


**LA TRANSIZIONE ENERGETICA IN PIANURA PADANA:  
UN'INFRASTRUTTURA CONDIVISA PER L'IDROGENO  
29/11/2018 SPILAMBERTO (MO) - ITALIA**

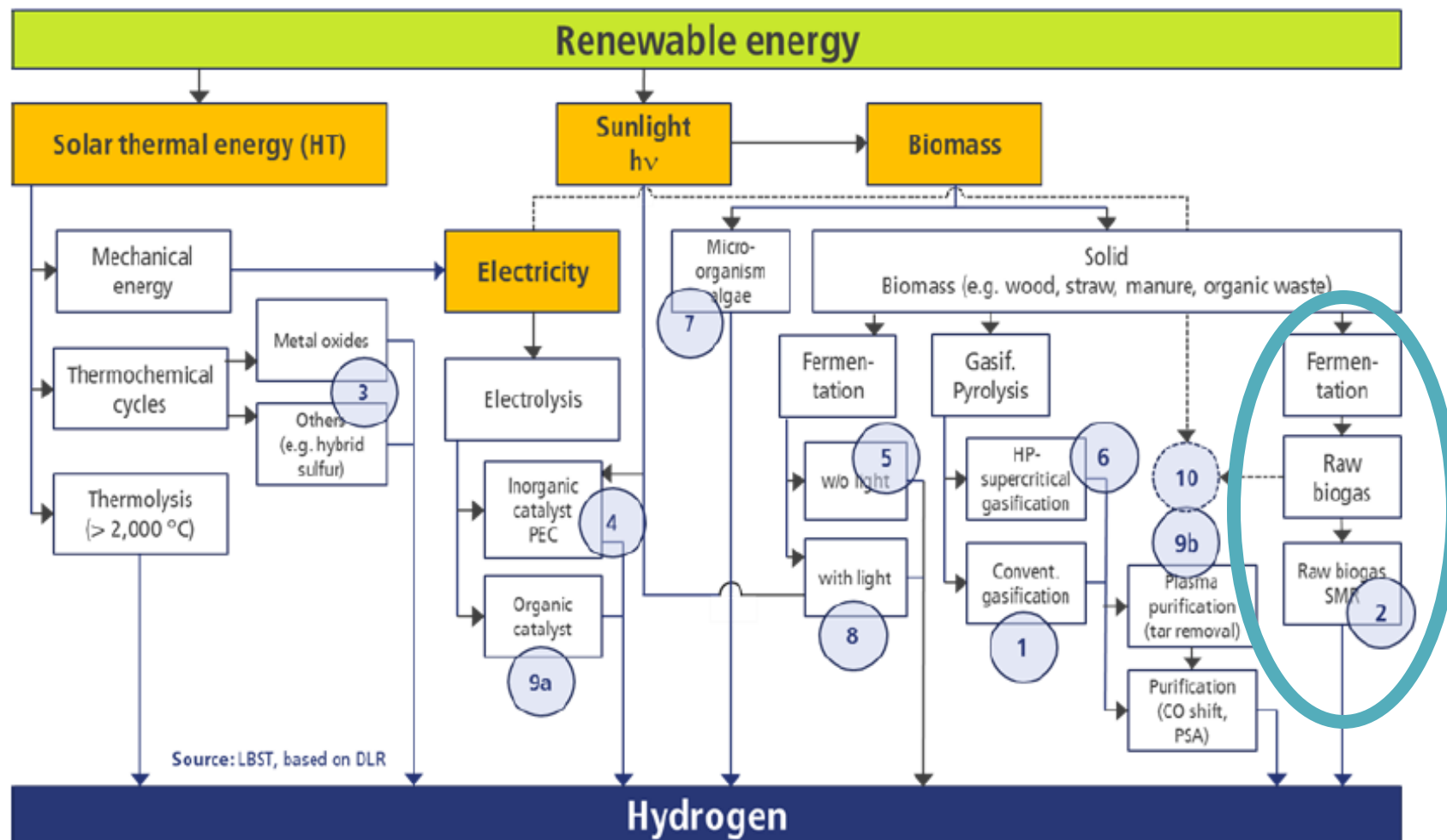
A decorative graphic on the left side of the slide, featuring a vertical chain of interconnected blue and green circles of varying sizes, resembling a molecular or network structure.

## **BIONICO BIOGAS MEMBRANE REFORMER FOR DECENTRALIZED H<sub>2</sub> PRODUCTION**

Call: H2020-JTI-FCH-2014-1 Topic: FCH-02.2-2014 Decentralized hydrogen production from clean CO<sub>2</sub>-containing biogas



# INTRODUCTION



*\*Fuel Cells and Hydrogen Joint Undertaking. Study on Hydrogen from renewable resources in the EU*



