Impact Objectives

- Scale-up of membranes developed in the ReforCELL project
- Develop new supported membranes more resistant to a fluidised-bed membrane reactor configuration and using less palladium per m^3/h of hydrogen production
- Demonstrate system high performance and flexibility under different compositions

Flexible membrane reactors for all of Europe

*With a huge market potential throughout Europe and beyond, new systems for distributed heat and electricity generation are gaining steam. Here we speak to **Dr Fausto Gallucci** about how he is working to simplify micro-cogeneration for the whole continent*

Can you briefly explain what the aim of the FERRET (A flexible natural gas membrane reformer for M-CHP applications) project is and how the reactor you have designed improves on conventional systems?

In a membrane reactor, pure hydrogen is produced and separated at the same time. In FERRET, we want to develop a reactor with a membrane-assisted fluidised bed that can produce pure hydrogen from natural gas streams with different compositions. Europe has a large variety of natural gas qualities and the latest legislation in Europe will lead to a broader range of natural gas specifications, and a gas quality that is allowed to change rapidly over time. The aim of FERRET is to develop a new reactor that will produce pure hydrogen and that can be used without modifications in all EU countries.

In a conventional system, a complicated control system is required for a cascade of at least three reactors and a final hydrogen separation, before the fuel cell. With a membrane reactor, the control system has to control a single reactor that produces the pure hydrogen for the fuel cell. Of course, this simplification comes at the expense of flexibility. In a membrane reactor new catalysts have to be developed that can work at the same conditions of the membranes, and this is what we are doing in the project.

How will FERRET address the gap between natural gas legislation and the gas in the home?

In a way we will simplify the lives of EU citizens. The system is very flexible, so we do not need legislators to be as strict on the quality of the natural gas since our system will work with high efficiency anyway. Of course, the efficiency will be higher with better quality natural gas, but the flexibility of our system will allow it to be used in other markets and for other applications, such as biogas reforming.

In what ways has the experience of previous projects, such as ReforCELL and DEMCAMER, been important to setting the pathway for FERRET?

In those previous projects we started with the development of the membranes and membrane reactors. During the meetings for those projects we were discussing what the problems were in further exploiting the membrane reactor and the problem of flexibility was one which would need to be solved sooner or later; this led to the idea for the FERRET project.

What do you see as being the main challenge that has arisen so far during this project?

As usual, scaling up and integrating the technologies at mass production scale is very challenging. It is relatively easy to develop technologies at very small scale in a controlled environment such as a laboratory. However, when this technology has to be scaled up, supplied to partners, and integrated in a bigger reactor, different challenges arise and even the logistics become very important. But I must say that looking at the challenges we had at larger scales has helped us develop new technologies at lab scale and form new ideas for further research.

How have you been sharing the results of FERRET with the wider community?

We have presented the results of FERRET in different workshops, in international conferences, and have submitted to international peer-reviewed journals. One of the FERRET posters received the best poster prize at the International Conference on Catalysis in Membrane Reactors in 2015 in Poland. We are organising a workshop for the final dissemination of the results of FERRET. Together with four other projects (ROMEO, MEMERE, FluidCELL and BIONICO) we are organising the Third European Workshop on Membrane Reactors in Verona, Italy, on 9–10 March 2017, where we also plan to demonstrate the prototype to a larger audience.

Simplifying power generation in the future

*An innovative new reactor system designed by the **FERRET** project will enable highly efficient generation of heat and power across Europe. Using a simplified membrane reactor design, these systems could reshape the landscape of energy distribution*

Efficient use of energy resources is the primary challenge of the modern world. The future of power generation could involve moving away from transmitting electricity long distances from large power stations, to small efficient generators right inside people's homes. Known as micro-cogeneration of heat and power (micro-CHP) systems, these single units can take the natural gas already piped around the continent and produce both heat and electricity when and where it is needed. In addition, this technology perfectly combines with non-predictable renewable energy sources (solar and wind) reducing the challenges of their penetration in the so-called smart-grid scenario.

Although the market potential for micro-CHP across Europe is enormous, the complexity of current systems makes them impractical for widespread adoption. Current systems use a series of reactors to separate pure hydrogen from natural gas. The hydrogen is then used to generate electricity within a proton exchange membrane (PEM) fuel cell. The quality and composition of natural gas varies widely from country to country, meaning that standardisation of these micro-CHP systems remains a significant challenge.

The FERRET project brings together six partners from four European countries to develop a new micro-CHP system with simplicity and flexibility built in from the very beginning. The core of the FERRET system adopts a single, newly developed membrane reactor to replace the cascade of reactors used to generate pure hydrogen in conventional systems. It also uses an innovative new design ensuring that the generator runs at high efficiency no matter where it is or what grade of natural gas is used for fuel. This new prototype system is designed with mass production in mind, in the hope that it will be rolled out across Europe as a more efficient way of generating heat and power, and reducing CO_2 emissions.

