Design and Manufacturing of DEMCAMER Catalytic Membrane Reactors

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How membrane reactors can affect H_2 production cycles

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Design and Manufacturing of DEMCAMER Catalytic Membrane Reactors

WGS Process Design and Simulation/1

Definition of industrial requirements for WGS - MR system

- H_2 production capacity
- Feed composition and feed pressure
- Feed temperature range
- Pressure Hydrogen output
- MR performance target

Simulation of WGS fixed bed MR

- MR operating conditions
- Membrane area required
- MR performance

WGS Process design and simulation

- Design of new process integrated with WGS-MR
- Retentate post processing
- Permeate post processing

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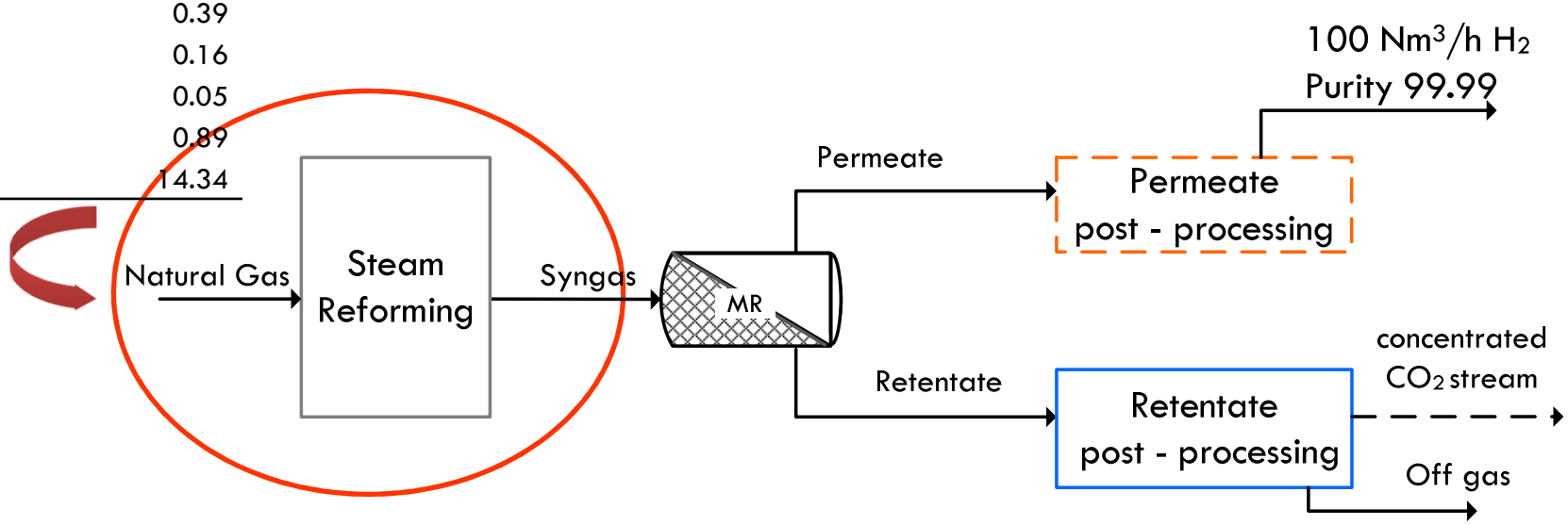
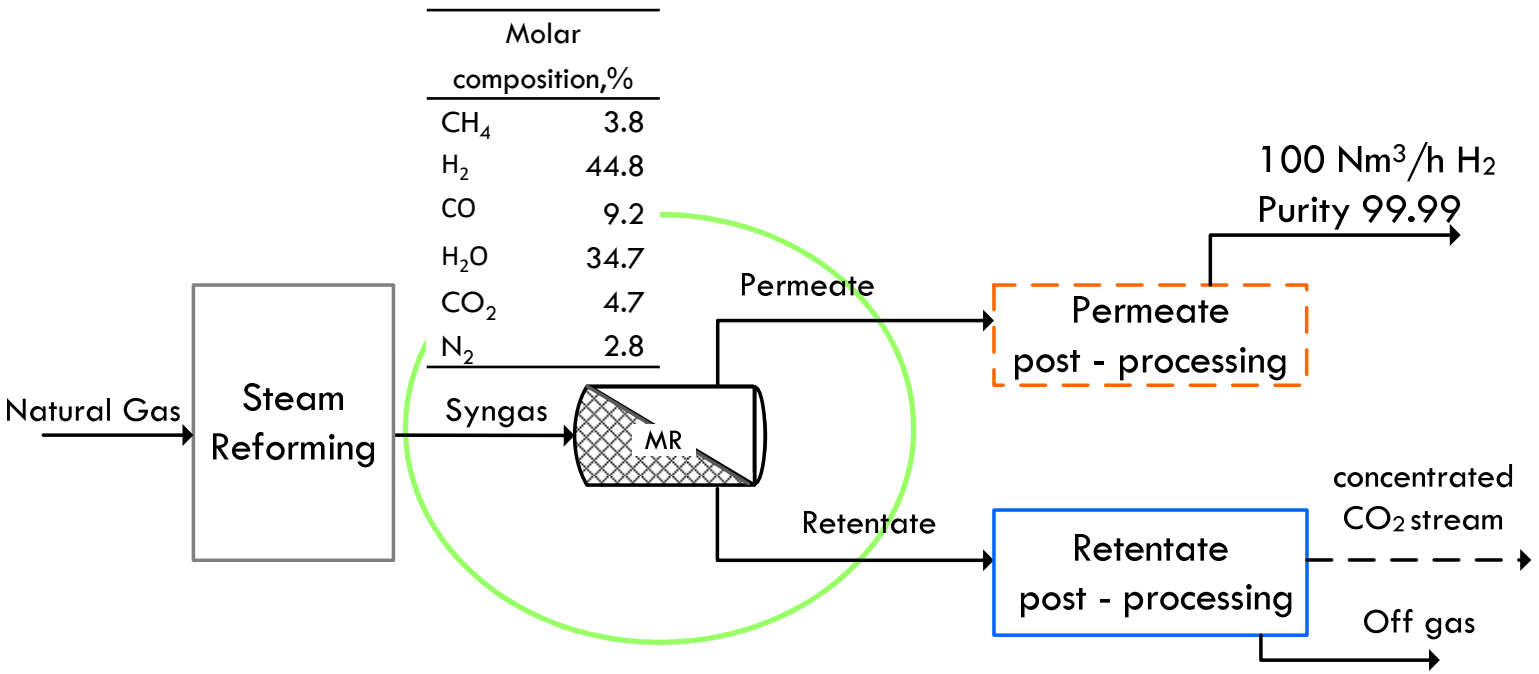
WGS Process Design and Simulation/3

