



Industrial decarbonisation: Next-generation pathways in thermal operations, processing, and material lifecycles

Case study

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Contact: **Jose Maria Jimenez Mingo**
E-mail: Jose.JIMENEZ-MINGO@ec.europa.eu

European Commission
B-1049 Brussels

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The primary aim of this project is to support, through the analysis of climate relevant activities of Horizon Europe, the development and implementation of EU policies. Policy briefs, along with case study reports and communication materials, are produced to support the development and implementation of EU policies based on the results of the EU Framework Programme for Research and Innovation and other relevant scientific sources.

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Introduction

Horizon Europe provides research and innovation funding for process efficiency and industrial circularity, among others, to support the transition of hard-to-abate industries and associated sectors toward climate neutrality by 2050. These initiatives focus on process-level mitigation strategies designed to reduce greenhouse gas emissions across the industrial value chains, including chemical synthesis, high-temperature thermal operations, and advanced material life cycles where direct electrification via standard power substitution is limited.

This case study report presents three Horizon Europe projects, describing their respective technological advancements, alignment with European deployment targets, and prevailing socio-economic barriers to market integration. Each project uses a different approach to solve a unique problem in the respective sectors:



HYPER: Pilots a decentralised chemical processing model by validating an on-site electro-chemical synthesis method to produce hydrogen peroxide (H_2O_2) directly at consumer facilities, thereby mitigating supply chain and logistical transport emissions.



METAWAVE: Addresses high-temperature thermal systems by replacing conventional fossil-fuel combustion with electric microwave heating, incorporating integrated grid-demand control systems across processing, manufacturing, and infrastructure sectors.



MC4: Explores structural material circularity by validating short-term and long-term processing pathways for the mechanical and chemical recovery of carbon and glass fibre composite waste streams.

The implementation of these projects corresponds with core European Union climate and industrial policy frameworks, specifically the Net-Zero Industry Act¹, the Clean Industrial Deal², and the Circular Economy Action Plan³. The regulations outline a clear path to expand clean tech capacity, increase material circularity, and secure domestic supply lines.

While these process innovations in electrification, chemical synthesis, and material circularity are vital for long-term decarbonisation, scaling them is a challenge that is difficult to address in the current market conditions. Because these emerging technologies may not achieve immediate cost-parity with optimised primary commodities, the associated financial risks make difficult voluntary market adoption. Ultimately, this cost asymmetry functions as an economic barrier, demonstrating that successful technical validation at the research and pilot scale does not automatically translate into market viability due to high capital requirements and operational expenditures.

HYPER:

Modular on-site electrochemical production of hydrogen peroxide

Main objective of the project

The primary objective of the HYPER project is to validate an automated, decentralised electrochemical process that produces hydrogen peroxide (H_2O_2) directly at the factory gate, eliminating additives needed for transportation, as well as the pollution caused by it. Rather than developing new chemistry, the project modernises the classic, pre-1950's electrochemical route to make it safer, more efficient, and suitable for localised industrial use.

The system operates as a closed chemical loop, feeding a sulfuric acid solution into an electrolyser to generate a temporary carrier chemical (persulfate) at the anode, while cleanly capturing green hydrogen as a byproduct at the cathode. This liquid intermediate then flows into a hydrolysis reactor, known as the utiliser, where it reacts with water to release pure H_2O_2 . The parent acid is fully recovered and recycled back into the stack, allowing continuous operation without raw chemical consumption.

Impact

HYPER's developed system automatically adjusts production to generate H_2O_2 at the exact volume and concentration required, ranging from a low 3% for disinfection to 35% for industrial bleaching. The project is evaluating integration across textiles, pulp and paper mills, and industrial coatings, with business models tailored by sector, ranging from ready-made "plug-and-play" units for large mills to shared localised production for smaller industrial clusters.

Project coordinator Richard Heyn (SINTEF AS) on the importance of this decentralised model:

"If you really want to divorce yourself from the use of fossil fuels to make chemicals and materials, you have to get away from this idea that everything has to be done on a large scale."

