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In the process industry, downstream processes are the most resource and energy consuming industrial operation steps. Moreover, the integration of new processes often requires a large portion of CAPEX and OPEX. To enhance the competitiveness of the European process industry and to contribute to Europe's goal of a clean and liveable environment, a very broadly applicable concept for efficient integration of downstream operations in the overall process chain is highly desired.
The MACBETH consortium provides a ***breakthrough technology by combining catalytic synthesis reaction with the corresponding separation units*** *in a single highly efficient* ***C****atalytic* ***M****embrane* ***R****eactor (CMR). With this disruptive technology a* ***reduction of greenhouse gas emissions (GHG)*** *and an* ***increase in resource and energy efficiency*** *of large volume industrial processes can be achieved. The revolutionary new reactor design will guarantee substantially smaller and safer production plants and thus* ***reduce operational and investment costs****.*

MACBETH
Membranes And Catalysts Beyond Economic and Technological Hurdles

Topics

OBJECTIVES

The MACBETH consortium with **24 partners** from **10 countries** provides a breakthrough technology combining **catalytic synthesis reaction with the corresponding separation units in a single highly efficient catalytic membrane reactor (CMR)** for highly relevant large-scale processes in the chemical sector: hydroformylation, hydrogen production and propane dehydrogenation. Additionally, the CMR technology will be transferred to the biotechnology sector for the enzymatical conversion of vegetable oils to fatty acids or their alkyl ester derivates.

Long-term operation of TRL 7 plants will demonstrate the direct industrial applicability of the technology, and the creation of the spin-off European **"Lighthouse Catalytic Membrane Reactors" (LCMR)**, a European competence center for CMR, will provide access to the combined knowledge of the MACBETH project to all industrial, academic and education communities in Europe concerned with CMRs and their applications.

Project Information

Project No.:
GA 869896

Call (ID) Identifier:
H2020-NMBP-SPIRE-2019

Topic:
CE-SPIRE-04-2019
Efficient integrated downstream processes (IA)

Project Duration:
54 (+6) months
Nov 2019 – Oct 2024

Project Budget:
20,7 M€

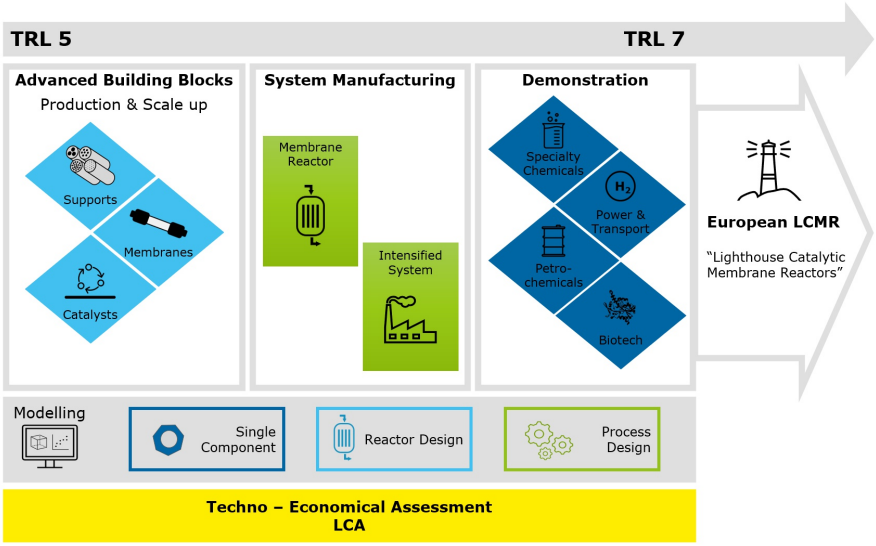
PROJECT SETUP

All MACBETH partners gain their manifold knowledge and background in membrane technology through various R&D projects on national and EU level. EU funded projects like *ROMEO*, *BIONICO* and *CARENA* have laid a strong basis showing the proof of concept for CMRs at TRL 5. Thereby, successful pilot plants have been operated for highly relevant and large-scale processes: i) **Hydroformylation (HYFO)**, ii) **Hydrogen production (H2)** and iii) **Propane dehydrogenation (PDH**). To show the transferability of CMR technology, MACBETH aims to implement the biotechnological process of **bio catalytical oil cleavage (BOC)** being conceptually proven in *COSMOS* project.