LARGE-SCALE MEMBRANE REACTOR PRODUCTION

In recent years, catalytic membrane reactors (CMRs) have been gaining much interest \

Pd-based membranes sealed and ready to be integrated in the FERRET prototype.

from researchers looking to simplify the separation of hydrogen from various fuel sources. CMRs allow for the selective separation of pure hydrogen from a steam and gas mixture which can then be used in a PEM fuel cell, all within a single unit. Previous European projects such as DEMCAMER and ReforCELL kick-started the development of CMRs, demonstrating the superior activity and selectivity of membrane reactors over conventional systems. Researchers at Eindhoven University of Technology and TECNALIA are developing new membranes for the FERRET reactor,

> *The setup of molecular simulation methods, where peeling of one layer from a stack of bulk 2D material is carried out, has enabled the team to gain valuable insight into the key factors that make a good solvent for exfoliation*

whose production can be scaled up to meet the demands of a mass market. This research focuses on making a membrane which is as reliable and stable as possible, whist maintaining highly efficient levels of hydrogen separation from natural gas. Palladium membranes had been shown to be very effective for this purpose in the past, however palladium is very expensive so the amount used in the reactors needs to be minimised. To do this, a new pore-filled membrane (PFM) has been developed. The PFM uses a nanoporous zirconia support with a palladium-silver alloy forming thin membranes inside the pores. This new design dramatically reduces the amount of palladium used but retains highly selective separation and permeation of hydrogen across the membrane. This PFM structure also has the benefit that the palladium alloy membrane is protected from the catalyst inside the CMR.

Researchers have found that small amounts of sulphur in the natural gas can dramatically reduce the effectiveness of the palladium membrane. This is a very significant problem for the flexibility of a micro-CHP system such as FERRET, particularly when it is fuelled by biogas. However, the FERRET researchers have shown that adding small amounts of gold to the palladium-silver alloy substantiallyaly reduces the negative effects of sulphur in the reactor, allowing this system to perform effectively across an even broader range of fuel sources.

INNOVATIVE FLEXIBLE DESIGN

The primary goal of the FERRET project is to design a micro-CHP PEM fuel cell system that can run efficiently using diverse qualities of natural gas, and effectively generate electricity on demand. This requires a new simplified system design in which the entire process is carried out within a single membrane reactor. The membrane reactor is used to separate pure hydrogen and feed the fuel cell for electricity generation. Effective separation increases the electric conversion efficiency of the fuel cell.

The FERRET layout is particularly designed around flexibility, using the palladium membranes on a zirconia support within the membrane reactor. Tests of the FERRET system show that the net electric efficiency is generally 15 per cent higher than commercially available micro-CHP systems. But most importantly, the tests showed that there was very little difference in performance and efficiency between the different qualities of gas and that the electrical efficiency was at least 39 per cent with even the most dilute gas.

THE FUTURE OF MICRO-CHP

With the FERRET reactor designed and built, the next stage in the project is to demonstrate its performance at a large scale: 'We are scaling up the membrane production to be able to enter the market with the new FERRET system', says Dr Fausto Gallucci, Project Coordinator for FERRET. 'We have test facilities for reactors, for hydrogen production and for prototypes and fuel cell systems.' The membrane reactors have already been shown to perform effectively in laboratory-scale tests, running for over 1000 hours at the operating temperatures.

The legacy of FERRET lies not just in the new technology that has been developed, but also in the experience of the people who have been involved. 'We have several young researchers working on FERRET, some of whom received their PhD during the project, and the technology of FERRET was part of their thesis. We strongly believe in educating young researchers who will be the developers of this technology in the near future,' says Gallucci. Furthermore, Gallucci explains that the connections fostered within this collaborative project has helped researchers quickly overcome difficult challenges: 'Instead of working on a problem for a long time, a partner can give you the solution in a few hours of discussion and during workshops we have the opportunity to discuss with other colleagues working in other projects but facing the same kind of problems – this can help us both find solutions faster.'

With prototype testing set to begin in late 2016, the FERRET project has shown that micro-CHP systems will soon be a viable alternative for efficient heat and electricity generation across all of Europe.

Project Insights

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PROJECT LEADER BIO

Dr Fausto Gallucci earned his MSc degree in Chemical Engineering from the University of Calabria and his PhD in Chemical Engineering from there in 2006. His research interest is the interaction of heterogeneous catalysis, transport phenomena, and fluid mechanics in novel multifunctional reactors. Gallucci has published more than 120 papers on topics ranging from gas separation systems, methanol synthesis from CO2 and hydrogen carried out in zeolite membrane reactors, and membrane reaction systems (partial oxidation, steam reforming, water gas shift) carried out in novel membrane reactors. He is coordinator of several national and international projects on fluidised-bed membrane reactors, chemical looping combustion systems, bio-based processes, etc.