Advanced MEMBranes and membrane assisted procEsses for pre- and post- combustion CO_2 captuRe

MEMBER

https://member-co2.com/

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Duration: 4 years.
Starting date: 01 January 2018
Budget: € 9 596 541,50
EU contribution: €7 918 901

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Outline

1. Summary

The key objective of the MEMBER project is the scale-up and manufacturing of advanced materials (membranes and sorbents) and their demonstration at TRL6 in novel membrane-based technologies that outperform current technology for pre- and post-combustion CO_2 capture in power plants as well as H_2 generation with integrated CO_2 capture.

Two different strategies will be developed and demonstrated at three different end users facilities to achieve CO_2 separation:

- A combination of Mixed Matrix Membranes (MMM) for pre- and post-combustion,
- A combination of metallic membranes and sorbents into an advanced Membrane Assisted Sorption Enhanced Reforming (MA-SER) process for pure H2 production with integrated CO2 capture

In both cases, a significant decrease of the total cost of CO_2 capture will be achieved. MEMBER targets CO_2 capture technologies that separate >90% CO_2 at a cost below 40€/ton for post combustion and below 30€/ton for pre-combustion and H_2 production.

1. Summary

Targets

Prototype A

Pre-combustion capture in power plants using MMMs at HYGEAR reforming equipment.

CCR > 90%

Capture Cost < 30 €/ton

Prototype B

Post-combustion capture in power plants using MMMs at the 8.8 MW CHP facilities of Agroger (GALP, Portugal).

CCR > 90%

Capture Cost < 40 €/ton

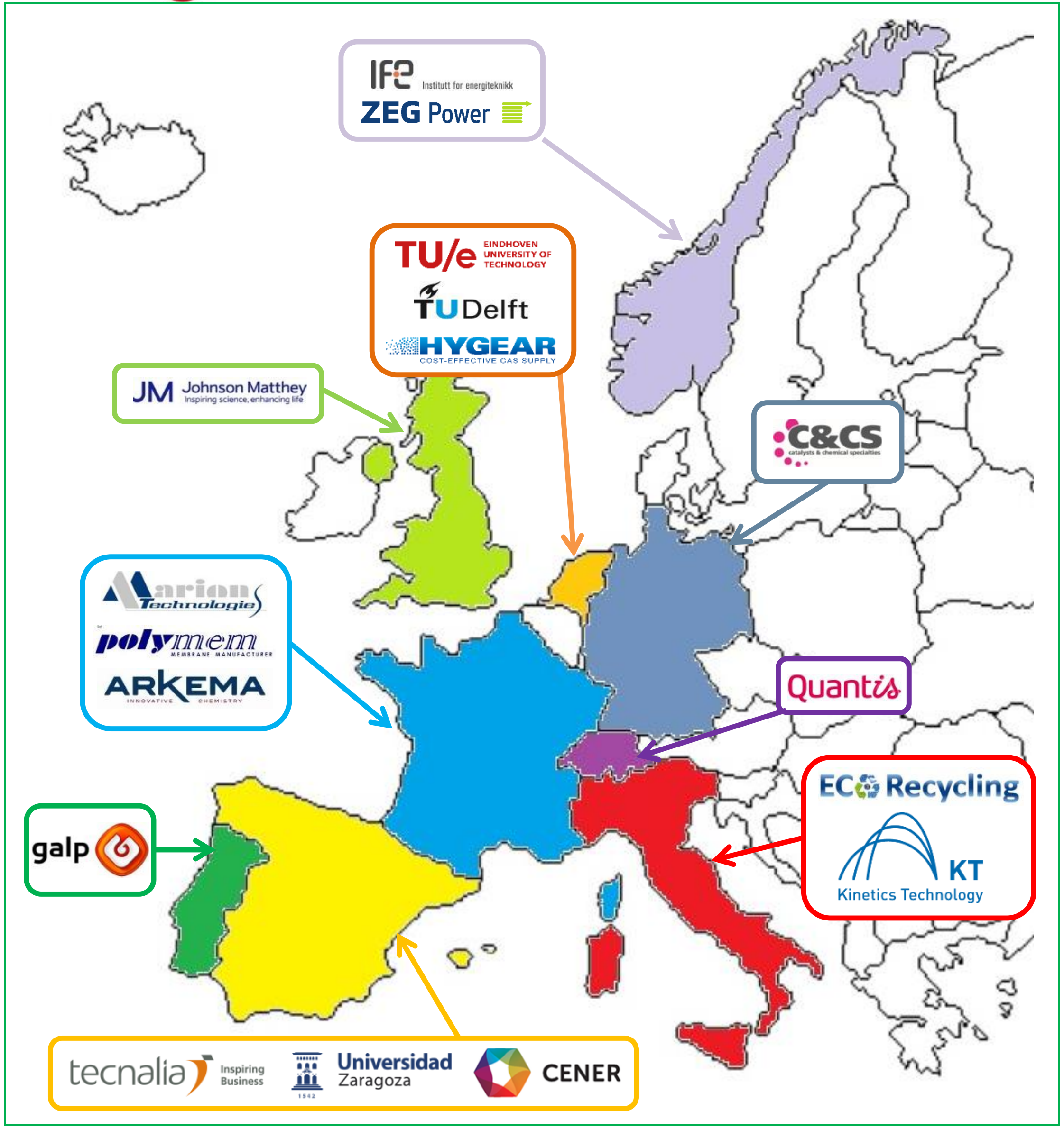
Prototype C

Pure hydrogen production with integrated CO_2 capture using MA-SER at the IFE-HyNor (Norway) under the supervision of ZEG POWER.

CCR > 90%

Capture Cost < 30 €/ton

2. Partnership



- ➢ Multidisciplinary and complementary team.
- ➢ 17 partners from 9 countries.
- ➢ Industrial oriented (65%):

  11 SME/IND + 6 RTO/HES
- ➢ 7 SMEs (41%) & 4 IND (24%)

2. Partnership

1 TECNALIA, RTO, Spain
2 TUE, HES, Netherlands
3 TUDELFT, HES, Netherlands
4 IFE, RTO, Norway
5 UNIZAR, HES, Spain
6 CENER, RTO, Spain
7 MTEC, SME, France
8 C&CS, SME , Germany
9 POLYMEM, SME, France
10 HYGEAR, SME, Netherlands
11 ECOREC, SME, Italy
12 ZEG, SME, Norway
13 QUANTIS, SME, Switzerland
14 KT, IND, Italy
15 GALP, IND,Portugal
16 ARKEMA, IND, France
17 JM, IND, United Kingdom

2. Partnership: Consortium synergies

MEMBER gathers the entire value chain:

- Commercial actors in Materials development, processing and supply (JM for MOFs, ARKEMA for polymers, C&CS for catalysts and MTEC for Sorbents)
- one industrial partner focused on membrane manufacturing (POLYMEM),
- two engineering companies focused on system design and integration (HYGEAR and KT),
- 4 partners for the demonstration of the technologies (HYGEAR and GALP for MMMs for pre-and post-combustion CO_2 capture respectively, and IFE-HYNOR H_2 Technology Center under the supervision of ZEG POWER for MA-SER concept),
- one SME focused on sustainability and recyclability of materials produced (ECO RECYCLING)
- one SME for Life Cycle Assessment (QUANTIS).
- industrial partners supported by recognized research organizations experts in the fields of material development (IFE, TUDELFT and UNIZAR), membrane development (TECNALIA) and process engineering (TUe).

3. Project Objectives

The key objective of the MEMBER project is the **scale-up and manufacturing of advanced materials** and their demonstration at industrially relevant conditions (TRL6) in **novel membrane-based technologies that outperform current technologies for pre- and post-combustion CO_2 capture in power plants as well as H_2 generation with integrated CO_2 capture and meet the targets of the European SET plan.**

Three different technological solutions involving advanced materials will be developed and demonstrated at three different end user's facilities:

- Advanced Mixed Matrix Membranes (MMMs) for pre- and post-combustion CO_2 capture in power plants (H_2/CO_2 & CO_2/N_2 respect.)
- A combination of metallic hydrogen membranes and CO_2 sorbent integrated into an advanced Membrane Assisted Sorption Enhanced Reforming (MA-SER) process for pure H_2 production with CO_2 capture.

3. Project Objectives

- Prototype A, targeted for **pre-combustion capture in power plants** using MMMs at HyGen production unit of HYGEAR**.**
- Prototype B targeted for **post-combustion capture in power plants** using MMM at the 8.8MW CHP facilities of **Agroger (GALP, Portugal).**
- Prototype C targeted for **pure hydrogen production with integrated CO_2 capture** using MA-SER at the **IFE-HyNor Hydrogen Technology Centre (Norway)** under the supervision of ZEG POWER.

Main operation conditions & performance targets for the MEMBER prototypes.

	Technology	CO_2 Capture [%]	Capture cost [€/ton]	Demo site
Pre-comb. Power (IGCC)	MMM	> 90	< 30	CENER
Post-comb. Power (Coal)	MMM	> 90	< 40	GALP
H_2 with integrated CO_2 capture	MA-SER	> 90	< 30	IFE-HYNOR

3. Project Objectives:
Main Goals and S&T objectives

OBJ. 1: MARKET & BUSINESS OBJECTIVES

- To overcome CCS market barriers with an ambitious set of CCS solutions.
- To take European industrial companies (Materials manufacturers, engineering companies and end users) to a leading position in the CCS market, generating economic growth and job opportunities.

OBJ. 2: ECONOMIC OBJECTIVES

- Compliance with strict cost-effectiveness and performance targets:
  - Pre-combustion Mixed Matrix Membrane system for Power generation
  - Post-combustion Mixed Matrix Membrane system for Power generation
  - Mixed Matrix Membrane materials for MEMBER
  - MA_SER system for pure hydrogen production with integrated CO2 capture
  - MA_SER materials for MEMBER

3. Project Objectives: Main Goals and S&T objectives

OBJ. 3: TECHNICAL OBJECTIVES

- To take to manufacturing development stage (from MRL 4-5 to MRL 6) a portfolio of materials and membranes of MMM technology:
    - Process optimization on pilot production lines (Polymers and MOFs).
    - Scaling production lines for the fine-tuned core material: MOF > 1kg/batch;
    - Scaling up the production of hollow fibres MMMs to >10.000 hollow fibers / batch
    - Scale up the membrane module size to >10 m2
    - Manufacturing of MMM modules for the pre- and post-combustion CO2 capture in Power Plants
    - ……
- Move from MRL 4-5 to MRL 6 a portfolio of materials of MA-SER technology:
    - Scale up production for core material: Sorbents: 50-100 kg/day; catalyst: 50 kg/batch;
    - Scaling up the production of Pd-based H_2 membranes to 8 membranes / batch
    - Lifetime Analysis of MA-SER at TRL6
    - Demonstration of compliance with CCS codes and standards. Installations in experimental demo plants to support and provide additional information on product characterization from qualification testing.

