Advanced m-CHP systems

Advanced Multi-Fuel Reformer for Fuel CELL CHP Systems (ReforCELL – 278997)

A Flexible natural gas membrane Reformer for m-CHP applications (FERRET – 621181)

Advanced m-CHP fuel CELL system based on a novel bio-ethanol Fluidized bed membrane reformer (FluidCELL - 621196)

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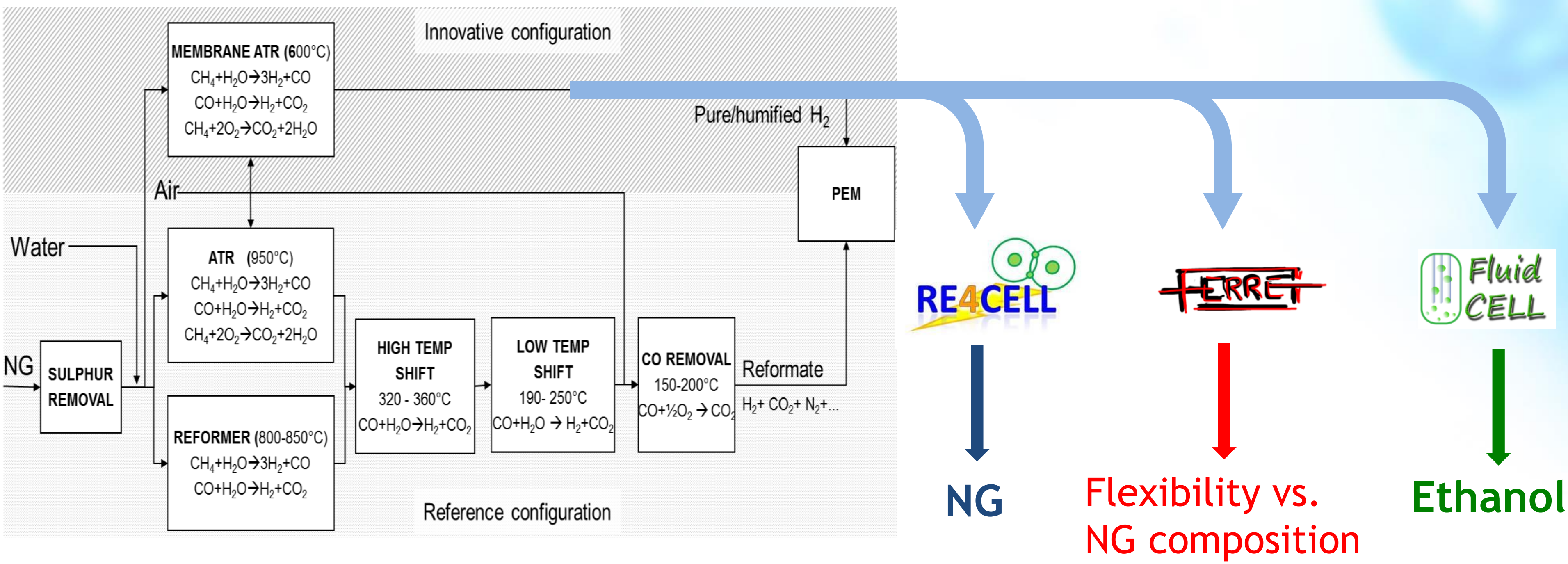
PROJECT TARGETS AND ACHIEVEMENTS: The concept



PROJECT TARGETS AND ACHIEVEMENTS

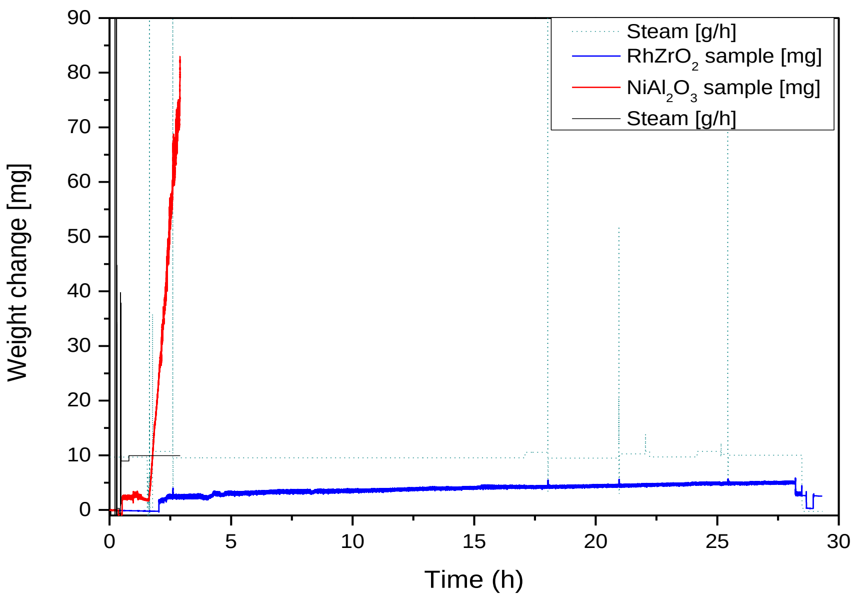
Programme objective/target	Project objective/target	Project achievements to-date	Expected final achievement
RE4CELL FERRET Fluid CELL	**MAIP**		
Micro-CHP (residential), natural gas based 2020 target: 5,000 € per system (1kWe + household heat).	5,000 € (1kWe + house heat) by 2020	Cost could be achieved for mass production. m-CHP system will be assembled beginning November.	Dynamic response of power and heat (RE4CELL) Feeding the FC with another H_2 source. m-CHP system validated (Fluid CELL)
Overall efficiency > 80% for CHP units	Overall efficiency > 90%	90 % can be achieved if the appropriate heat exchanger and insulation is adopted	Overall efficiency > 90%
Lower emissions and use of multiple fuels (FERRET, Fluid CELL)	Different natural gas (FERRET) Reduced CO_2 emissions . Bio-ethanol as fuel (Fluid CELL)	NA	100%