NG from Groningen region (The Netherlands)	
Molar composition %	
CH_4	81.30
C_2H_6	2.87
C_3H_8	0.39
C_4H_{10}	0.16
C_5H_{12}	0.05
CO_2	0.89
N_2	14.34



WGS Process Design and Simulation/4



Membrane characteristics	
Membrane	Pd-Ag supported (Tecnalia)
Target permeance at 400 °C, mmol m^{-2} Pa^{-1} s^{-1}	2.17
Ea, kJ mol^{-1}	8
Pre-exponential factor in permeance expression, mmol m^{-2} Pa^{-1} s^{-1}	9.06
Length tubes in packed bed, m	0.44

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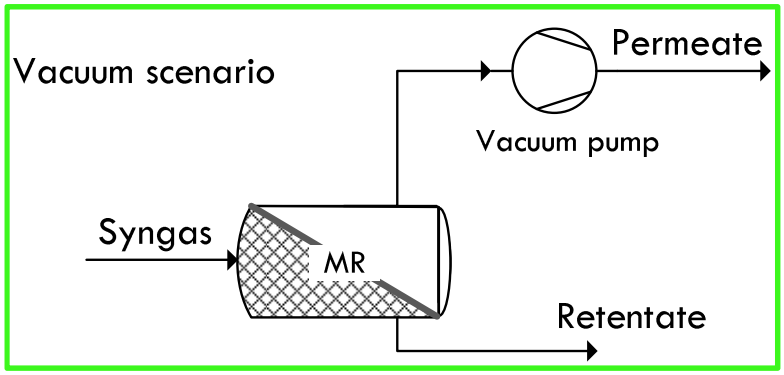
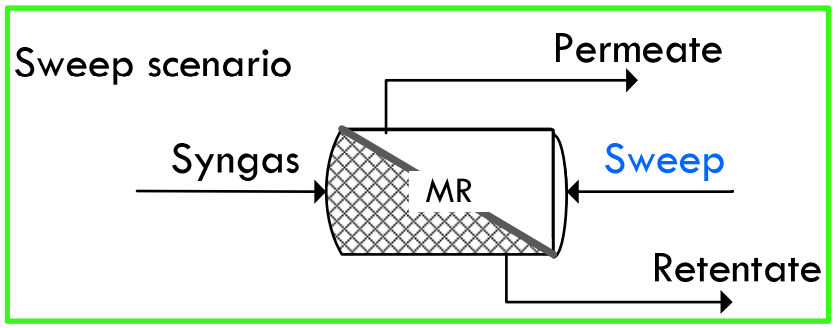
WGS- MR section

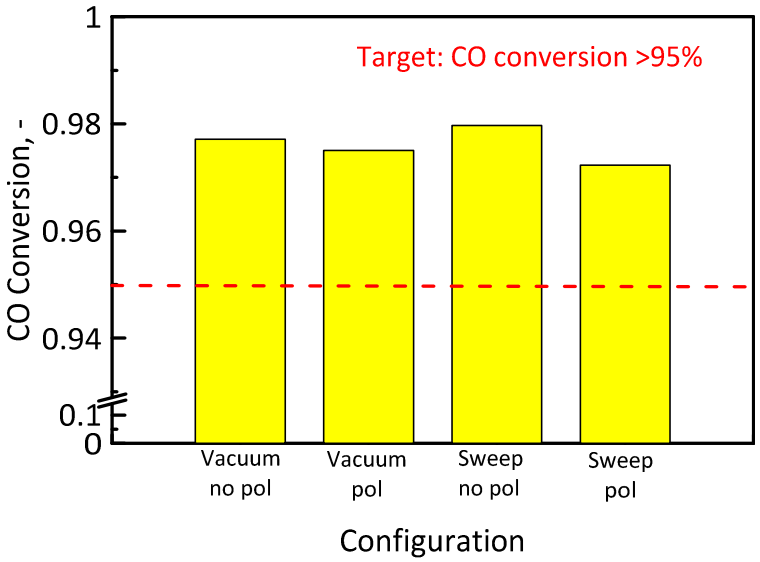




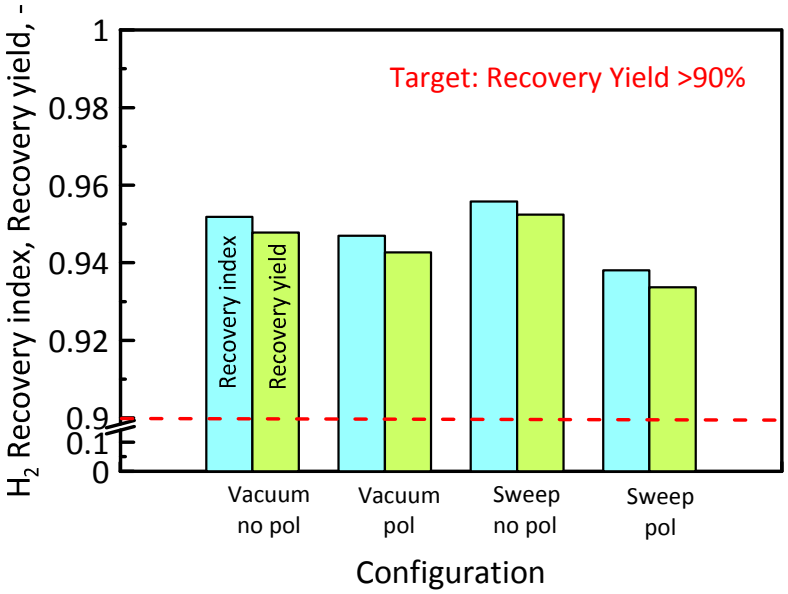
Operating Condition	Vacuum	Sweep
Feed pressure, bar	7	
Permeate pressure, bar	0.35	1.2
Feed temperature, C	360	
Sweep Factor, -	N.A.	0.12
Membrane area, m^2	3.6	

$$* \text{Sweep factor} = \frac{\text{Sweep molar flow rate fed in the permeate side}}{\text{Syngas molar flow rate fed in the reaction side}}$$