3. Project Objectives: Main Goals and S&T objectives

OBJ. 3: TECHNICAL OBJECTIVES

- Development of a software tool to simulate MEMBER components and CO_2 capture energy performance from the earliest design phases:
  - Module/reactor design and process simulation (at large scale) for full integration of the MMM systems for pre- and post-combustion, and for MA-SER for pure H_2 production with integrated CO_2 capture
  - Development of a model of the MA-SER reformer
  - Validation of the models through demonstration in relevant conditions (demo site)

OBJ. 4: DEMONSTRATION OBJECTIVES

- Demonstration of MEMBER systems and related business models in 3 representative demonstration sites across Europe, covering different sectors, membrane-based technologies and CO_2 containing streams

3. Project Objectives:
Main Goals and S&T objectives

OBJ. 5: ENVIRONMENTAL OBJECTIVES

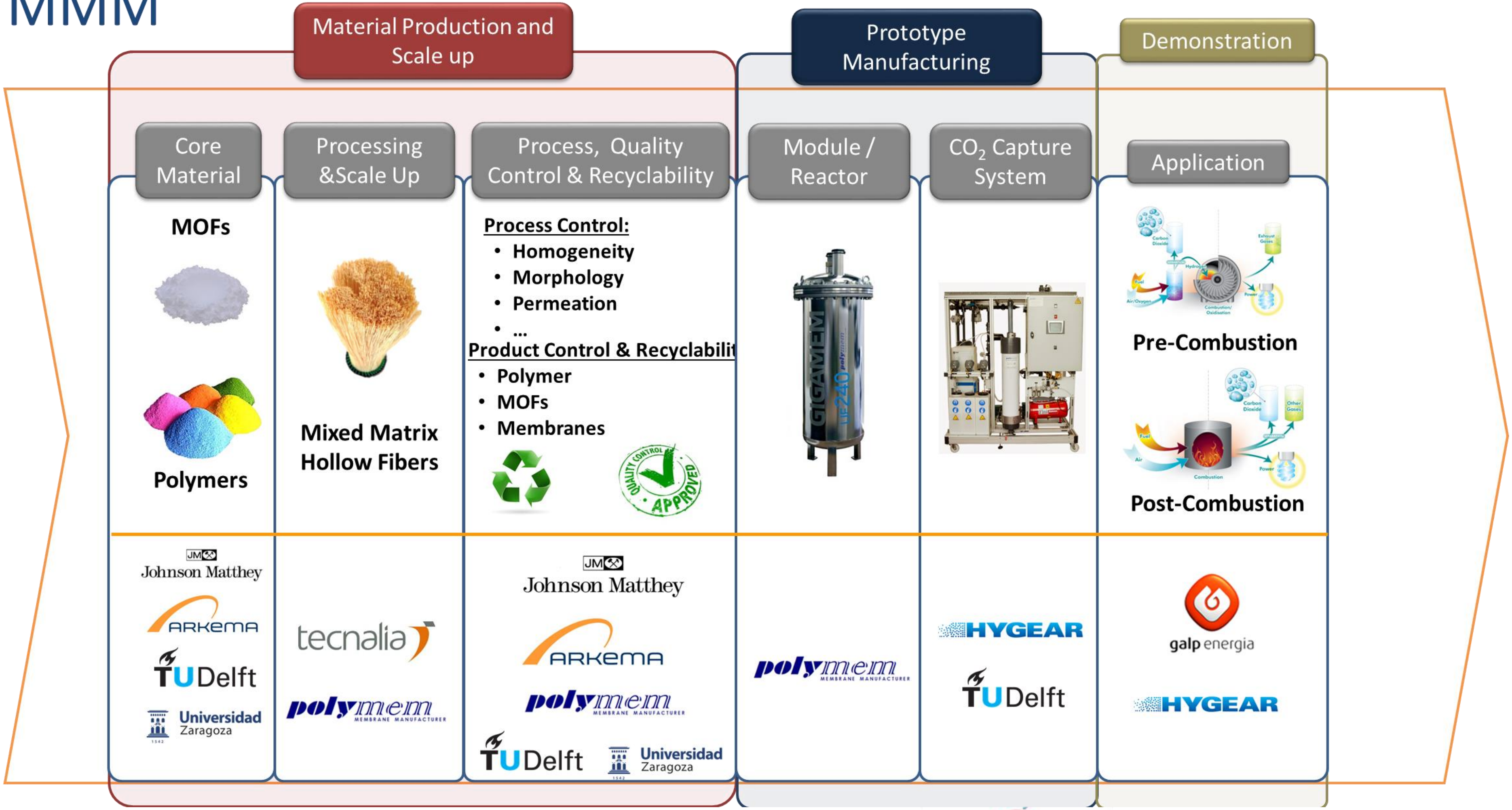
- To quantify the environmental impacts of the proposed holistic solutions through life cycle assessment based on 3 case studies throughout Europe

OBJ. 6: SOCIAL OBJECTIVES

- Job creation and increase awareness and involvement within the whole social & industrial chain: plant owners, manufacturers, installers, authorities, students, CCS organizations, general public, etc.

4. Overall approach and methodology

MMM



Material Production and Scale up

Prototype Manufacturing

Demonstration

Core Material

MOFs

Polymers

Johnson Matthey
ARKEMA
TUDelft
Universidad Zaragoza

Processing &Scale Up

Mixed Matrix Hollow Fibers

tecnalia
polymem

Process, Quality Control & Recyclability

Process Control:

- Homogeneity
- Morphology
- Permeation
- …

Product Control & Recyclabilit

- Polymer
- MOFs
- Membranes

Johnson Matthey
ARKEMA
polymem
TUDelft
Universidad Zaragoza

Module / Reactor

polymem

CO_2 Capture System

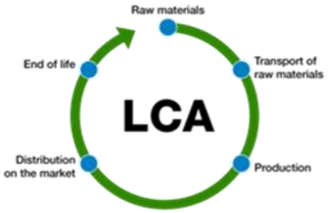
HYGEAR
TUDelft

Application

Pre-Combustion

Post-Combustion

galp energia
HYGEAR



Quantis

4. Overall approach and methodology

MA-SER

Material Production and Scale up

Core Material Manufacturing & Scale up

Sorbents

Membranes

Catalyst

Marion Technologie

tecnalia

C&CS catalysts & chemical specialities

IFE

Process, Quality Control & Recyclability

Process Control:
- Homogeneity
- Morphology
- Permeation
- …

Product Control & Recyclability
- Catalyst
- Sorbents
- Membranes

QUALITY CONTROL APPROVED

Marion Technologie

tecnalia

C&CS catalysts & chemical specialities

ECO Recycling

Prototype Manufacturing

Module / Reactor

KT Kinetics Technology

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

CO_2 Capture System

KT Kinetics Technology

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

IFE

Demonstration

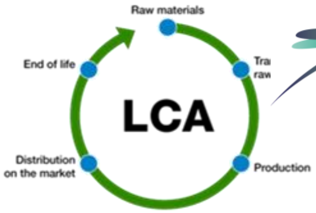
Application

Hydrogen production with integrated CO_2 capture for industrial sectors

Hynor Lillestrøm

IFE

ZEG Power



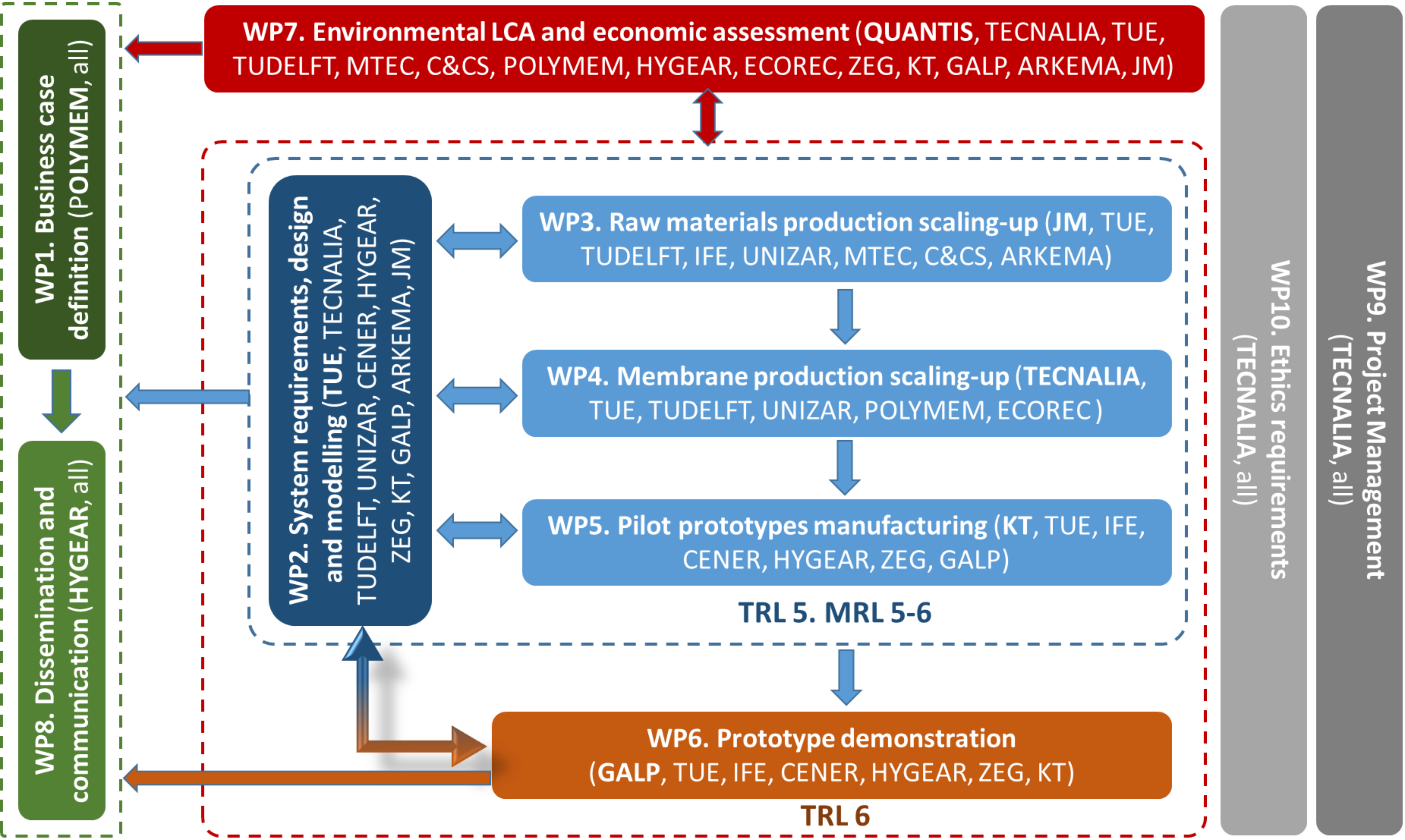
Quantis

4. Overall approach and methodology

The technical content of the project is divided on different work packages representing key developments in the chain of value.

WP No	Work Package Title	Lead Part. Name
1	Business case definition	POLYMEM
2	System requirements, design and modelling	TUE
3	Core materials production scaling-up	JM
4	Membrane production scaling-up	TECNALIA
5	Pilot prototypes design, construction & testing	KT
6	Prototype demonstration	GALP
7	Environmental LCA and economic assessment	QUANTIS
8	Dissemination and communication	HYGEAR
9	Project Management	TECNALIA
10	Ethics requirements	TECNALIA

4. Overall approach and methodology



WP7. Environmental LCA and economic assessment (**QUANTIS**, TECNALIA, TUE, TUDELFT, MTEC, C&CS, POLYMEM, HYGEAR, ECOREC, ZEG, KT, GALP, ARKEMA, JM)

WP1. Business case definition (POLYMEM, all)

WP2. System requirements, design and modelling (**TUE**, TECNALIA, TUDELFT, UNIZAR, CENER, HYGEAR, ZEG, KT, GALP, ARKEMA, JM)

WP3. Raw materials production scaling-up (**JM**, TUE, TUDELFT, IFE, UNIZAR, MTEC, C&CS, ARKEMA)

WP4. Membrane production scaling-up (**TECNALIA**, TUE, TUDELFT, UNIZAR, POLYMEM, ECOREC)

WP5. Pilot prototypes manufacturing (**KT**, TUE, IFE, CENER, HYGEAR, ZEG, GALP)

TRL 5. MRL 5-6

WP6. Prototype demonstration
(**GALP**, TUE, IFE, CENER, HYGEAR, ZEG, KT)

TRL 6

WP8. Dissemination and communication (**HYGEAR**, all)

WP10. Ethics requirements (TECNALIA, all)

WP9. Project Management (TECNALIA, all)

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4. Overall approach and methodology

- **WP1: Business case definition**, will set the foundation for effective development and exploitation of results into the market.
- **WP2: System requirements, design and modelling,** will define a coherent set of specifications for the membrane based CO_2 capture systems as well as defining the requirements of the different materials and their scale up.
- **WP3 Core materials production scaling-up**, will scale-up the production processes of the core materials required for the three CO_2 capture solutions.
- **WP4: Membrane production scaling-up,** will tackle the production of the membranes for the three CO_2 capture prototypes.
- **WP5: Pilot prototypes design, construction & testing,** all the different materials (membranes, sorbents and catalyst) and balance of plant components will be integrated into the prototypes constructed for demonstrating and validating the performance of the materials and associated processes.
- **WP6: Prototype demonstration,** will be focused on the demonstration at TRL 6 of the three CO_2 capture systems developed in MEMBER, each of them being located at different relevant demonstration sites.

4. Overall approach and methodology

- **WP7: Environmental LCA and economic assessment,** LCA, LCC and techno-economic assessment will be performed, in order to prove the viability of the developed materials and technologies, and to give insights about the further use of the technologies.
- **WP8: Dissemination and communication,** runs throughout the whole project, feeding from the results of previous work packages, and providing support to exploitation of project results through highly focused communication and dissemination activities.
- **WP9: Project Management,** ensures an effective project management all along the execution of the work plan.
- **WP10: Ethics requirements,** will address ethical requirements including Environment, Health and Safety as required in H2020.

