MACBETH

Membranes And Catalysts Beyond Economic and Technological Hurdles

MACBETH – A REVOLUTION IN CATAYLTIC REACTION TECHNOLOGY

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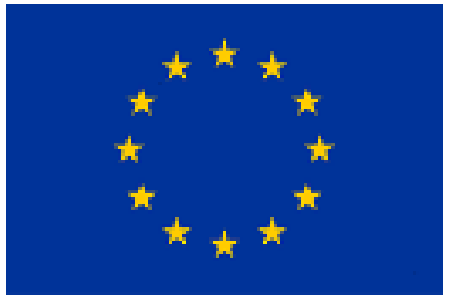
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°869896.

Acknowledgment



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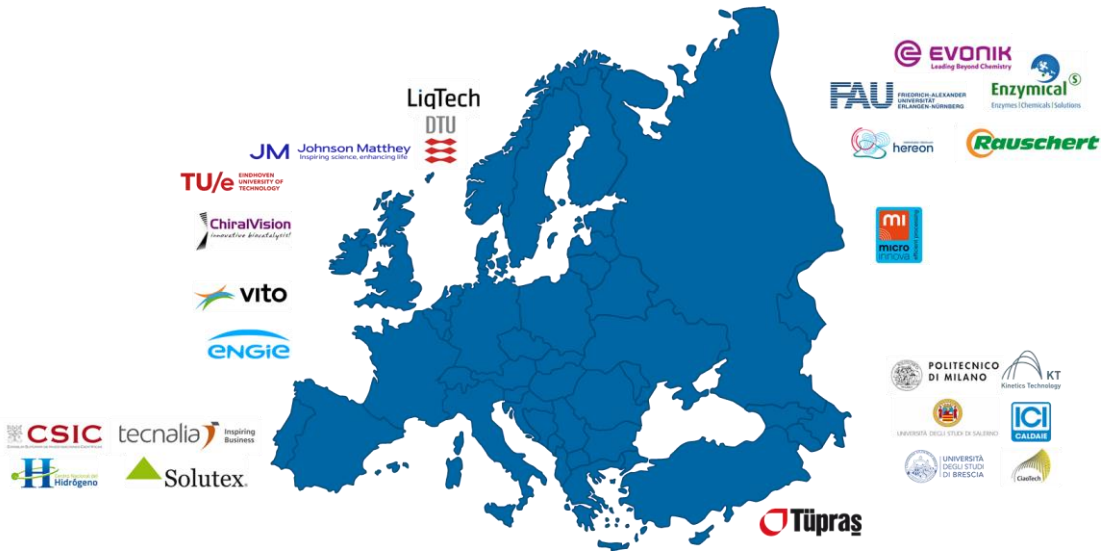

PROJECT BUDGET: 20,7 M€

PROJECT DURATION: 11/2019 – 10/2024

CONSORTIUM: 24 partners

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Agenda

- Motivation
- Project - Overview
- Introduction to Show Cases
- Outlook

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Motivation

- In all sectors of the process industry, **downstream processing** requires a **significant share of the overall energy and resource consumption** and contributing for a large portion of the CAPEX and OPEX of the process.
- Significant enhancement of the competitiveness of the European process industry and contribution to Europe's goal of **more sustainable** and **environmentally friendly processes**
- Make process intensification happen: Very broadly applicable concept for an efficient **integration of downstream operations** in the overall process chain.

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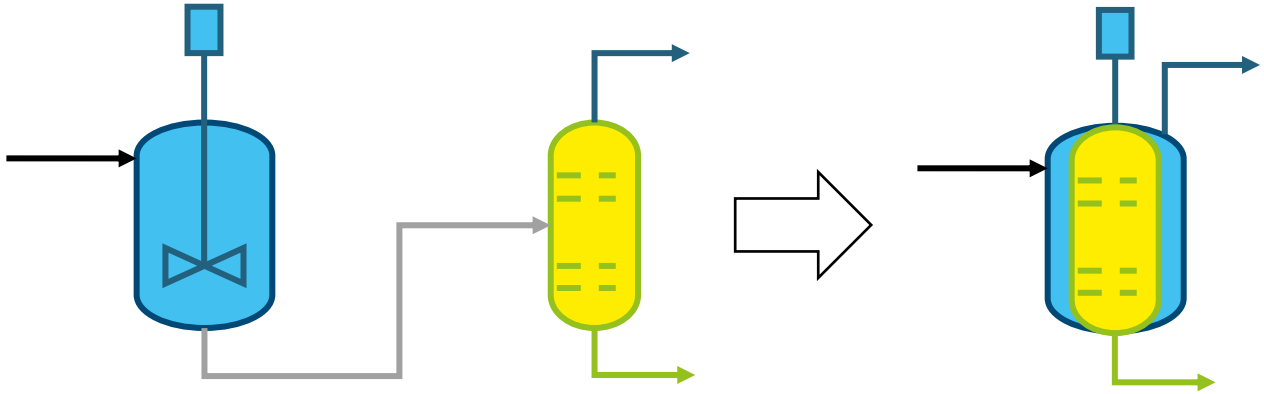
Project Goals

