Impact Objectives

- Design and construction of the largest catalytic membrane reactor for hydrogen production from biogas in the world
- Experimental activity at laboratory and industrial scale and modelling activities
- Techno-economic and environmental assessment of the novel technology

A clean fuel future

__Dr Marco Binotti__, __Dr Giampaolo Manzolini__ and __Dr Gioele Di Marcoberardino__ highlight the challenges and successes of the joint __BIONICO__ innovative membrane reactor technology project, which has helped to pave the way toward a new future for sustainable hydrogen fuel production

The BIONICO project was previously shared in *Impact* where you talked about the work underway to convert biogas to hydrogen using an innovative membrane reactor. What progress has been made?

MB: A lot of work has gone into developing the innovative membranes and the catalyst for the BIONICO reactor. The reactor was finally assembled in January 2019, including 125 new finger-like membranes and 35 kg of the new catalyst for biogas reforming. The BIONICO system was then completed, including all the auxiliaries required to run the reactor, and tested in November 2019. The testing activity demonstrated the capability of the CMR to produce high purity hydrogen, but a severe failure of auxiliary components ultimately damaged the reactor stopping its activity. In parallel to the design and construction of the BIONICO system and components, the experimental activity at a laboratory scale and the modelling activities were developed, providing information for an overall techno-economic and environmental assessment of the novel technology.

You mentioned the difficulties with auxiliary components, what other challenges did you face and how were these overcome?

GM: Now that the project is completed the next challenge for catalytic membrane reactor technology is related to the necessity of long-term testing activity to further prove the reliability of the technology. The project itself was full of challenges and innovations as the scaling up of the technology within BIONICO has been significant. With respect to previous projects on membrane reactors such as FluidCell and Ferret, the size of the membrane tubular supports was considerably increased both in diameter and length, allowing the deposition of a larger membrane area per support. These improvements, coupled with the newly developed finger-like asymmetric supports, allowed for the considerable reduction of leakages through the membranes. Moreover, not only the size but also the number of membranes produced was significantly incremented, requiring a nearly-industrial process. The membrane area inside the BIONICO reactor was finally 10 times higher with respect to previous projects, making BIONICO the largest catalytic membrane reactor for hydrogen production from biogas in the world.

With the project officially complete, what are the next steps for this research?

GDM: Catalytic membrane reactors have shown the potential to increase efficiency through process intensification and reduced costs, but testing activity at a large scale in BIONICO was unfortunately limited. The main goal now is to further test the technology for thousands of hours at an industrially-relevant scale to show its reliability and to verify that no significant performance decays will occur. The MACBETH project (www.macbeth-project.eu), which started in November 2019 and in which most of the scientists from the BIONICO project are involved, will apply this technology to different industrially-relevant cases for a cumulative demonstration of more than 30,000 hours.

How important was it for this work to be collaborative across institutions?

MB: The academic and industrial points of view can be very different, and I think within the collaboration framework of the project it was possible to merge these two points of view to bring innovation forward. The tight and effective collaboration within BIONICO is one of the reasons why new projects involving most of the consortium are already up and running. ●

Delivering efficient, renewable hydrogen fuel production

Now completed, the __BIONICO__ collaboration has designed and built the world's largest catalytic membrane reactor for hydrogen production from biogas, delivering a major innovation that improves efficiency and production capacity

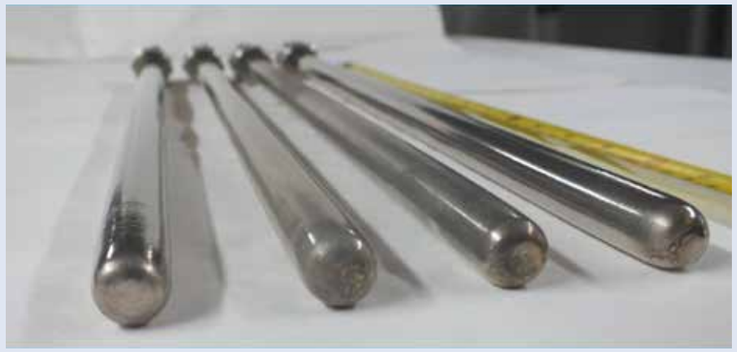
With the race to replace the burning of fossil fuels as the major source of energy ramping up, more and more alternative strategies are beginning to come online. Wind, solar and hydro-power are mainstays in the green energy movement and while they are still being incrementally improved other lesser known technologies are beginning to enter large scale testing phases. The push these technologies are receiving and the outcomes of these trials are immensely important too. A shift to a carbon neutral society will be a large undertaking and likely won't involve any one technology on its own but rather a combination of different energy sources that together replace our vast reliance on fossil fuels.