5. Expected results

#	Main exploitation product/ technologies/ others
1	MMM based system for pre-combustion CO_2 capture
2	MMM based system for post-combustion CO_2 capture
3	MA-SER system for pure H_2 production with integrated CO_2 capture
4	Advanced polymers for post-combustion MMMs
5	Advanced MOFs for pre- and post-combustion MMMs
6	Advanced MMMs for pre- and post-combustion
7	Advanced sorbents for MA-SER
8	Advanced catalysts for MA-SER
9	Advanced Pd-based H_2 membranes for MA-SER
10	Software tool for Membrane reactor and SER design. Membrane separation modules
11	Consulting services on LCA of CO_2 capture

6. Progress:

WP02 – System requirements, design and modelling

- Industrial requirements ✓
- Membrane modelling ✓
  - Polymeric membranes (flat sheet and HF)
  - MMMs membranes (flat shet and HF)
  - Pd-based membranes
- Reactor modelling (MA-SER concept) ✓
- MMMs system modelling ✓

6. Progress:
WP02 – System requirements, design and modelling

Modelling of pre-combustion gas permeation through flat sheet and HF membranes

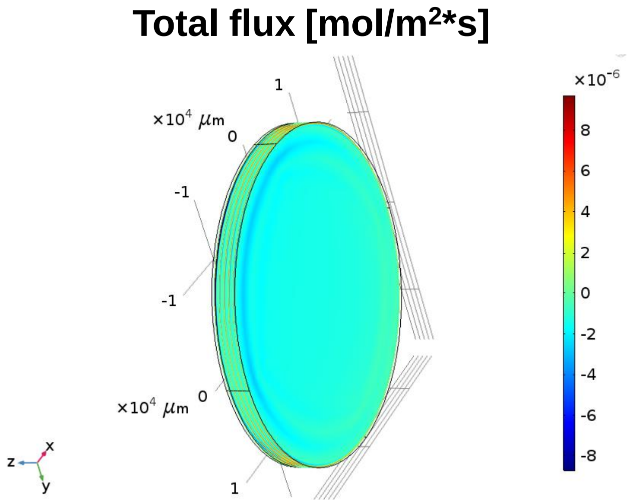
COMSOL

$$\rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot\left[-p\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T) - \frac{2}{3}\mu(\nabla\cdot\mathbf{u})\mathbf{I}\right] + \mathbf{F}$$

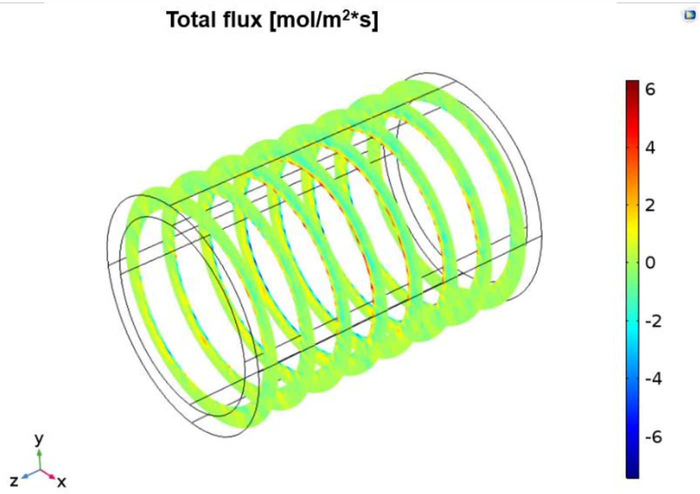
$$\nabla\cdot(\rho\mathbf{u}) = 0$$

$$\mathbf{u}\cdot\nabla c_i = D\cdot\nabla^2 c_i$$

CO_2 total flux (convective + diffusive) through a PBI flat sheet membrane



CO_2 total flux (convective+diffusive) through a PBI HF membrane



Total flux CO_2 (mol/m²·s)	Total flux H_2 (mol/m²·s)	Sel H_2/CO_2	
$1.18\cdot10^{-4}$	$6.83\cdot10^{-4}$	5.8	Exp
$1.20\cdot10^{-4}$	$6.00\cdot10^{-4}$	5.0	Model
$7.33\cdot10^{-3}$	$7.52\cdot10^{-2}$	10.2	Exp
$5.80\cdot10^{-3}$	$6.30\cdot10^{-2}$	10.9	Model

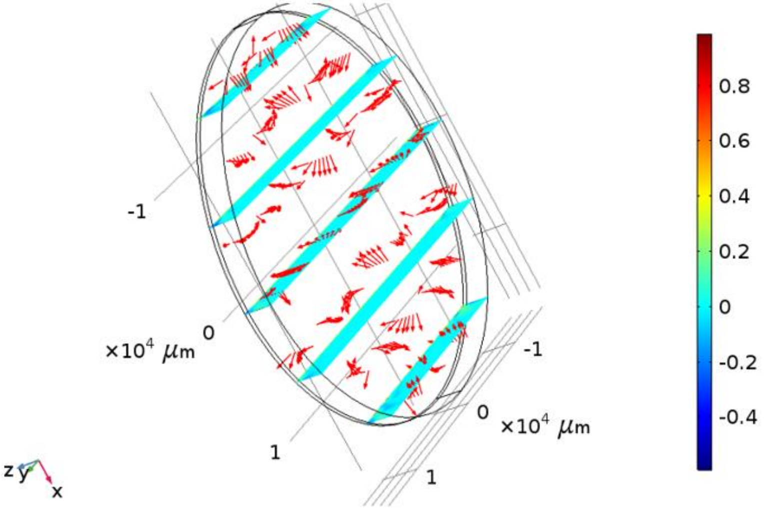
6. Progress:
WP02 – System requirements, design and modelling

Modelling of post-combustion gas permeation through flat sheet and HF membranes

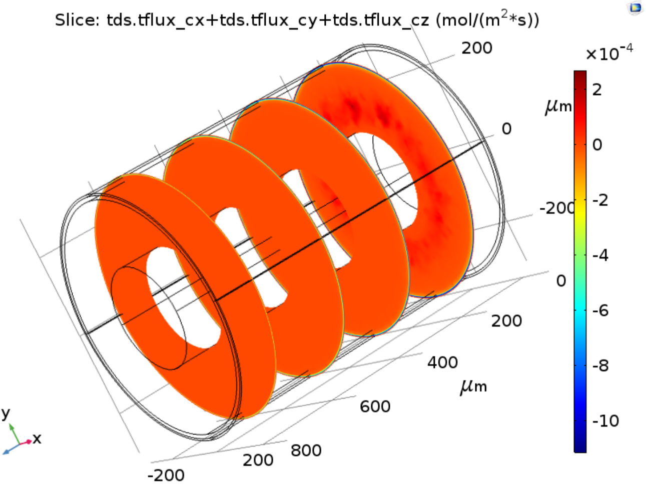
CO_2 total flux (convective+diffusive) through a Pebax 1657 flat sheet membrane

CO_2 total flux (convective + diffusive) through a Psf/PDMS/Pebax 1657 HF membrane

Total flux [mol/m²*s]



Total flux [mol/m²*s]



Total flux CO_2 (mol/m²·s)	Total flux N_2 (mol/m²·s)	Sel CO_2/N_2	
$2.68 \cdot 10^{-5}$	$4.69 \cdot 10^{-6}$	32.3	**Exp**
$3.30 \cdot 10^{-5}$	$6.10 \cdot 10^{-6}$	30.7	**Model**

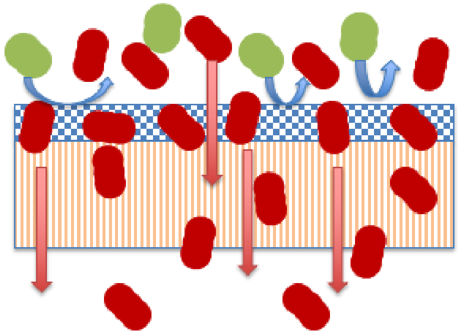
Total flux CO_2 (mol/m²·s)	Total flux N_2 (mol/m²·s)	Sel CO_2/N_2	
$1.90 \cdot 10^{-4}$	$3.52 \cdot 10^{-5}$	30.7	**Exp**
$2.70 \cdot 10^{-4}$	$3.41 \cdot 10^{-5}$	44.9	**Model**

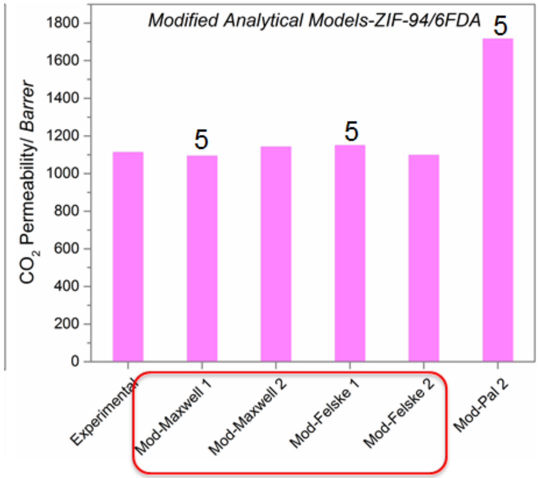
6. Progress:

WP02 – System requirements, design and modelling

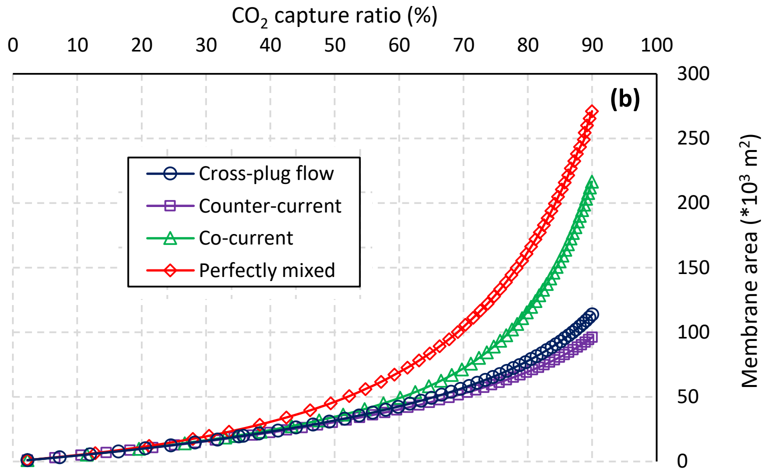
Modelling Modelling MMM – Mixed Matrix Membranes

- Selective layer models
- Inclusion porous support
- Contacting flow pattern

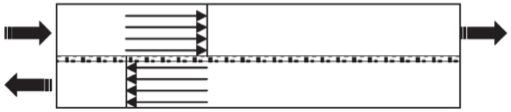




- Felske and modified Felske and Maxwell models describe MMM data best
- Sorption & diffusion p,T incorporation
- Knudsen transport support

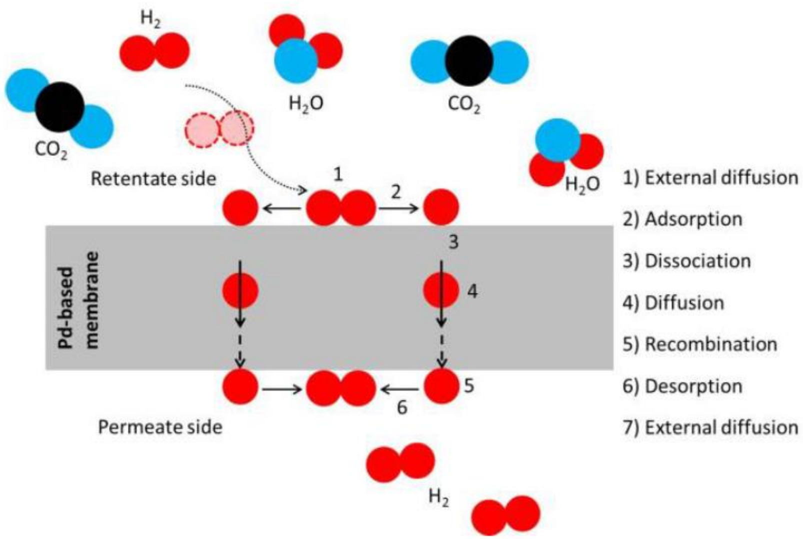


- Countercurrent operation optimal



6. Progress:
WP02 – System requirements, design and modelling

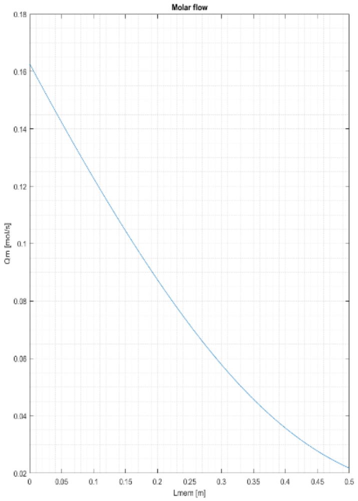
Dense membrane module modelling

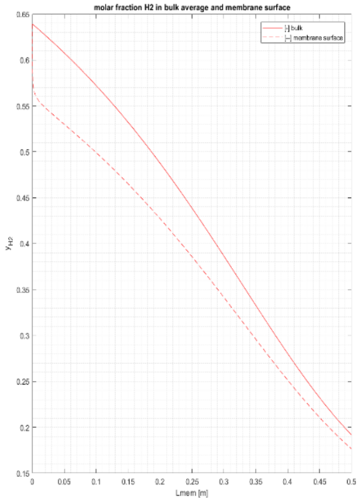


- Identified the transport mechanisms throughout the membrane module

- Determined the largest transfer resistance

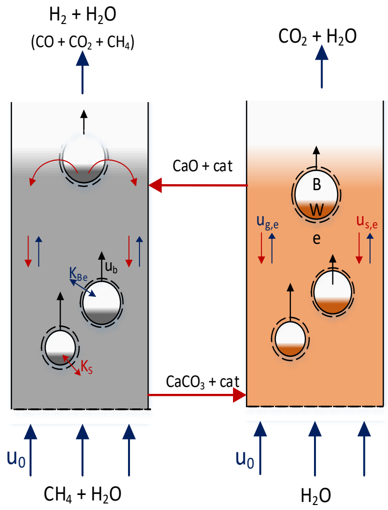
- Modelled the dense membrane module for H_2 separation