- The **MACBETH** consortium provides a **breakthrough technology by combining catalytic synthesis with the corresponding separation units in a single highly efficient catalytic membrane reactor (CMR).**



Catalytic reactor **Separation unit(s)** CMR = Catalytic membrane reactor

- **Demonstration** at TRL 7
- **Transfer** of the CMR technology to a new sector: Biotechnology
- Creation of the spin-off **European "Lighthouse Catalytic Membrane Reactors" (LCMR)**

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Main Predecessor Projects

- Romeo project developed and demonstrated **"two-in-one" reactors for chemical synthesis and downstream processing** of two important reactions: **hydroformylation** (conversion of olefins and syngas to aldehydes) and **water-gas shift reaction** (use of CO-containing syngas derived from biomass to generate hydrogen). Optimized membrane modules and immobilized, highly active and selective catalysts **improve selectivity and productivity**, **reduce energy and emissions**

- BIONICO project developed, manufactured and demonstrated a novel reactor concept integrating **H2 production and separation** in a single vessel for real biogas production plants with a hydrogen production of 100 kg/day and a target purity of 99.99%, resulting in an overall efficiency increase, component savings and potential cost reduction.

- CARENA technology enables **efficient conversion of light alkanes and CO2 into higher value chemicals** by Process Intensification (PI) and smart implementation of catalytic membrane reactors, contributing therefore to the reduction of dependency of the European community on imported oil.

- Cosmos technology utilizes domestic oil crops camelina and crambe as sources for **medium-chain fatty acids (MCFA, C10–C14)** and **polymer building blocks** needed by **the oleochemical industry.** Besides optimization of seed and plant properties, **the fractionation of extracted oils into various fatty acids was improved by highly selective enzyme technologies and extraction processes**.

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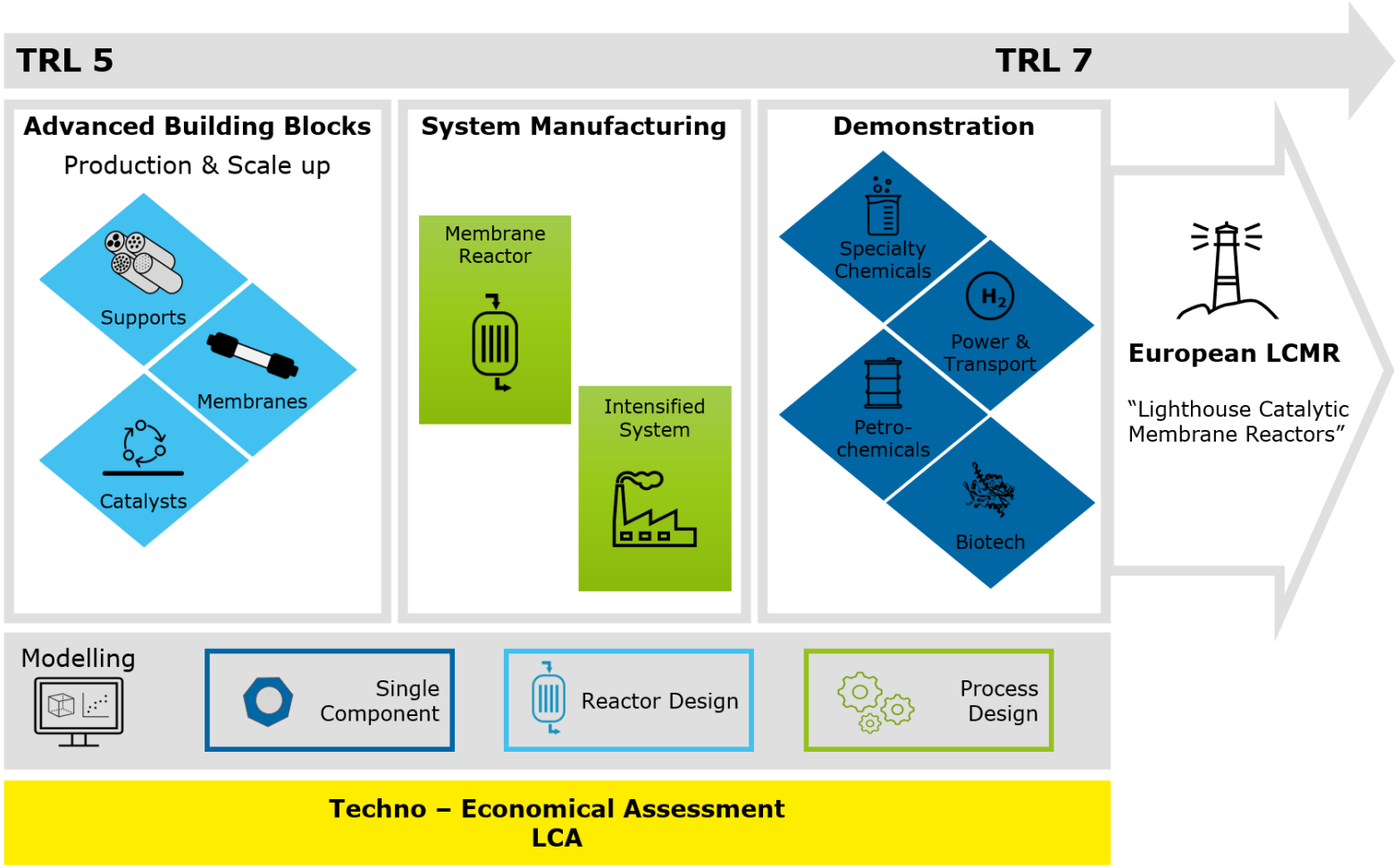
Project setup



