POTENTIALITY OF A BIOGAS MEMBRANE REFORMER FOR DECENTRALIZED HYDROGEN PRODUCTION

G. Di Marcoberardino, M. Binotti, G. Manzolini

Department of Energy - Politecnico di Milano, Via Lambruschini 4, 20156 Milano, Italy

gioele.dimarcoberardino@polimi.it - www.bionicoproject.eu

MOTIVIATION

The current challenges of energy saving and reduction of CO_2 emissions must deal with the significant growth of energy demand. Hydrogen is a promising energy carrier that can replace fossil fuels in power generation and transportation, drastically reducing local pollution and CO_2 emission. In order to have a sustainable hydrogen economy, conventional production processes based on natural gas steam reforming have to be replaced with alternative production systems relying on renewable energy sources. The BIONICO project uses biogas, obtained by anaerobic digestion of residual biomass or other waste material, as a renewable source for green hydrogen production. Direct conversion of biogas to pure hydrogen can be achieved in a single step, thanks to the introduction of a membrane reactor, resulting in a strong decrease of volumes and auxiliary heat management units.

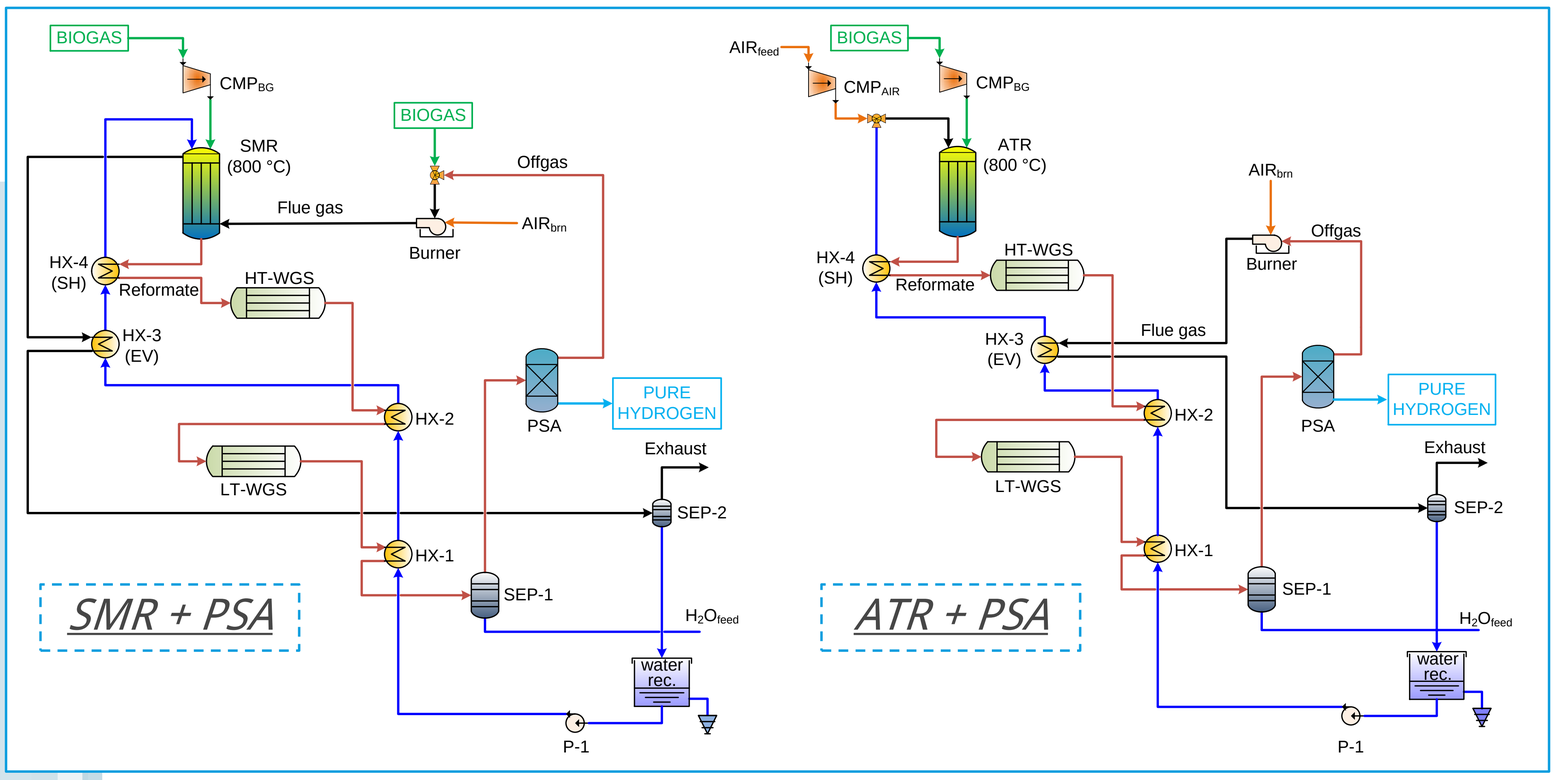
HYDROGEN PRODUCTION SYSTEMS