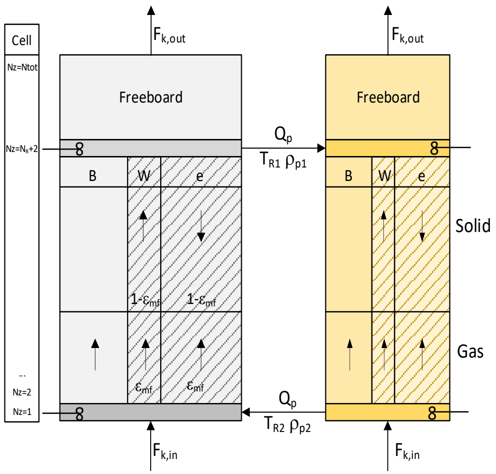




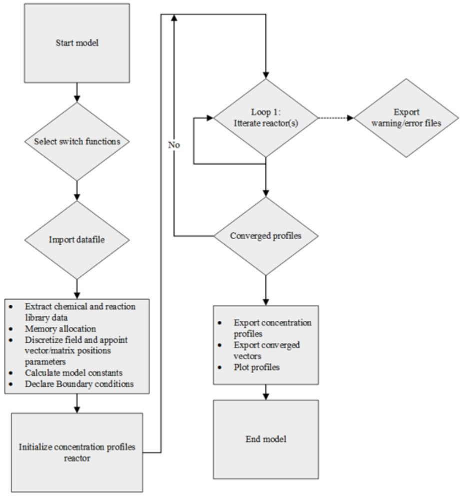
6. Progress:
WP02 – System requirements, design and modelling

MA-SER reactor modelling





- Modelled the MA-SER reactor system using phenomenological model
- Analyzed the reactor performance for improvement based on process limitations
- Model can be used for full scale process simulations for (dual) fluidized bed design



Start model

Select switch functions

Import datafile

- Extract chemical and reaction library data
- Memory allocation
- Discretize field and appoint vector/matrix positions parameters
- Calculate model constants
- Declare Boundary conditions

Initialize concentration profiles reactor

Loop 1:
Itterate reactor(s)

Export
warning/error files

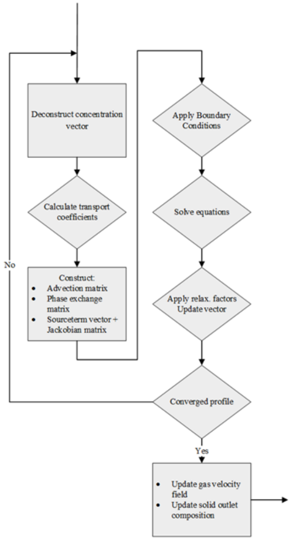
No

Converged profiles

- Export concentration profiles
- Export converged vectors
- Plot profiles

End model

(a) Model code construction



Deconstruct concentration vector

Calculate transport coefficients

Construct:
- Advection matrix
- Phase exchange matrix
- Sourceterm vector + Jackobian matrix

No

Apply Boundary Conditions

Solve equations

Apply relax. factors
Update vector

Converged profile

Yes

- Update gas velocity field
- Update solid outlet composition

(b) Loop 1: Reactor evaluation

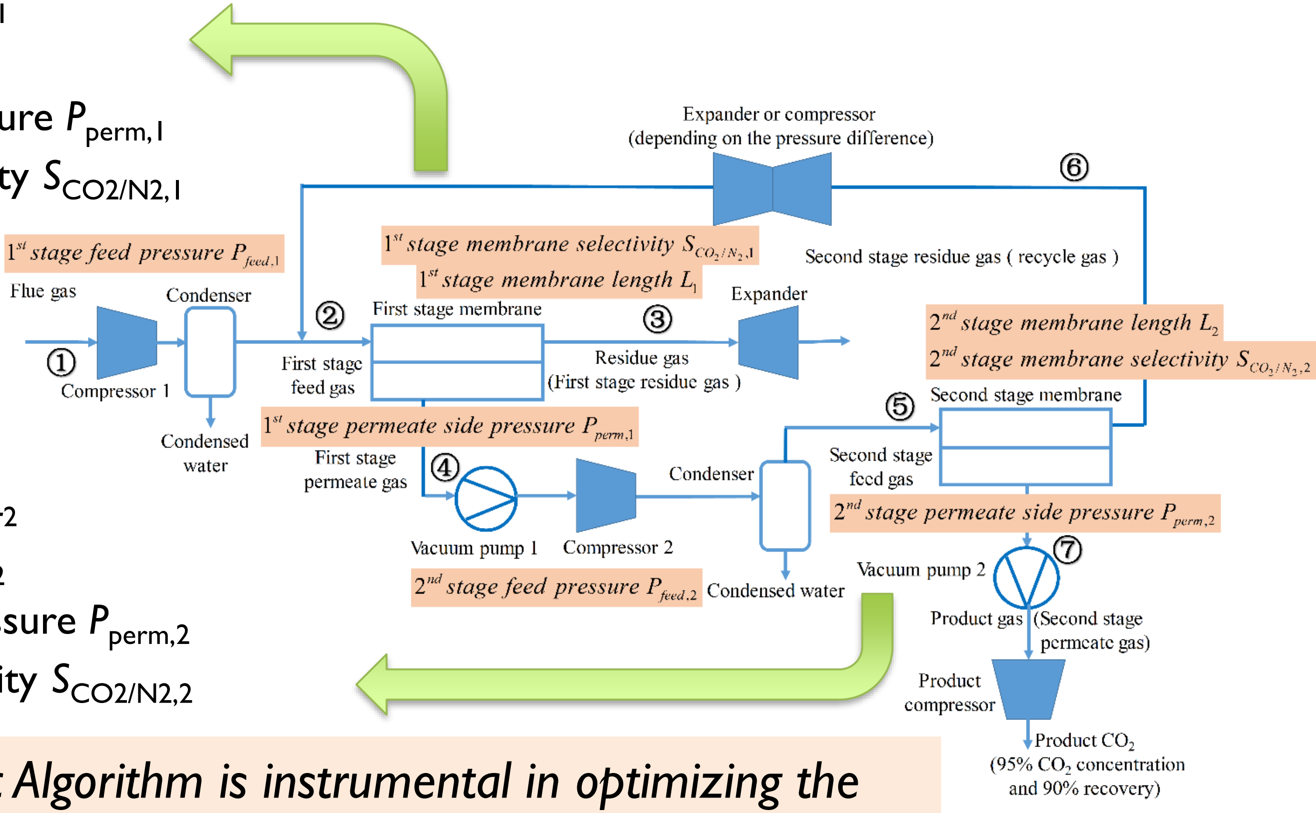
6. Progress:
WP02 – System requirements, design and modelling
MMM systems modelling

- Genetic Algorithm for process optimization
  - For the typical two-stage membrane separation process, **eight** independent variables are to be optimized:

- 1^{st} stage membrane length L_1
- 1^{st} stage feed pressure $P_{feed,1}$
- 1^{st} stage permeate gas pressure $P_{perm,1}$
- 1^{st} stage membrane selectivity $S_{CO2/N2,1}$

Multivariable Optimization

- 2^{nd} stage membrane length L_2
- 2^{nd} stage feed pressure $P_{feed,2}$
- 2^{nd} stage permeate side pressure $P_{perm,2}$
- 2^{nd} stage membrane selectivity $S_{CO2/N2,2}$



Genetic Algorithm is instrumental in optimizing the multivariable CO_2 capture processes

6. Progress:

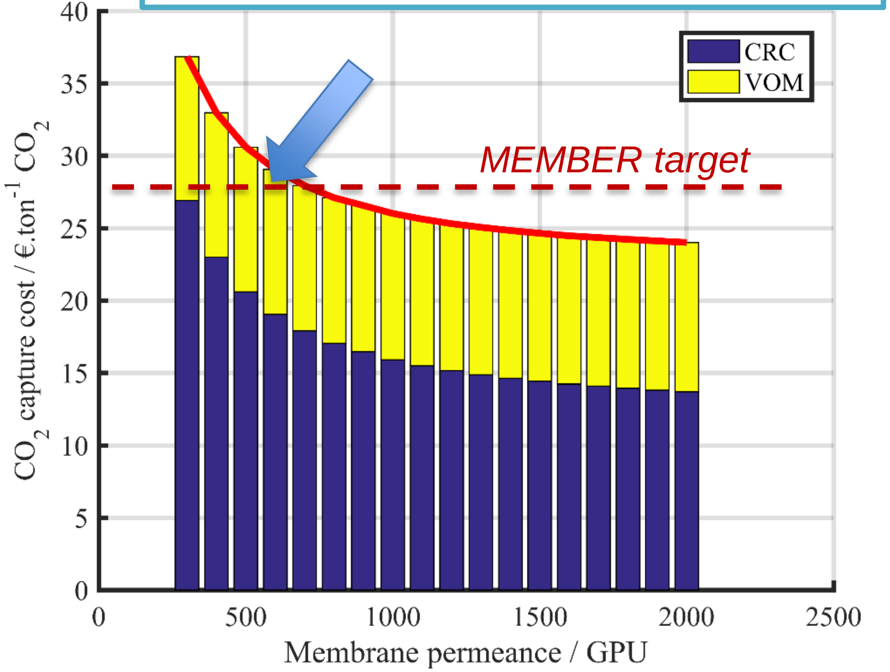
WP02 – System requirements, design and modelling

Technical and economic assessment Prototype A & B

- Ongoing activity
- Based on GA system lay-outs, includes:
  - Sensitivity analysis regarding
    - Permeance
    - Selectivity
  - Cost breakdown
  - Reference: 300 GPU/ 70 Sel.