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OBJECTIVES

- Benefits of integrated catalytic membrane reactors (CMR) demonstrated at TRL7
- Improvement and scaled up building blocks (TRL7) implemented in CMR
- Modelling for building blocks (micro) and system (macro) established for four application sectors
- Development of a business case for Lighthouse Catalytic Membrane Reactors (LCMR)
- Education tools for disseminating project results to wide audience

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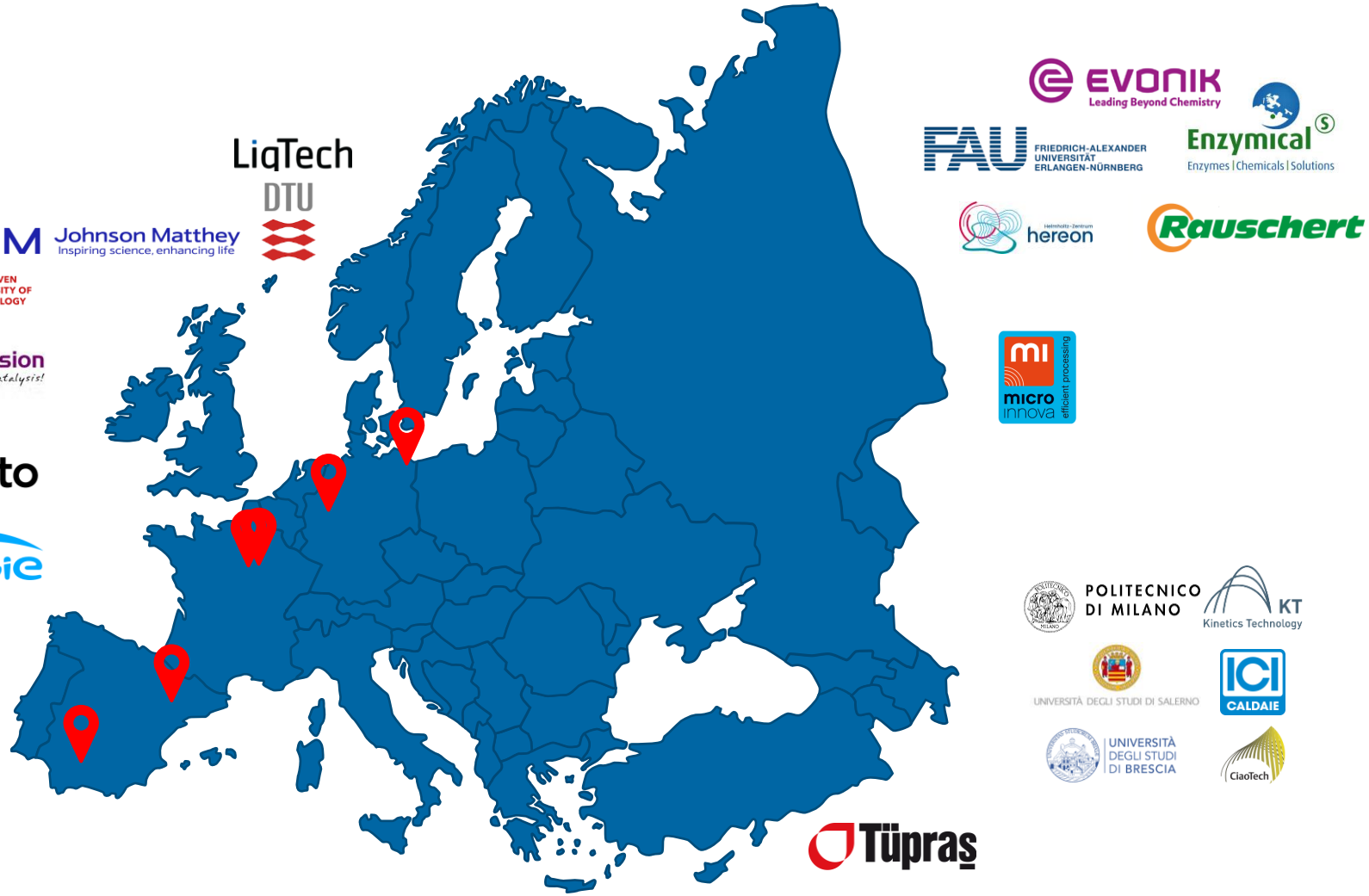
CONSORTIUM