# SUMMARY

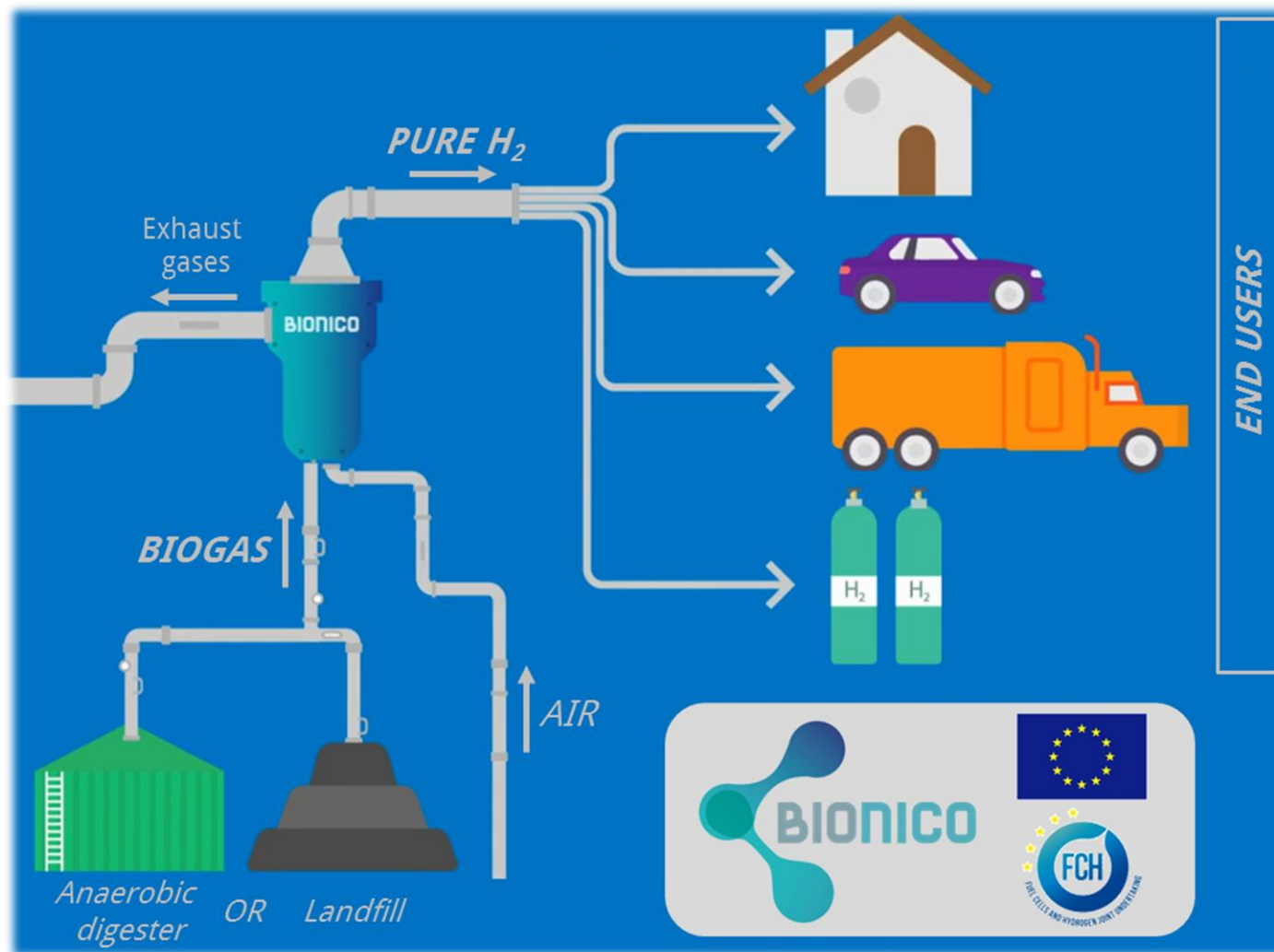
BIONICO **aims** at developing a **novel reactor** configuration at a **larger scale** to produce **100 kg/day** of **H<sub>2</sub>** from **biogas** production power plant based on:

- Design, develop and test a **new concept** reactor integrating hydrogen **production** and **purification** on a **single unit**
- Design, develop and testing of a **catalytic membrane reactor** for the production of highly-purity hydrogen from biogas, scaling up new H<sub>2</sub> selective **membranes** and **catalyst** production
- Develop a **flexible system** (including the advance control and BoP components) capable of producing pure hydrogen from **biogas of different compositions** in a unique reactor system.

The main idea of BIONICO is to design and demonstrate an **efficient biogas-to-hydrogen conversion system** at real plant conditions using process intensification.



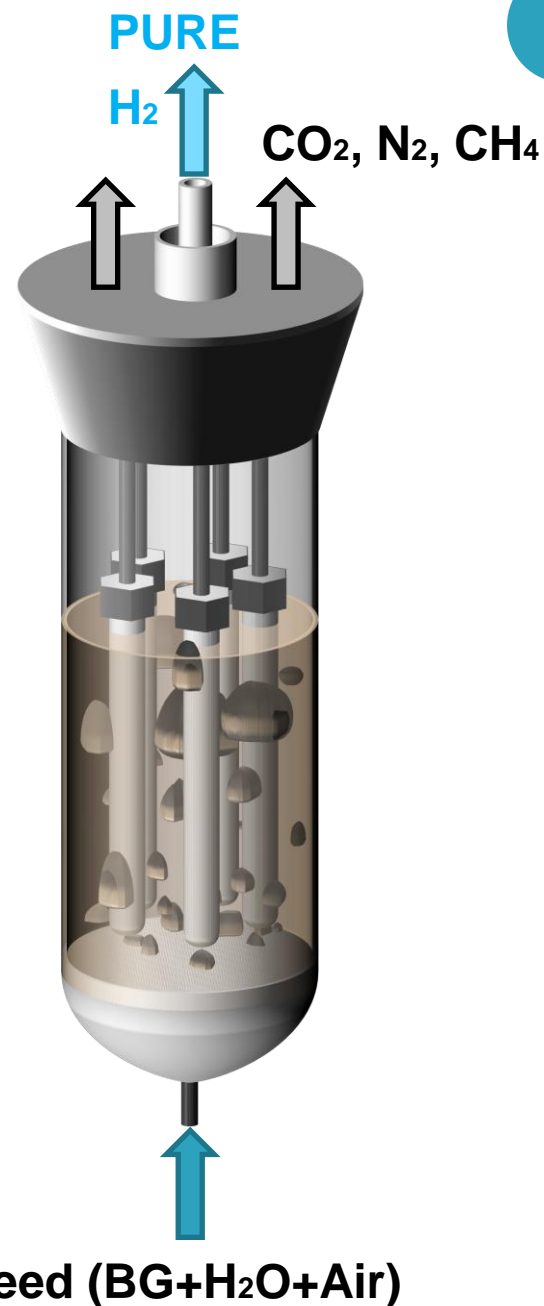
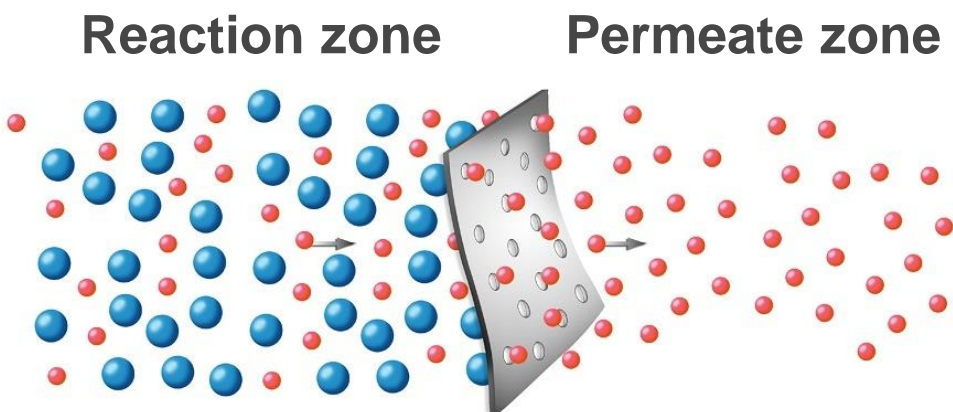
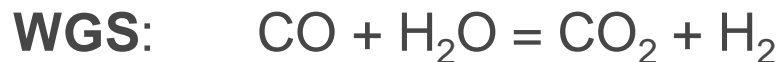
# CONCEPT





