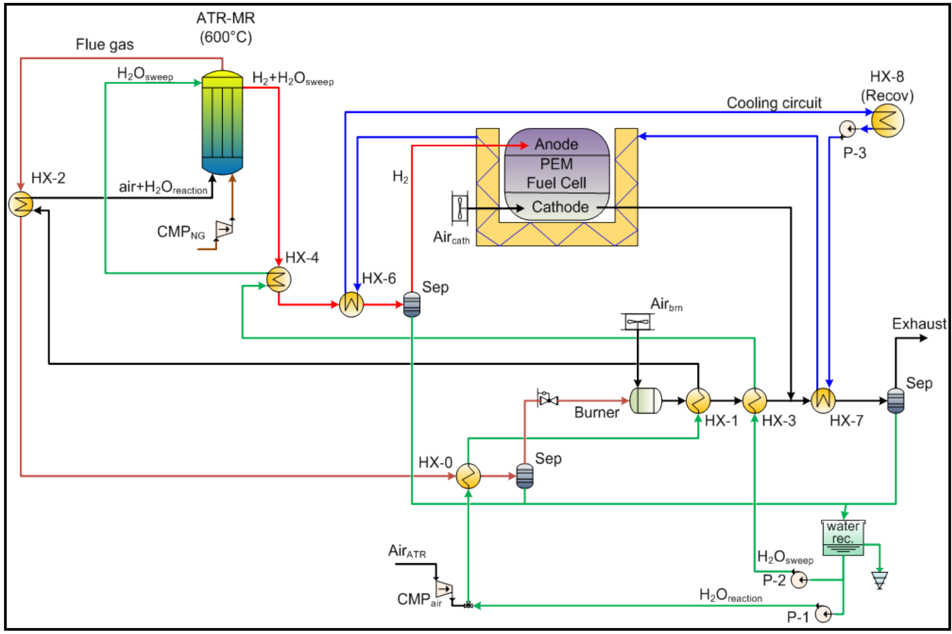
- Improved **performance** (high conversion at low temperature for the autothernal reforming reaction)
- Enhanced **efficiency** (reduction of the energy consumption of at least 7 – 10 %)
- Long **durability** (30.000 hours) under CHP system working conditions

1. Project achievements in relation to the AIP/MAIP: ReforCELL concept

PEM m-CHP unit



Tradicional reforming for fuel processing



ReforCELL concept with CMR for fuel processing

1. Project achievements in relation to the AIP/MAIP: Alignment to MAIP/AIP

ReforCELL correspond to MAIP/AIP objectives for Stationary Power Generation & CHP and especially: "**SP1-JTI-FCH.2010.3.3 Component improvement for stationary power applications**"

a) Improve the performance of individual components of fuel cell systems (e.g. fuel cell units, reformer, heat exchangers, fuel management and power electr.);
b) The understanding and optimization of interaction between BoP components and mature stacks.

ReforCELL *will contribute* to the development of mass market by reducing the cost of micro-CHP systems for stationary application (i.e.; domestic).

ReforCELL *will contribute* to the development of European industry by proposing alternative solution compared to competitors

1. Project achievements in relation to the AIP/MAIP: Alignment to MAIP/AIP

Expected output AIP **Topic: 14** **Call: 2010**		**Objectives Project**	**Status at 50% of the project**	**Expected revised objectives**
Viable mass production		*Mass production technologies are considered in the development*	N/A	
CHP life time (years)	*> 10*	*> 10*	N/A	
Electrical efficiency (%)	*> 42*	*> 42*	N/A	
Overall efficiency CHP (%)	*> 80*	*> 90*	N/A	
Cost target by 2020 (kW)	*5000*	*5000*	N/A	
Reciclability	*yes*	*LCA and safety study*	N/A	

1. Project achievements in relation to the AIP/MAIP: Approach

WP1. Management [TECNALIA]

WP8. LCA and Safety analysis [QUANTIS]

WP2. Industrial specifications of FC micro-CHP [ICI]

WP3. Catalysts development [HYBRID]
- Catalyst preparation
- Catalyst characterisation
- Activity test