- 24 partners
- 10 countries
- 6 plant/testing site locations (📍)



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CASES - Overview

H2 – Hydrogen Production

HYFO – Hydroformylation

PDH – Propane Dehydrogenation

BOC – Bio Catalytical Oil Cleavage

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CASES - Overview

H2 – Hydrogen Production

Conversion of from biogas or natural gas

For production of pure hydrogen

HYFO – Hydroformylation

Conversion of olefins and syngas to aldehydes

To produce specialty chemicals.

PDH – Propane Dehydrogenation

Conversion of propane to propylene

For the production of petrochemicals

BOC – Bio Catalytical Oil Cleavage

Conversion of vegetable oils to fatty acids or their alkyl ester derivatives

For the food industry and biofuels

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H2 Case– Hydrogen Production

- Compared to past reactor projects, MACBETH will demonstrate:
  - The membrane reactor will run at a much larger scale
  - Small scale hydrogen production, very close to a commercial unit
- The reactor will be tested:
  i. in a real biogas plant (H_2a) at ENGIE
  ii. in a plant for natural gas (NG) (H_2b) in the CNH2 facilities located in Puertollano (Spain)

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H2 Case– Hydrogen Production

- **Example of biogas**

Sulphur Removal

CONVENTIONAL SYSTEM

REFORMER SR / ATR **(800°C)**

HT-WGS (350°C)

LT-WGS (200°C)

PSA (H_2 Purification)

η 0.59

HYDROGEN

MEMBRANE REACTOR **(500-600°C)**

BIONICO

Retentate

η >0.70

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H2 Case– Hydrogen Production

- **Hydrogen production from biogas or natural gas** in a **novel reactor concept integrating hydrogen separation in situ during the reforming reaction** in a single vessel under industrially relevant conditions
- Biogas or natural gas methane will be converted to hydrogen at a **much lower temperature**
  - Increase in overall process efficiency
  - Strong decrease of volumes and auxiliary heat management units.
- The novel membrane reactor system will greatly **simplify plant layouts**
  - Resulting in a **decrease of CAPEX** (much less components/reactors) and **OPEX** (raising efficiency from 59% to more than 70% (for biogas))

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HYFO Case - Hydroformylation

- The **conversion of olefins and syngas to aldehydes** is a key reaction in chemical industry to produce specialty chemicals.
- Heterogenization of homogeneously catalysed reactions
- Based on the knowledge and results of ROMEO, the HYFO case will focus on **optimization** of:
  - **Support structure** for efficient use of catalytic system: pore structure as well as support material
  - **Catalytic system** for improved yield and selectivity: ratios between ionic liquid phase, ligand and active species
  - **Polymeric membrane** for separation efficiency and permeate flow: polymeric composition, coating procedure
  - **Operating parameters** for improved process: start-up procedure, pressure & temperature range, through-put

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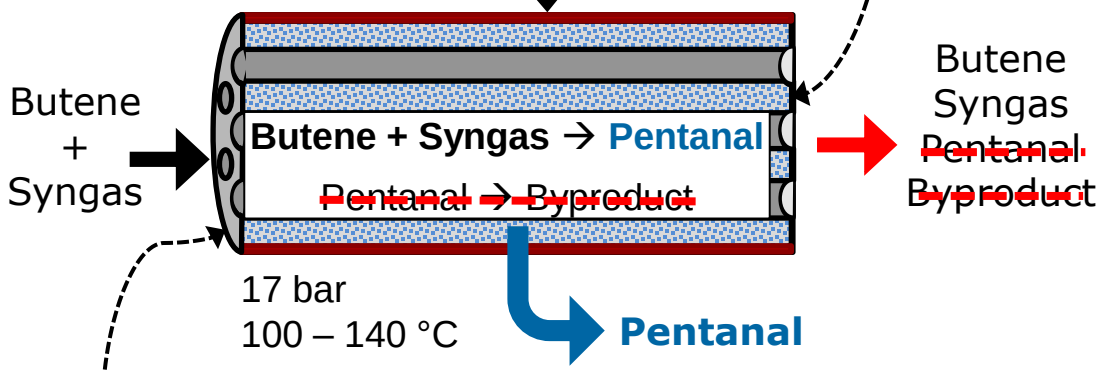
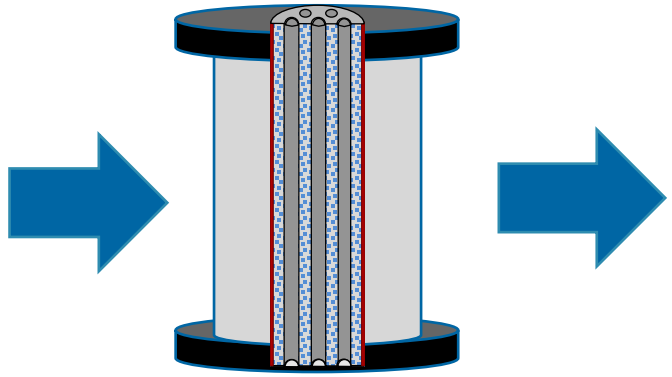
Realization needs a great team and experts in all fields