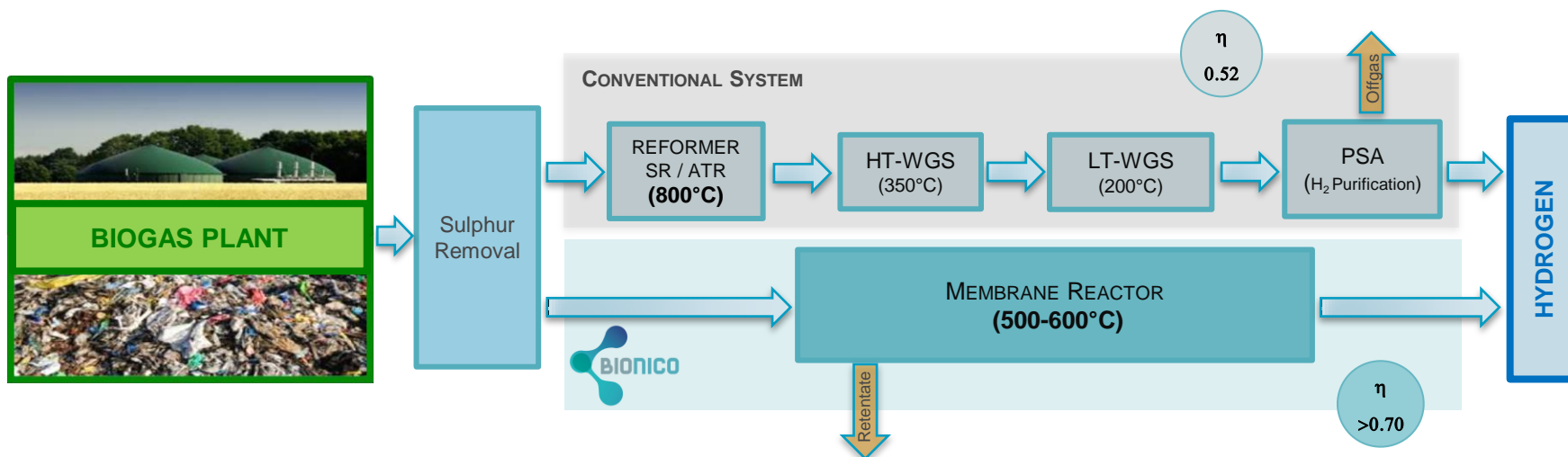
# CONCEPT

**Fuel conversion** and **H<sub>2</sub> separation** take place in a single reactor thanks to a **membrane** perm-selectivity for H<sub>2</sub>





# WHY BIONICO?



Reference Case Results

	units	SR	ATR
Biogas feed	Nm <sup>3</sup> /h	39.5	63.5
Total Biogas Input	kW	229	368
System efficiency	% <sub>LHV</sub>	51.7	27.8
Hydrogen delivery pressure	bar	20	20
Hydrogen production cost	€/kg	4.21	6.37

Two reference cases (based on SR and ATR) are identified to benchmark the performance of the BIONICO concept

