BAroC - Bio-Aromaat Concept Fabriek

10-11-2022 -Final public end report

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Sub-contractors

Rijksdienst voor Ondernemend Nederland

Het project is uitgevoerd met subsidie van het Ministerie van Economische Zaken, Nationale regelingen EZ-subsidies, Topsector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.

BAroC PROJECT FINAL PUBLIC END REPORT

The following document represents a summary of the main tasks and results achieved during the BAroC project.

1. Background

Relement's vision is to facilitate the transition of the chemical industry to become more sustainable by developing the necessary concepts, technological solutions, and business models to re-design the value and supply chains of aromatic ingredients in coatings and lubricants. This is achieved by demonstrating new, biobased chemical pathways to manufacture bio-aromatics since up to now all commercially available aromatics are made from fossil feedstocks.
Relement will produce and sell biobased aromatic ingredients to replace fossil-based aromatic ingredients for e.g., coatings, as depicted in the figure below.

The BAroC project successfully resulted in:
1) A cconceptual process design of a first (pre)commercial factory – or DEMO – for bio-aromatics MPA and HMA, starting from furfural conversion, including a cost estimate for CAPEX and OPEX and preliminary CO_2-footprint calculation.
2) Sensitivity analysis with recommendations for further research.
3) A business case for bio-aromatics 3-Methyl Phthalic Anhydride (from now on MPA) and Emimellitic acid (from now onHMA), including critical non-technical aspects such as PPORD and REACH.

2. Timeline Overview

The BaroC project started 10th May 2021 and ended 31st October 2022.
A six-month extension was necessary to let engineering company Transition Hero collect more empirical data on MPA manufacturing and purification from experiments to better design the layout and forecast the performance of the future first commercial factory for bio-aromatics MPA and HMA manufacturing.

3. Achieved Objectives per WP

Below we report a non-confidential summary of all the research activities carried out during the project for every work package (WP).

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WP1 – Assess techno economic feasibility

a. furfural market and acetic anhydride overview and development. The data collected in this task were used by subcontractor Transition Hero to formulate the business case.
   Key takeaways.
   - There will be an increasing output of furfural., It will be mainly generated as a byproduct from various types of biorefinery processes, notably the production of sustainable cellulose fibers for textile. Furfural supply is expected to grow at a CAGR of more than 5% in the next 5 years.
   - Furfural is mainly used in the manufacturing of furfuryl alcohol, which is a declining market..
   - Acetic anhydride is an important reagent in organic synthesis of several chemicals. The global acetic anhydride market reached a volume of 2.8 Million Tons (USD 2.77 billion) in 2020. Looking forward, the market is expected to grow at a CAGR of 4.9% in the forecast period of 2021-2026 to reach a volume of 3.6 million Tons (USD 3.68 billion).
   - Pricing of Acetic anhydride heavily impacted by current recession and expected to decrease in the coming years.

b. The Early-Stage Evaluation of (MPA with an extension to HMA production was performed at a stage of the research in which the fully detailed concept for the final commercial plant was not available, neither was pilot plant data process information. The breakdown of the cost price showed that feedstock costs constituted the major cost factor whilst the second was financing i.e., CAPEX, depreciation, interest, taxes, insurance, and maintenance. The early study depicted also that the contribution to financing of the bio-MPA plant is tied to the number of individual unit operations. Also, Transition Hero preliminary evaluation determined that raw materials represent the highest costs of OPEX.

The above-described scenarios were used by Transition Hero to evaluate the business case and prepare a design for the conceptual layout of the bio-aromatics MPA and HMA commercial plant. Due to the lack of pilot data, it's been decided to consider a 5kton/year as greater capacities would represent an excessive stretch of assumptions.

WP2 – Laboratory support to optimize identified process bottlenecks

WP2 focused on better understanding of 2 key areas that influence the business case most:

1. Throughput and yield/selectivity during the 'Aromatization' processing phase.
2. Purification/downstream processing (DSP) of bio-aromatic MPA.

Experimental investigations were performed by TNO and Relement to investigate these key areas which led to significant improvements on solvent reduction and increased isolated yield crude MPA resulting in reducing the complexity and cost of recovering the rest of the material. Furthermore, catalyst research shortened the residence time from ~6-7 hours to ~1 hour. This increases the throughput by 7 times.

Finally, a new approach to DSP was investigated by TNO, however deemed to be unsuitable for further scale-up. Relement decided to further investigate this matter outside the BAroC project.