Provison of membrane at industrial scale

System optimization

Process optimization, engineering, set-up & operation of pilot demonstration plant





Testing of optimized set-up on mini plant scale

Optimization & delivery of support

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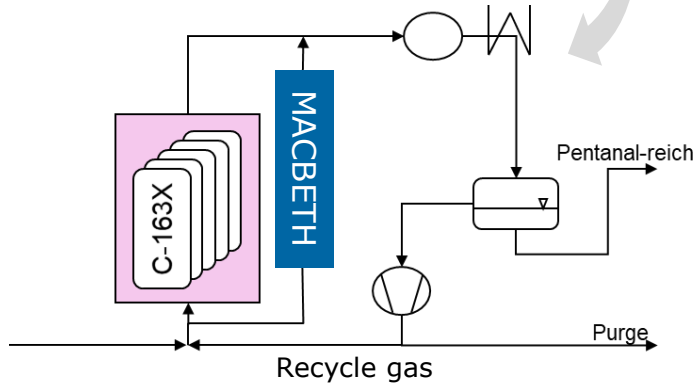
HYFO Case - Hydroformylation

- For the **pilot plant**, different engineering phases will **focus on infrastructural modifications** in the production environment **to obtain real industrial conditions** for the demo phase.
- HYFO case will be placed **in bypass to the conventional hydroformylation production plant** at Evonik's Marl site and run in the recycle stream of the plant (TRL 7) obtaining ideal stream composition to simulate a possible brownfield as well as green field implementation at a later stage.
- The demo case will show case the benefits in terms of CAPEX (< 50%), OPEX (< 80%) and energy efficiency (GHG < 35%).



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PDH Case – Propane Dehydrogenation

- **Selective dehydrogenation of propane to propylene** requires harsh operation
- PDH case technology will mitigate this by optimized operation at lower temperature resulting in:
  - Reduction of catalyst deactivation
    - ✓ less subsequent regeneration steps
    - ✓ improved process management
    - ✓ Longer plant/catalyst lifetime
- Increasing selectivity to propylene
    - ✓ dramatically reducing the presence of gaseous side products in the process stream.

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PDH Case – Propane Dehydrogenation

➢ Key process features

- Process intensification by Catalytic Membrane Reactors
- Smaller separation section
- lower energy penalty for PDH reaction and propylene recovery

➢ Expected impacts

- GHC decrease > 20% (mitigation of operating conditions)
- RE increase > 20% (fuel reduction, reduced duty of separation)
- CAPEX decrease > 15%
- OPEX decrease > 16%

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PDH Case – Propane Dehydrogenation

- A smart design of PDH optimized CMR system will be established and implemented in a demonstration pilot plant to be installed at ENGIE Lab CRIGEN in Stains, France.

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BOC Case – Biocatalytic Oil Cleavage

- Based on the knowledge and experiences of the other MACBETH cases, tailor-made building blocks will be developed for a time-efficient transfer of the entire system to an industrial pilot plant

- **Vegetable oils and animal fat are promising resources to produce fatty acids or their alkyl esters** with vast market potential in the food industry and as biofuel

- BOC Case will develop and demonstrate a **CMR based reactor combining enzyme catalysed selective ethanolysis of fish oil followed by an integrated membrane separation to isolate selected fatty acids**