Key members of these consortiums have now joined forces in MACBETH to bring CMR from TRL 5 to the level of TRL 7 and build the basis to move forward for commercialisation of the novel technologies.

Based on modelling studies, CMR building blocks (supports, catalysts, membranes, and reactor) and systems will be developed and optimized for all four application cases. Existing micro and macro models for each case will be integrated into a single modelling software tool allowing a reliable scale up of building blocks and reactor systems for each case to TRL7 and to evaluate the further applicability of CMRs in other sectors. Thereby, intense knowledge sharing among cases and partners will accelerate the progress to improve and upscale the building blocks of each case, and to select the best solutions for the BOC case. To demonstrate the capability to operate CMRs across a wide parameter range, demo plants at TRL7 will be engineered, manufactured, installed, commissioned, and operated for all four application cases.

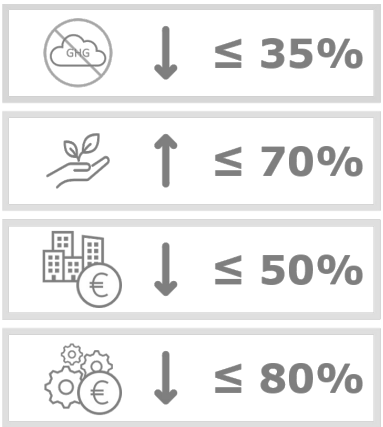
The technological development process is concomitated with LCA, LCC and techno-economical assessment to prove the viability of the technology and identify the exploitation potential of CMRs. Additionally, all results and findings of MACBETH will support the development of a business case for the European competence centre **"Lighthouse Catalytic Membrane Reactors (LCMR)"**.



IMPACT

The disruptive MACBETH project technology of combining catalytic synthesis with the corresponding separation units in a single highly efficient catalytic membrane reactor (CMR) has the ability to **reduce greenhouse gas emissions (GHG)** of large volume industrial processes **by up to 35 %**.

Additionally, by intensive optimisation of CMR building blocks, systems and processes, **resource and energy efficiency will be increased by up to 70%**. The revolutionary new reactor design will not only guarantee substantially smaller and safer production plants but also has a tremendous competitive advan-tage since **CAPEX is decreased by up to 50% and OPEX by up to 80%.**



CASES

With the goal to achieve highest reduction of OPEX and CAPEX and highest efficiency gains, MACBETH will develop, build and demonstrate CMRs in industrial environment for the following highly relevant application cases.

HYFO - Hydroformylation

The conversion of olefins and syngas to aldehydes, is a key reaction in chemical industry to produce specialty chemicals. HYFO case will focus on the optimization of: i) Support material and structure for efficient use of the catalytic system, ii) catalytic system to increase yield and selectivity, iii) polymeric membrane for separation efficiency and permeate flow and iv) operating parameters.

For demo phase, HYFO case will be placed in bypass to the conventional hydroformylation production plant at Evonik's Marl site for real industrial-scale conditions.

H2 - Hydrogen Production

In H2 case, natural gas or biogas methane will be converted to H2 at a much lower temperature by using a novel reactor concept integrating H2 separation in situ during the reforming reaction in a single vessel. This will increase the overall process efficiency (from 59% to more than 70% (for biogas)) and decrease volumes & components (e.g. auxiliary heat management units) resulting in much lesser CAPEX and OPEX.

Demo reactors will be tested in a real biogas plant (H2a) at ENGIE and in a plant for natural gas (H2b) in the CNH2 facilities.

PDH - Propane Dehydrogenation

PDH case technology will mitigate the required hash conditions of selective propane dehydrogenation by optimized low temperature operation resulting in the avoidance of catalyst deactivation. This will lead to less regeneration steps, improved process management and longer plant/ catalyst lifetime. Additionally, the improvement of propylene selectivity significantly reduces gaseous side products in the process stream.

A smart design of PDH optimized CMR system will be established and implemented in a demo plant at ENGIE.