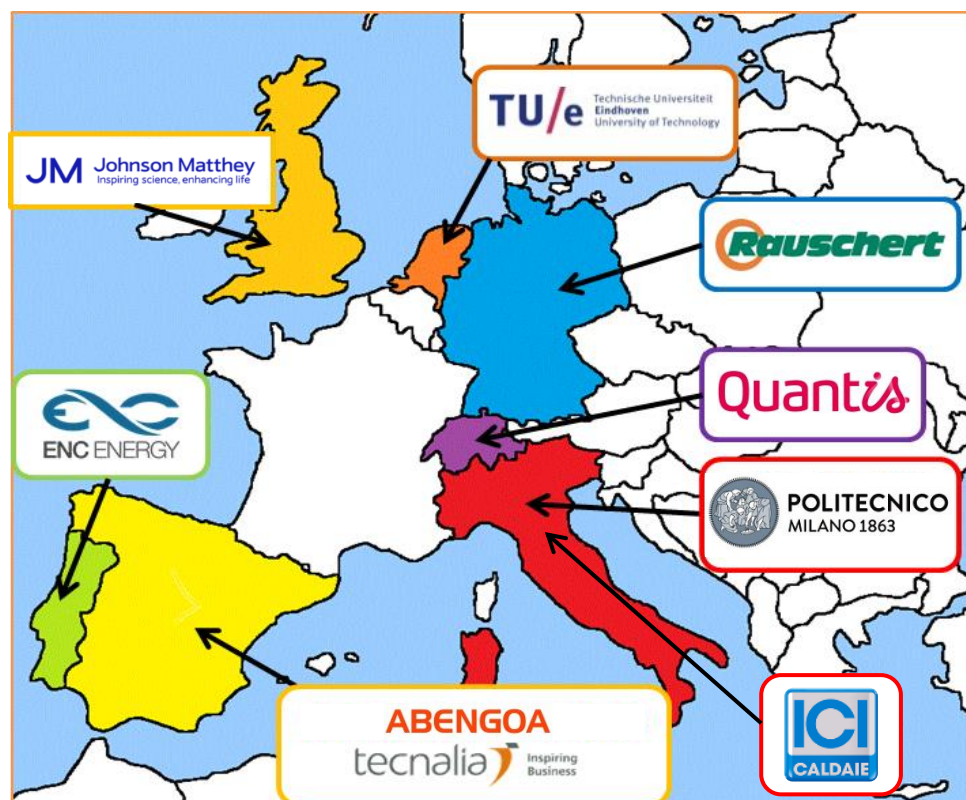
The target of BIONICO is a system efficiency above 70%<sub>LHV</sub>, which is about 25% higher than SR (52%<sub>LHV</sub>). The higher efficiency together with equipment savings will end up in lower hydrogen production costs.



# PARTNERSHIP

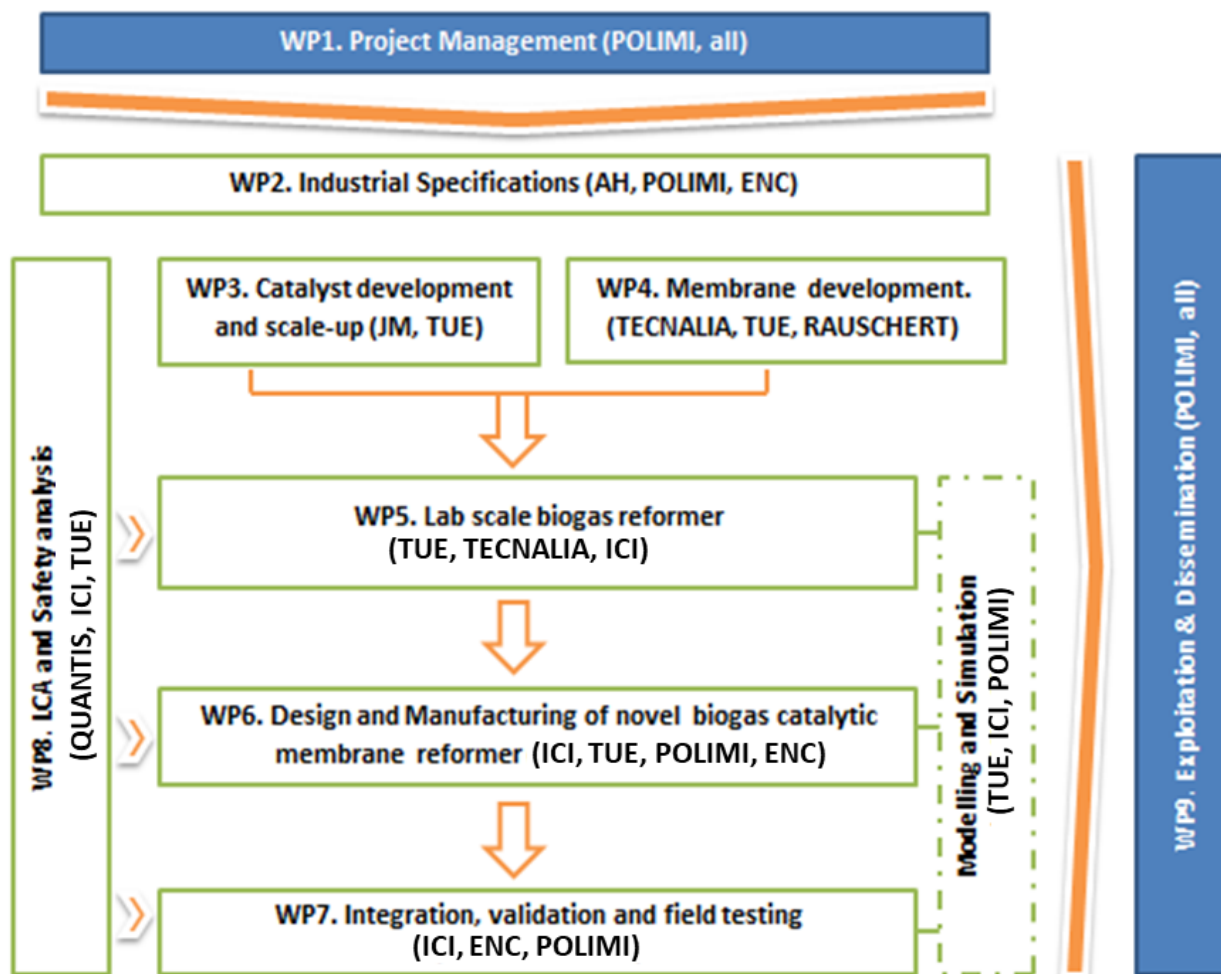
Multidisciplinary and complementary team: 8 top level European organisations from 7 countries including 3 Research Institutes and Universities and 4 representative top industries in different sectors (from catalyst to membranes to chemical and process engineering, etc.)

