

PLASTICE

New technologies to integrate PLASTIC waste in the Circular Economy

Training materials

Module 1: Innovative technologies to enable circular plastic value chains

Unit 1.1: Microwave-assisted thermochemical processing: prospects and scalability



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement n° 101058540.

MODULE 1 Overview

This module is divided into three units, each of which addresses specific challenges in plastic waste management and demonstrates how advanced methods can transform **waste into valuable resources** through sustainable and scalable processes. These technologies are:

- **Unit 1.1: Microwave-assisted thermochemical processing: prospects and scalability**
- Unit 1.2: Gasification and catalytic post-treatment for circular plastic valorisation: syngas to olefins conversion
- Unit 1.3: Enzymatic hydrolysis: a green approach to separate waste streams for recycling

These technologies have been developed and validated within the framework of the **PLASTICE project**, funded by the European Commission, which aims to promote circular solutions for plastic waste valorisation through **chemical recycling**.



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement n° 101058540.

Unit 1.1

Microwave-assisted thermochemical processing: prospects and scalability

*Two-thirds of energy consumption in most industrial processes is dedicated to heating. **Microwave-assisted Heating (MWH)** is emerging as a promising and energy-efficient alternative. This unit explores the key prospects of MWH systems, including the state-of-the-art in MWH-enhanced thermochemical transformation processes, technology components, readiness levels, industrialisation progress, scaling strategies, advantages and limitations compared to conventional heating methods, and implementation challenges.*

Special emphasis is placed on design strategies, process integration, and considerations required to bridge the gap between lab-scale and industrial demonstration.

Key Points of Unit 1.1

- **Environmental & Economic:** MWH can cut costs, improve quality, and lower emissions through technologies like electrified pyrolysis.
- **Standards & Safety:** unified standards are needed to ensure safe, consistent, and reliable MWH operations.
- **Renewables:** integrating MWH with renewables boosts efficiency and reduces fossil fuel use.
- **Education & Outreach:** training and collaboration are key to raising awareness and promoting MWH's sustainability benefits.



Introduction

The energy gap between supply, demand, and consumption in industrial processes continues to widen. Microwave-assisted heating is emerging as a promising solution to improve energy efficiency in **thermochemical applications**. However, its industrial implementation and scale-up face significant challenges across all components and stages of the technology.

Three key areas of knowledge are essential for the successful deployment of this technology:

- (1) a comprehensive understanding of the microwave heating system;
- (2) an assessment of operational challenges;
- (3) an in-depth analysis of the physical properties of materials, including their behaviour and interaction with microwave energy.

Description of the MWH technological process

Since the dawn of industrialisation, external and conventional heating methods have dominated as the primary way of achieving high temperatures for industrial processes, particularly in thermochemical applications. Heat is transferred externally between materials using conductive properties or convective diffusion, leading to energy losses and long processing times.

The rise of microwave heating is revolutionising industrial heating by taking a different path: **internal heating**. As microwaves interact directly with materials at a molecular level, due to their **dielectric properties**, it allows a rapid, selective and efficient heating.

Despite these advantages, scaling MWH to industrial size faces key challenges. The effectiveness of microwave heating depends on the material's dielectric properties, reactor cavity design and MW energy distribution. In a lab-scale setting, these factors are easier to control. However, ensuring the effectiveness of these variables at an industrial scale becomes a complex task.

Successful industrial-scale implementation requires addressing the following technical challenges:

- Shape and size of the cavity must guarantee the uniform distribution of MW radiation to prevent uneven heating and losses of energy.
- Scaling up requires enhancing the material arrangement to optimise its MW absorption.



- Advanced contact and contactless temperature monitoring techniques, such as optical sensors, IR pyrometers or thermal image systems, are required.