Compared to traditional centralised production, the modular HYPER system cuts climate emissions by 40% using current, EU averaged grid electricity, and by 93% when powered entirely by low carbon renewable electricity. Furthermore, the green hydrogen byproduct can power an on-site fuel cell to cover approximately 40% of the process's own electricity needs. This eliminates the financial and environmental costs of long-distance trucking, where traditionally half of the cargo weight is simply water mixed with stabilisers to prevent H_2O_2 decomposition.

Connections to relevant EU policy

The development of the HYPER process serves as a technical enabler for major European climate directives, including the European Green Deal⁴ and Clean Industrial Deal⁵ mandates.

Fact sheet

Duration	1 January 2023 until 31 December 2026
EU contribution	€ 7 254 450,00
Type of action	Research and Innovation Action
Coordinating organisation	SINTEF AS
Consortium size	14 partners

By providing a real-world model for converting green electricity directly into industrial chemical products, the project delivers critical empirical data needed to help decouple heavy processing sectors from foreign fossil fuel import dependencies.

Status of implementation

The project has transitioned from laboratory trials to automated pilot testing inside a secure container, **cutting power consumption** by nearly

↓ **40%**

against the historical industry baseline

However, because standard metal parts degrade hydrogen peroxide, the reactor currently relies on specialised glassware that must be re-engineered into durable materials before commercial factory deployment. The project will demonstrate five 200-hour validation runs that will gradually be ramped up from daytime to 24/7 operation as potential mechanical risks and practical challenges are resolved. Scale-up studies, doubling capacity from initial trials, have shown that efficient hydrolysis from persulfate to H_2O_2 requires some sulfuric acid, limiting the use of persulfate as a chemical energy storage vector.

Next steps

To address remaining commercialisation gaps, the consortium has initiated conversations with an engineering firm from the pharmaceutical sector to re-engineer the glass components in the utiliser, using more robust and durable materials, making it ready for commercialisation. Currently, the production cost of H_2O_2 with these decentralised modular units is slightly higher than that of commercial, fossil fuel-derived H_2O_2 . Crucially, the electricity price is a key parameter for determining production cost, and different renewable energy use scenarios are being evaluated to find production cost sweet spots.

Furthermore, major northern European paper mills have expressed formal interest in hosting permanent full-scale units once higher industrial readiness is achieved, and the consortium is planning to pursue European innovation funding instruments to scale the technology into regional supply chains.

METAWAVE:

Decarbonising high-temperature industrial processes via advanced microwave technologies

Main objective of the project

The primary objective of the METAWAVE project is to validate an automated, decentralised high-temperature heating process that targets heavy manufacturing furnaces. Rather than relying on traditional gas-fired or fossil-fuel combustion, the system applies advanced microwave technologies to heat industrial components from the inside out. This approach directly heats the inner core of low-conductivity materials, mitigating the substantial thermal energy losses and slow processing times characteristic of conventional external heating. The project targets three distinct, energy-intensive industrial sectors:

- the firing stage of porcelain tiles in ceramics,
- aggregates heating in asphalt manufacturing, reducing the operation temperatures and enabling the use of 100% Reclaimed Asphalt Pavement (RAP),
- and a hybrid microwave-induction baking process for carbon anode production in aluminium processing.

As project coordinator, María Herrando (Instituto Tecnológico de Aragón) notes, targeting these diverse sectors is a deliberate strategy for broader industrial deployment:

"We [each] are applying a different heating way for a completely different process (...), this will allow the replication after the project to more sectors because we are already tracking different technologies to target different requirements in greener manufacturing."

To complement this hardware configuration, the project develops sustainable circular refractories, which function as heat-resistant furnace linings, created from industrial processing waste—such as copper slag—enabling the system components to reliably withstand extreme process environments exceeding temperatures as high as 1300°C.

Impact

Transitioning to this modular electrification framework offers substantial opportunities to curb pollution and refine operational performance across heavy industry.