- POLIMI, Italy
- TU/e, The Netherlands
- Abengoa, Spain
- Tecnalia, Spain
- ICI caldaie, Italy
- Johnson Matthey, UK
- ENC Energy, Portugal
- Rauschert, Germany
- Quantis, Switzerland



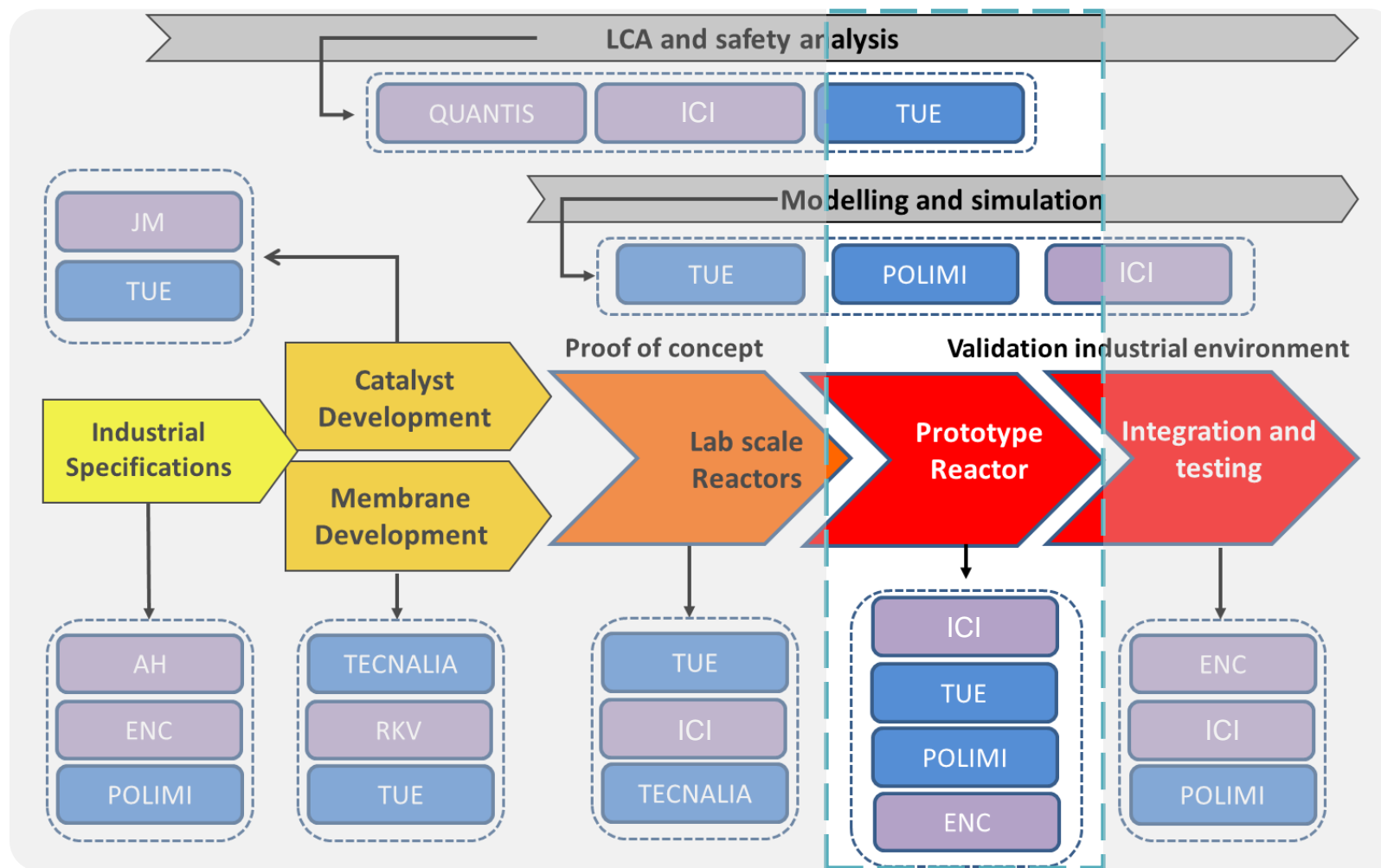


# WORK STRUCTURE





# PARTNERSHIP SYNERGIES





# NOVEL CATALYST

## GOAL

Development of highly active reforming catalysts to produce hydrogen from diverse biogas mixture coupled with steam and air in a fluidised bed regime.

## THREE YEARS PROJECT ACTIVITIES

- PGM doped alumina catalysts have been tested under biogas reforming conditions for dry, steam or autothermal reforming
- Coke formation resistance improvement

## ACHIEVEMENTS

- 1<sup>st</sup> generation catalyst and 2<sup>nd</sup> generation catalyst able to work under fluidisation regime and at low temperature
- Final Catalyst formula produced and shipped to ICI



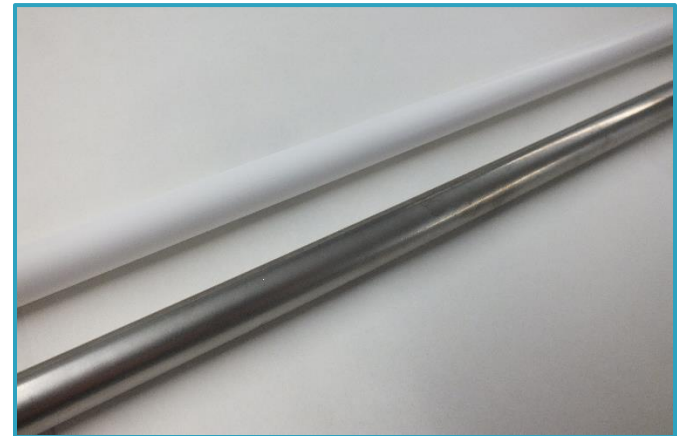
# NOVEL MEMBRANE & SUPPORT

## GOAL

Development of Pd based tubular supported membranes, for application in biogas reforming catalytic membrane reactors