PROJECT TARGETS AND ACHIEVEMENTS

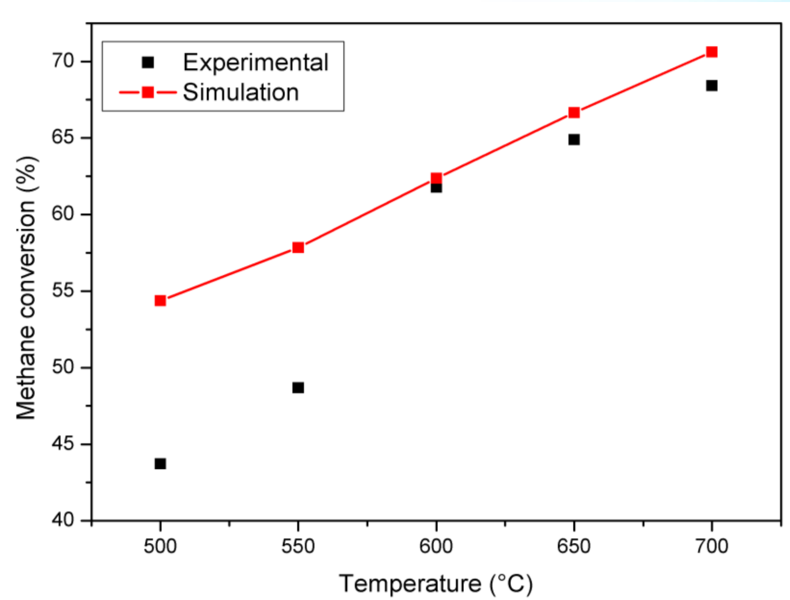
Programme objective/target	Project objective/target	Project achievements to-date	Expected final achievement
AIP			
Viable mass production	Mass production technologies	Mass production technologies	100%
CHP life time (years) > 10	> 10 but not tested in the project	N/A. Test <10 years	400 h test 2000 h test
Electrical efficiency (%) >42%	> 42%	42 % net electric efficiency is feasible	100%
Recyclability	LCA and safety study	Preliminary LCA	100%
Proof-of-Concept of CHP in lab	TRL 4 – technology validated in lab	60%	100%
Durability of several hundreds of continuous operating hours	1000h of operation at nominal power output	50%	100%

PROJECT TARGETS AND ACHIEVEMENTS: Catalyst development ReforCELL

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



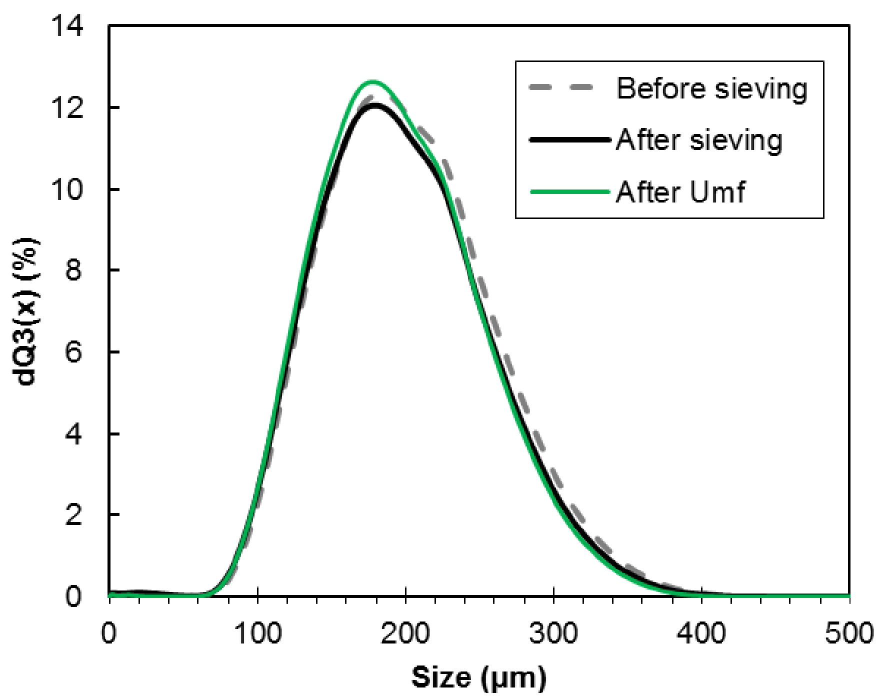
Carbon formation on commercial and new catalyst



Experimental results and modeling

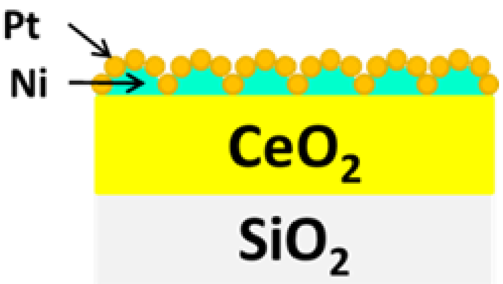
PROJECT TARGETS AND ACHIEVEMENTS: Catalyst development FERRET

- Catalyst surpasses activity and stability targets for FERRET
- Displays activity across a wide range of natural gas compositions
- Stable to fluidization testing without loss of particle size or sphericity
- Scalable preparation methods



Particle size distribution of catalysts before sieving, after sieving and after cold and hot fluidization in air.