WP4. Membrane development [SINTEF]
- Material for membranes
- Membranes development and characterization

WP5. Lab scale reactors [TU/e]
- Integration in micro-structured membrane reactors
- Testing and model validation

WP6. Novel ATR prototype [HYGEAR]
- Design of Pilot
- FAT
- Process design & Simulation
- Set up and testing
- Testing and validation

WP7. Integration and validation of micro-CHP system [ICI]
- Fuel Cell stack selection
- Integration and testing
- FC - CHP system optimization

WP9. Dissemination and Exploitation [HYGEAR]

1.2. Project Achievements:
WP2 Industrial specification of Fuel Cell CHP-System (I)

✓ The Industrial requirements of m-CHP system has been completed

- ❑ WP2, industry driven, focalizes on definition of industrial requirements for a successful introduction of the REFORCELL system into the market.
- ❑ Guidelines for product development were identified based on market study and state-of-the-art review

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1.2. Project Achievements:

WP2 Industrial specification of Fuel Cell CHP-System (II)

- Cost effective approach for:
  - design (components and total system)
  - dedicated production line
  - materials – recycling
  - maintenance.

- Competitiveness of the system is shown when compared with other fuel cell system as well as with other different systems.

- In this commercial offer, the investment payback time is fundamental. In order to start large sales volumes, it is necessary to drop below 3 years. Differently, we will be talking about only a few hundred pieces.

1.2. Project Achievements:
WP3 Novel catalytic materials (I)

Objective: Development and supply of experimentally validated catalysts for application in the ATR membrane reactors.

✓ Selection of experimentally validated catalysts for lab scale membrane reactor.

- The activities were focussed in two different set of catalysts:
  i) Nickel based catalysts (commercial and synthesized catalysts)
  ii) Catalysts based on noble metals (i.e. Pt, Rh) supported on oxide carriers (i.e. CeO_2, CeO_2-ZrO_2).
- Detailed physico-chemical characterization of fresh and used samples as well as catalytic activity under reforming condition at laboratory scale.

1.2. Project Achievements:
WP3 Novel catalytic materials (II)

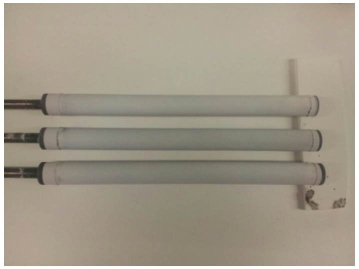
- Catalyst screening in steam methane reforming (SMR) revealed a catalyst that meets the requirements set by REFORCELL (i.e. 600-650 °C)
  - ✓ The catalyst is comprised of ruthenium supported on mixed Zr/Ce-oxide.
  - ✓ The catalyst is also active at significant lower temperature (500 °C) than originally anticipated.
  - ✓ It's synthesis has been scaled up to afford Kg quantities.

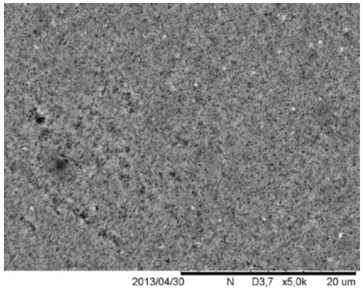
1.2. Project Achievements:
WP4 Membranes development (I)

Objective: Development of novel materials and membranes for application in ATR reactors with improved flux and selectivity and durability under reactive conditions

✓ Improved membrane supports.

❑ Development of suitable interdiffusion-barrier layer by plasma spray and/or wet deposition techniques with right properties (suitable gas permeation, suitable surface quality for depositing thin selective layers (< 3 µm), working at high temperatures (600 - 650° C).