## ACHIEVEMENTS

- 1<sup>st</sup> generation membrane & support
- Installation of a new plating system for preparation of >40 cm long membranes.
- 2<sup>nd</sup> generation membrane & support.
  - Thin Pd-Ag layers have been deposited onto the 50 cm long finger-like supports.
- Definition of criteria for support quality
- Improvement of manufacturing procedure for membrane prototype production
- Membranes for prototype preparation



*2<sup>nd</sup> generation thin film Pd-alloy supported membranes (>40 cm long)*





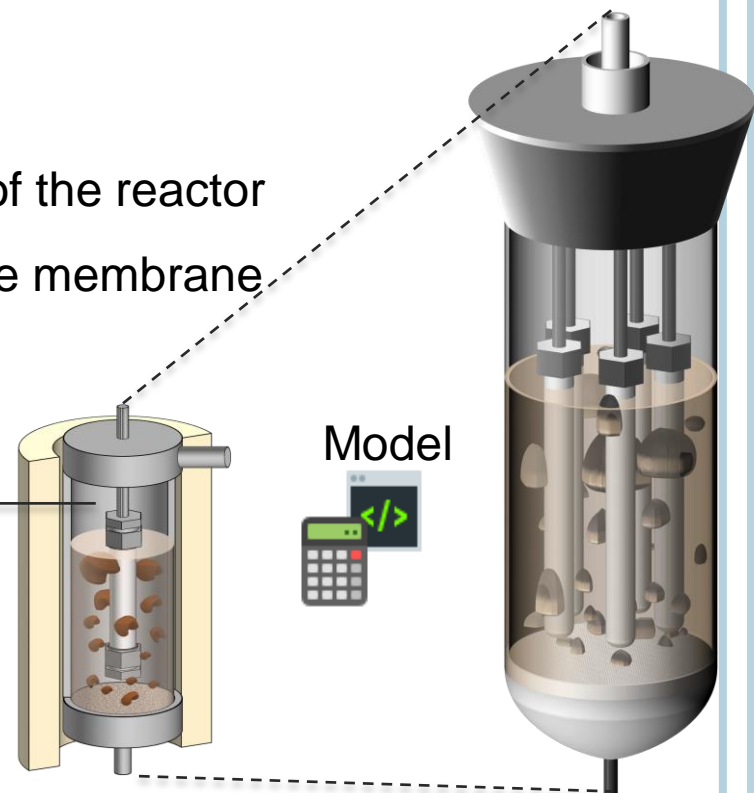
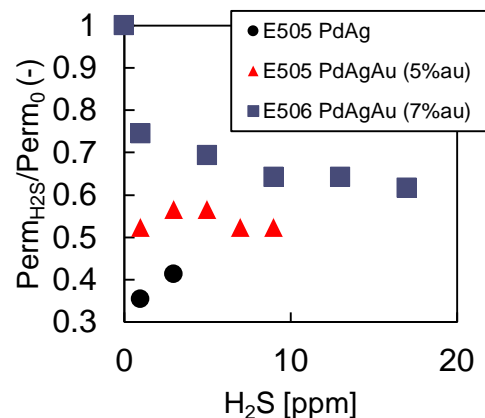
# LAB SCALE REACTOR

## GOAL

Definition of the lab scale reactors performances and identification of the best design for prototype pilot.

## ACHIEVEMENTS

- Integration of catalyst and membrane
- One dimensional phenomenological model of the reactor
- Effect of Au addition on  $H_2S$  resistance of the membrane



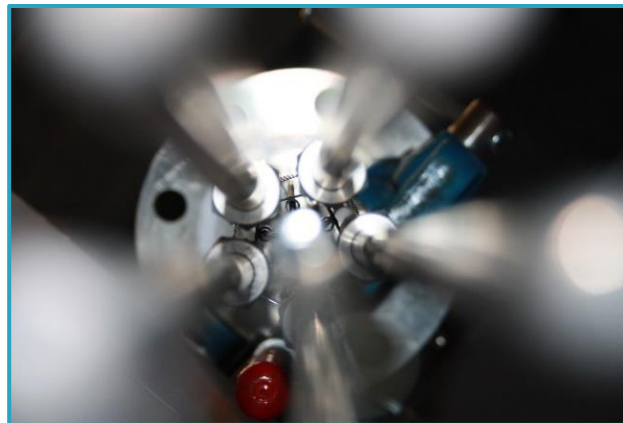


# LAB SCALE REACTOR

## GOAL

Definition of the lab scale reactors performances and identification of the best design for prototype pilot.

## ACHIEVEMENTS



- Successful description of concentration polarization in the reactor model
- Lab scale system with 5 membranes equal to the once that will be used in the pilot, as well as the catalyst, have been tested





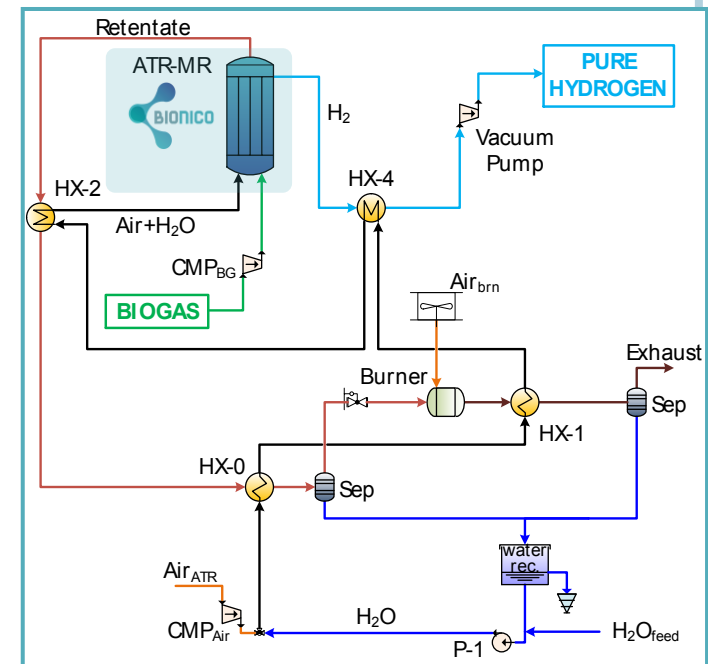
# PROTOTYPE REACTOR

## GOAL

Final design and construction of MR prototype for the production of approximately 100 kg/day of pure hydrogen