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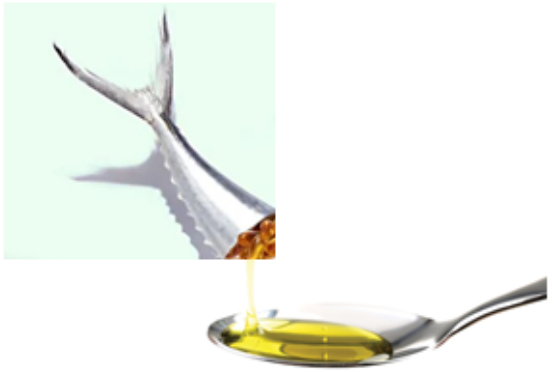
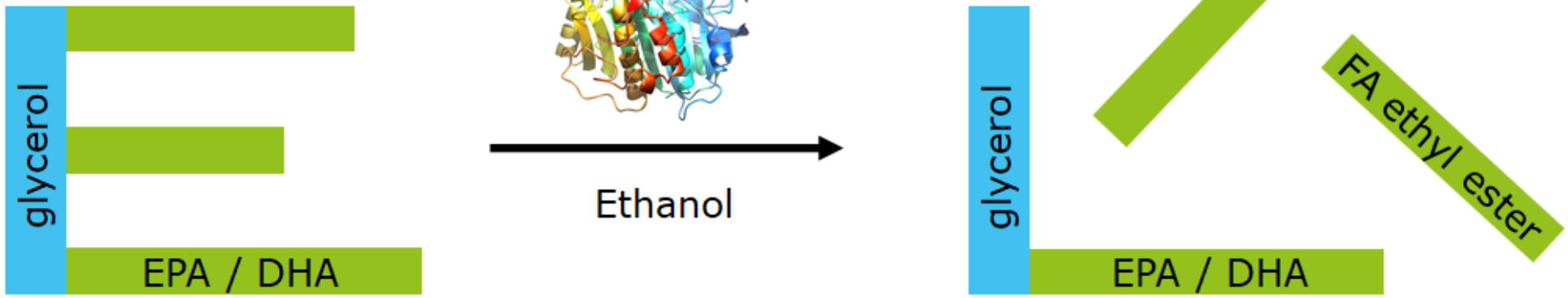
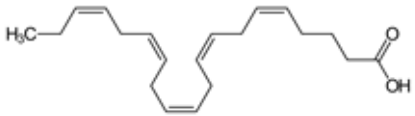
BOC Case – Biocatalytic Oil Cleavage

- Enzymatic Enrichment of Omega-3-Fatty Acids

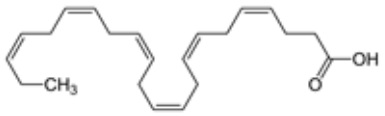
  EPA and **DHA** in Fish Oil







eicosapentaenoic acid (**EPA**)



docosahexaenoic acid (**DHA**)

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BOC Case – Biocatalytic Oil Cleavage

- For local flexibility, a **containerized set up of the system** is foreseen
- Demonstration of BOC Case on 2 testing sites at Enzymicals in Germany and SOLUTEX in Spain

Expected impacts

- GHG decrease >40%
- RE increase >25%
- CAPEX decrease >30%
- OPEX decrease >16%