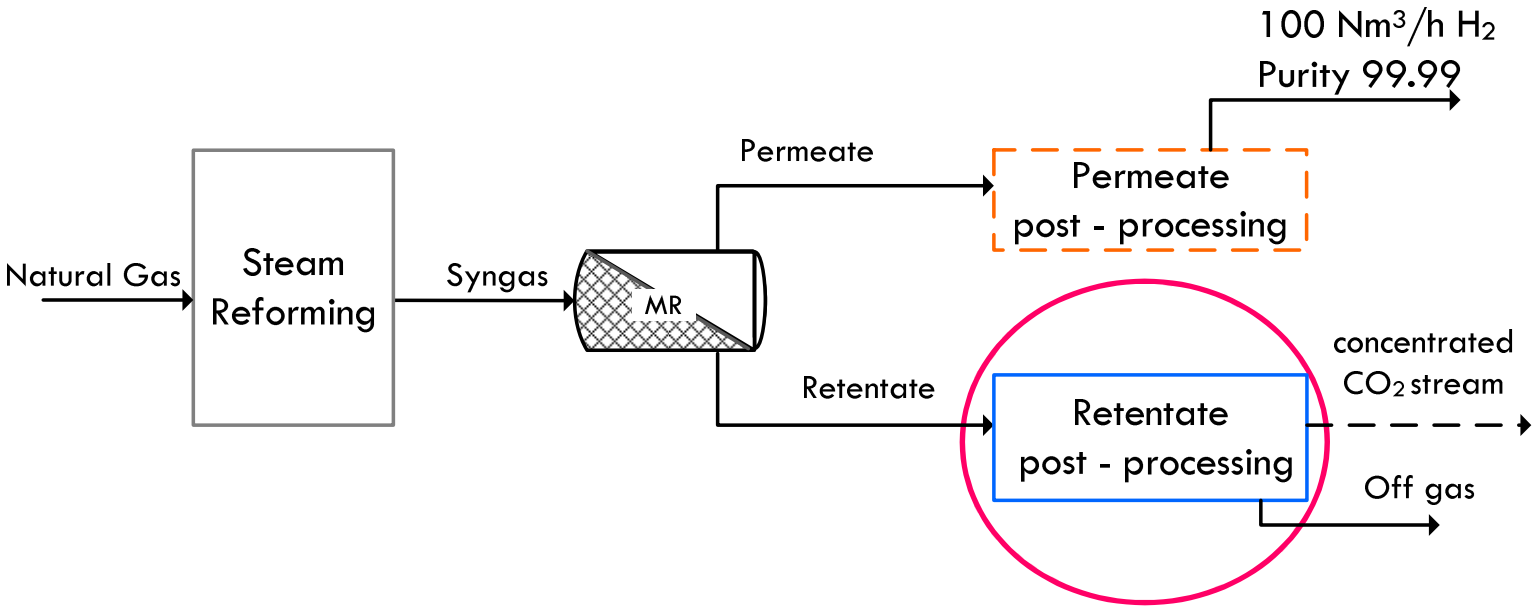
Membrane area scaled-up from pilot of 5 Nm^3/h of H_2 produced by MR unit



Performance	Vacuum (CPC)	Sweep (CPC)
CO conversion, %	97.5	97.2
H_2 Recovery (R_{H2}), %	94.3	93.4



WGS Process Design and Simulation/5



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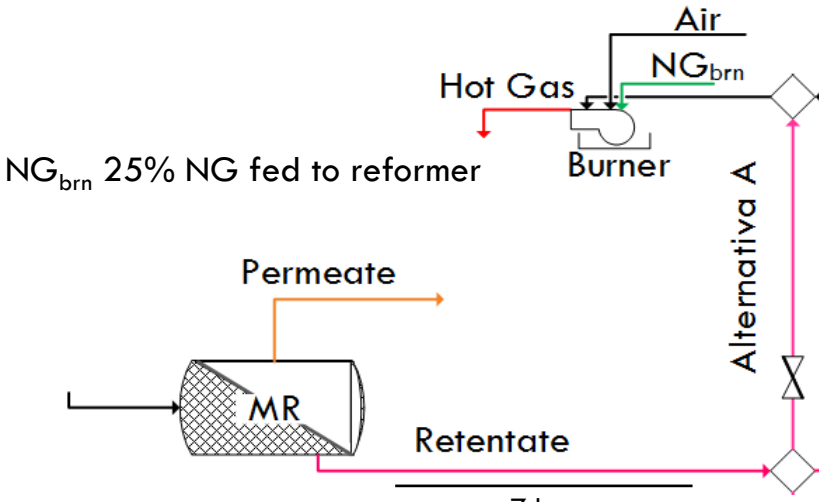
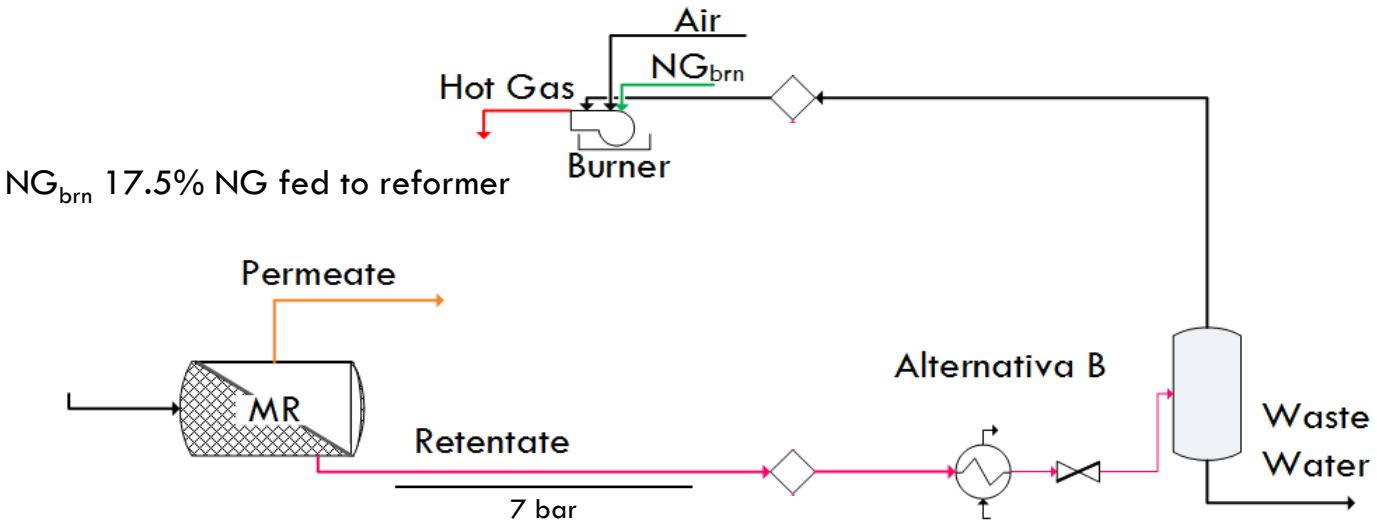
Retentate post-processing