Engineering projections indicate a:

40%

reduction in direct climate emissions for both the ceramic and aluminium lines

64%

reduction within the asphalt sector.

Moreover, by 2032, commercial deployment of these clean technologies is estimated to:

avoid over

95,000

tonnes of climate pollution

increase overall industrial manufacturing productivity by more than

19%

and generate **900** new jobs.

Fact sheet

Duration	1 January 2024 until 31 December 2027
EU contribution	€ 9 487 573,87
Type of action	Research and Innovation Action
Coordinating organisation	Instituto Tecnológico de Aragón (ITA), Spain
Consortium size	20 partners

To maximise efficiency, a digitalised Virtual Power Plant together with an Energy Management System coordinates furnace workloads, allowing facilities to match production schedules dynamically with clean electricity availability—accelerating work when renewable supply peaks and reducing power draw during high-tariff periods. Furthermore, localising the heating sequence directly within existing production lines eliminates the high financial and environmental overhead of trucking heavy raw aggregates or processing loads across extended highway networks.

Connections to relevant EU policy

The development of the METAWAVE technology serves as a direct technical enabler for major European industrial policy initiatives, most notably the Clean Industrial Deal⁶ priorities and the Net-Zero Industry Act⁷. By providing a real-world model for converting green electricity directly into industrial thermal processing, the project delivers critical empirical data needed to help decouple heavy processing sectors from foreign fossil fuel import dependencies, as well as reinforce the sector's competitiveness. Additionally, by focusing on the total reuse of Reclaimed Asphalt Pavement (RAP) and incorporating secondary resources into durable equipment components, the project actively addresses the resource efficiency goals outlined under the EU Circular Economy Action Plan⁸.

Status of implementation

The project has successfully transitioned from laboratory trials to automated pilot testing inside secure industrial settings. Most of the primary technological developments have been completed, and the system has entered its demonstration phase:

- The prototype for the asphalt sector is fully assembled, with sensors and control automation currently being integrated before field shipment.
- For the aluminium sector, the hybrid microwave-induction heating system is already operating on-site.
- For the ceramic sector, lab-scale plasma torches successfully achieved target operating temperatures, and the assembly of the large-scale roller kiln is on track for delivery by September.

Nevertheless, a key technical challenge is integrating advanced monitoring sensors into the airtight, vacuum-sealed aluminium system, while operational focus remains on overcoming workforce and public perceptions regarding microwave radiation safety.

Next steps

Future project activities focus on deploying the automated prototypes directly across active manufacturing plants to monitor long-term mechanical reliability under different operating conditions. Overcoming the non-technical barrier of public and industrial acceptance due to the perception of microwaves being hazardous remains an essential aspect of future deployment.

Looking further ahead, the technology aims to generate over €230 million in total revenues by 2032, supported by targeted standardisation frameworks, certification rules, and workforce training suites to scale the technology safely into regional supply chains.

MC4:

Multi-level circular process chains for carbon and glass fibre composites

Fact sheet

Duration	1 April 2022 until 31 March 2025
EU contribution	€ 7 503 545,00
Type of action	Research and Innovation Action
Coordinating organisation	PROFACTOR GmbH, Austria
Consortium size	16 partners

Main objective of the project

The primary objective of the MC4 project is to establish and validate automated, circular process chains for the recycling and reuse of carbon and glass fibre composite materials. The project focuses on industrial scaling across **four distinct technological pathways** in the short- and long-term, evaluated by material type, processing timelines, and Technology Readiness Levels (TRLs). Within this project, the distinction of short- and long-term pathways reflects supply chain complexity, differentiating the estimated time needed to fully perform one full cycle of the process.