CO_2 capture cost

VOM -- Variable Operating and Maintenance
CRC -- Capital Related Cost



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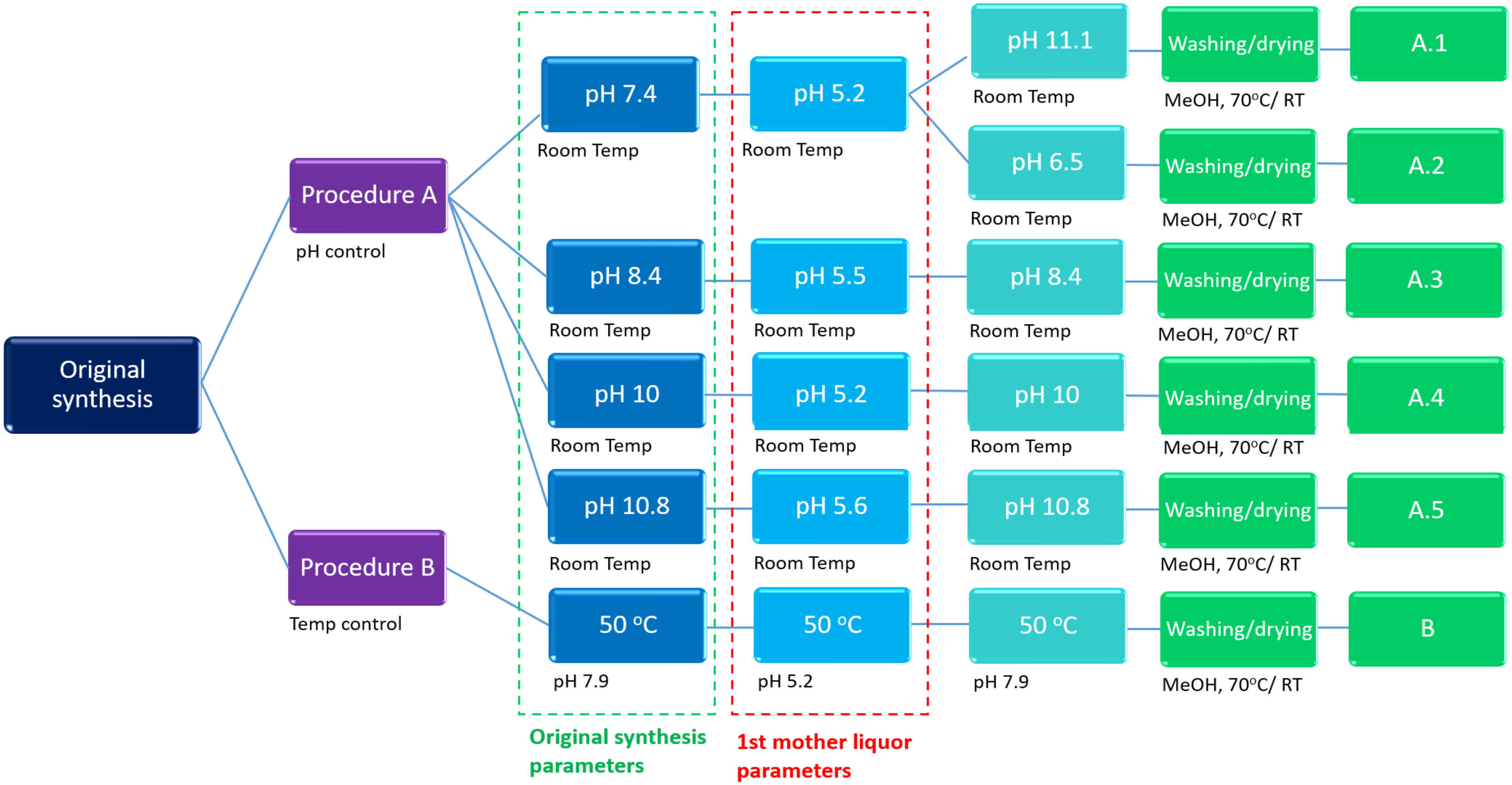
6. Progress:
WP3 – Core materials production scaling up

MOF and polymer development

- Synthesis of scalable MOFs for screening and prototypes (1 kg ZIF-8 & ZIF-94). ✓
- Large scale synthesis routes developed ✓
- Investigation of solvent and excess ligand recycling ✓
- Deliver commercial Pebax® polymers ✓
- Characterise synthesised materials ✓
- Process quality assessment ✓
- Technical and economic evaluation of MOF synthesis pilot lines ✓
- Industrial scale manufacturing concept and evaluation completed ✓

6. Progress:
WP3 – Core materials production scaling up

Solvent and ligand recycling in ZIF-94 syntheses



Original synthesis

Procedure A
pH control

pH 7.4 Room Temp → pH 5.2 Room Temp → pH 11.1 Room Temp → Washing/drying MeOH, 70ºC/ RT → A.1
pH 7.4 Room Temp → pH 5.2 Room Temp → pH 6.5 Room Temp → Washing/drying MeOH, 70ºC/ RT → A.2
pH 8.4 Room Temp → pH 5.5 Room Temp → pH 8.4 Room Temp → Washing/drying MeOH, 70ºC/ RT → A.3
pH 10 Room Temp → pH 5.2 Room Temp → pH 10 Room Temp → Washing/drying MeOH, 70ºC/ RT → A.4
pH 10.8 Room Temp → pH 5.6 Room Temp → pH 10.8 Room Temp → Washing/drying MeOH, 70ºC/ RT → A.5

Procedure B
Temp control

50 ºC pH 7.9 → 50 ºC pH 5.2 → 50 ºC pH 7.9 → Washing/drying MeOH, 70ºC/ RT → B

Original synthesis parameters

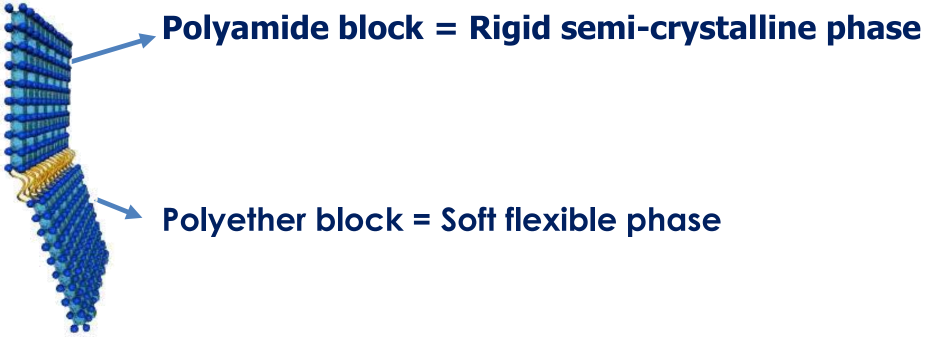
1st mother liquor parameters

The pH was measured by diluting the NaOH/THF/MetOH mixture in water in the ratio 1:100 (base mixture:water)"

6. Progress:
WP3 – Core materials production scaling up

PEBAX® Materials for CO_2 Capture

- Thermoplastic Elastomer (TPE)
- Poly Ether Block Amide (eXtreme)
- Two phases



- The compositions of the PA and the PE blocks, as well as the PA/PE ratio, are basic structural characteristics allowing to tune the membrane permeability and selectivity to gases
- The polyamide phase can be 100% bio-based
- A new partially bio-based Pebax® material has been developed with a high permeability and a high CO_2/N_2 selectivity

6. Progress:

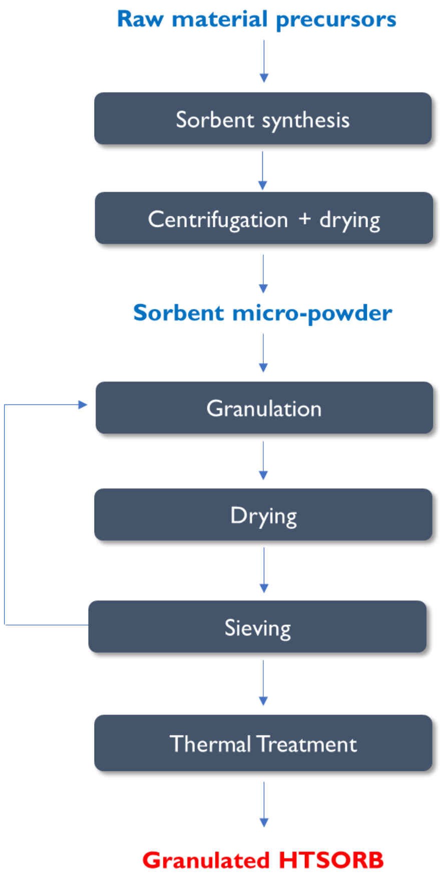
WP3 – Core materials production scaling up

Sorbent development

- The sorbent has been optimised with respect to chemical and mechanical performance investigating liquid-to-solids ratio of the sorbent synthesis, as well as the temperature and time of the thermal treatment of the granules.
- Several larger scale batches (20 kg) for evaluation have been produced and tested. An initial sorption capacity of 0.25 g-CO_2/g has been found to be optimum for the sorbent stability.
- Quality control of the of 20 kg optimized HTSORB ongoing.
  - FBR tests
  - SER-TGA test (200 cycles)
  - Attrition test and comparison with reference materials
- Knowledge needed to produce the 200 kg batch for the prototype C test campaign has been generated, and manufacture will start once final material pre-validation is completed.

6. Progress:
WP3 – Core materials production scaling up

Sorbent development



Raw material precursors

Sorbent synthesis

Centrifugation + drying

Sorbent micro-powder

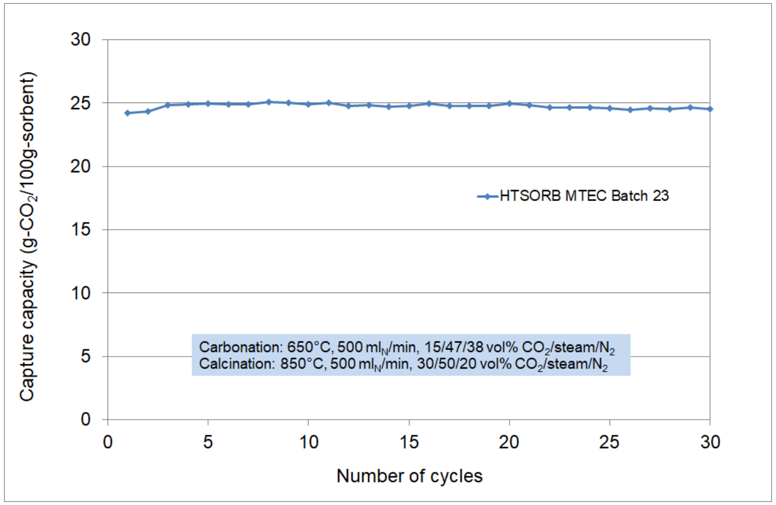
Granulation

Drying

Sieving

Thermal Treatment

Granulated HTSORB



Stable sorption capacity of granulated HTSORB in relevant process conditions

Granulated HTSORB sorbent

6. Progress:
WP3 – Core materials production scaling up

Catalyst development

- After a catalyst screening campaign, a Nickel reforming catalyst formulation (C&CS #1005 Mod 2) meeting the target requirements on the mechanical properties in multicycling reforming – regeneration operation under fluidizing conditions has been developed.
  - A stable high catalytic activity of the catalyst in Sorption Enhanced Reforming (SER) in a 57 cycles TGA test in a mixture with a CO_2-sorbent HTSORB 021 was confirmed.
  - A SER-FBR test in a mixture with the CO_2-sorbent HTSORB 021 has shown a high catalytic activity in methane steam reforming. In this test H_2 with a purity between 97 – 98% was produced (dry basis, N_2 free).
  - In a 200 cycles SER-TGA test of a mixture of catalyst and HTSORB 024 an acceptable long-term stability was found.

6. Progress:
WP3 – Core materials production scaling up

Catalyst development

- An appropriate European patent application EP19201909.9 with the title "Fluidizable steam reforming catalyst and use of a catalyst in methane steam reforming" was filed on October 8, 2019.
- Scale-up of C&CS #1005 Mod 2 from 1 to 5 kg scale for a pre-validation test was successfully realized and the same BET surface area was obtained on 5 kg scale as on 1 kg scale.
- Based on these results, scale-up of the production of C&CS #1005 Mod 2 from 5 to 50 kg scale was started.

6. Progress:

WP4 – Membrane production scaling-up

Scale-up the manufacturing processes of membranes for the CO_2 capture prototypes

Prototype A

Pre-combustion CO_2 capture

MMM hollow fiber membranes

Prototype B

Post-combustion CO_2 capture

MMM hollow fiber membranes

Prototype C

Pure H_2 production with integrated CO_2 capture

Pd-based membranes

Recycling of critical membrane materials and membrane modules

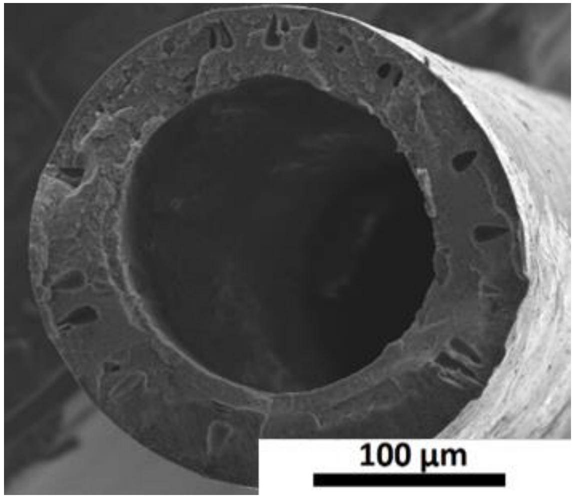
6. Progress:

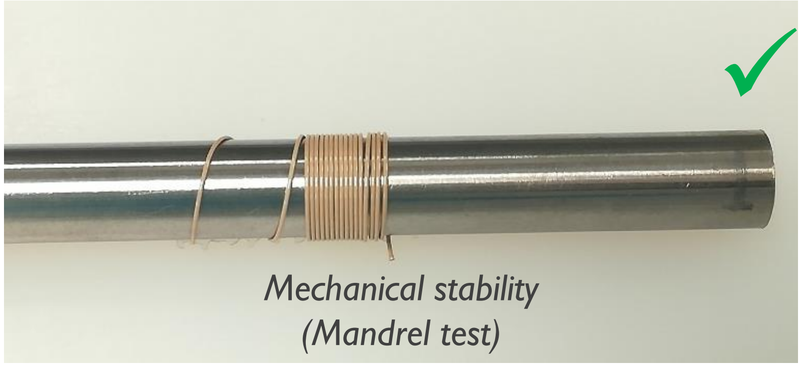
WP4 – Membrane production scaling-up

MMM hollow fiber membranes for **pre-combustion** CO_2 capture

Optimization of membrane preparation

- Spinning parameters optimized at lab-scale for the PBI based mixed matrix hollow fiber preparation.
- Achieved improvements on hollow fiber processability compare to the reference spinning recipe (M4CO2 project): industrially relevant take up rate reached (25m/min), substantial reduction on fiber diameter (270 µm), mechanical stability improvement and PBI quantity required to produce a m^2 of hollow fiber has been halved.