7 bar	
≈460 °C	
1.8 kmol/h	
Molar composition %	
H_2O	52.1
CO_2	27.6
CH_4	7.7
H_2	6.5
N_2	5.6
CO	0.5

Design and Manufacturing of DEMCAMER Catalytic Membrane Reactors

Retentate post-processing section/2



7 bar
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Molar composition %

H_2O	52.1
CO_2	27.6
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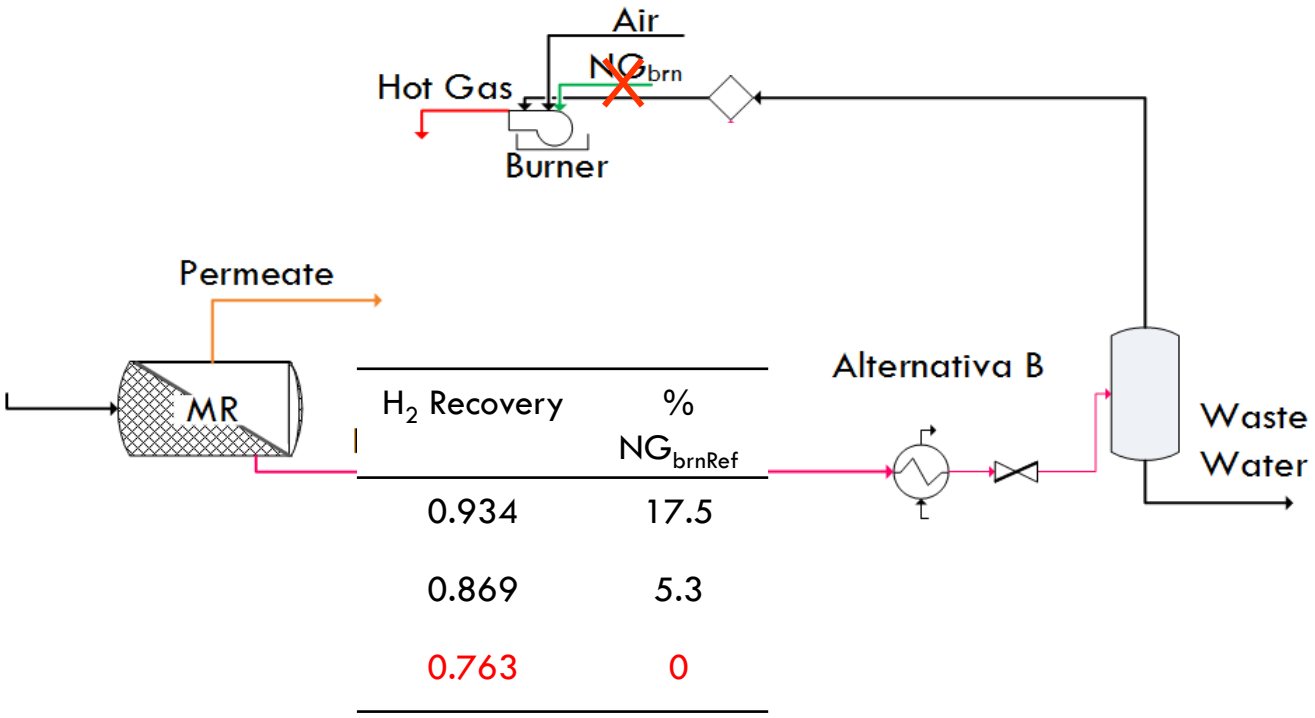
Design and Manufacturing of DEMCAMER Catalytic Membrane Reactors

Retentate post-processing section/2



H_2 Recovery	% NG_{brnRef}
0.934	17.5
0.869	5.3
0.763	0

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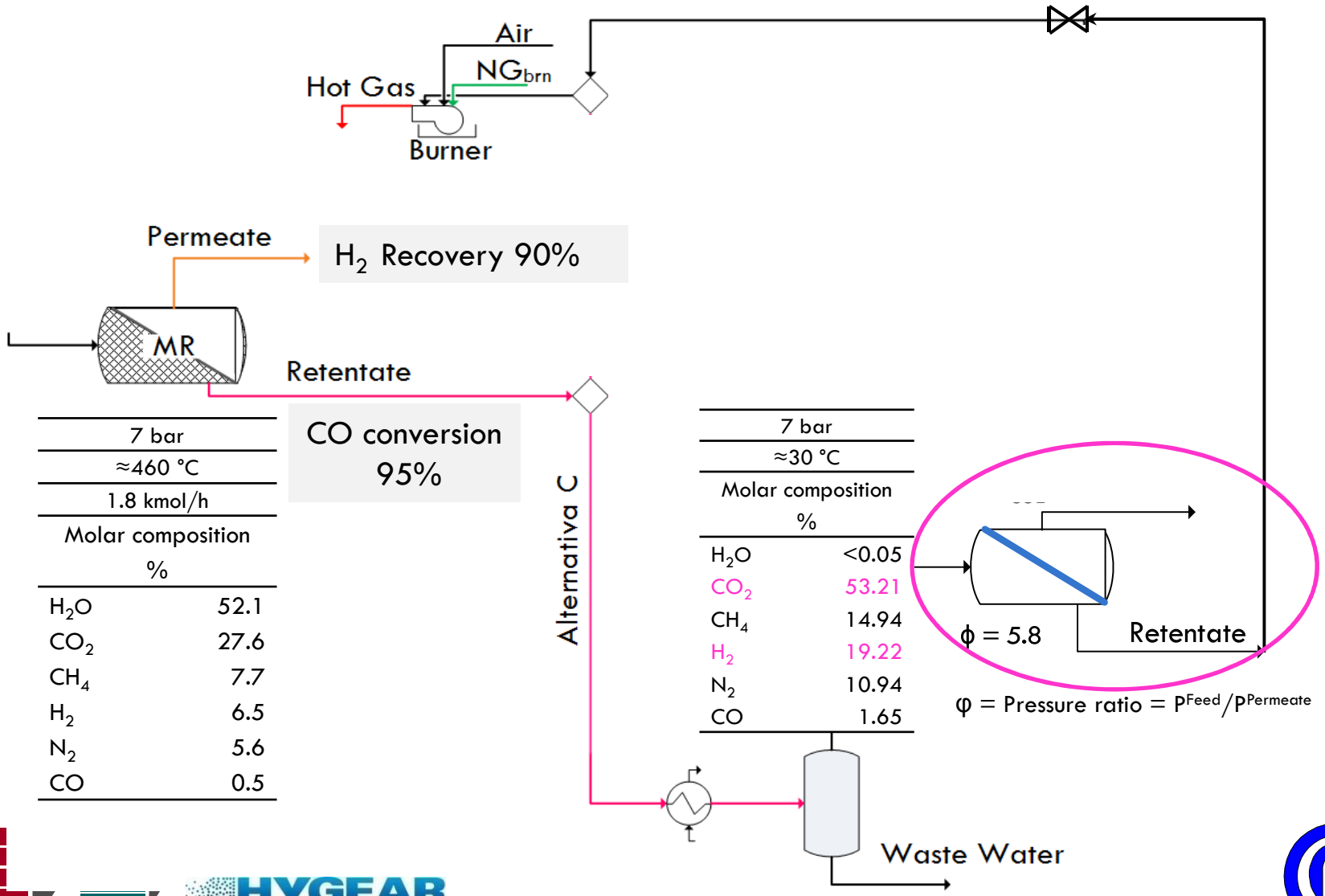
Retentate post-processing section/3



