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REFRESH

Microwave-assisted WTB recycling

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CIRCE – Technology Centre (Spain)

circe TECHNOLOGY CENTRE

First Stakeholder Workshop
17 November 2026, online event

Photo by Nicholas Doherty on Unsplash

Introduction to CIRCE

+300	PEOPLE
37,5	AVERAGE AGE
32	PhDs
36%	WOMEN
17	NATIONALITIES

- Power generation and renewables
- Climate change mitigation
- Smart grids
- Industrial technologies
- Hydrogen and renewable gases
- Energy efficiency and decarbonization
- Circular (bio)economy, recycling
- IA and digitalization
- Industrial modeling and simulation
- Mobility and sustainable urbanism

The challenge of WTB recycling

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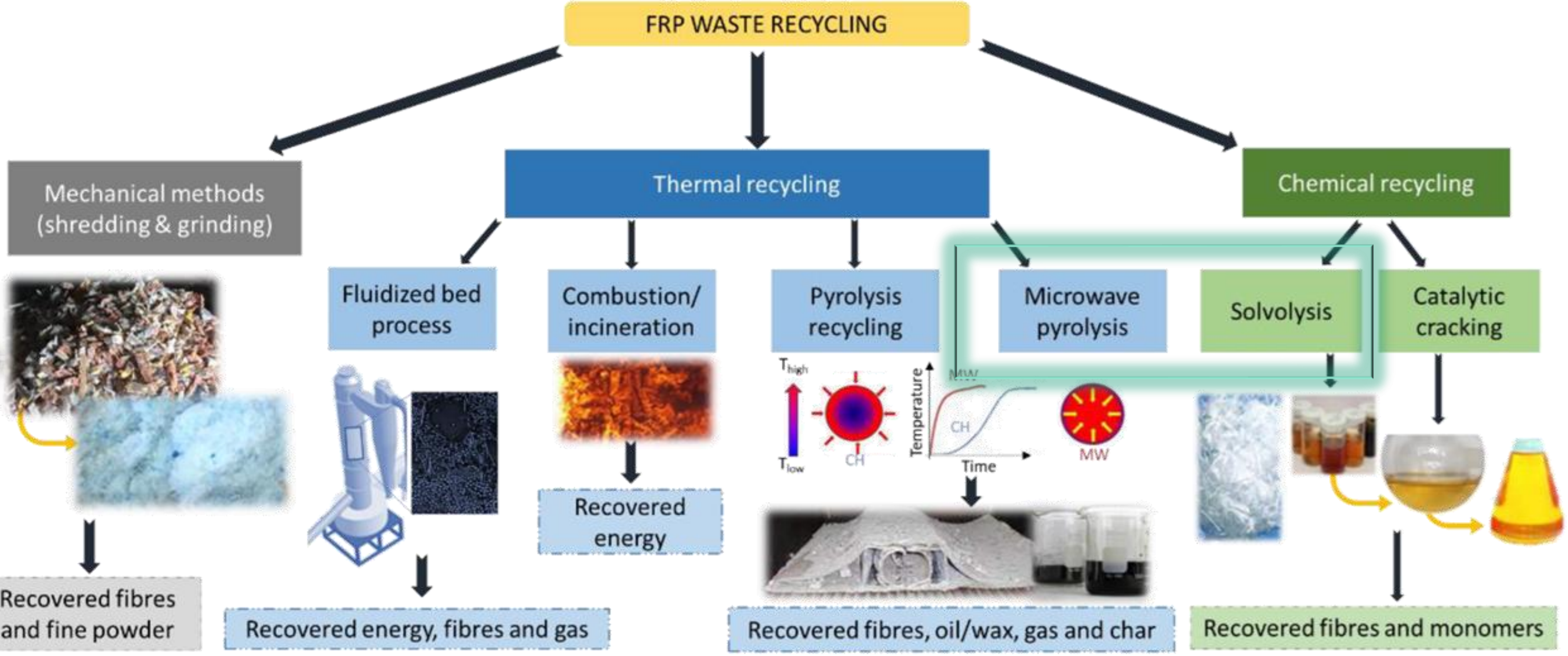
Blades repurposing

Recycling options for FRP waste from EoL WTB



I. Julian et al. Chemical Engineering and Processing - Process Intensification 178 (2022) 109015

WTB recycling: why using microwaves?