A second aspect to this conversion is underpinned by the notion of a circular economy. In short this means extending the life of products or resources by using waste created from one process in the production of another. In this way there are no dead-end streams to a resource life-cycle, instead there is a closed loop. One alternative energy source is leveraging this and is poised to become another player in the renewable energy market - being the conversion of biogas to hydrogen. This renewable energy source starts with the anaerobic (without oxygen) digestion of residual biomass and other waste material. Primarily biogas can be used for heat and electricity generation but it can also be upgraded to biomethane and used to produce hydrogen. In turn hydrogen can replace fossil fuels for generating power and in vehicles, and can do so with reduced pollution and CO_2 emissions. Better still, waste material is used to produce biogas, and this biogas is then used to produce hydrogen, further lowering the emissions.

DEMONSTRATING VALUE

Membrane reactor technology can be applied to generate hydrogen from biogas. In order to address some of the challenges with the existing membrane reactors, an innovative design has been under development since 2015. Along with collaborators at the Politecnico di Milano University and abroad, Project Coordinator Dr Marco Binotti has been overseeing the progress of BIONICO. Officially completed in late 2019 BIONICO set out to demonstrate a new membrane reactor concept for converting biogas into hydrogen in a real biogas plant. The novel design the BIONICO team introduced meant that hydrogen production and separation could be completed in a single vessel. A big innovation that would improve efficiency and production capacity.

This novel catalytic membrane reactor design is expected to increase overall efficiency up to 72 per cent and produce extremely pure, 99.99 per cent hydrogen. 'Not only were the ▶



BIONICO palladium based finger-like supported membranes for hydrogen production

application and the scale of testing through the project new, but also the components developed to see the reactor come to life,' highlights Binotti. For the past four years the BIONICO team have been hard at work on these challenges, while at the same time conducting preliminary economic analyses of the BIONICO plant in order to identify the right market for the innovative technology. This is no small feat and ended in the reactor achieving positive test results at the manufacture site before needing to be shut down just short of the main goal, a full test at a biogas reactor in Portugal.

> *The project allowed us to introduce a significant number of innovations on the components and to make a leap forward in the industrialisation of the catalytic membrane reactor*

STRUGGLE FOR CLEAN FUEL

'After 52 months of hard work the BIONICO project has finally ended but unfortunately, due to a current dispersion which caused severe damage to the reactor, we had to close the project without being able to demonstrate the systems operation in a real biogas plant,' says Binotti. While this minor setback was disappointing the team still made huge leaps forward towards their overall goals. 'The project allowed us to introduce a significant number of innovations on the components and to make a leap forward in the industrialisation of the catalytic membrane reactor technology,' he outlines. The team always knew the project was going to be full of significant challenges associated with scaling up their new technology.

Despite the challenges, they were able to make major progress on the components side and performance in the limited hours of testing. 'We achieved the targets set in terms of components development, energy-economic-environmental performance, laboratory experiments and reactor construction,' explains Binotti. 'Regarding the energy-economic and environmental performance the modelling activity showed biogas-to-hydrogen conversion up to 72 per cent and a 10 per cent potential cost reduction with respect to commercial technologies all with reduced environmental impact.'

The main achievement was the design, manufacturing and testing of the largest reactor of this type. Because the testing was cut short the main goal is now to further test the technology for thousands of hours at an industrially-relevant scale to show its reliability and to verify that no significant performance decay will occur. For Binotti the project was a fulfilling and successful experience. 'The experience gained in these years are of inestimable value for further developing the technologies related to membrane reactors,' he says. 'The industrial interest for the project and the technological innovations brought by BIONICO point to a promising future for catalytic membrane reactors as key components for green hydrogen production and for process intensification.'

BUILDING ON SOLID FOUNDATIONS

The technological success of this project was built on a strong foundation of collaboration brought together by the BIONICO consortium. This included two universities, one research centre, three industries and two innovative SME's resulting in an overall well-balanced team. Not stopping here, the group also reached out to groups across Europe by organising a workshop on Membrane Reactors to share ideas and results. 'This workshop was a valuable moment for exchanging information and discussion of common problems and brought together most of the scientists and industries working on the membrane reactor technology.'

The recognition of the importance of a strong, diverse team and the networks built during the BIONICO project are already bearing fruit for the future of reactor technology. A new project, named MACBETH, is currently underway and includes many of the BIONICO scientists. It will apply catalytic membrane reactor technology to four industrially relevant scenarios, the hydrogen production from biogas and natural gas, just like BIONICO did, along with propane dehydrogenation, hydroformylation and bio-catalytic oil cleavage.

The BIONICO team near the BIONICO reactor during a consortium meeting at ICI Caldaie

Project Insights

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