## ACHIEVEMENTS

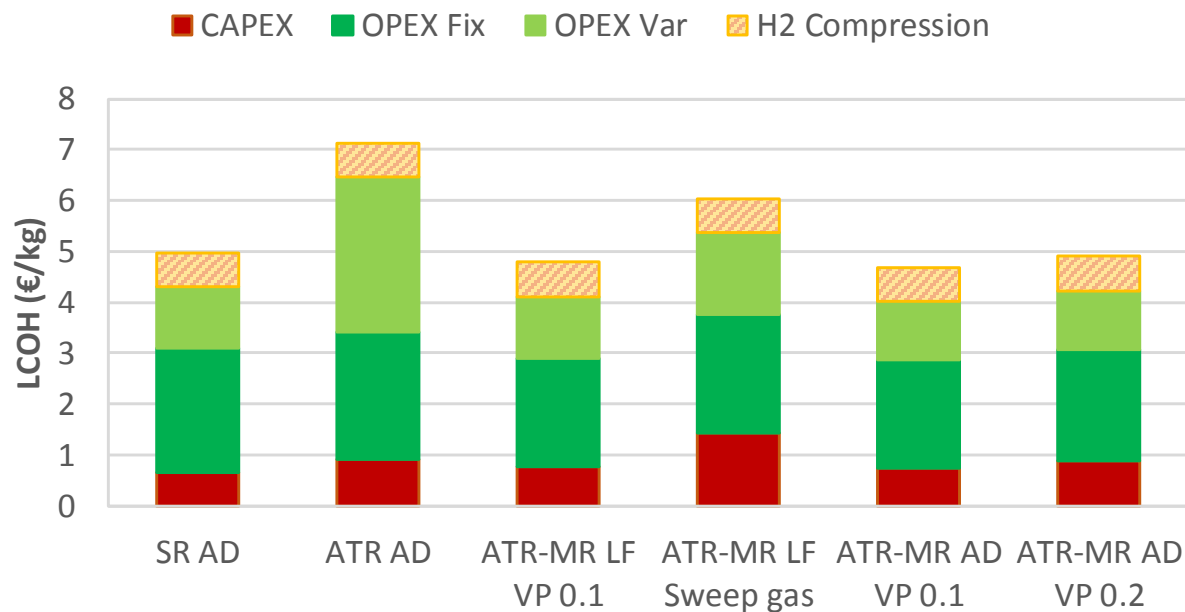
- A techno-economic optimization of BIONICO system was assessed
- Different operating conditions (T, p, S/C), biogas compositions and permeate side configuration were investigated
- Membrane reformer designed and manufactured by ICI





# BIONICO PERFORMANCE

Parameter	units	BIONICO LF			BIONICO AD	
Temperature	°C	550	550	550	550	550
P feed	bar	12	10	20	12	12
P permeate	par	0.1	0.1	1.1/sw	0.1	0.2
BG Feed	Nm <sup>3</sup> /h	35.2	35.3	50.8	26.8	27.1
BG Input	kW	154.6	155.0	223.3	154.8	156.7
H <sub>2</sub> production	kg/day	100	100	100	100	100
System efficiency	%	71.5	71.9	55.4	73.0	73.8
System efficiency (H <sub>2</sub> @ 20 bar)	%	65.1	65.2	51.2	66.1	66.7
System efficiency (H <sub>2</sub> @ 700 bar)	%	56.2	56.4	45.6	57.0	57.5





# BIONICO PROTOTYPE REACTOR





# INTEGRATION & TESTING AT BIOGAS PRODUCTION SITE

## GOAL

Final evaluation of the innovative process to directly produce pure hydrogen in a real biogas production site (ENC Landfill plant)

## THREE YEARS PROJECT ACTIVITIES

- Definitions of input needed for starting the plant licensing procedure
- Evaluating the integration of the prototype reactor in the overall BIONICO system at biogas production site