PROJECT TARGETS AND ACHIEVEMENTS: Catalyst development FluidCELL



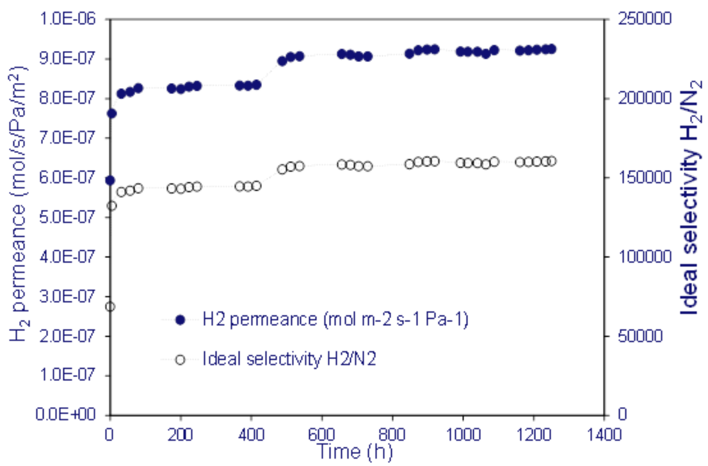
- **Mechanical support:** SiO_2 assures proper resistance during fluidization
- **Catalytic support:** CeO_2 promotes dissociation of H_2O and C_2H_5OH molecules and prevents coking
- **Non-noble metal:** Nickel favors C-C bond break
- **Noble metal:** Platinum enhances WGS activity

Preparation: Sequential impregnation of CeO_2, Ni and Pt followed by drying overnight at 120ºC and calcination at 600ºC for 3h

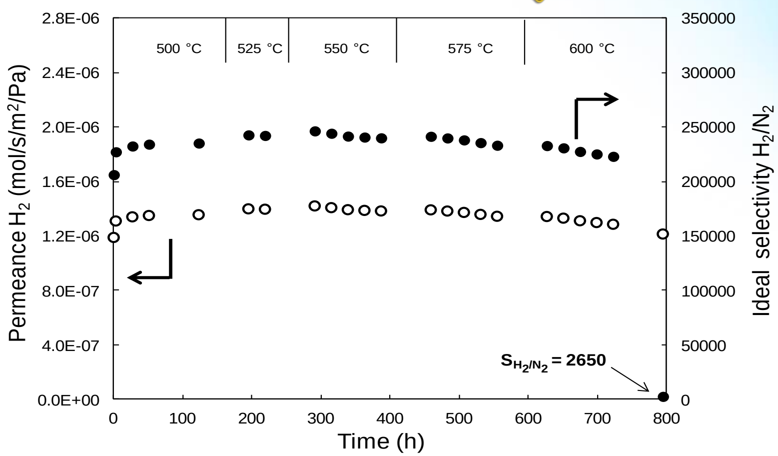
Final formulation: 3wt%Pt-10wt%Ni/CeO_2/SiO_2

PROJECT TARGETS AND ACHIEVEMENTS: Membrane development

- Pd-based membranes by direct deposition of thin dense metal layers (< 5 µm) onto ceramic and metallic tubular supports by simultaneous ELP or combined ELP & PVD.
- 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 project targets (and DoE targets).
- Work is ongoing to increase the stability at high temperature (600 - 650 ºC)



Metallic supported membrane M14.
Long-term stability test over time at 400 ºC

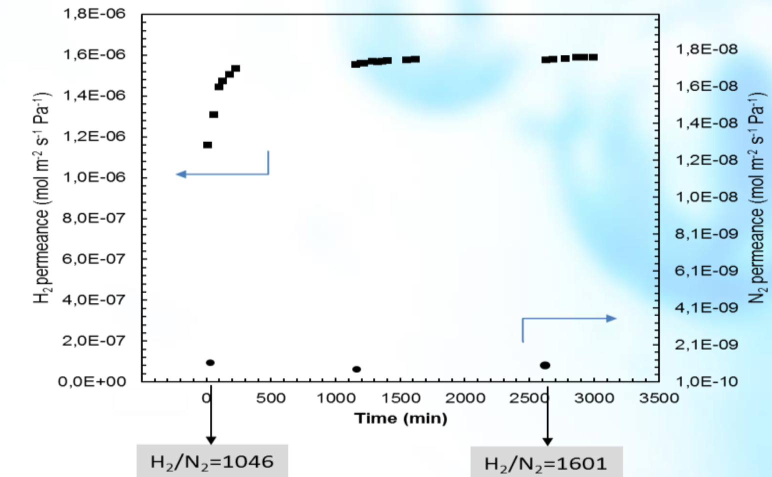


Membrane M17-E94.
Long-term stability test

PROJECT TARGETS AND ACHIEVEMENTS: Membrane development

- Pd-Ag-Au membranes by ELP (Au layer onto a Pd-Ag membrane + thermal treatment
- H_2 permeance=1.6 x 10^{-6} mol m^{-2} s^{-1} Pa^{-1}; Ideal H2/N2 selectivity= ~1600

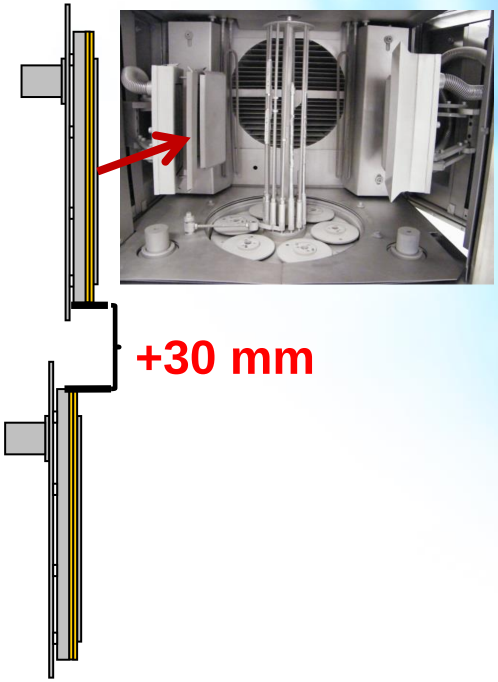
H_2, N_2 permeation test (550°C, ~1 bar)



- Pd-Ag membranes supported onto ZrO_2 tubular porous supports (Ø10 mm) prepared by simultaneous Pd & Ag ELP deposition.
- Length of the Pd-Ag membrane 22-23 cm (50% longer than planned).
- Thickness of the selective layer: ~4 µm.