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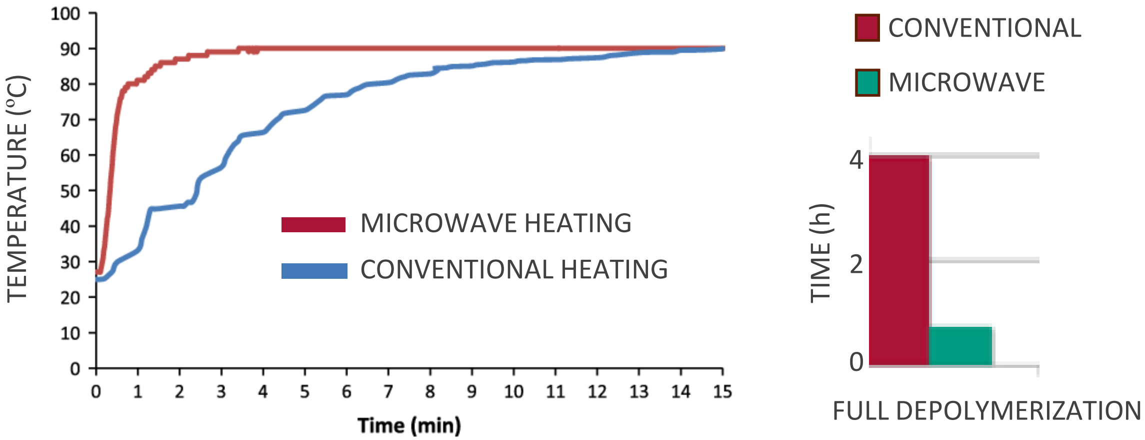
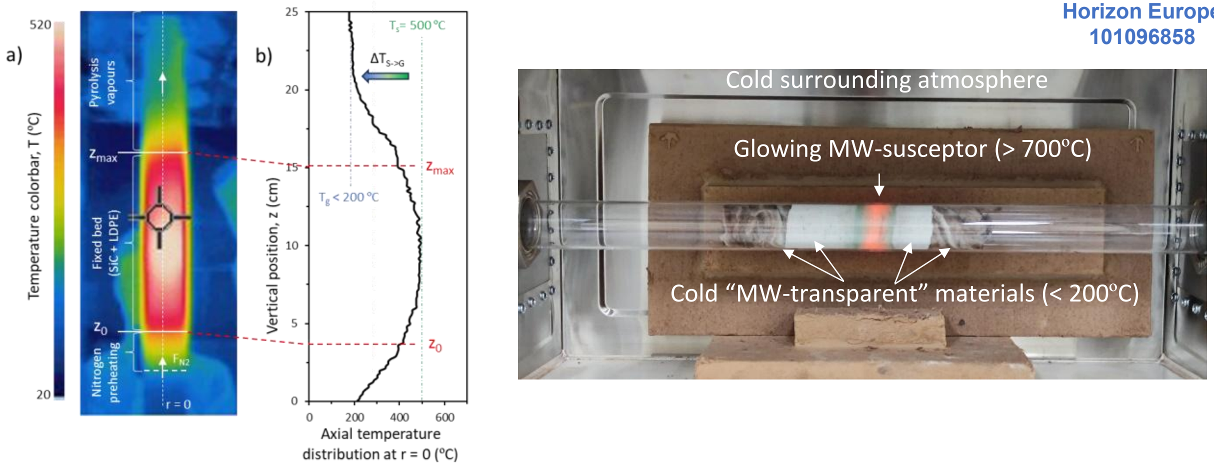
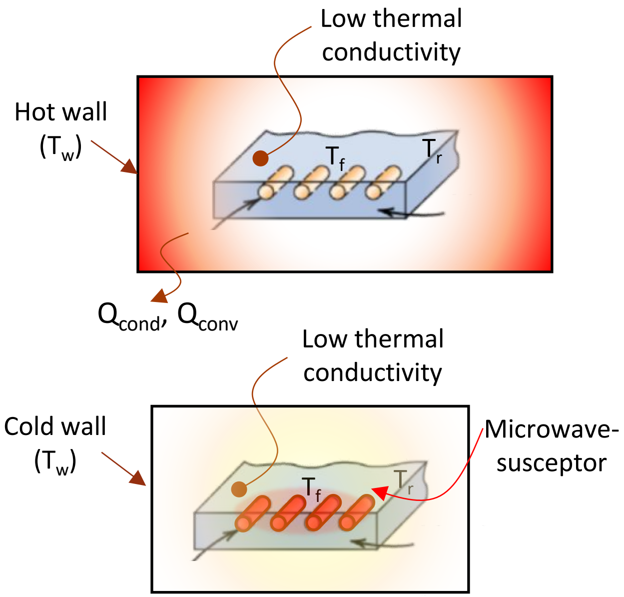