Short-term pathway refers to processes designed for rapid industrial implementation, typically operating within a single organisation to immediately collect and re-manufacture production-generated manufacturing scrap or off-cuts:

- **Carbon fibre pathway (Technology at TRL 7-8):** This approach focuses on the immediate reuse of pre-impregnated carbon fibre fabric (prepreg) scrap generated during the manufacturing layup stage. Leftover fabric off-cuts are processed via calendaring to create uniform sheets for non-structural applications, such as aircraft interior components, before the material undergoes ambient curing.
- **Glass fibre pathway (Technology at TRL 8):** This mechanical recycling route shreds end-of-life composites into large, centimetre-scale pieces. Preserving the larger physical size allows the material to retain its native mechanical performance when reintroduced into new component manufacturing at a recycled material rate of 60%.

Long-term pathway refers to processes requiring more extensive and time-consuming development or a broader multi-partner supply chain to reprocess post-consumer components at their end-of-life phase, or to deploy novel materials that must complete a full operational cycle before recovery is possible:

- **Carbon fibre pathway (Technology at TRL 5-6):** Housed within a multi-partner supply chain, this pathway focuses on extracting fibres from end-of-life composite components using a chemical solvolysis process. The recovered short fibres are reprocessed using specialised textile technologies to manufacture new technical non-wovens and tapes.
- **Glass fibre pathway (Technology at TRL 5-6):** This route introduces a new class of vitrimer resins into the manufacturing process. These specialised polymers allow finished composite parts to be thermally reshaped, modified, or repaired under heat and pressure at the end of their initial operational cycle.

Impact

Historically, approximately 98% of carbon and glass fibre composites were disposed of in landfills at the end of their lifecycle. The necessity of researching recycling processes is further illustrated by large numbers of commercial aircraft reaching the end of their operational lifespan, therefore, implementing technical alternatives is necessary to avoid landfill accumulation.

Project coordinator Christian Eitzinger (PROFACTOR GmbH) highlighted how MC4 showcased technical proof-of-concept:

“What we could demonstrate is we manufactured a kayak from this type of material [glass fibre and 3R resin] and then cut the kayak into pieces and reshaped it to a set of paddles that could then be used.”

Additionally, the process addresses Europe's reliance on external raw materials, as 80% of virgin carbon fibre used in Europe is currently manufactured by third countries. Retaining these materials within a circular economy helps secure supply chains for critical domestic sectors, including aerospace and defence applications.

Connections to relevant EU policy

The technical outcomes of the MC4 project align with European industrial directives, specifically the Circular Economy Action Plan⁹ and the Clean Industrial Deal¹⁰ priorities. The project's results relate directly to regulatory targets, such as EU automotive regulations requiring the recycling of at least 85% of end-of-life vehicle materials¹¹. By demonstrating methods to reprocess manufacturing scrap into standardised raw materials, the project provides manufacturing supply chains with empirical evidence to meet these legislative quotas.

Status of implementation

The three-year project, completed in March 2025, successfully transitioned composite material reprocessing from laboratory configurations to automated pilot testing. The pilot lines validated the technical feasibility of these circular pathways by processing a total volume of 250 kilograms of recovered carbon fibre. However, the scale-up operations highlighted clear material limitations - the reclaimed fibres are non-continuous and require a significantly larger volume of resin during re-manufacturing. This reduces the total fibre volume content and lowers the mechanical performance of the final component compared to continuous virgin fibres, presenting a key engineering challenge against material downcycling.

Next steps

Following the conclusion of the project, consortium partners retain individual ownership of all project intellectual property, facilitating market integration strategies across the four technological pathways:

- **Short-term carbon fibre:** Having reached advanced maturity, this layup scrap reprocessing technology is currently transitioning directly into commercial aviation production lines.
- **Short-term glass fibre:** Mechanical reprocessing faces price competition from virgin glass fibre, which averages just €1 per kilogram; industrial adoption is in progress and will be enhanced by the enforcement of statutory recycling quotas to justify legacy equipment modifications.
- **Long-term carbon fibre:** Commercial uptake of this specific chemical solvolysis variant is limited, as competing industrial operators successfully scaled equivalent recycling infrastructure within Europe during the project timeline.
- **Long-term glass fibre:** The commercial pathway for these re-shapeable polymer matrices rests on active performance testing to secure necessary structural certifications within the aerospace sector.

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