Three different fuel processors and their relative balance of plant are modelled in Aspen Plus®, where mass and energy balances are solved; all the modelled reactors (SMR, ATR, ATR-MR, HT-WGS, LT-WGS), considering the relatively high catalyst load, were assumed to achieve chemical equilibrium determined through Gibbs free energy minimization. The size of the reference cases is consistent with the target of BIONICO pilot plant which corresponds to a hydrogen production of 100 kg/day with a purity of at least 4.0. The analysis consider that biogas flow is already exempt of sulphur content adopting a sulphur removal unit (e.g. based on active carbon) upstream the reforming system in order to avoid poisoning of both catalysts and membranes. This step is not shown in the layout being neutral to the purpose of the work and common to all the configurations. The auxiliary values adopted for the BoP result from benchmark technologies, typical O&M specifications, requirements for the materials.

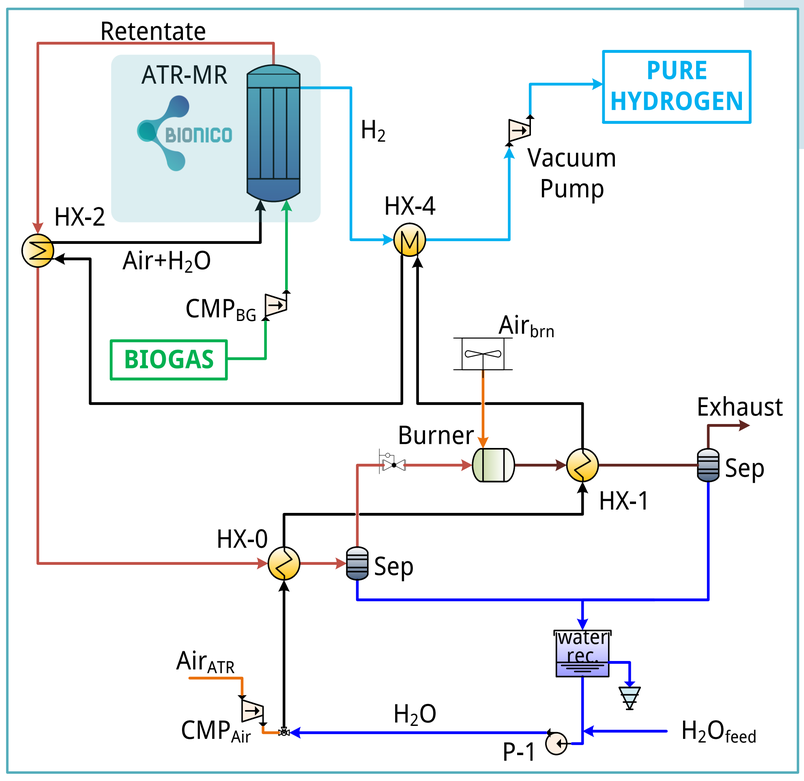
MAIN PARAMETERS		REF. TECHNOLOGY		BIONICO
	units	SR	ATR	ATR-MR
H_2 target	kg/day	100	100	100
Max Temperature	°C	800	800	550
Pressure	bar	8-14	8-14	8-14
S/C	-	4	3	3
λ_{ATR}	-	-	0.32	0.18
PSA efficiency	%	78-86	78-86	-
Compressor/pumps efficiency	%	70	70	70