1.2. Project Achievements:
WP4 Membranes development (II)

✓ Membrane for lab-scale

- ❑ Pd-based membranes by PVD direct deposition of thin dense metal layers onto ceramic and metallic tubular supports.
- ❑ Pd-based tubular membranes on metallic supports by the 2-step coating method (PVD + wrapping).
- ❑ H_2 permeance and H_2/N_2 ideal selectivity above the targets of ReforCELL.
- ❑ Work is ongoing to increase the stability at the targeted temperature (~650°C)

1.2. Project Achievements:
WP4 Membranes development (III)

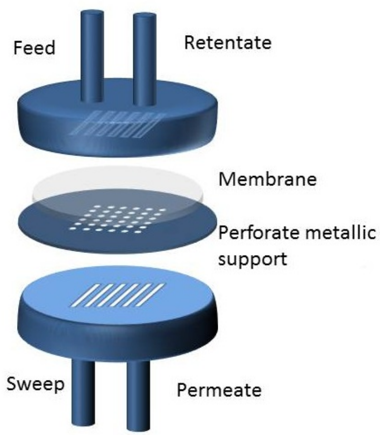
- ❑ Pd-based planar membranes for membrane micro-channel reactor.
- ❑ Integration of porous stainless steel permeate section and intermetal diffusion barrier layers is ongoing to increase T and P stability.

✓ Membrane for prototype

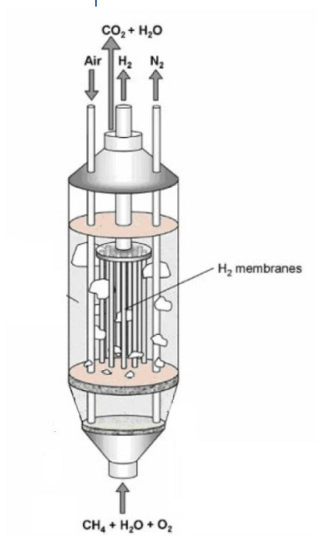
- ❑ Number of membranes for the prototype have been defined.

1.2. Project Achievements:
WP5 Lab-scale ATR-CMR fuel reformer (I)

1) Design, construction and testing of the lab-scale reactors specifically designed for ATR.



membrane micro-channel reactor



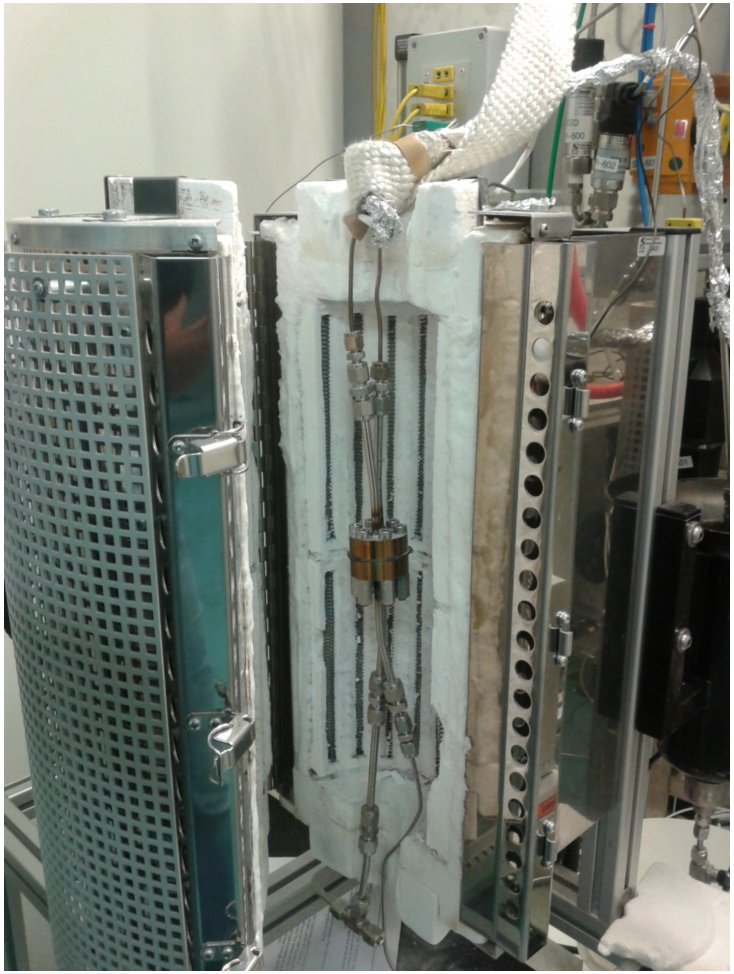
membrane assisted fluidized bed

2) Integration strategies for the different CMR components: catalysts, membranes and supports (i.e. sealing)