PROJECT TARGETS AND ACHIEVEMENTS: Membrane development: Ongoing/next activities

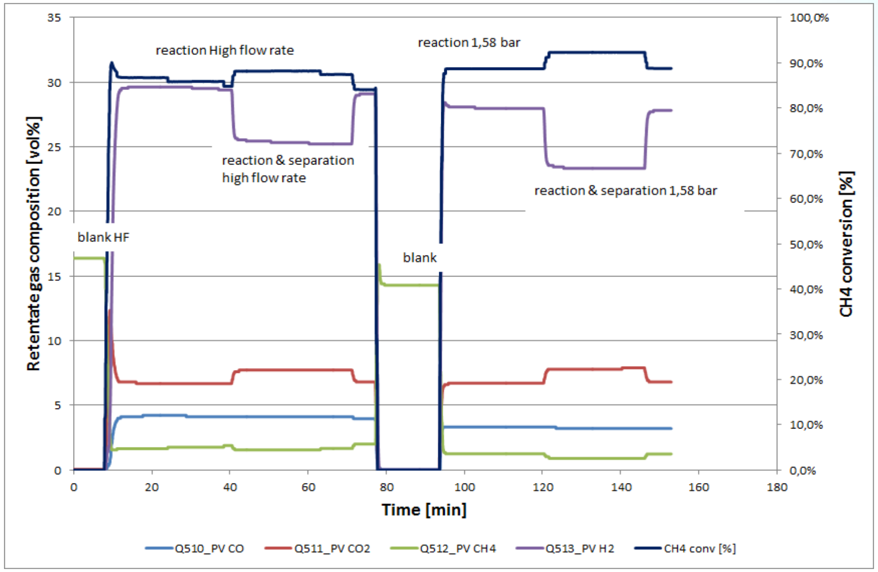
- Pd pore filled membranes for high (>500 °C) and moderate conditions (< 500 °C).
- Using thicker ceramic porous support (10/4 mm instead of 10/7 mm) for improving mechanical stability.
- Optimising the process for developing metallic supported membranes.
- Pd-Ag-Au and Pd-Ag-Ru based membranes by ELP and/or combined ELP & PVD.
- PVD will be used for adding a 3rd metal (i.e. Au, Ru,..) to Pd-Ag membranes developed by ELP.



PROJECT TARGETS AND ACHIEVEMENTS: Lab-scale testing - ReforCELL

RE4CELL

- Design, construction and testing of the lab-scale reactors specifically designed for ATR.
- Integration strategies for the different CMR components: catalysts, membranes and supports (i.e. sealing)
- Modeling of ATR reactor types and Validation of the lab scale reactor concepts



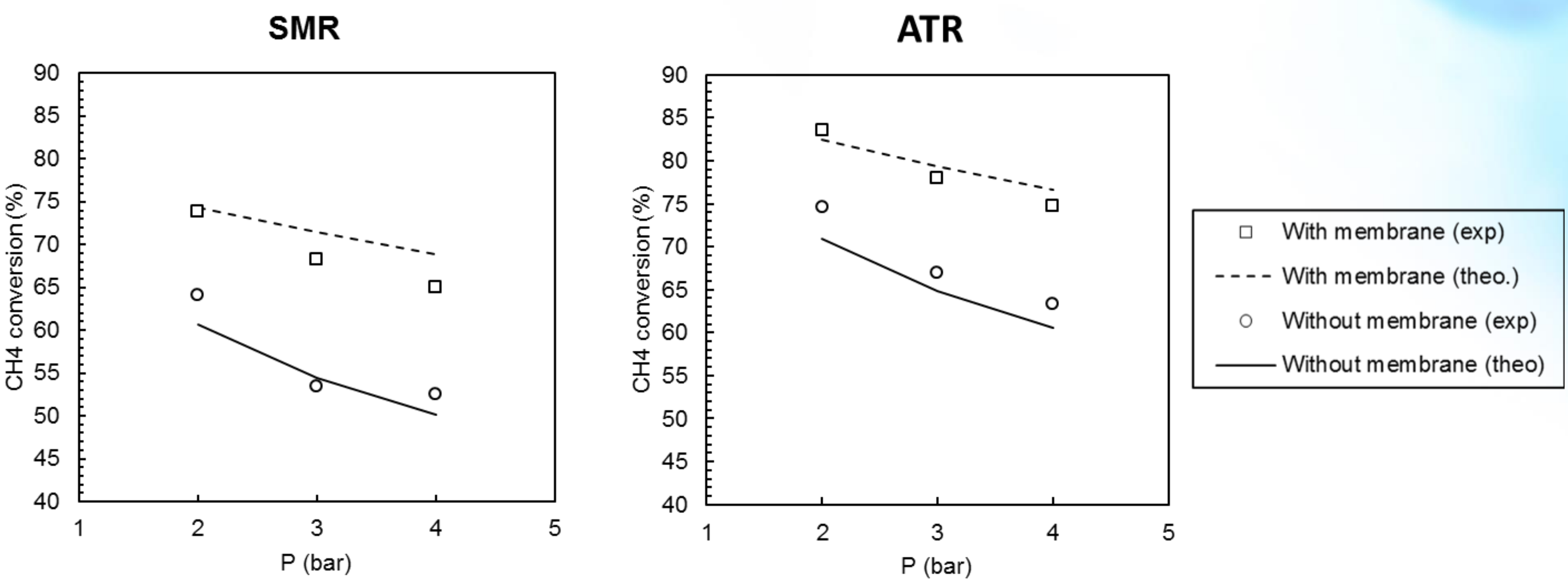
- System operated for 2 weeks continuously
- Good catalyst stability but membranes to be improved