7 bar
≈460 °C
1.8 kmol/h
Molar composition %

H_2O	52.1
CO_2	27.6
CH_4	7.7
H_2	6.5
N_2	5.6
CO	0.5

7 bar
≈30 °C
Molar composition %

H_2O	<0.05
CO_2	53.21
CH_4	14.94
H_2	19.22
N_2	10.94
CO	1.65

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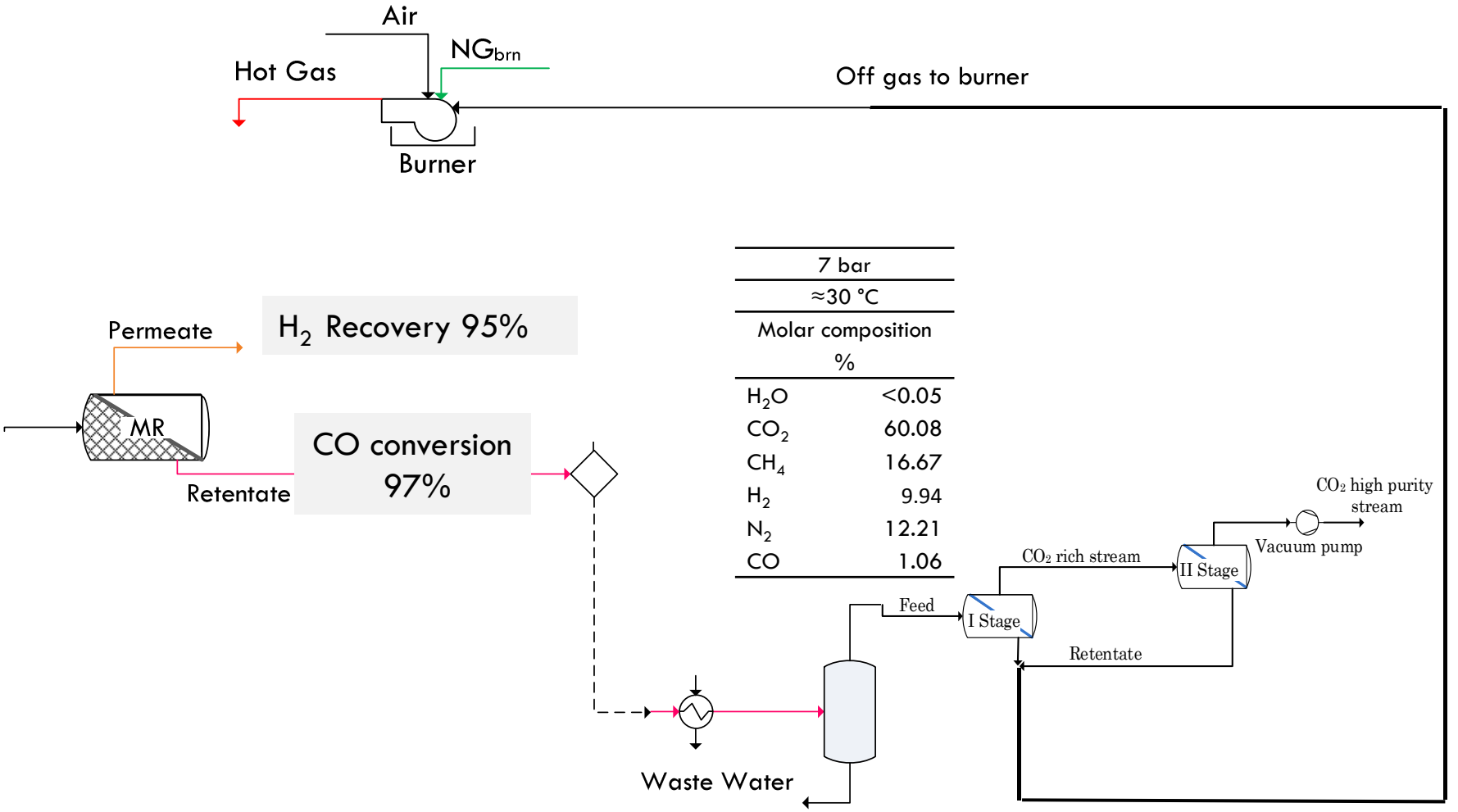
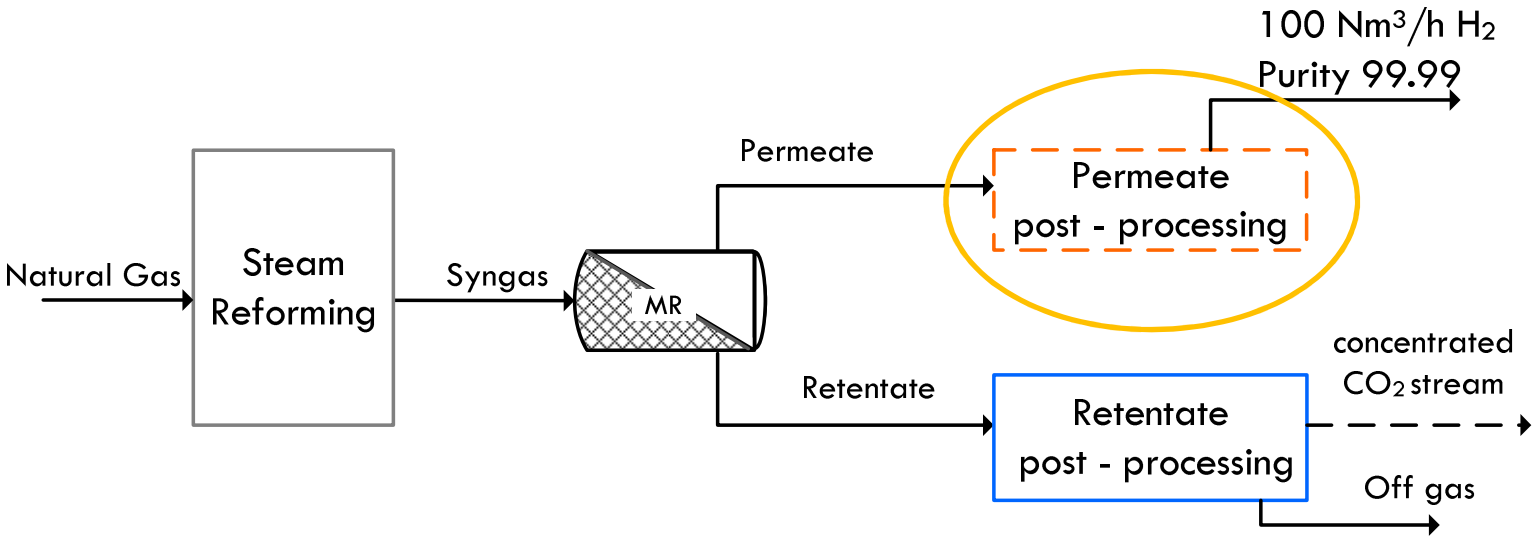
Retentate post-processing section/3