3) Modeling of ATR reactor types and Validation of the lab scale reactor concepts

1.2. Project Achievements:
WP5 Lab-scale ATR-CMR fuel reformer (II)

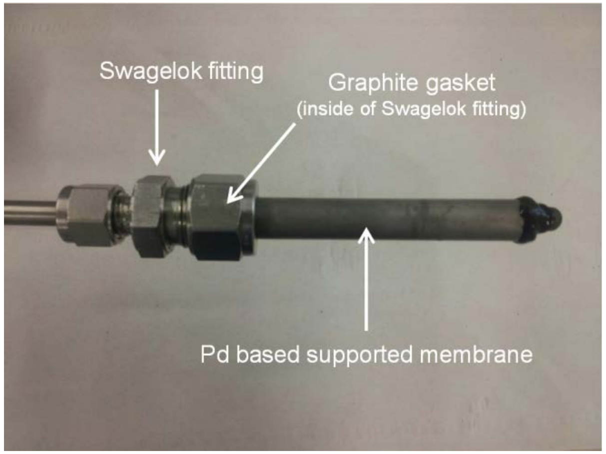
Setup for permeation tests



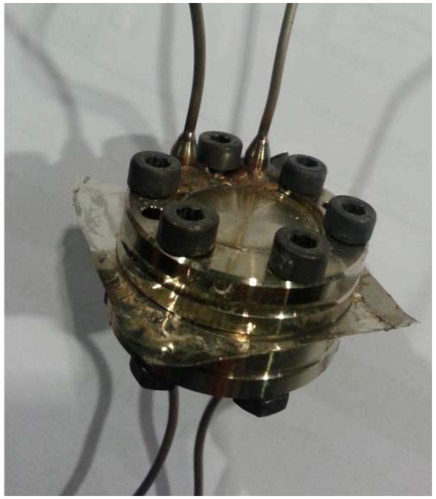
Sievert`s law for H_2 flux

$$J_{H_2} = P^0_{H_2} \cdot e^{\frac{-E_a}{RT}} \left(p_{H_{2,ret}}{}^n - p_{H_{2,perm}}{}^n \right)$$

ReforCell Membranes



TECNALIA (FBR)

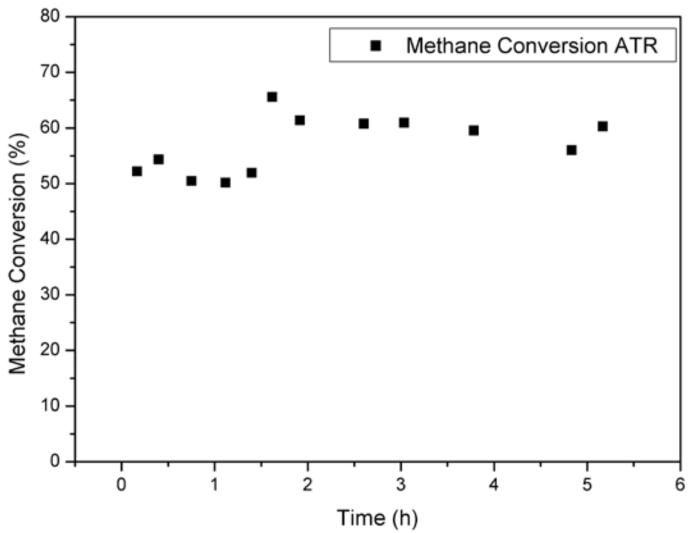


SINTEF (μ-reactor)

1.2. Project Achievements:
WP5 Lab-scale ATR-CMR fuel reformer (III)

Catalytic tests of Rh/ZrO_2

Stability Test (ATR)