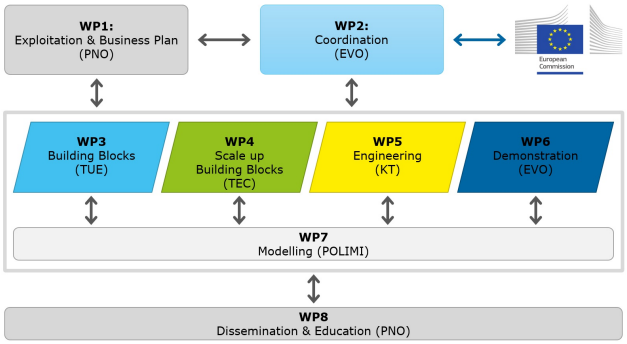
BOC - Bio Catalytical Oil Cleavage

The BOC case will develop a CMR-based reactor combining enzyme-catalysed selective hydrolysis of oil fatty acids in an aqueous-organic system followed by an integrated membrane separation to isolate selected fatty acids. Supported by all MACBETH cases, tailor-made building blocks will be developed for a time-efficient transfer of the entire system to an industrial pilot plant. For local flexibility, a containerized setup of the system is foreseen.

The BOC case reactor will be demonstrated on 2 testing sites at Enzymicals and SOLUTEX.

WORKPLAN

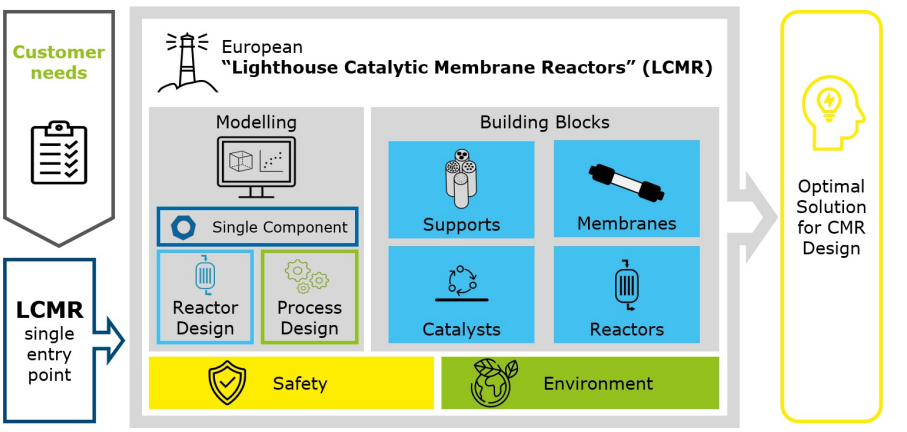
Structured in 8 work packages (WP), MACBETH project aims to implement all activities in 54 (+6) months.



WP1 comprises an early business case definition and clear understanding of market barriers and needs, regulatory framework and potential risks to guide the project towards highly deployable results and fulfilling the needs of the target market. The performance of LCA, LCC and techno-economic assessment will prove the viability of the developed materials and technologies and identify future applications. In parallel, **WP7** translates the general framework established in WP1 into a coherent set of specifications and requirements by modelling of each building block, CMR system and process in an integrated multi-scale approach. In **WP3**, individual building blocks will be further optimized and tested before for each case. **WP4** comprises the scale-up of the optimized building blocks from WP3 to TRL7 for the installation in all demo plants. These demo plants (5 in total for 4 cases) will be engineered in **WP5**. The final commissioning and demonstration of the demo plants for a cumulative demonstration (< 35000 h) is carried out in **WP6**. **WP8** is focussed on the communication and dissemination of the results from the WPs to support the exploitation of the projects outreach and pave the way for an effective education of the chemical industry in the CMRs field. **WP2** ensures an effective project management all along the execution of the workplan.

LCMR

In order to go beyond the demonstration of CMR in the project cases and to bring their outstanding benefits to other sectors and applications, a European competence centre will be established, finally leading to the foundation of a spin-off company, tentatively called "Lighthouse Catalytic Membrane Reactors" (LCMR) which will have two aims: i) commercialisation of the advanced models developed in the project, both in terms of software and as services for companies that need to integrate advanced reactors in their facilities, and ii) acting as a common knowledge platform, integrating all project experiences and tools. By combining best-in-class knowledge and competences with innovative technological solutions for single building block, integrated reactor, and overall downstream process level, this platform aims to become the reference point in Europe for catalytic membrane reactors for the benefit of strategic industrial market sectors in Europe, starting with the ones already included in the project. An additional plus of the approach taken is that LCMR members are industries and stakeholders that know very well the market insights and trends on each single building block, as well their industrial feasibility in a certain sector, thus acting as specialist consultants to the final clients. At the end, the platform should become a "one-stop-shop" for the entire industrial, academic and education communities in Europe, concerned with catalytic membrane reactors and their applications.