RE4CELL Fluid CELL FERRET

PROJECT TARGETS AND ACHIEVEMENTS: Lab-scale testing - ReforCELL

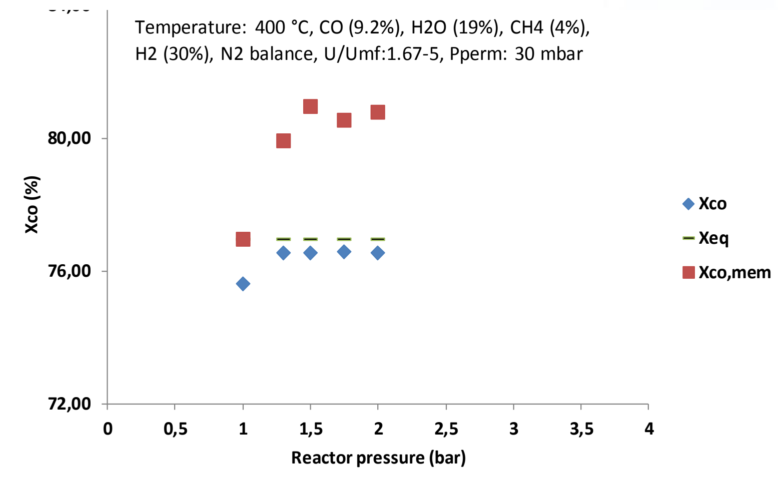
- ❑ Catalyst stable under fluidized conditions in MR
- ❑ MR system has higher conversions than equilibrium for conventional systems

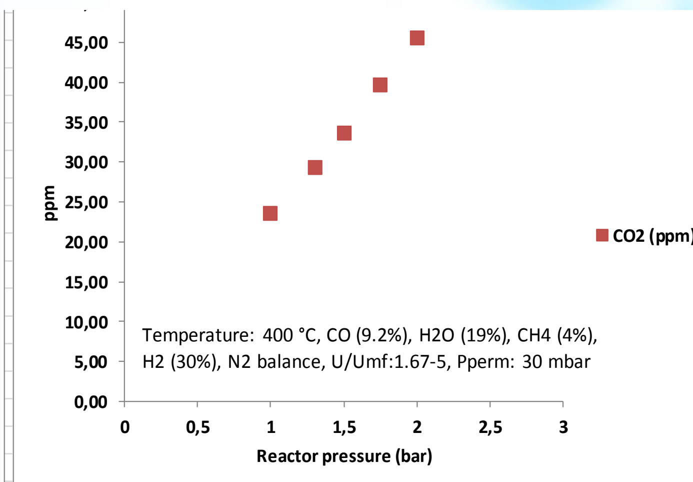
Methane conversion at different pressures (550°C; SMR: S/C=3; ATR: O/C=0.25)

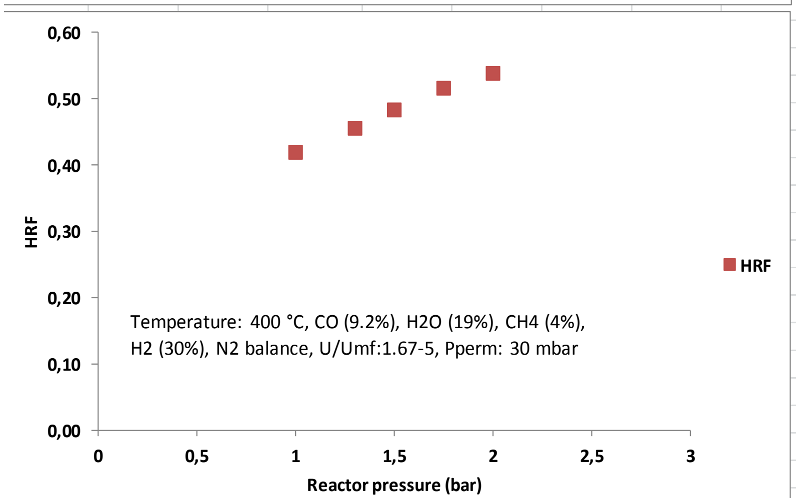


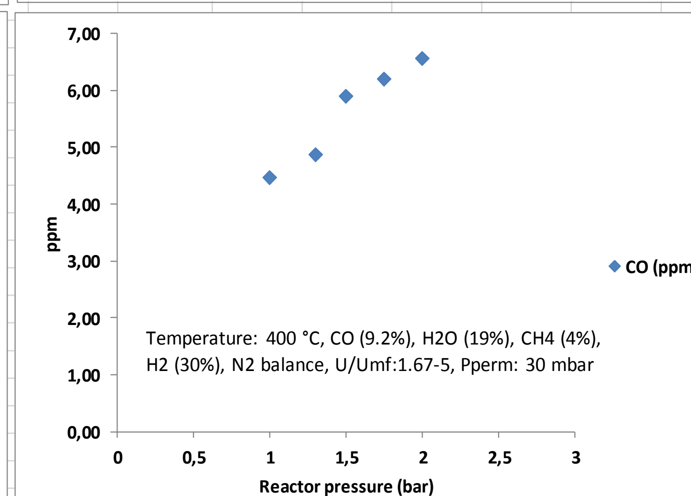
PROJECT TARGETS AND ACHIEVEMENTS: Lab-scale testing - FluidCELL

- Preliminary results with 5 membranes – up to 60% recovery and < 10 ppm CO in H_2