DRASTICALLY REDUCED **HEATING** **&** FULL **DEPOLYMERIZATION TIMES**



GAS-SOLID **THERMAL GRADIENTS** ON DEMAND



Limitations of conventionally-heated pyrolysis/solvolysis processes:

- Resins heat transfer is very poor: large temperature gradients along the heated medium **limit recycling process controllability**
- Gas-phase cracking in the hot reaction system atmosphere also **limits oil product distribution controllability**

Microwave-assisted heating advantages:

- Fast, selective and volumetric heating
- Enhanced control over pyrolysis process and oil product distribution
- Lower apparent processing temperature for a given depolymerization extent
- Enhanced preservation of mechanical properties of the fibres

Technology assessment: MW-pyrolysis and MW-solvolysis (I) proof of concept

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MWPYR


MWPYR set-up


Shredded GFRP & SiC susceptor


Recovered Pyrolyzed fibers


Isolated pyrolysis oil & waxes

MWPYR technology	
Configuration	Fixed bed reactor (FBR)
Temperature range	**100 – 1000 ºC**
Max. MW power	**3.2 kW**
Loading	**15 – 20 g GFRP/CFRP** 100 – 200 g SiC
Scope	1) Oil & fiber quality characterization 2) Oil yield maximization

MWSOLV


MWSOLV set-up


Reclaimed glass fibers


Washed and dried glass fibers


Oil phase

MWSOLV technology	
Configuration	Batch stirred tank reactor (BSTR)
Solvolysis medium	Acid/caustic or organic solvents
Temperature range	**150 – 250 ºC**
Max. MW power	**1.5 kW**
Pressure range	**10 – 80 bar**
Loading	**30 – 35 g GFRP/CFRP** 300 – 350 mL solvolysis medium
Scope	Oil & fiber quality characterization

Technology assessment: MW-pyrolysis and MW-solvolysis (II)

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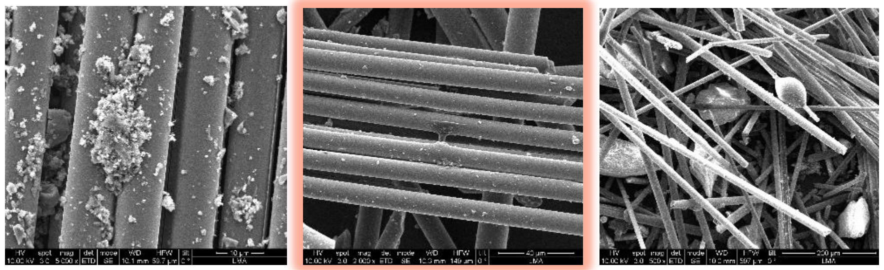
Glass fiber reinforced FRP: MW-PYROLYSIS

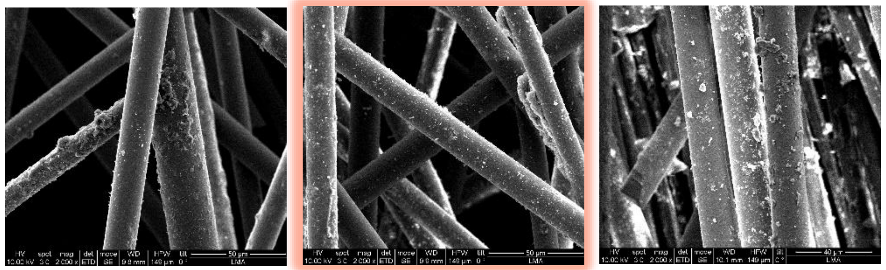
Pyrolysis temperature

epoxy-FRP



Resin deposits remaining | Optimum fibers cleaning | Damaged fibers

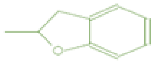
polyester-FRP



Resin deposits remaining | Mid-temp coupled with **optimized residence time** | Coke deposits on fibers

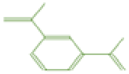
epoxy-FRP oils

BENZOFURANS

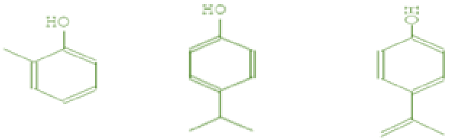


PYRIDINES

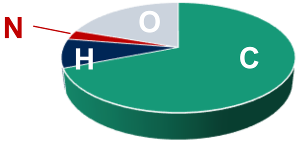
STYRENES



PHENOLS

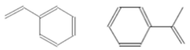


> 80 wt%

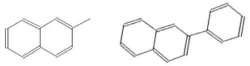


polyester-FRP oils

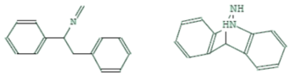
BTX / STYRENES



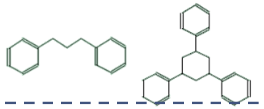
PAH



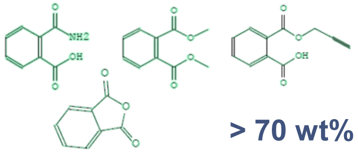
N-PHENYLS



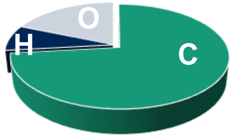
PHENYLS



PHTHALATES and PHTHALIC ACID derivatives



> 70 wt%



Technology assessment: MW-pyrolysis and MW-solvolysis (III)