*Biogas cleaning unit*



*Landfill plant*



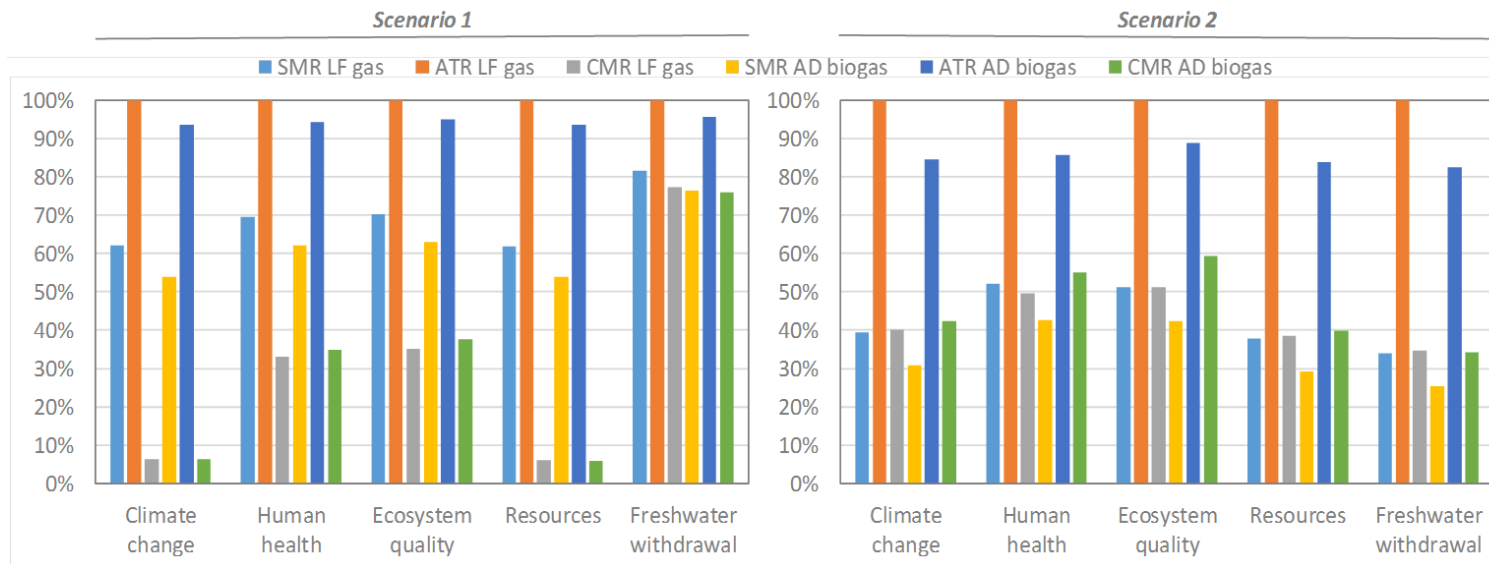
# LIFE CYCLE ASSESSMENT & SAFETY ISSUES

## GOAL

Development strategy towards sustainable solutions

## ACHIEVEMENTS

- Refined LCA modeling and results: BIONICO CMR only performs significantly better for most environmental indicators than reference systems when biogas utilization is limited (Scenario 1, Left)





# DISSEMINATION ACTIVITY

BIONICO partners travelled for thousands of kilometers to disseminate the project and its achievements in the first three years of the project

- Papers (6)
  - Potentiality of a biogas membrane reformer for decentralized hydrogen production, *Chem. Eng. and Processing: Process Intensification*, Open Access
  - On concentration polarisation in a fluidized bed membrane reactor for biogas steam reforming: Modelling and experimental validation, *Chemical Engineering Journal*, Open Access
  - Palladium based membranes and membrane reactors for hydrogen production and purification: An overview of research activities at Tecalia and TU/e, *Int. Journal of Hydrogen Energy*
  - Green hydrogen production from raw biogas: a techno-economic investigation of conventional processes using pressure swing adsorption unit, *Processes*, Open Access
  - Achievements of EU projects on membrane reactor for hydrogen production, *Journal of Cleaner Production*, open access
  - Effect of Au addition on hydrogen permeation and the resistance to H<sub>2</sub>S on Pd-Ag alloy membranes, *Journal of Membrane Science*



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- **Presentations (12+) & Posters (7)**

- 2018 - Life cycle assessment and economic analysis of an innovative biogas membrane reformer for hydrogen production, *ICH2P 2018, Croatia*
- 2018 - 15 Times More Memb. Area: How scaling-up affects biogas steam reforming in a fluidized-bed membrane reactor, *ICIM 2018, Germany*
- 2018 - On the mass transfer rates in fluidized bed membrane reactors, *ICIM 2018, Germany*
- 2018 - On the mass transfer rates in fluidized bed, *ISCRE 25, Italy*
- 2018 - Palladium membrane reactors for hydrogen production, *EHEC 2018, Spain*
- 2018 - Design and Demonstration of a lab-scale fluidized-bed membrane reactor for biogas steam reforming, *EHEC 2018, Spain*
- 2017 - Stability of Ceramic supported PdAg membranes for hydrogen production in a fluidized bed membrane reactor, *ICCMR, USA*
- 2017 - MRPI workshop: BIONICO activities mentioned together with other projects, *MR4PI, Italy*
- 2016 - Achievements of EU projects on membrane reactor for hydrogen production, *SDEWES conference, Portugal*
- 2016 - Palladium based membranes and membrane reactors for hydrogen production and purification, *WHEC 2016, Spain*
- 2016 - Fluidized bed membrane reactors for hydrogen production using thin Pd-based (<5 µm) supported membranes, *ICIM conference, USA*
- 2016 - Effect of the addition of Au in Pd-Ag alloy membranes on the hydrogen permeation performance under the presence of H<sub>2</sub>S, *ICIM conference, USA*
- 2017 - Bionico project - preliminary assessment of hydrogen production from biogas using a fluidised bed catalytic membrane reactor, *Regatec, Pacengo, Italy*
- 2017 - Potentiality of a biogas membrane reformer for decentralized hydrogen production, *MR4PI workshop, Verona Italy*
- 2016 - Biogas membrane reformer for decentralized H<sub>2</sub> production, *EBA conference, Belgium*
- 2016 - Biogas membrane reformer for decentralized H<sub>2</sub> production, *WHEC, Spain*
- 2016 - Steam reforming of biogas in a fluidized bed membrane reactor for pure hydrogen production, *Dutch Membrane Society, The Netherlands*
- 2016 - Preparation and characterization of thin Pd-ag-au supported membranes for hydrogen separation, *Poster at EMS Summer School, Italy*

- **New Press Release in CIB magazine: [LINK](#)**



# Grazie per l'attenzione!



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LinkedIn Group: <https://www.linkedin.com/groups/8513530>

ResearchGate: <https://www.researchgate.net/project/BIONICO>