$RhZrO_2$ <u>7 times more active</u> than $NiAl_2O_3$

New catalyst very stable against carbon formation

$20wt\%Ni/Al_2O_3$: $g_{coke}/g_{cat} = 1,57$

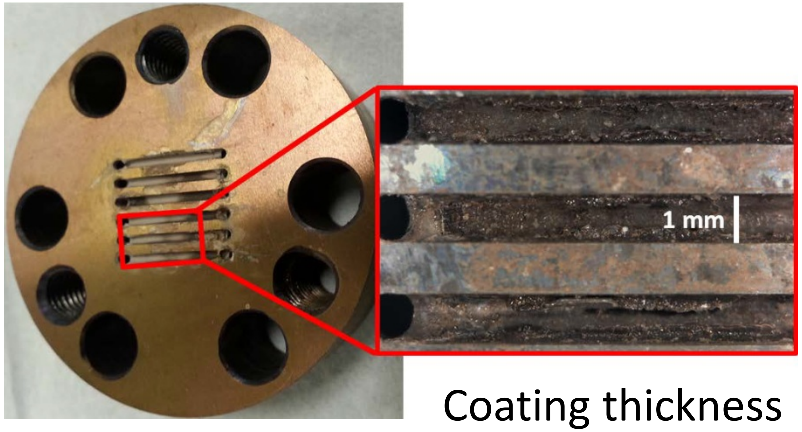
$1.4wt\%Rh/ZrO_2$: $g_{coke}/g_{cat} = 0,045$

Catalyst integration in the microreactor

Catalyst Mass required to reach a production capacity of $5Nm^3/h$

$$Mcat = 1,3\ g$$

Coated-wall microchannels



Coating thickness

$$l_{experimental} = 200\mu m$$

$$l_{required} = 10\mu m$$

1.2. Project Achievements:

WP5 Lab-scale ATR-CMR fuel reformer (V)

Catalytic tests of Ru/Ce-Zr oxide

Fluidized Bed Reactor - Setup

Development of 2nd generation of catalyst (HYBRID) for the FBR lab scale reactor …

Good mechanical stability of the catalyst particles during fluidization tests at T= 650 °C

Thermo-Gravimetric Analysis (SMR)

Stability Test (ATR)

in progress …

1.2. Project Achievements:

WP6 Design and manufacturing of novel ATR reformer (I)

Objective: Design and set up of the pilot scale ATR catalytic membrane reactor.

- Design novel ATR reformer according PED 97/23 EC (M18)
  - 5 Nm/h hydrogen production
  - Metallic hydrogen selective membranes
  - Fluidized bed
- Manufacturing of ATR reformer
- Assembly of ATR reformer including controls and balance of plant components
- Factory Acceptance Test of ATR
- Test of ATR under real conditions

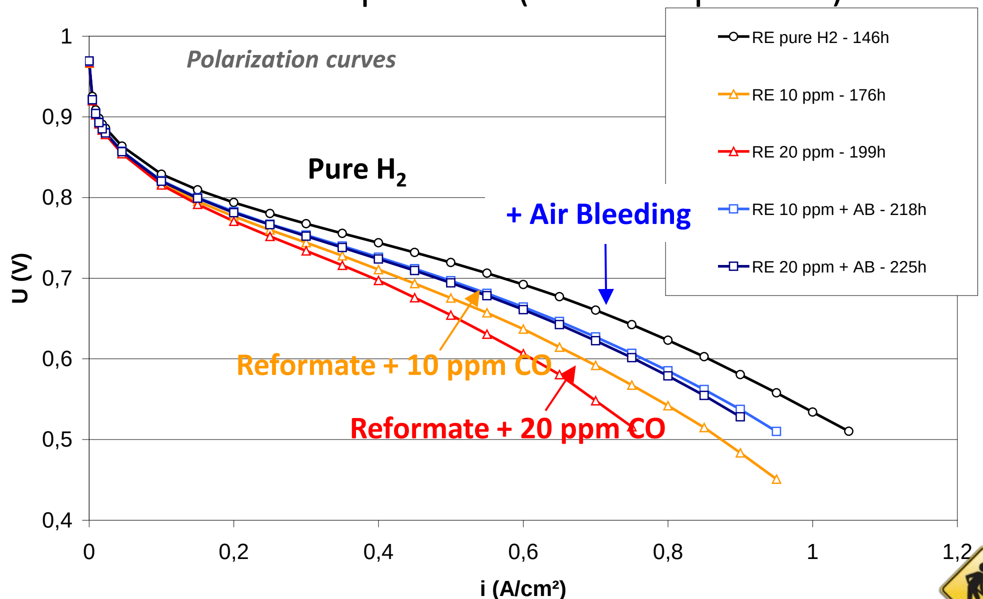
- Design novel ATR reformer according PED 97/23 EC (M18)ready