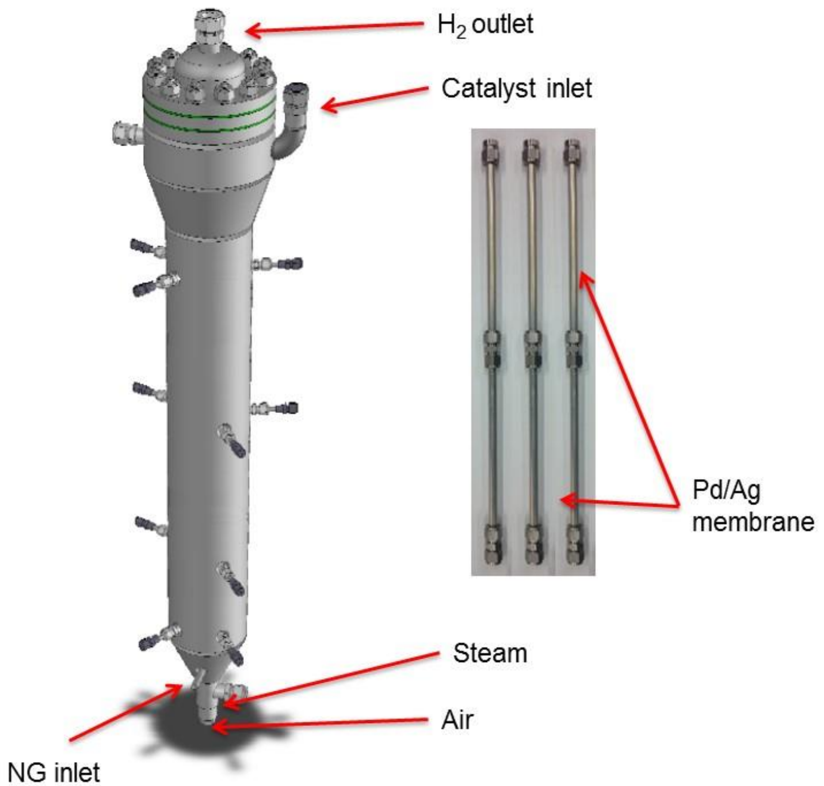




PROJECT TARGETS AND ACHIEVEMENTS: Design and manufacturing of novel ATR reformer

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

- Design novel ATR reformer according PED 97/23 EC
  - 5 Nm^3/h hydrogen production
  - Fluidized bed
  - Partial loads down to 30%
  - Maximum temperature 600 ^0C
  - Nominal pressure 8 bar_a
  - Vacuum on permeate side



PROJECT TARGETS AND ACHIEVEMENTS: Design and manufacturing of novel ATR reformer

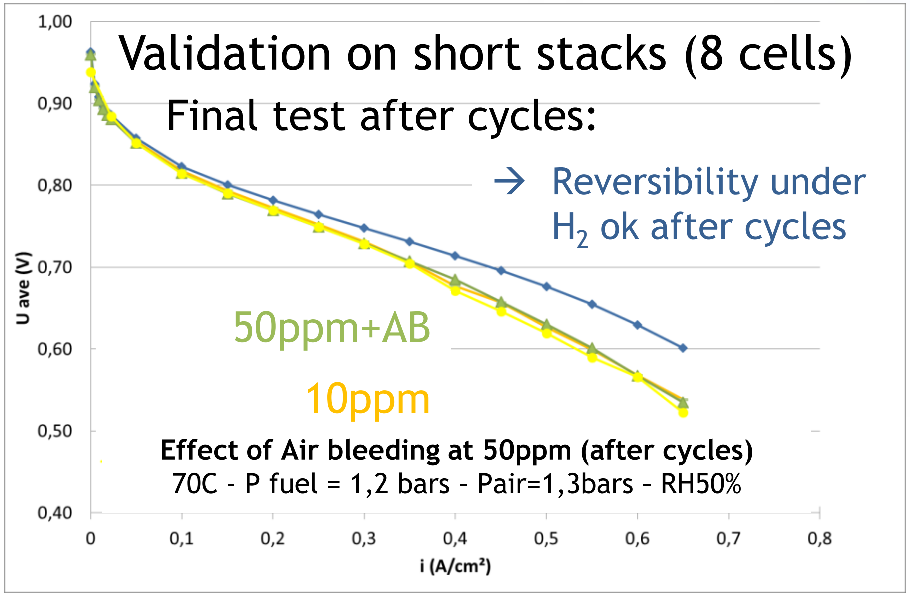
Future work: ATR testing. Feedstock flexibility. Ethanol

- Testing under reactive conditions
- Modulation at partial loads.
- Tuning of controls
- Feedback to other projects using similar technology for different feedstock

  - FERRET: Flexibility to varying NG compositions across EU
  - FluidCELL: Ethanol membrane reformer

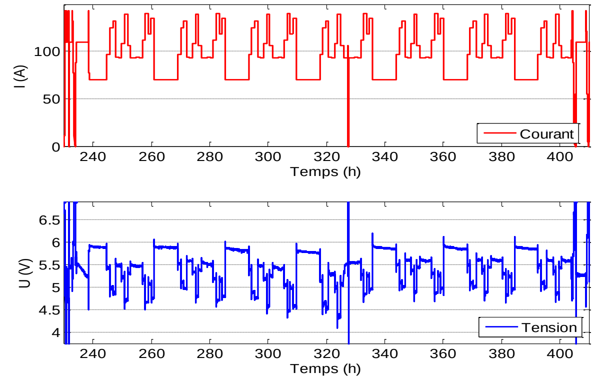
PROJECT TARGETS AND ACHIEVEMENTS: Integration and validation of the CHP system

Fuel cell stack



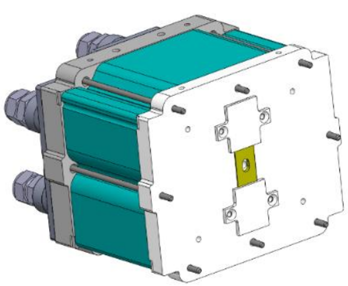
Load cycles (based on 1 day use)