LANDFILL BIOGAS		
	units	values
CH_4	% mol	44.2
CO_2		34
N_2		16
O_2		2.7
H_2		0.0165
CO		0.0006
H_2O		Saturated
LHV	MJ/kg	12.7

REFERENCE TECHNOLOGIES



BIONICO



The ceramic supported membranes are integrated in a autothermal reforming reactor (ATR-MR). The investigated layout adopt a vacuum pump in order to reduce the hydrogen partial pressure on the permeate side. Thanks to the choice of the vacuum pump, instead of a sweep gas, the total required membrane area will be lower. The reactor operating temperature for the reference case is assumed up to 550-600 °C, in order to preserve the membranes lifetime.

MEMBRANE CHARACTERISTICS		
	units	values
OD	m	0.014
L	m	0.45
n	-	0.5
Ea	kJ/mol	10
Permeance @ 500°C	$mol/m^2sPa^{0.5}$	$2.74 \cdot 10^{-3}$

RESULTS & CONCLUSIONS

The main simulations results show that the BIONICO system efficiency (69.2%) is about 25% and 17% higher with respect to ATR and SMR cases respectively. This record efficiency is reached at a much lower temperature with respect to SMR and ATR thanks to the use of the CMR that allows for hydrogen production and separation in a single step, moving the equilibrium of the reactions towards the products.

RESULTS		REF. TECHNOLOGY		BIONICO
	units	SR	ATR	ATR-MR
Biogas feed	Nm^3/h	35.7+14.6	47.0	36.8
Total Biogas Input	kW	221	207	162
BG compressor	kW	6.2	8.1	4.4
Air compressor	kW	-	11.6	3.4
Vacuum pump + H_2 compressor	kW	-	-	8.6
System efficiency	$\%_{LHV}$	59.2	55.4	69.2
Membrane Area	m^2	-	-	3.1

$$\eta_{sys} = \frac{\dot{m}_{H_2} LHV_{H_2}}{\left(\dot{m}_{BG_f} + \dot{m}_{BG_{aux}}\right) LHV_{BG} + {W_{aux}}/{\eta_{el,rif}}}$$

- LHV_{H2} is equal to 120 MJ/kg
- W_{aux} is the sum of the electric consumptions of the system auxiliaries (i.e. compressors, pumps, control system)
- $\eta_{el,rif}$ is set equal to 45%, as the average electric efficiency of the power generating park

3RD EUROPEAN WORKSHOP ON MEMBRANE REACTORS: MEMBRANE REACTORS FOR PROCESS INTENSIFICATION, MR4PI 2017 – 9/10 MARCH 2017, VERONA, ITALY

THIS PROJECT HAS RECEIVED FUNDING FROM THE FUEL CELLS AND HYDROGEN 2 JOINT UNDERTAKING UNDER GRANT AGREEMENT NO 671459. THIS JOINT UNDERTAKING RECEIVES SUPPORT FROM THE EUROPEAN UNION'S HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME HYDROGEN EUROPE AND N.ERGHY. NOTE: THE PRESENT WORK REFLECTS ONLY THE AUTHOR'S VIEWS AND THE FCH JU AND THE UNION ARE NOT LIABLE FOR ANY USE THAT MAY BE MADE OF THE INFORMATION CONTAINED THEREIN