Selection and testing of fuel cell stack (task 7.1)

Technical objective: evaluate the performance and short term durability of PEMFC short stacks in operating conditions representative of the application and compatible with reformer and system requirements → Information for system dimensioning and integration of 5kW stack.

Tests conducted on a short stack for reformate operation

- Comparison of pure H_2 with reformate incl. or not CO (10 & 20 ppm)
- Effect of Air Bleeding
- Effect of st Air and st Fuel
- Effect of dead-end operation (first with pure H2)



Nominal conditions: 65° C, 1.2 bars, st1.5/2, RH90%/50%

Test bench for up to 1kW stack

Open or dead-end

Mixtures of fuels:

H_2; CO_2; CH_4 + CO;

Air + CO for air bleeding tests

→ Performance in the expected range (vs. reference case definition)

→ More impact of fuel at high i

→ Cell voltage losses (@0.4A/cm²):

~ 6% with CO and ~ 2% with CO + AB

→ More impact of St Fuel (than St Air)

Next steps: further tests with pure H2 + CO in dead-end mode and short term durability with application load cycles.

1.2. Project Achievements:
WP7 Integration and validation of the CHP system (II)

Fuel cell CHP system optimisation (task 7.2)

- Definition of reference configuration and performance to use as benchmark for comparing ReforCELL system. Two fuel processing technologies were studied:
  - Steam Reforming reactor (most typical configuration)
  - Autothermal reforming reactor (more similar to ReforCELL)

Results	units	SMR	ATR	ReforCELL Objectives
Net electric efficiency	$\%_{LHV}$	34.2%	32.3%	> 42%
Net thermal efficiency	$\%_{LHV}$	46.3%	50.5%	> 48%
Overall efficiency	$\%_{LHV}$	80.5%	82.8%	> 90%
Fuel Cell single cell voltage	V	0.740	0.728	~0.752

1.2. Project Achievements:

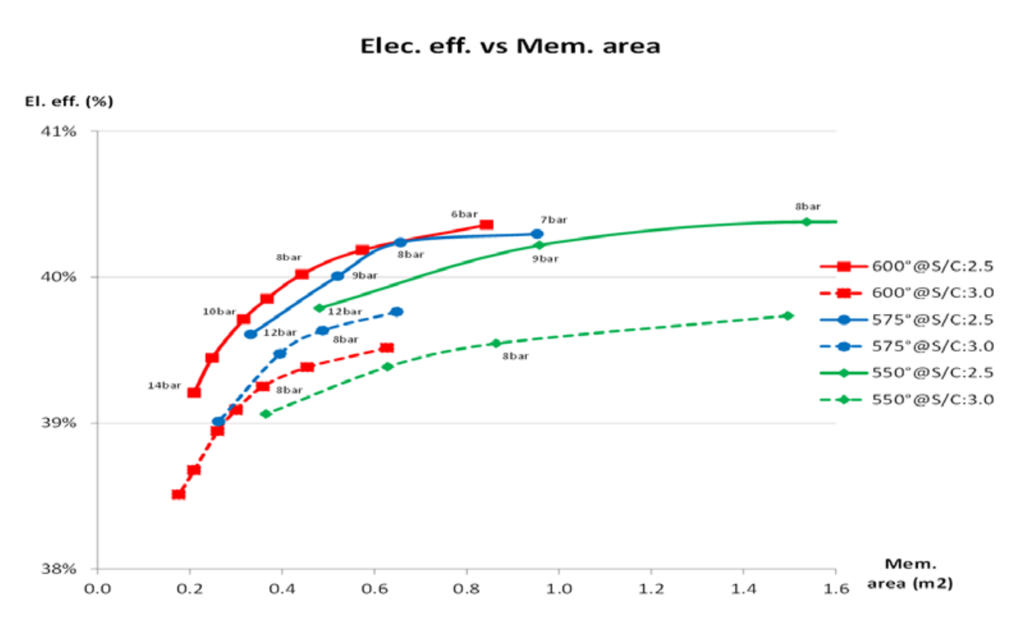
WP7 Integration and validation of the CHP system (III)