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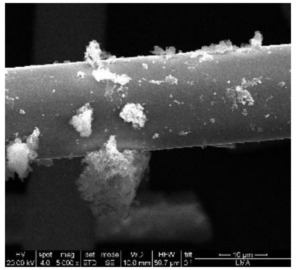
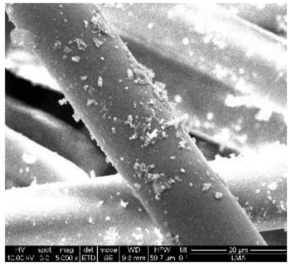
Glass fiber reinforced FRP: MW-SOLVOLYSIS

Solvolysis temperature, catalyst

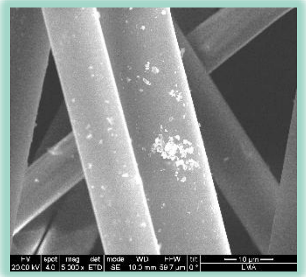
epoxy-FRP



Resin deposits remaining

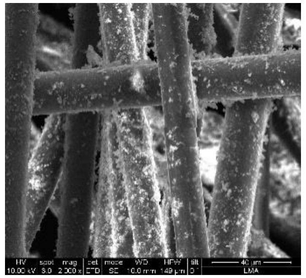


Catalytic salts on surface

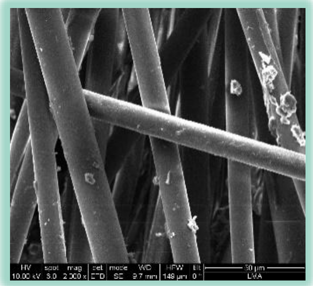


Improved catalyst, fairly cleaned fibers

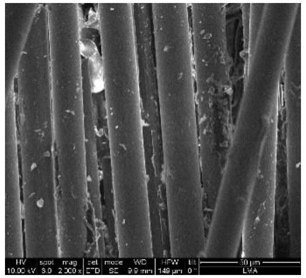
polyester-FRP



Resin deposits remaining



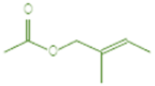
Fairly cleaned fibers



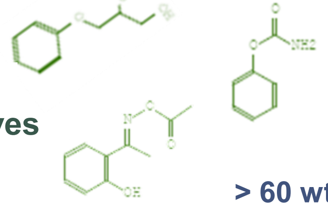
Salt deposits due to catalyst overloading

epoxy-FRP oils

Ester

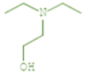


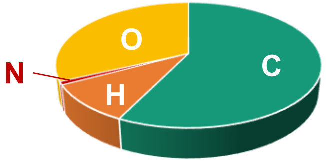
Phenol derivatives



> 60 wt%

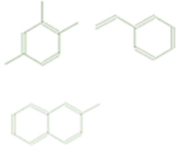
Amines



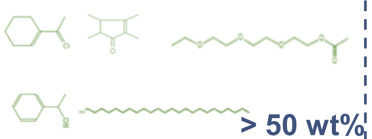


polyester-FRP oils

Linear & Aromatic Hydrocarbons

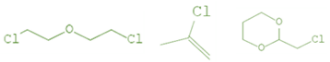


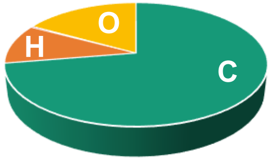
Oxygenated



> 50 wt%

Chlorinated





Technology assessment: MW-pyrolysis and MW-solvolysis (IV)

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PYROLISIS

PYROILS
Relatively high value as chemical building blocks (phenols, phthalic derivatives) as well as additives for naphtha production

FIBERS
Typically low value, although better textural properties preservation w.r.t. conventionally heated pyrolysis due to the use of lower apparent process temperatures

PROCESS
Energy-demanding due to high temperature but easy products isolation. Coke combustion step required for clean fibers reclaiming