Mechanical stability
(Mandrel test)

6. Progress:
WP4 – Membrane production scaling-up

MMM hollow fiber membranes for **pre-combustion** CO_2 capture

Membrane fabrication scale-up :

- Transfer of the recipe developed at laboratory scale : 100 m batch
- Adaptation of the spinning recipe on Polymem semi-industrial line for production of a large-scale batch
- Fabrication of a **17,000 m batch**

6. Progress:

WP4 – Membrane production scaling-up

MMM hollow fiber membranes for **post-combustion** CO_2 capture

Membrane development :

- Construction and start up of an innovative pilot line for continuous coating.
- Optimization of the recipe for the fabrication of a multiple layer composite membrane with very thin and defect free dense layer.
- Status: adaptation of the initial recipe (developed during M4CO2 project) by replacing previously used polymers with suitable ones for continuous coating process.

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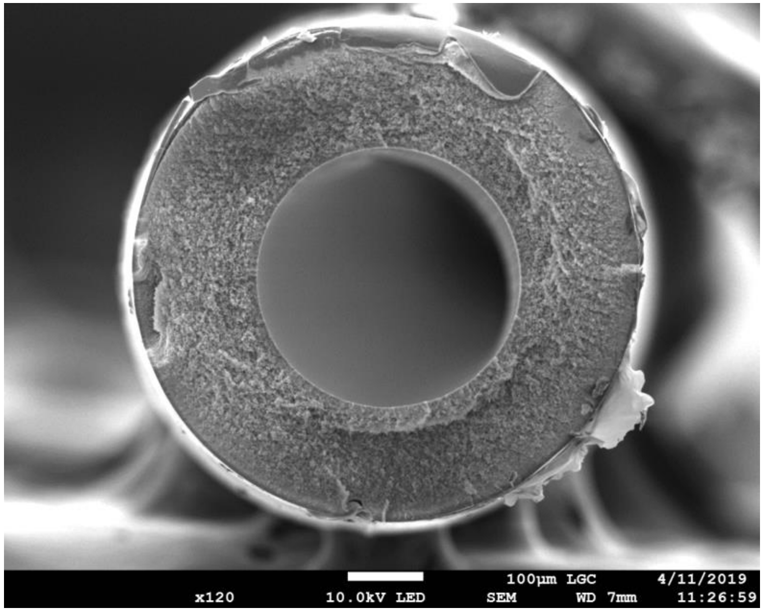
6. Progress:

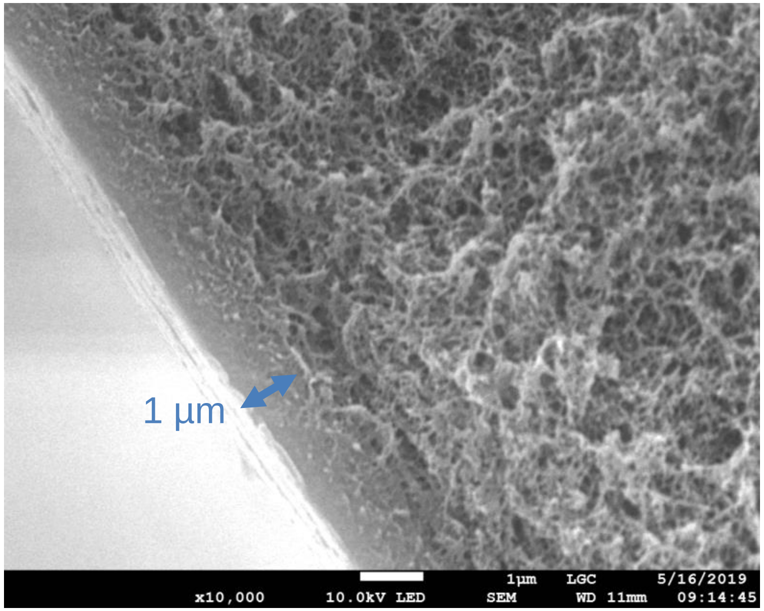
WP4 – Membrane production scaling-up

MMM hollow fiber membranes for **post-combustion** CO_2 capture

Membrane scale-up :

- Fine tunning of the parameters for the fabrication of a large-scale batch
- Major increase of productivity by **multiplying the production speed by 50** (from 30 mm/min to 1,500 mm/min)
- **Production of several thousands meters** of single layer composite membrane





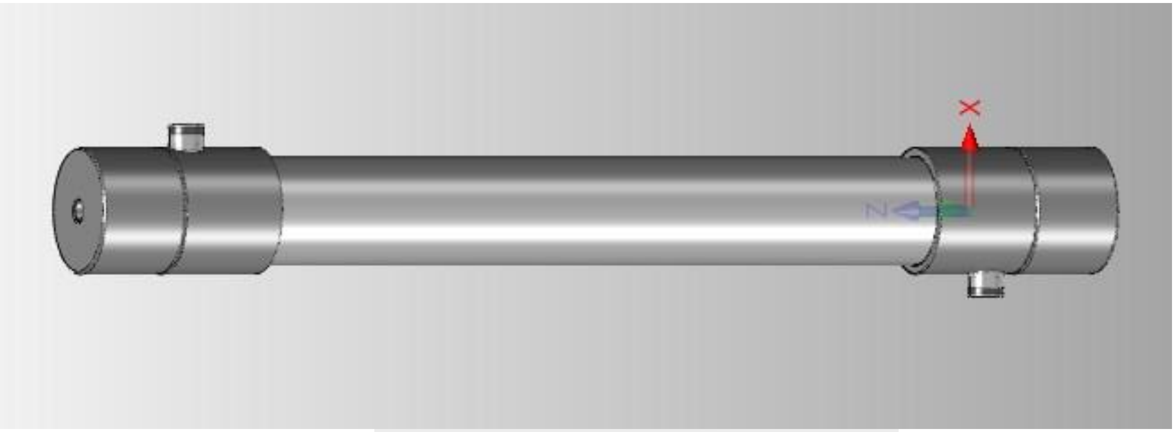
6. Progress:

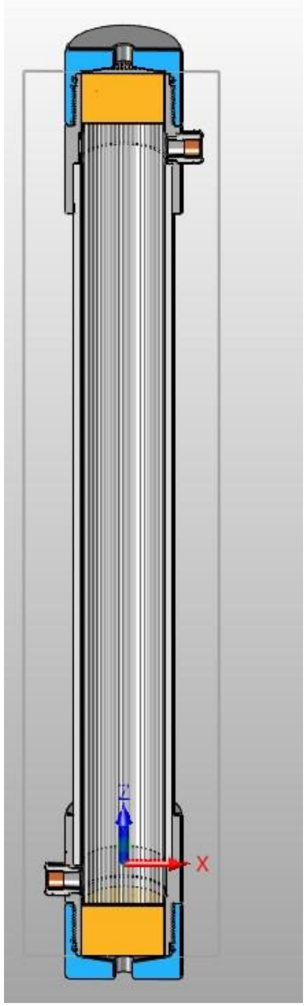
WP4 – Membrane production scaling-up

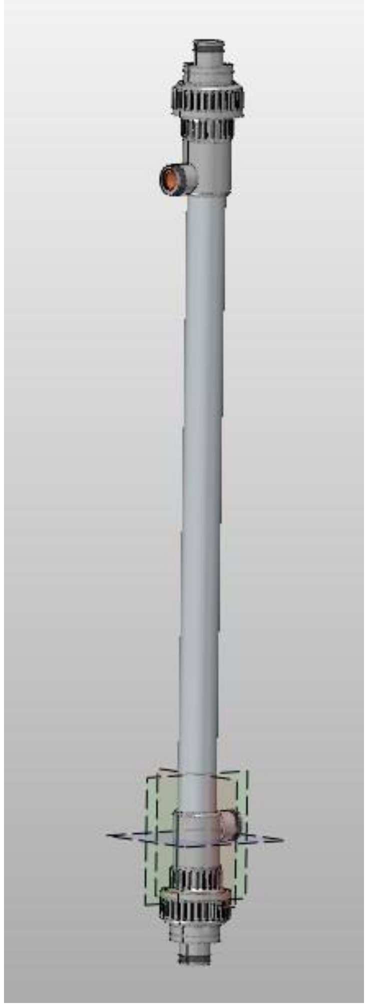
MMM hollow fiber membranes

Fabrication of 10 m² modules for prototypes A and B

- Design of the 3 prototypes modules





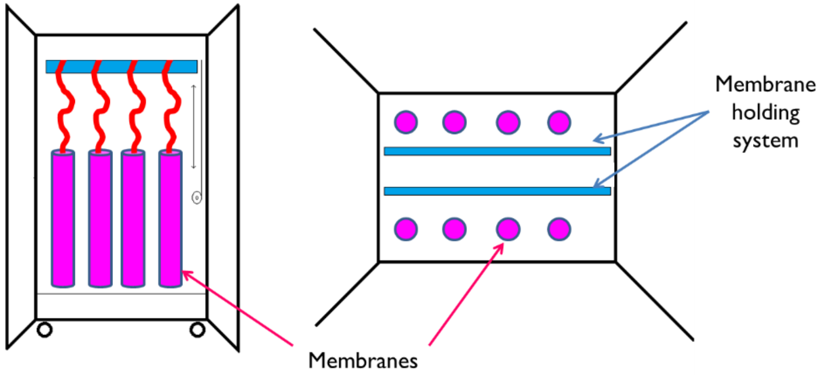


6. Progress:

WP4 – Membrane production scaling-up

Pd-based membranes for the MA-SER prototype reactor

- A new plating system has been designed and set up for depositing 8 Pd-Ag membranes per batch (50 cm length membranes)
- 50 sealed Pd-Ag membranes for the prototype have been successfully manufactured by TECNALIA. The membranes have been delivered to TUE for being integrated in the MA-SER prototype



Sketch of the new plating system for preparation of 8 Pd-Ag membranes per batch

Ceramic supported thin double skin Pd-based membranes prepared for the prototype

6. Progress:

WP4 – Membrane production scaling-up

Recycling critical membrane materials and modules

- Realization of the technical documentation for the authorization request of the prototype and its obtaining.
- Basic and detailed engineering for the pilot plant revamping has been carried out and includes the main process documents (P&ID, PFD, equipment list, data sheet, mechanical drawing, 3D plant).
- Assessment (literature and lab test) of the possible protective coating layer for the reactor and mixer.
- Bibliographic studies (activity initially not foreseen) on the recovery of Pd from leachate and related laboratory tests.
- Lab tests on the metallic and ceramic MEMBER membranes samples (characterization and hydrometallurgical process) provided by TECNALIA.

CERAMIC MEMBRANE

METALLIC MEMBRANE

6. Progress:

WP4 – Membrane production scaling-up

Recycling critical membrane materials and modules

- Revamping of the pilot plant, leakage test and blank tests completed.
- Pilot plant ready for the demonstration campaign.

Eco Recycling's pilot plant for the metallic and ceramic membrane recycling process.

6. Progress:

WP5 – Pilot prototypes design, construction & testing

Targets

Prototype A

Pre-combustion capture in power plants using MMMs at HYGEAR reforming equipment.

CCR > 90%

Capture Cost < 30 €/ton

Prototype B

Post-combustion capture in power plants using MMMs at the 8.8 MW CHP facilities of Agroger (GALP, Portugal).

CCR > 90%

Capture Cost < 40 €/ton

Prototype C

Pure hydrogen production with integrated CO_2 capture using MA-SER at the IFE-HyNor (Norway) under the supervision of ZEG POWER.