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Plant locations

- **HYFO case demo plant**

  Evonik, Marl, DE

- **H2 case demo plants**

  real biogas plant (H_2a): at Crigen lab of ENGIE in Paris (Stains), FR

  natural gas (NG) (H_2b): at CNH2 facilities in Puertollano, ES

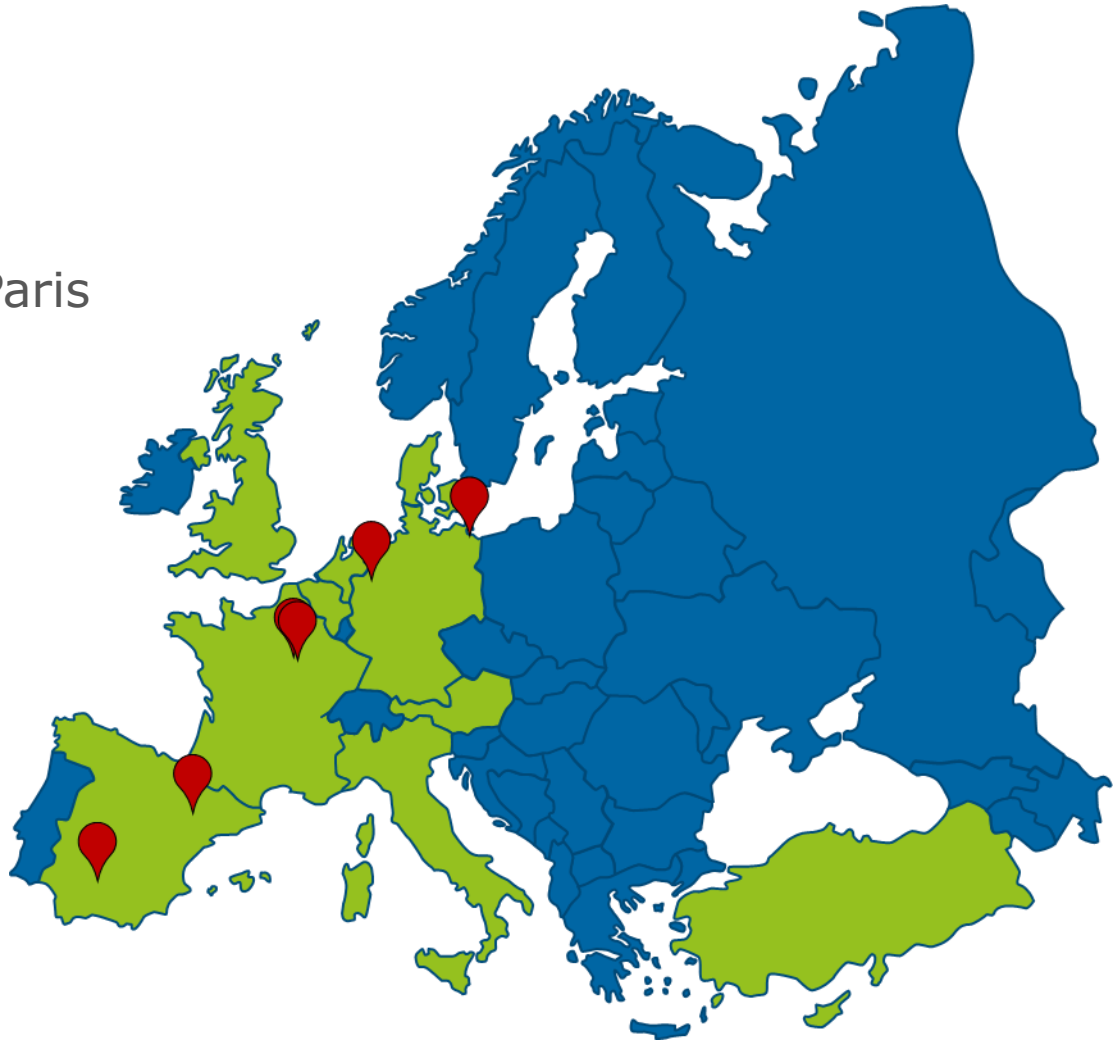
- **PDH case demo plant**

  at Crigen lab of ENGIE in Paris (Stains), FR

- **BOC case field tests**

  Enzymicals in Greifswald, DE

  SOLUTEX in Sarragossa, ES



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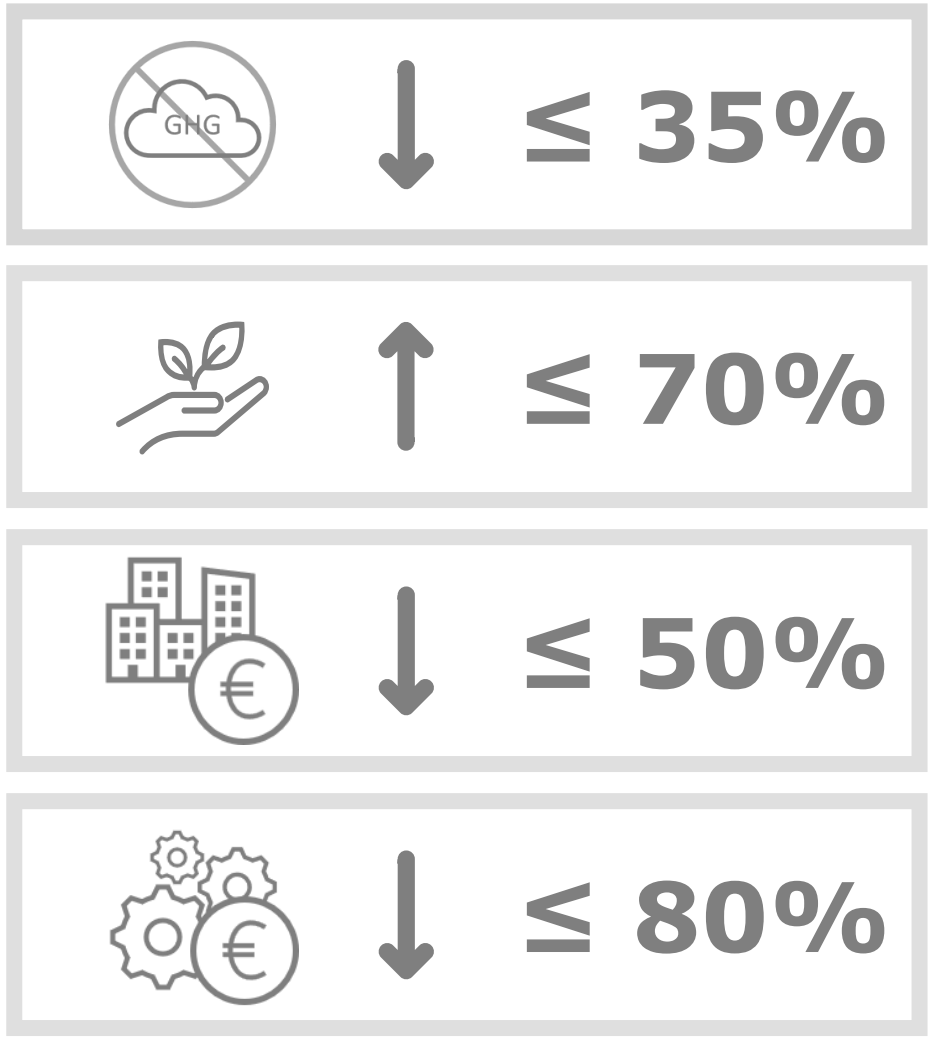
IMPACT