Fuel cell CHP system optimisation (task 7.2)

- ❑ Lay-out of the new m-CHP system in case of Natural Gas fuelled Membrane Reactor has been proposed.
- ❑ Evaluation of integration aspects, configuration and layout and their effects on performance has been analysed. System optimization from efficiency and economic point of view.

Optimization parameters:

- ➢ Reformer operating conditions (S/C, feed pressure, temperature);
- ➢ Permeate conditions (sweep or vacuum pump);
- ➢ FC operating conditions (V / I, λ_{cath}, anodic purges);



1.2. Project Achievements:
WP8 LCA and safety analysis

- A Life Cycle Inventory (LCI) data collection questionnaire has been prepared in order to start the data collection process.
- The LCI data collection questionnaire is based on a FC-HyGuide template named "Guidance Document for performing Life Cycle Assessment (LCA) on Fuel Cells (FCs) and Hydrogen (H2) Technologies".

Quantis

STACK PRODUCTION

RAW MATERIAL TYPES & QUANTITIES

Please report the total quantity of each material used per stack, and specify the loss rate for each material. In the co

Components	Materials	Mass input	Unit	Loss rate during stack manufacturing (%)	Mass per fuel cell stack	Unit
Fuel cell	Various		kg input/stack		0	kg/final stack
Endplates	Alluminium alloy		kg input/stack		0	kg/final stack
Insulators	PTFE		kg input/stack		0	kg/final stack
Tie-rods	Steel		kg input/stack		0	kg/final stack
Buss plates	Copper		kg input/stack		0	kg/final stack
Manifolds	Stainless steel		kg input/stack		0	kg/final stack
Fittings	Stainless steel		kg input/stack		0	kg/final stack

Add lines if necessary

[1]Please include any standard identifying information, such as a CAS number for chemical substances and describe how the component is received (raw, formed, as a foil, a bar, etc.)


FC-Hy Guide

Guidance Document for performing LCAs on Fuel Cells and H_2 Technologies

GUIDANCE DOCUMENT FOR PERFORMING LCA ON FUEL CELLS
Deliverable D3.3 – Final guidance document
Work Package 3 – Preparation and Consultation of the Guidance Document

Author(s): P. Masoni, A. Zamagni
Reviewer(s)/Advisory Board: P. Fullana I Palmer, M. Bode, M. Finkbeiner, K. Chomkhamsri
WP/Task No: WP3/Task 3.5

Approved by the
X External reviewer
X Work Package Leader
X Project Coordinator
○ European Commission / FCH JU

Keywords: Guidance document, Fuel cells, Life Cycle Assessment (LCA), International Reference Life Cycle Data System (ILCD)

Abstract: This document gives guidance for conducting a LCA study on fuel cells. Adapted from the ILCD Handbook and the ISO 14040 series, the document gives an overview of how to carry out a LCA on fuel cells. This is done by delivering a specific set of rules with clear specifications about the information and issues that have to be considered and reported in a LCA study on fuel cells.

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Number of pages: 109
Dissemination Level: PU

Date of Delivery to the EC
Contractual: 31/07/2011
Actual: 30/09/2011

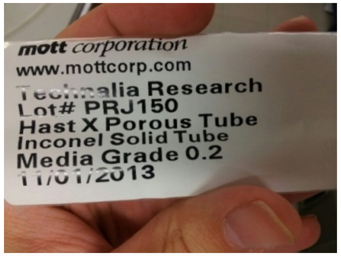
1.3. Bottlenecks and Risks (I)