7 bar
≈30 °C
Molar composition %
H_2O <0.05
CO_2 60.08
CH_4 16.67
H_2 9.94
N_2 12.21
CO 1.06

CO_2 purity	CO_2 Recovery
~ 97 %	51 %


100 Nm³/h H₂
Purity 99.99
Permeate
Permeate
post - processing
Natural Gas
Steam
Reforming
Syngas
MR
Retentate
concentrated
CO₂ stream
Retentate
post - processing
Off gas

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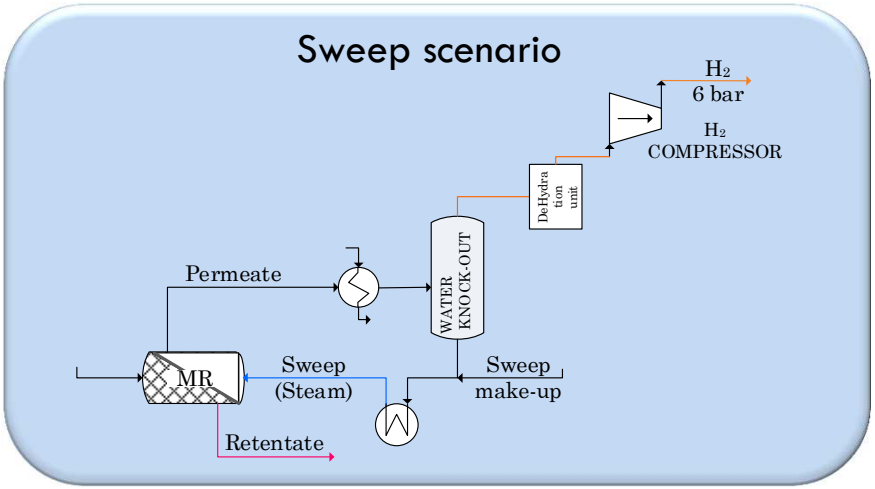
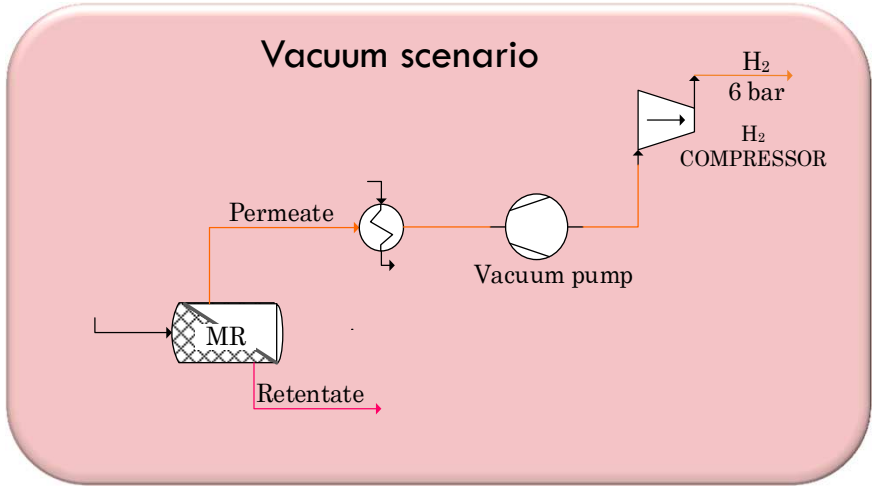
Permeate post-processing section