- **Reduce greenhouse gas (GHG) emissions** of large volume industrial process by **up to 35 %**.
- **Resource and energy efficiency** will be increased by **up to 70%.**
- **CAPEX is decreased by up to 50%**
- **Substantially smaller and safer** production plants
- **OPEX by up to 80%.**



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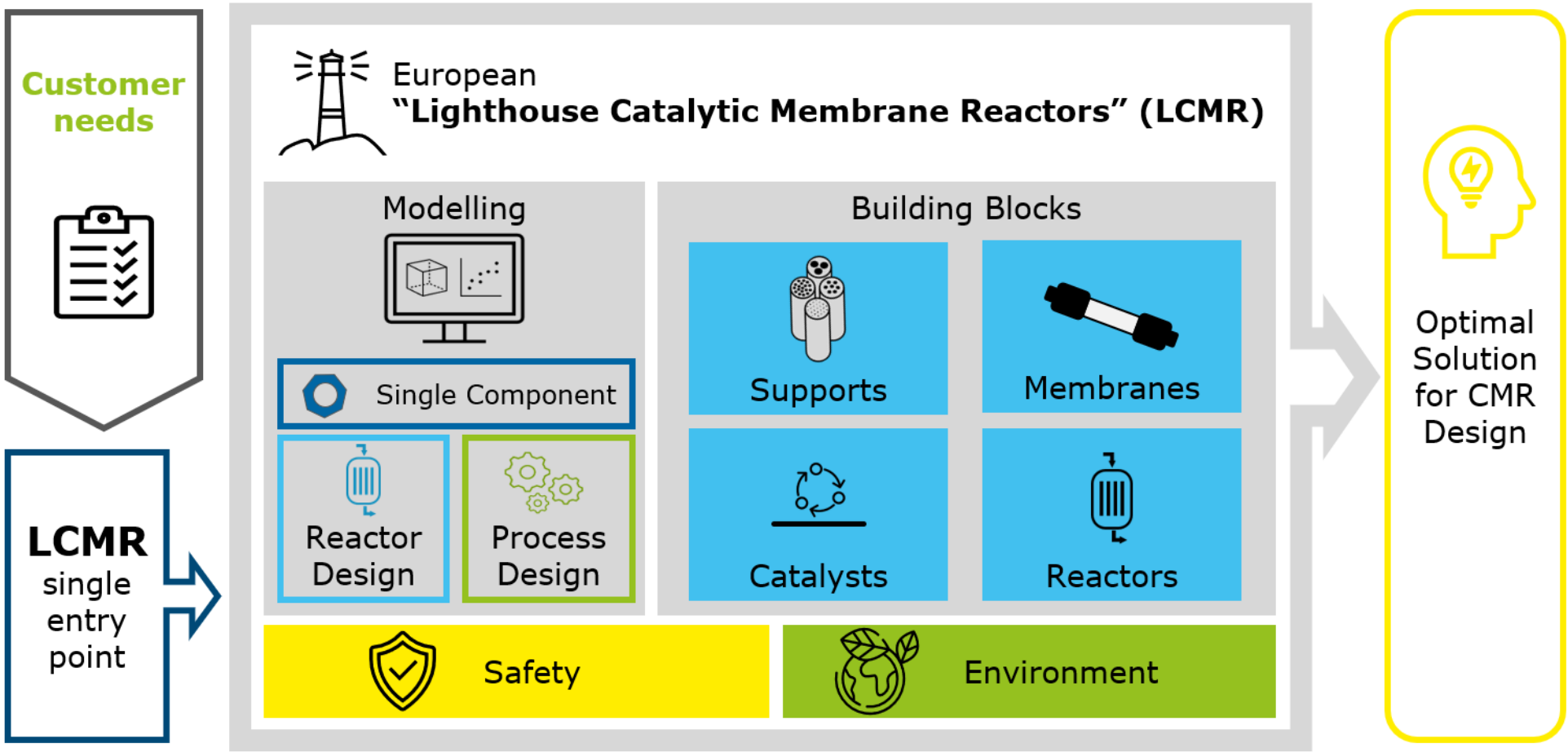
Lighthouse – Catalytic Membrane Reactors



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