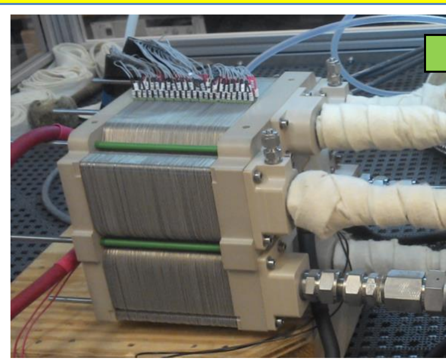
H2 + 10ppm CO or 50ppm+AB

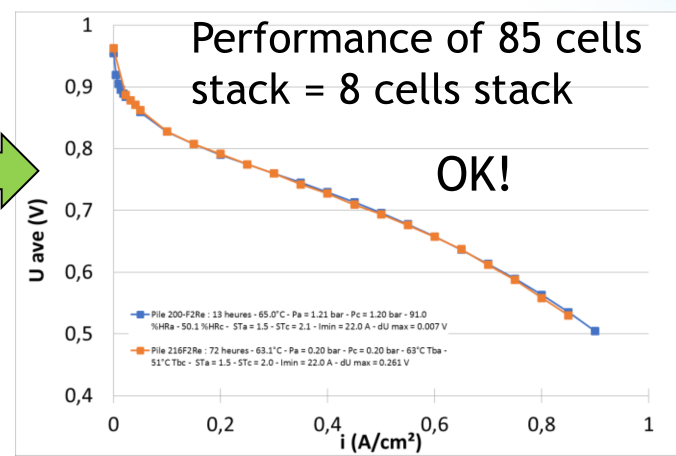


Note: short validation with High CO contents & AB (up to 300ppm)

- ❑ Stack prototype (85cell) designed, made and validated for system integration



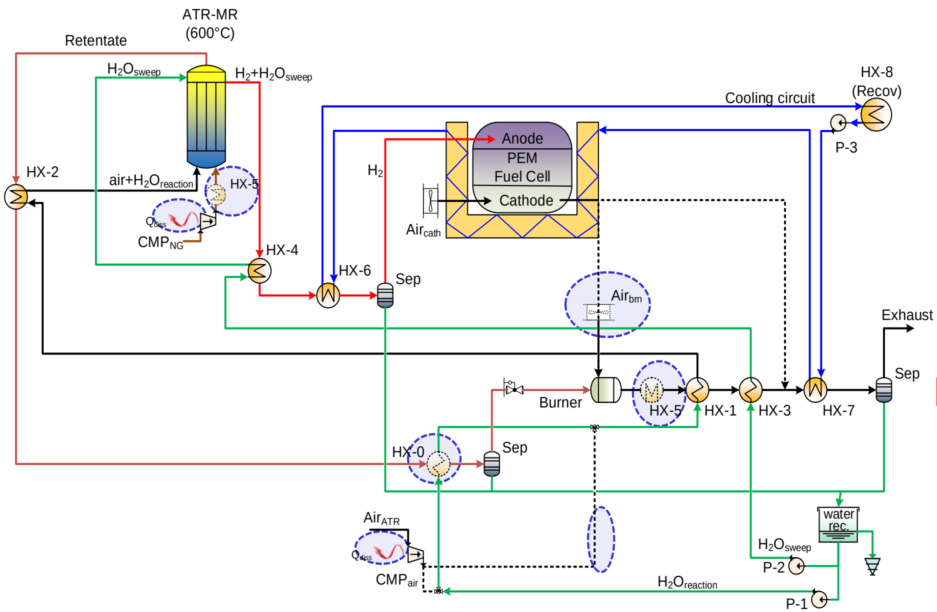




PROJECT TARGETS AND ACHIEVEMENTS: Integration and validation of the CHP system

Fuel cell CHP system optimisation

- In ReforCELL, the plant lay-out and operating conditions were optimized to achieve high efficiency (>40%), while limiting the membrane surface area (<0.3 m^2); Reference system efficiency 32%;
- Different options were evaluated both for the membrane reactor permeate side and heat recovery arrangements;