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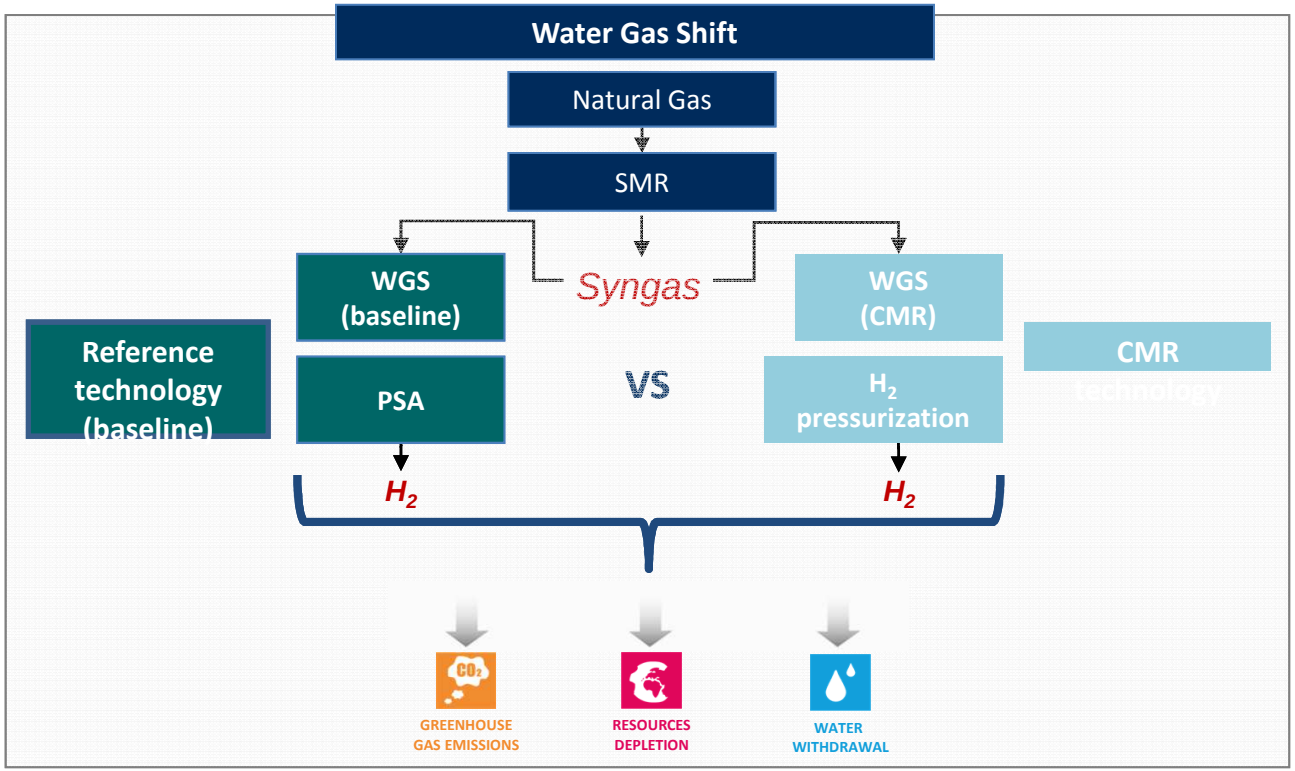
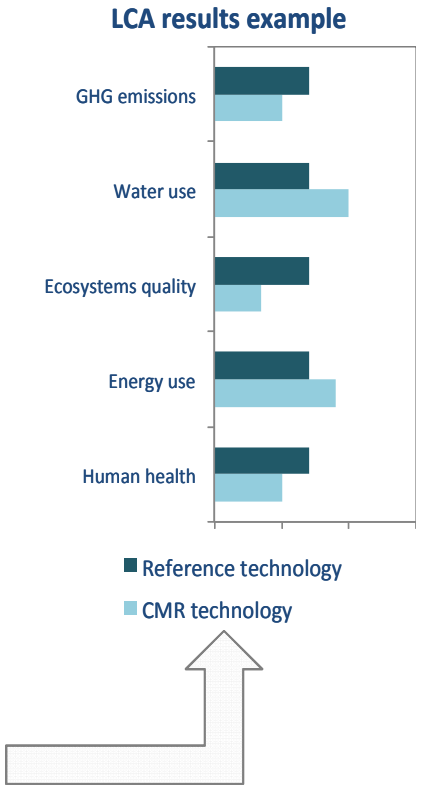
Quantis

What about the environmental impacts of the CMR technologies compared to the reference technology?





Not included in the screening LCA:

- Product (H_2 or C_2H_4) distribution and use (equivalent for compared systems)
- Infrastructure (reactor and membranes)
- Downstream separation with membranes

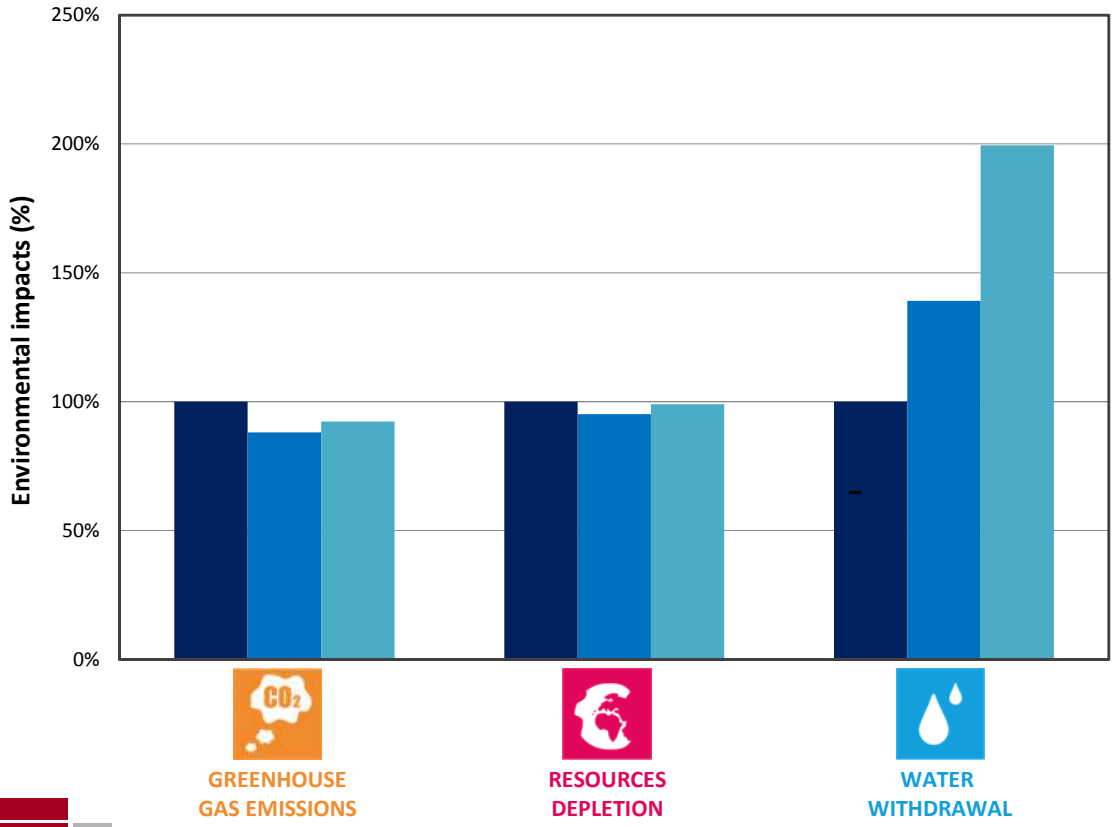
The impact of the electricity consumption for the different processes depends on the geography. Conclusions can be drawn only for average European technologies