CCR > 90%

Capture Cost < 30 €/ton

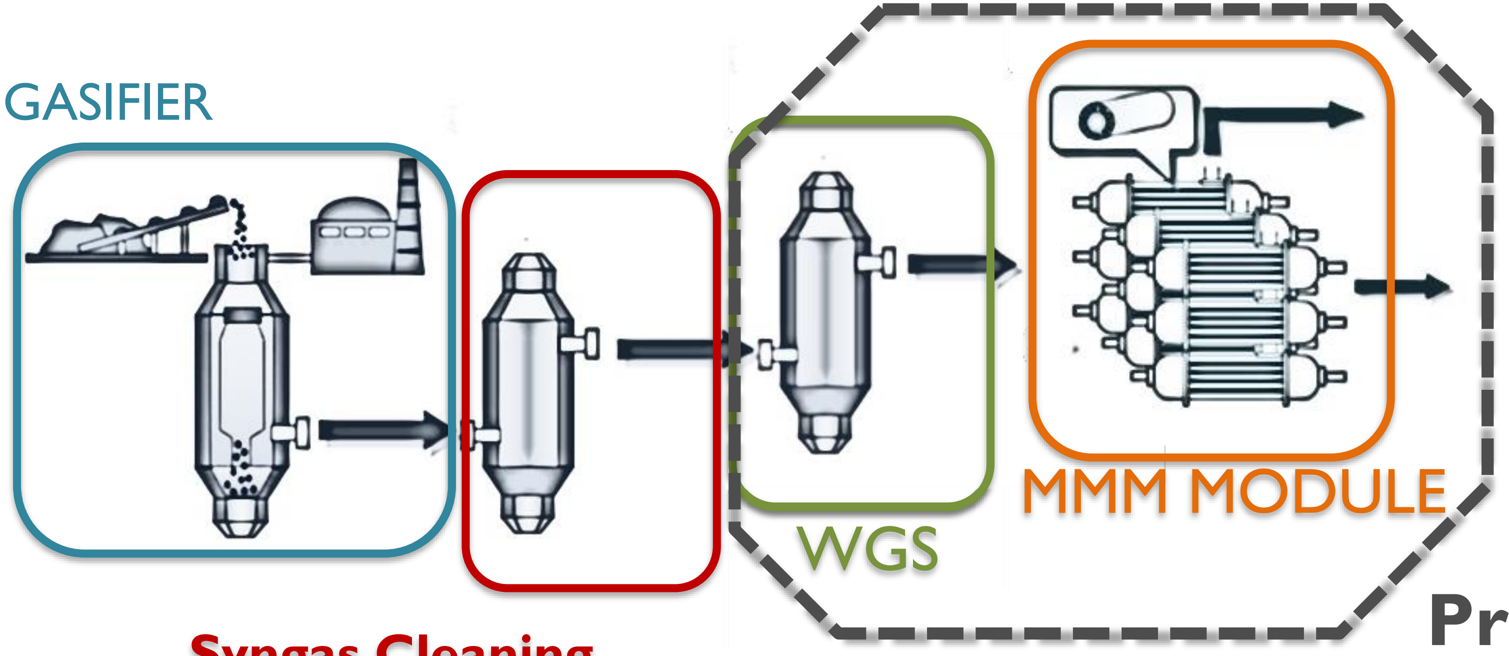
6. Progress:

WP5 – Pilot prototypes design, construction & testing

- Basic Design of the system concluded.
- The detailed engineering of the three prototypes and the syngas cleaning finalised.
- The specifications for all components and mechanical designs made for those components not commercially available.
- 3D designs of the prototypes made.
- Using the specifications most of the components have been sourced and purchased.
- In the next phase construction will start and Factory Acceptance Tests will be performed.

6. Progress:
WP5 – Pilot prototypes design, construction & testing

PROTOTYPE A



Syngas Cleaning System

REQUIRED to purify process gas from Gasifier before being fed to Prototype A

6. Progress:
WP5 – Pilot prototypes design, construction & testing

PROTOTYPE A: Syngas Cleaning System

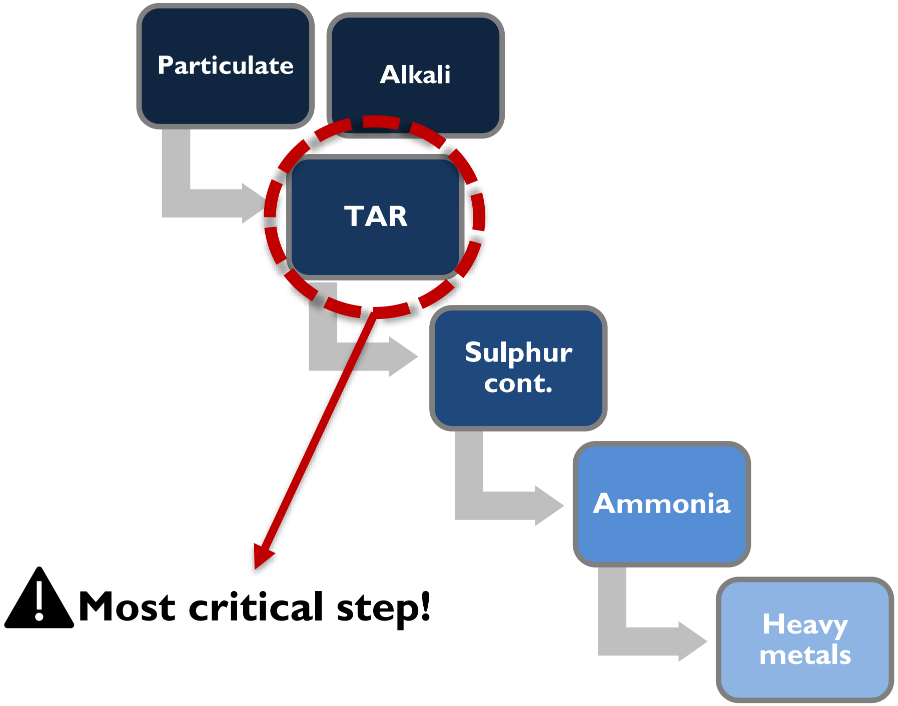
- Feed & Specification

Typical syngas from gasification of biomass with impurities:

- ○ Alkali
- ○ Particulate
- ○ Tar
- ○ Chlorine compounds
- ○ Sulphur contaminants
- ○ Nitrogen contaminants
- ○ Heavy metals

Specifications provided by downstream units

- Optimized sequence of removal identification



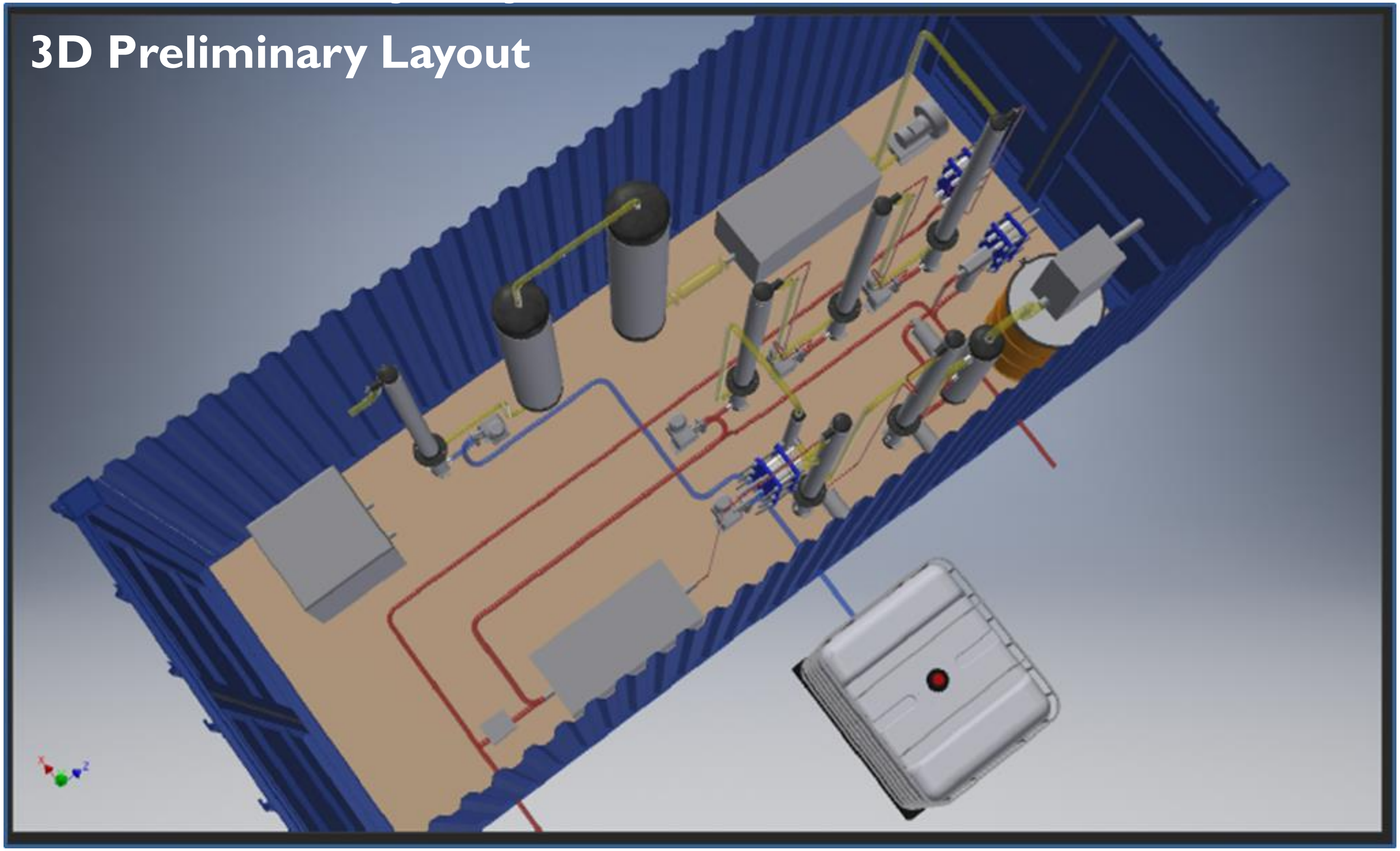
Final configuration has resulted as compromise between site requirement and downstream unit specification

- Basic Design concluded
- Detailed Engineering concluded

6. Progress:

WP5 – Pilot prototypes design, construction & testing

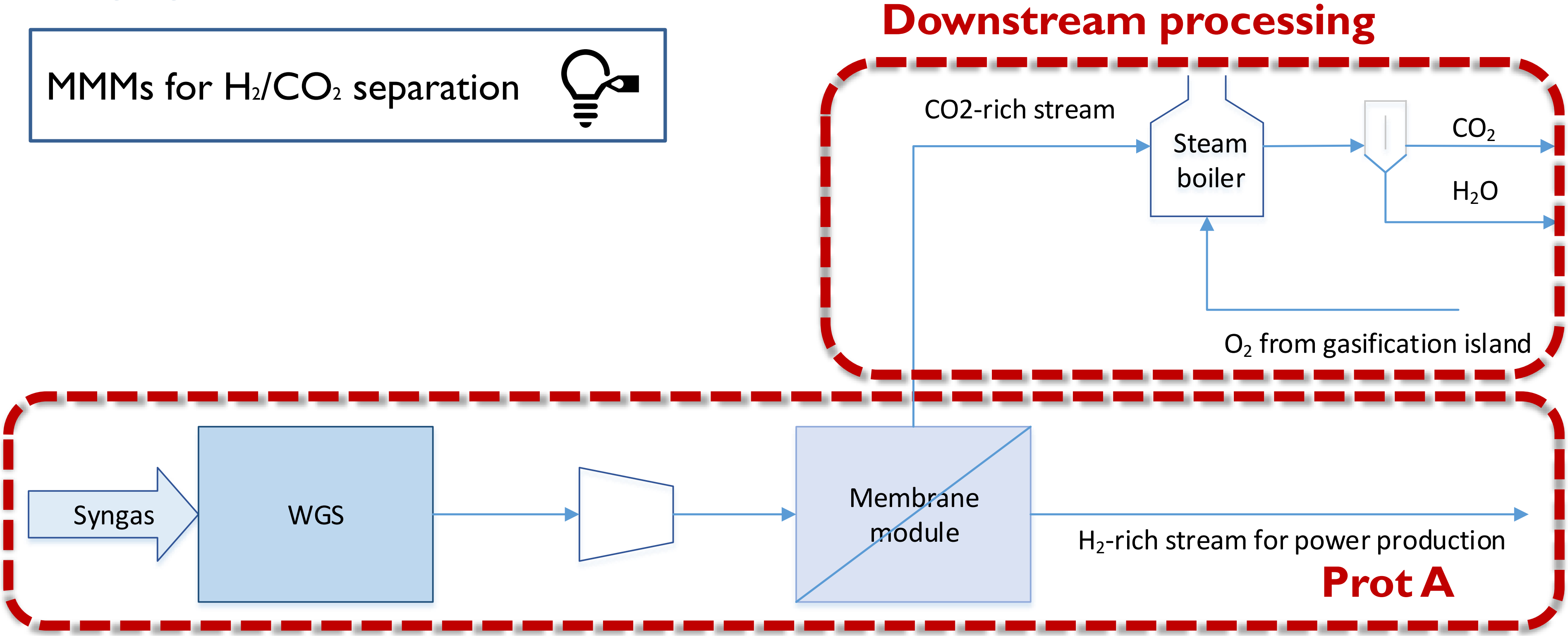
PROTOTYPE A: Syngas Cleaning System



6. Progress:
WP5 – Pilot prototypes design, construction & testing

PROTOTYPE A

MMMs for H_2/CO_2 separation



- Syngas from biomass gasification unit / SCS
- CO_2 separation from the shifted syngas after Water Gas Shift reactor
- The heating value contained in the original feedstock is re-allocated in a "decarbonized“ fuel → Hydrogen

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6. Progress:
WP5 – Pilot prototypes design, construction & testing

PROTOTYPE B

- Demo Site: AGROGER CHP plant - property of Galp Energia - Portugal

- Galp Energia is a vertically integrated multi-energy operator operating in the oil and natural gas business and as a producer and seller of electricity for industrial and home consumption.