Indicator	Advantages	Challenge
Energy-efficiency	Direct heating reduces energy losses.	It depends on the material's dielectric properties
Process speed	Quick and uniform heating	Difficult to maintain this uniformity when scaled.
Temperature control	Instantaneous application	Requires more complex systems of monitoring
Scalability	High potential for the electrification of industry	High economic costs and engineering complexity

Table 1 MWH Technology Overview (Julian & Fresneda-Cruz, 2023)

Besides evaluating the state-of-the-art in technology development and its scalability prospects, this document presents a real case study undertaken within the framework of the European project PLASTICE, in which a unique continuous microwave-assisted unsortable plastic waste pyrolysis pilot plant has been developed and installed. This pilot plant aims to **test** and **demonstrate** the **scalability and feasibility** of MWH for plastic valorisation, bridging the gap between batch lab-scale promising findings and a continuous industrially-relevant microwave-assisted pyrolysis plant.





Figure 1 Microwave-assisted unsorted plastic waste pyrolysis pilot plant

The developed set-up features an overall **9 kW microwave power** devoted to **process up to 30 kg/h LDPE-rich plastic waste**, converting it into valuable **pyrolysis oil** which contains linear paraffins and olefins in the range C6 – C25. The **pyroil quality becomes readily available** to be fed into industrial steam crackers for second generation olefins production. This set-up was conceived based on a preliminary lab-scale experimental assessment (Fresneda-Cruz, et al., 2025), followed by the conceptual design of an upscaled continuous facility, its modelling & simulation, engineering and manufacturing, all of them tackled within the project.

Note to the picture: The service offered is classified as a trade secret following the provisions of Spanish Law 1/2019 of February 20, 2019 (Directive (EU) 2016/943 of the European Parliament and of the Council of 8 June 2016), on the protection of trade secrets, and enjoys full legal protection



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement n° 101058540.

Conclusions

Microwave-assisted Heating offers a cleaner, safer, and more energy-efficient alternative to conventional heating systems commonly used in the chemical industry. By using **electromagnetic radiation** to directly heat materials, MWH **reduces the costs and energy losses** associated with indirect heating methods. Its high efficiency and **compatibility with renewable energy sources** position it as a key enabler in industrial decarbonisation strategies.

However, large-scale industrial implementation of MWH still faces several challenges. These include the need for technological adaptation, redesign and optimisation of reactors and equipment, and the development of microwave generators capable of operating under large-scale industrial conditions.

To support its broader adoption, four key areas must be addressed:

1. **Environmental and economic impact**

MWH has the potential to deliver significant long-term environmental and economic benefits. Promoting investment in electrified pyrolysis and similar emerging technologies can reduce operational costs, increase product quality, and contribute to global emission reduction targets.

2. **Standardisation and safety protocols**

The development of industry-wide standards is essential to ensure the robustness, reproducibility, and safety of microwave-assisted processes. This includes unified quality control procedures, maintenance protocols, and safety regulations.

3. **Renewable energy integration**

MWH systems should be integrated with renewable energy infrastructures to further reduce reliance on fossil fuels. This synergy enhances process efficiency and supports global decarbonization efforts.

4. **Social and educational impact**

Awareness and understanding of MWH technology must be expanded through dissemination, education, and training programs. Collaboration between research institutions, industries, and policymakers is crucial to promote knowledge transfer and highlight the sustainability benefits of MWH.



Bibliography

Fresneda-Cruz, A., Murillo-Ciordia, G., Figueirêdo, M. B., Tovar-Lasheras, F., AL Farra, A., Arauzo, J., & Julian, I. (2025). Microwave-assisted pyrolysis of waste LDPE: unveiling the role of induced gas-solid thermal gradients on pyrolysis oil product distribution. *Journal of Analytical and Applied Pyrolysis*.

Julian, I. A., & Fresneda-Cruz, A. (2023). Scale-up of Microwave-assisted Heterogeneous Catalytic Processes. En *Advances in Microwave-assisted Heterogeneous Catalysis* (págs. 368-404).

Contact the authors!

Rafael Torres Franco (rtorres@fcirce.es)

Ignacio Antonio Julián Burillo (iajulian@fcirce.es)

Want to know more about the PLASTICE project?

Visit www.plastice.eu or scan the QR code



NEXT

UNIT 1.2

Gasification and catalytic post-treatment for circular plastic valorisation: syngas to olefins conversion



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement n° 101058540.