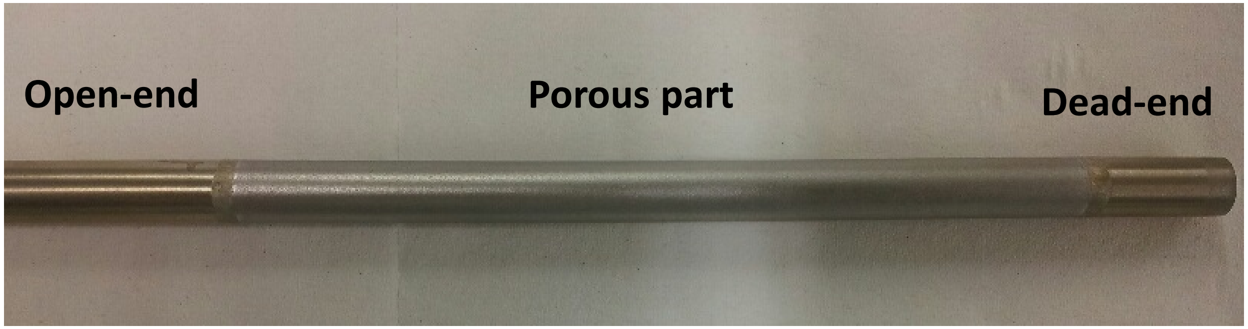
- Sealing stability at high temperature

  - Tubular ceramic membranes

Graphite gaskets

  - Tubular metallic membranes.
    - different approaches (i.e. micro-Tig, orbital or laser welding; buying welded support)





1.3. Bottlenecks and Risks (I)

- Membrane stability under fluidisation.
  - Protective porous layer
  - Fixed bed membrane reactor

- Membrane area requested for the prototype ⇒ nº of membranes to be manufactures.

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Summary

- ✓ Based on the industrial requirements we successfully define the framework in which the targets can be achieved
- ✓ New catalyst successfully developed at small scale (scale-up in progress)
- ✓ Targets for membrane permeation and selectivity reached (membrane stability is being improved)
- ✓ Lab scale setups built and validated
- ✓ Prototype reactor designed (waiting for components to be built)
- ✓ Guidelines for LCA defined

2. Complementary information (I)

✓ Interaction with projects/programmes:

- CACHET II (Carbon Capture and Hydrogen Production with Membranes – FP7)
- CARENA (Catalytic membrane reactors based on new materials based on new materials for C1-C4 valorization – FP7)
- DEMCAMER (Design and manufacturing of catalytic membrane reactors by developing new nano-architectured catalytic and selective membrane materials – FP7)
- COMETHY (Compact Multifuel-Energy to Hydrogen converter – FCH JU)
- MICROGEN 30 (30 kWe CHP system with PEFC for residential applications – Italy)
- PREMIUM ACT (Predictive Modelling for Innovative Unit Management and Accelerated Testing procedures of PEFC – FCH JU)

2. Complementary information (II)

- Dissemination & public awareness
  - Public website (www.reforcell.eu)
  - 6 monthly newsletter & public project presentation
  - Towards national and international organisation related to ReforCELL
  - Participation in international and national conferences and workshops
  - Final dissemination workshop
- Safety, Regulations, Codes and Standards
  - Safety issues addressed in WP8 (LCA and safety issues) for both the CMR and the complete system. Identification and evaluation of safety parameters (i.e. CMR: prevent thermal runaways or hot spots)
  - The development of the final m-CHP system could provide a feedback on regulation, codes and standards

2. Complementary information (III)

- ✓ Exploitation
  - Mid-Term exploitation internal workshop
  - Final dissemination and exploitation workshop (including an open event)
  - Plan for using and dissemination of foreground & exploitation plans relevant for the ATR membrane reactors and the micro-CHP system
- ✓ Needs/opportunities for increasing cooperation
  - ReforCELL is a clear example of collaboration between industry, research centers and universities
  - This partnerships can be increased in future projects and common initiatives to improve the research collaboration and to exploit the benefits of ReforCELL
- ✓ Future research approach (examples)
  - Micro-CHP systems fueled by biogas
  - Micro-CHP systems fueled by liquid fuels

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Thank you for your attention

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