PUBLICATIONS

Press releases and public media article about MACBETH project were published on the partners websites and in various journals and platforms like chemeurope.com, La Tribuna de Ciudat Real and Turkchem.

Additionally, an open access articles on the MACBETH predecessor project BIONICO was published in the Impact Journal 2020 October Edition. Please find a comprehensive publication list on MACBETH website for download.

Moreover, project news and updates will be continuously provided via MACBETHs Social media accounts on Twitter and LinkedIN (see contact info).

EVENTS

Project Kickoff Meeting in Waischenfeld, Germany

November 20-22, 2019

In November 2019, the MACBETH project started with a successful Kickoff Meeting. FAU invited all project partners to the picturesque town of Waischenfeld in Bavaria, DE. With focus on scientific and technological exchange, the event established a sound collaboration basis for all project partners and the defini-tion of a detailed approach for the MACBETH project.

Presentations on the four MACBETH cases updated all project partners about the individual perspectives, objectives and challenges. In individual case meetings, the work and objectives of each case were discussed and coordinated in more detail, resulting in appropriate roadmaps for the upcoming project period.

A marketplace on day 2 provided a platform for intensive multidisciplinary discussions and exchange to find further synergies among the partners. Moreover, socializing events like tabletop football and table tennis competitions as well as vespertine get-together facilitated the communication among consortium members and strengthened team spirit. Thus, all project partners were enthusiastic to start collaboration on MACBETH.

Virtual Project meetings

May & November 2020

Exceptional circumstances require extraordinary measures. Due to the global pandemic and our responsibility to limit the spread of COVID-19, the planned MACBETH Project Meeting in Geesthacht, DE in May as well as the 3rd Project Meeting in November 2020 were cancelled.

However, knowledge transfer, result discussions and detailed project planning are prerequisites for a successful project execution, even in these days. Therefore, the 2nd and 3rd project meeting as well as all further case meetings were organized virtually. Besides exchange on the project progress achieved for all consortium members, individual virtual workshops for each MACBETH case and collaborative meetings on cross-fertilization resulted in concepts and roadmaps for successful project collaboration during and beyond COVID-19 to bring MACBETH technology to industrial scale.

Meet MACBETH

Are you interested to meet our partners and learn more about the project?

Upcoming Events:

September 20-21, 2021
virtual event
"ECCE/ECAB 2021 - 13th European Congress of Chemical Engineering and 6th European Congress of Applied Biotechnology "
www.ecce-ecab2021.eu

MACBETH IN TIMES OF PANDEMIC

Despite a difficult working period with drastic restrictions in all participating countries caused by the COVID-19 pandemic, MACBETH project is proceeding as expected.

Thanks to virtual tools, close collaboration and cross-fertilization activities among all MACBETH partners accelerates proceedings in all cases. Online meetings and workshops were a useful opportunity for extensive dialogue and an exchange of information.

In all MACBETH cases, fundamental results were obtained in the last months enabling to move forward to the next phases. A successful selection and optimization of building blocks for the HYFO, H2 and PDH case leads to the preparation of the pilot reactor units for the demonstration phase. In BOC case, the process to enrich valuable fatty acids is ready to be transferred to a continuous flow process, while solutions are being developed for the challenging separation problem in a MACBETH-wide collaboration.

NEWS FROM THE CONSORTIUM

To compensate the impacts of COVID-19 restrictions, a 6 months extension was granted for MACBETH resulting in a **project duration of 60 months** ending in October 2024.

Since January the 18th 2021, **Università degli Studi di Brescia** (UNIBS) is a new partner of MACBETH project. UNIBS will mainly contribute to work package WP7 supporting the modelling of CMR building blocks and systems. All consortium partner welcome UNIBS and are looking forward for a successful collaboration.

The project partner Evonik Performance Materials GmbH (EPM) and Evonik Technology & Infrastructure GmbH (ETI) were joined to **Evonik Operations GmbH (EVO)**, a part of the Evonik Group. For MACBETH project, the business lines Process Technology & Engineering and Performance Intermediates will undertake the tasks of ETI and EPM.

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MACBETH has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 869896.