Design and Manufacturing of DEMCAMER Catalytic Membrane Reactors

Quantis

Screening results: water gas shift (packed bed)

The production of 1 Nm^3 of H_2 using CMR technologies results in impact **reductions for greenhouse gas emissions and resources depletion, and an increase for water withdrawal**



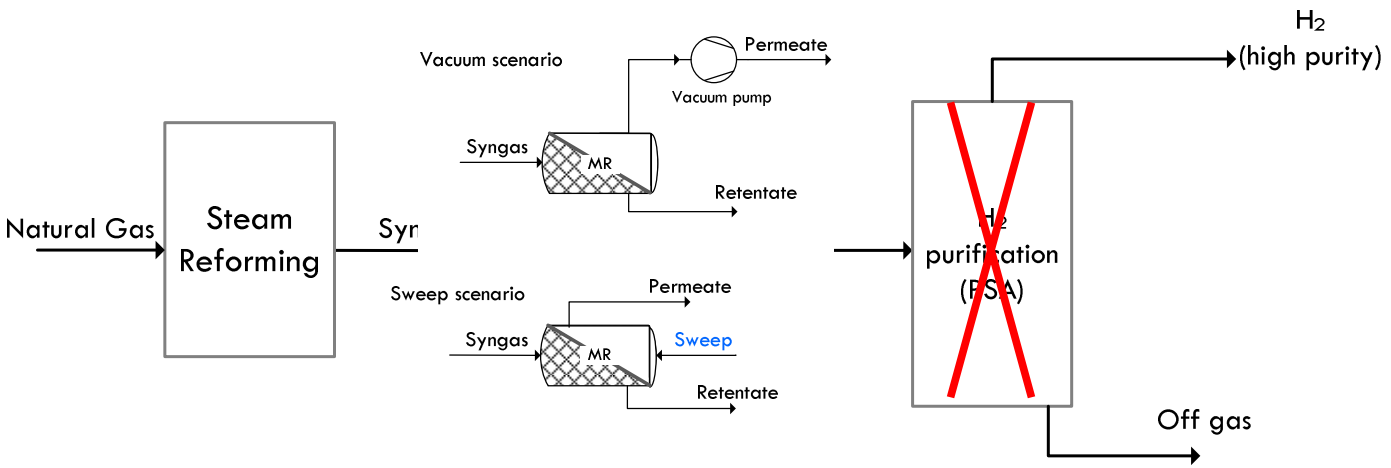
Key learnings

The **key contributors** to overall environmental impacts of WGS process are the following:

- ✓ Feedstock (steam and natural gas)
- ✓ Direct emissions from burner (only for GHG emissions indicator)
- ✓ Electricity consumption (only for water withdrawal indicator)

- WGS reference technology
- WGS PBMR Sweep
- WGS PBMR Vacuum

Conclusion



- A new process integrated with WGS-MR has been designed
- H_2 separation and purification (PSA) is NO more required → more than 90% of H_2 produced is directly recovered in the permeate stream
- Permeate post processing only requires H_2 compression
  (for sweep scenario the steam used as sweep gas has to be condensed and removed).
- Retentate post processing:
  - Retentate can be sent to the burner
  - Retentate can be sent to a CO_2 membrane separation unit recovering a concentrated CO_2 stream
- Lower impacts related to lower feedstock consumption
  - natural gas
  - Steam
- Higher impacts related to higher electricity and heat requirements

Design and Manufacturing of
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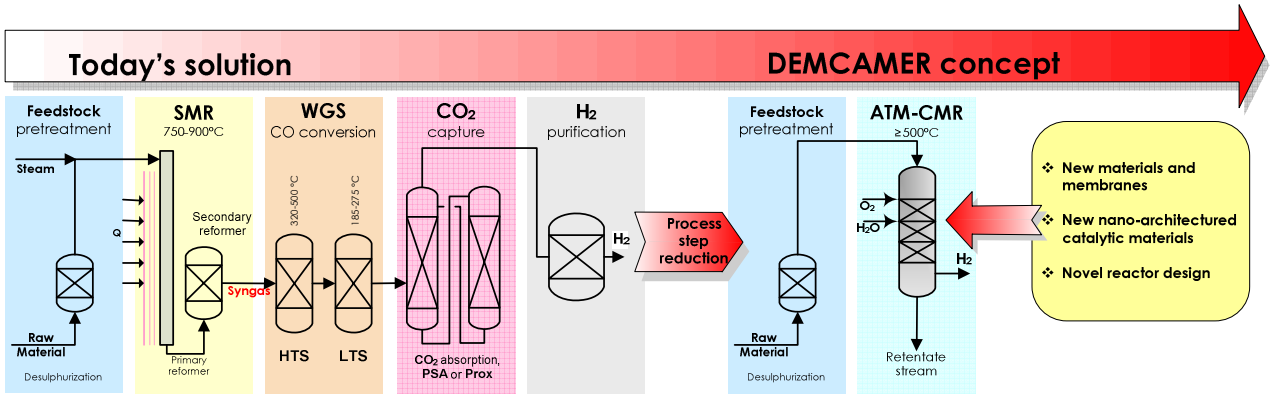
Catalytic Membrane Reactors

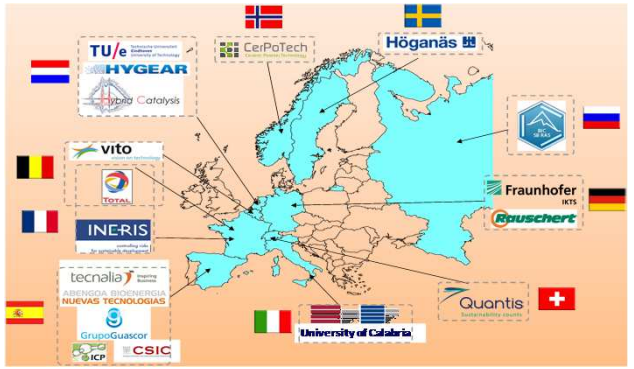
Design and Manufacturing of Catalytic Membrane Reactors by Developing New Nano-architectured Catalytic and Selective Membrane Materials



www.demcamer.org

Consortium

18 Partners from 10 different countries; 8 Research Centres and Universities; 4 SMEs; 6 Large Enterprises.



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Thank you for your attention

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