- AGROGER cogeneration plant consists of 2 sets of Natural Gas fuelled electrical power-generators providing up to 8.8 MW of Power.

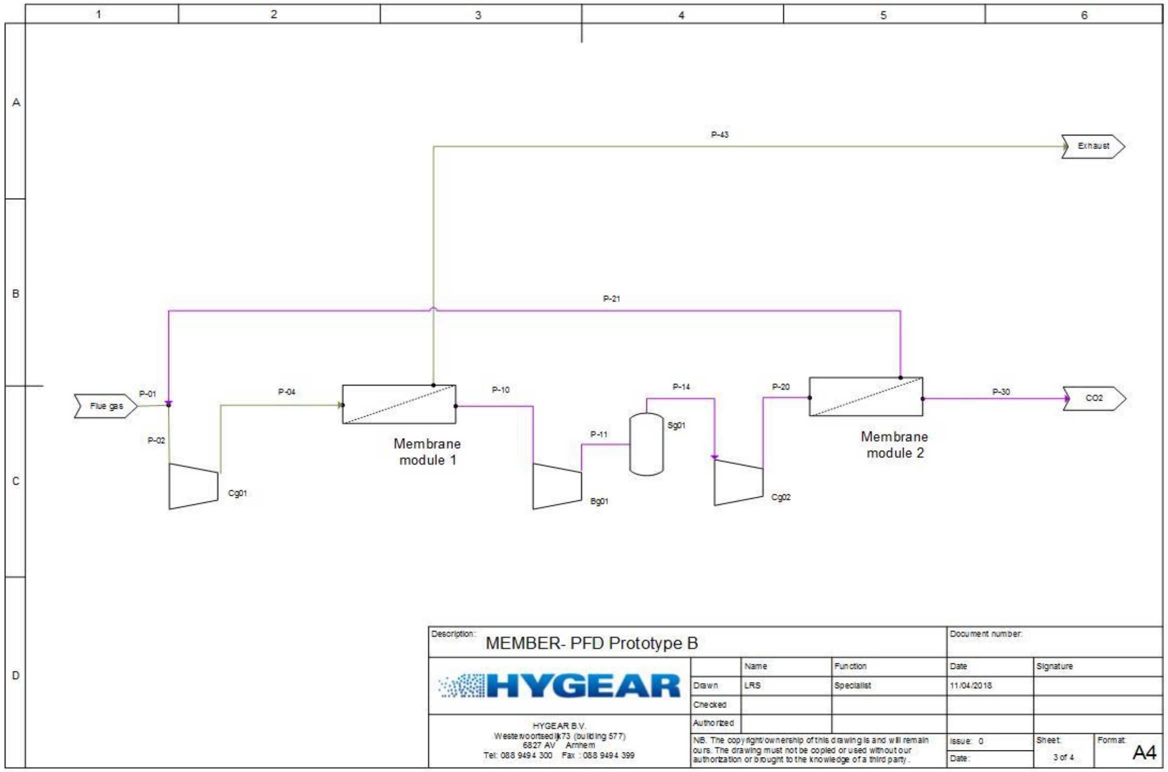
6. Progress:

WP5 – Pilot prototypes design, construction & testing

PROTOTYPE B

- Prototype B is a two-stage post-combustion CO_2-recovery system
- Two membrane modules in series,
  - module 1 larger than module 2
- Operating conditions are RT and 7 barg
- Recovery over 90%
- Purity to be reached >95%

MMMs for CO_2/N_2 separation



Description: MEMBER- PFD Prototype B					Document number:	
HYGEAR		Name	Function	Date	Signature	
	Drawn	LRS	Specialist	11/04/2018		
	Checked					
HYGEAR B.V. Westervoortsedijk73 (building 577) 6827 AV Arnhem Tel: 088 9494 300 Fax : 088 9494 399	Authorized					
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6. Progress:
WP5 – Pilot prototypes design, construction & testing

PROTOTYPE C

- Demo Site: IFE-HyNor Hydrogen Technology Centre - Norway

- Advanced infrastructure fully dedicated to the test and demonstration of future clean hydrogen technologies.

A combination of metallic H_2 membranes, reforming catalyst and CO_2 sorbent into an advanced Membrane Assisted Sorption Enhanced Reforming (MA-SER) process

Target process	Value	Unit
CCR	≥90	%
CO_2 purity	≥95	%
H_2 production	10	Nm^3/h
H_2 purity	≥99.9	%
CH_4 conversion	>95	%

6. Progress:

WP5 – Pilot prototypes design, construction & testing

PROTOTYPE C

MA-SER SYSTEM

BioMethane + Steam

Hydrogen

CO_2

- Identification of Target for innovative materials

Target Membrane	Value	Unit
Life time	>4000	h
Design temperature	500	°C
Membrane area	1	m^2
Target Sorbent	**Value**	**Unit**
Sorption Capacity	Min 0.2	g_{CO2}/g_{sorb}
Cycling stability	Min. 1000	cycles
Attrition jet index	Max. 10	%
Target Catalyst	**Value**	**Unit**
Cycling stability	Min. 1000	cycles
Attrition jet index	Max. 10	%

- Catalyst Development

- Sorbent Development

- Pd-based membrane development

- Basic Design of the system concluded
- Detailed Engineering of the system concluded
- Purchasing of all items (equipment, piping, instrumentation, etc.) under finalization

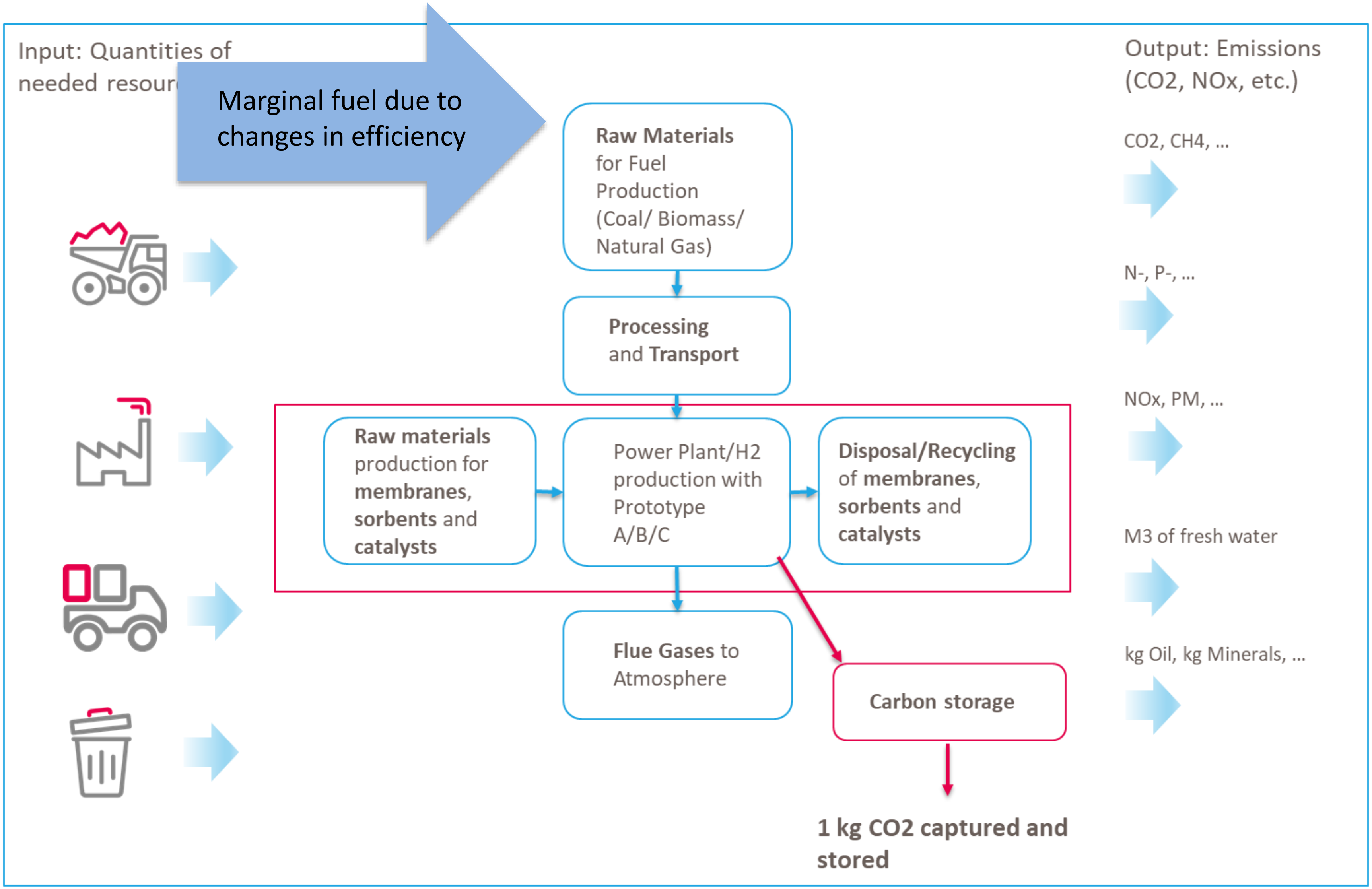
6. Progress:

WP7 – Environmental LCA and economic assessment

- Goal and scope of the environmental LCA and LCC completed ✓
- Preliminary environmental LCA and LCC completed ✓
- Final environmental LCA and LCC ongoing
- Economic assessment of the MEMBER materials and technology ongoing
- Footprint ongoing

6. Progress:
WP7 – Environmental LCA and economic assessment

System Boundaries of LCA / LCC



Input: Quantities of needed resour

Marginal fuel due to changes in efficiency

Raw Materials for Fuel Production (Coal/ Biomass/ Natural Gas)

Processing and **Transport**

Raw materials production for **membranes**, **sorbents** and **catalysts**

Power Plant/H2 production with Prototype A/B/C

Disposal/Recycling of **membranes**, **sorbents** and **catalysts**

Flue Gases to Atmosphere

Carbon storage

1 kg CO2 captured and stored

Output: Emissions (CO2, NOx, etc.)

CO2, CH4, …

N-, P-, …

NOx, PM, …

M3 of fresh water

kg Oil, kg Minerals, …

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6. Progress:

WP7 – Environmental LCA and economic assessment

Reference Systems

MEMBER system	**Reference system**
Pre-combustion	Coal fired advanced IGCC power plant with CO_2 capture using Selexol as a physical solvent
Post-combustion	Coal Power Plant with CO_2 capture using MEA (monoethanolamine) as a chemical solvent
Integrated H_2 production	Steam reforming process with natural gas feedstock and CO_2 capture

6. Progress:

WP7 – Environmental LCA and economic assessment

Economic assessment, technical and economic viability

- Preliminary economic assessment (CAPEX and OPEX) of the MEMBER technologies ongoing.
- Economic assessment of the benchmark cases ongoing.
    - Economic assessment of benchmark case (conventional methane steam reforming with CO_2 capture), reference case (SER process) and innovative MEMBER case (MA-SER process) is in progress for different capacities

6. Progress:

WP8 – Dissemination and communication

Main tools, communications documents and activities:

- A public web-site (https://member-co2.com) that it is continuously updated with all the publishable information and news from the project partners.
- Public documents such as presentations, newsletters, videos and public reports.
- Dissemination of the project in press and/or social media (LinkedIn groups).
- Organisation of two workshops:
    - "Membrane processes for CO_2 capture" organised by MEMBER and hosted by TUE on January the 15th, 2020. 53 persons attended the workshop.
    - Internal workshop on "CO_2 Capture and Utilization". Workshop organised jointly between 11 EC funded projects on February 16th-17th, 2021.
- Up to now 25 contributions to various conferences, 3 articles in scientific journals published or submitted, one patent filled out and one thesis presented (see https://www.member-co2.com/content/publications).

Thank you for your attention

https://member-co2.com/

Contact:
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