WP3 – Feasibility study on processing and molecules registration

a. Literature research by Catalok
   This work package provided detailed technical analysis and literature insights on emerging technologies in the field of Diels/Alder chemistry, hydrogenation and oxidation of furfural, oxidation of MPA and acetic acid synthesis processes. These gave valuable insights and increased confidence level to the consortium to make the conceptual design of future commercial bio-aromatics factory.
b. PPORD and REACH roadmap for registration.
   Subcontractor Triskelion prepared a PPORD and REACH roadmap which gives insight to the consortium what is needed for initial commercialization of bio-aromatics MPA and HMA. Relement has now a clear view what is needed for REACH registration, specifically for the 1-10 ton and 10-100 volume production. Current TNO lab samples are however not sufficient for REACH registration. A sample from pilot production plant is needed to move the registration forward.

WP4 – Design of a conceptual process design for pre commercial factory of bioaromatics.

Subcontractor Transition Hero integrated the data from all work packages into a conceptual design for this process, to identify the main cost drivers to a positive business case and scale up the design from bench scale to a demo plant. The design is based on a (semi) continuous production process with product output of 5 kton/year MPA and 1 kton/year HMA. The process design was approached in the following way: an initial optioneering study was carried out, with an initial mass and energy balance, OPEX and CAPEX estimation to identify the main cost drivers to the business case. This gave a direction to which parameters the business case was more sensitive to and where more emphasis should be placed. The process was broken down into distinct blocks (or packages), to simplify the boundaries of the main processes. Each block was conceptually designed, and assumptions, risks, opportunities, and future tests have been identified and recommended. Furthermore, TransitionHero provided a detailed equipment list and layout of a future bio-aromatics manufacturing factory.

The study revealed that to produce 5kton of MPA and 1kton of HMA (per year), there is a need for Capital investment of circa €33 Million[1]. The high cost arises mainly from the purification protocol and the process step from MPA to HMA, which requires the use of expensive equipment. The investment cost can drop to €21 Million if the HMA process is not considered. The study nonetheless showed a profitable business case for bio-aromatics.

[1] A 20% contingency must be considered to manage risks during this early-stage study.

The cost price of MPA will be higher than the fossil equivalent, yet market introduction and percolation is proving as customers are reporting that MPA offers improved performance to certain applications.

Preliminary LCA evaluation of bio-MPA reports that CO2 emissions 2 kg CO2 eq/kg bio-MPA which represents a Reduction of 43% compared to petrochemical anhydride and standard electricity mix in NL. Furthermore, the factory was assumed to use 100% *green* electricity which also lowers carbon footprint by an extra 21%. Finally, the use of biogenic maleic anhydride (not yet available in the market) would lead to an even greater reduction in carbon emissions. This data makes the pursue for this technology extremely attractive for Relement in future.

In conclusion, MPA offers a sustainable solution and better properties which justifies a higher price for this ingredient.

WP5 – Communication

Along the course of the project the consortium members communicated the projects' main activities and evolution on their websites and across the most relevant social media. Similarly, a conjunctive communication will be implemented soon, signaling the successful completion of this Project.

Conclusions and next steps

It can confidently be concluded that all partners in the consortium contributed valuably in making this project a success as all the research objectives were addressed and important insights to scale up the bioaromatics technology had been found.

The main output of the project, a conceptual design for a (pre)commercial bio-aromatics MPA and HMA production plant, is going to be a very helpful asset in further development and scale-up of these bio-aromatics value proposition.

Due to high investment in terms of money and time needed to build the envisioned factory, Relement has decided to pivot its strategy in scaling up bio-aromatics MPA and HMA by pursuing an asset light strategy. The opportunity cost that derives from Relement choice is to exploit existing, underutilized chemical pilots and pre-commercial scale infrastructures to start production of bio-aromatics, starting with MPA.

Relement will revisit the opportunity to build a production facility further in the coming period, only after MPA is successfully launched at kton scale.

Yet, technology aside, whether the realization of this project can be implemented is also very much dependent on costs, region (funding availability and policies), and the global economic landscape. As indicated earlier, compared to well-established petrochemical-based equivalents, biobased raw materials (and products) are often more expensive. Like any product, the laws of supply and demand influence prices, and during the project we have witnessed how natural disasters or/and wars could potentially disrupt production,

supply chain therefore impact pricing. The direction taken of the interest rates also negatively influenced the price of all commodities and building materials. Production costs influence prices, along with storage capacity. (World Bank 2020).

Although this BAroC project has been very valuable from a conceptual process design perspective, implementing such design on a tangible pre-commercial production campaign of MPA, is key. For a chemical start-up, it is difficult to raise sufficient capital to build a factory. For Relement, the route leading to a construction of a DEMO factory with a production capacity of 5 kton MPA, passes through the demonstration of the technology by providing the market with sufficient material that will trigger revenues. Current shareholders and potential future ones all seemed favorably promoting an "asset light" strategy.

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