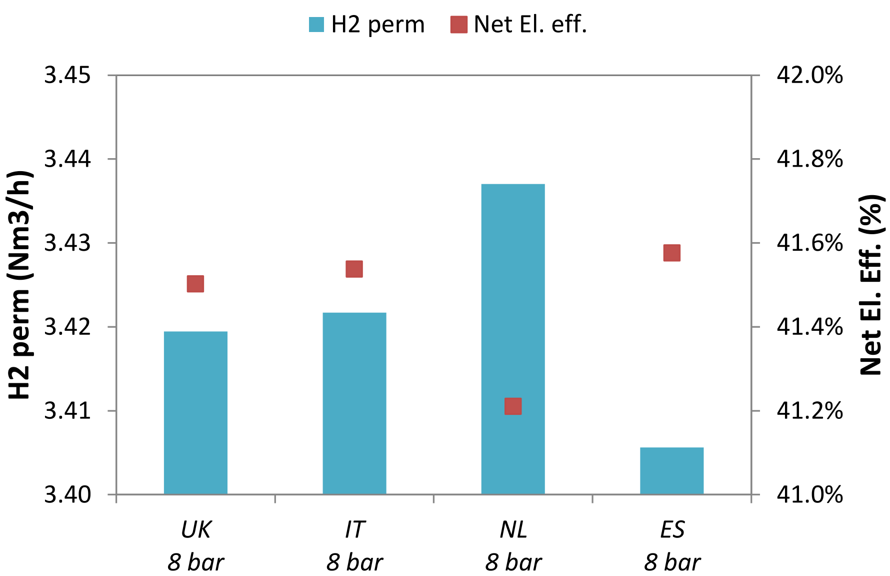


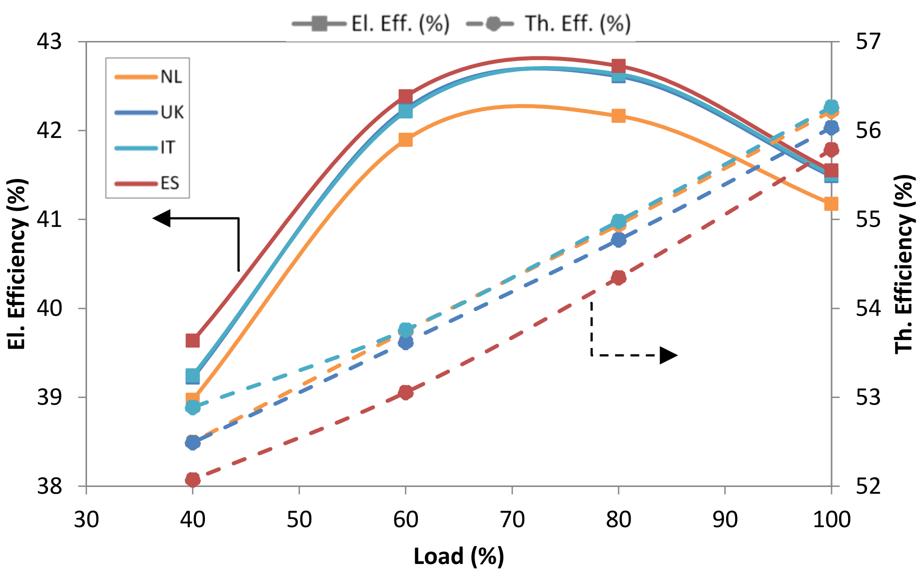
Results	units	Sweep	VP
S/C[a]	-	2.5	3
Pressure reaction side	bar	8	8
Pressure permeate side	bar	1.2	0.3
NG power input [LHV base]	kW	12.50	13.05
Net AC power output	kW	5.00	5.00
Fuel Cell AC power output	kW	6.31	6.63
Net electric efficiency	$\%_{LHV}$	40.02	38.32
Net thermal efficiency	$\%_{LHV}$	51.97	51.86
Total efficiency	$\%_{LHV}$	91.99	90.18
Total membrane area	m^2	0.29	0.19

PROJECT TARGETS AND ACHIEVEMENTS: Integration and validation of the CHP system

Fuel cell CHP system optimisation FERRET

- In FERRET, the lay-out was defined according to ReforCELL achievements and the system performances with different natural gas compositions was assessed (simulation). In addition, electric and thermal efficiency at partial load were also determined.





PROJECT TARGETS AND ACHIEVEMENTS: LCA and safety assessment

- Regarding the Life Cycle Assessment (LCA) activities, **data specific to ReforCELL m-CHP system and for alternative systems** have been collected from project partners and in literature

- The environmental impacts of the ReforCELL system have been calculated, showing the **interest of ReforCELL in comparison with other fuel cell m-CHP systems and with conventional electricity and heat.** ReforCELL is however more impacting than wind power and solar thermal (i.e., green available technology)

- The LCA identified the **efficiency**, the **dimensioning** and **rare metals use** (in fuel cell and fuel processor catalyst) as **key parameters** for the environmental impacts

PROJECT TARGETS AND ACHIEVEMENTS: LCA and safety assessment: next steps - synergies

Next steps and synergies with other projects

- Assess the **influence of dimensioning** on the environmental impacts of fuel cell m-CHP systems
  - Through detailed LCA assessment for ReforCELL (by end 2015)
  - Through FluidCELL project
- Explore **other input fuels** (e.g., biofuels)
  - Through FluidCELL project
- Include more scenarios on fuel cell, fuel processor and balance-of-plant components and use LCA as a **decision support tool**
  - Through FluidCELL project

RISKS AND MITIGATION

- Failure of the membrane reactor prototype.
  Mitigation: - Dynamic response of power and heat production assessed feeding the Fuel Cell with another H2 source. So the m-CHP new design system will be validated.
  - Improving the FAT procedure for the prototype.

- Failure of the membrane when integrating them in the prototype.
  Mitigation: - Using membranes with higher mechanical stability such as:
  i) Thicker ceramic supported membranes (i.e. 10/4 instead of 10/7 mm) or ii) Metallic supported membranes.
  - Sealing more stable at high temperature (already OK for 2 weeks).
  - Improving the handling procedure for the integration of the membranes.

- Long term stability of the membranes
  Mitigation: - Improving membrane stability by:
  i) adding Ru and/or Au in the selective layer,
  ii) better interdiffusion layer and lower thermal expansion mismatch
  iii) thicker ceramic supported membranes.

HORIZONTAL ACTIVITIES

- Technology oriented workshop has been organised with other FCH JU/ EC funded projects that share similar technological challenges:
  - Joint workshop "Scale-up of Pd Membrane Technology From Fundamental Understanding to Pilot Demonstration" with other FCH JU/EU projects (DEMCAMER, CARENA, ReforCELL and CoMETHy) held in November 20-21, 2014 at ECN, Westerduinweg 3, 1755 LE Petten,The Netherlands

- 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

DISSEMINATION ACTIVITIES

- Dissemination & public awareness
  - Public website (www.reforcell.eu; www.ferret-h2.eu; www.fluidcell.eu
  - 6 monthly newsletter & public project presentation
  - Towards national and international organisation related to the R&D field.
  - Participation in international and national conferences and workshops (i.e. 22 presentations, 5 posters).
  - 6 articles, 3 book chapters.
  - Final dissemination

EXPLOITATION PLAN/EXPECTED IMPACT

- The R&D is opening the way to novel and cheaper m-CHP systems for grid and decentralized off-grid applications.
- Flexibility to use different natural gas qualities and bioethanol grades as fuels.
- Reduced CO2 emissions compared to conventional reformers.
- Reduced anthropogenic CO2 emissions compared to conventional fossil fuels.
- Industrial partners in the value chain are members of the consortia. Ownership of the different components are clearly identified.
- Development are considering mass production technologies as well as standard components when possible.

Thank you for your attention

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