SYNOILS
The potential value as building blocks strongly depends on the solvolysis medium, catalysts and operating conditions, being typically lower than that of MWPYR products

FIBERS
Relatively low value: no structural damage and cleanliness but low length, since pre-shredding is required

PROCESS
Typically less energy-demanding thermal process, but complex oil isolation and materials-demanding (solvent, catalyst, post-processing agents,…)

SOLVOLYSIS

FAQ

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1 **Which is the most appropriate Technology, among the evaluated ones, from a techno-economic point of view?**

2 Is this Technology scalable?

Answers (I)

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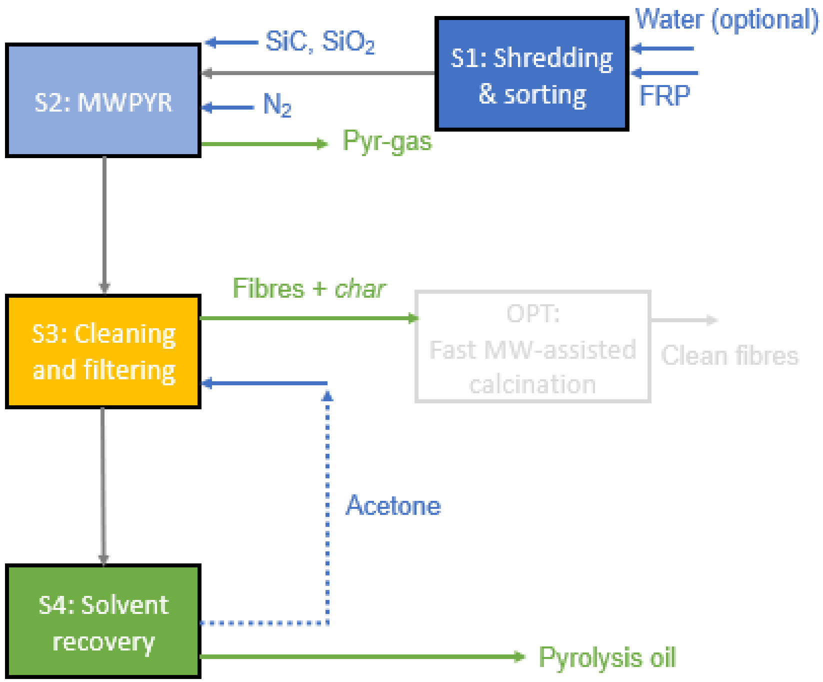
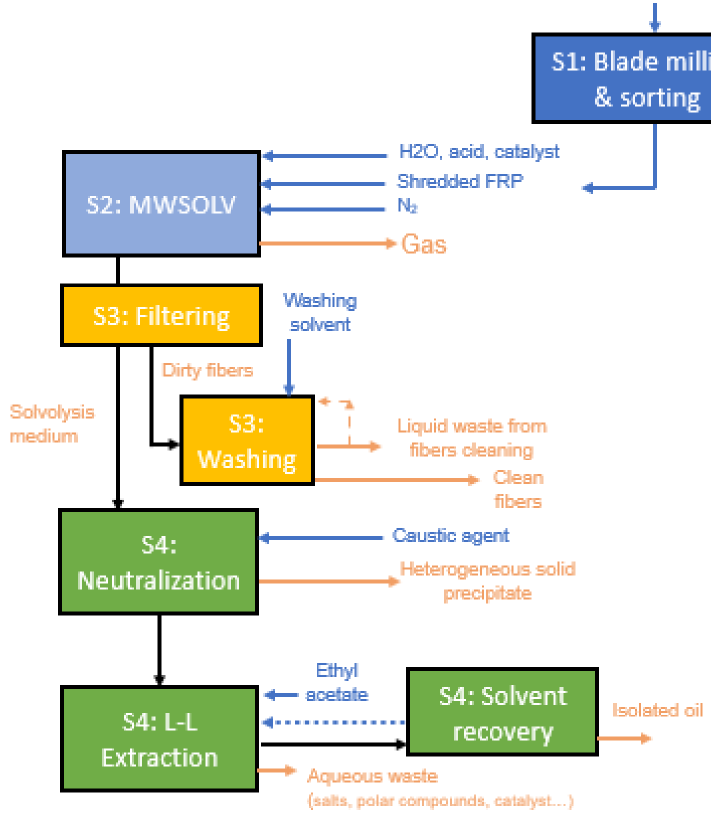
1 Process Flow diagram of MW-assisted thermochemical WTB recycling

Thermal recycling: MW-pyrolysis



Chemical recycling: MW-solvolysis



Answers (II)

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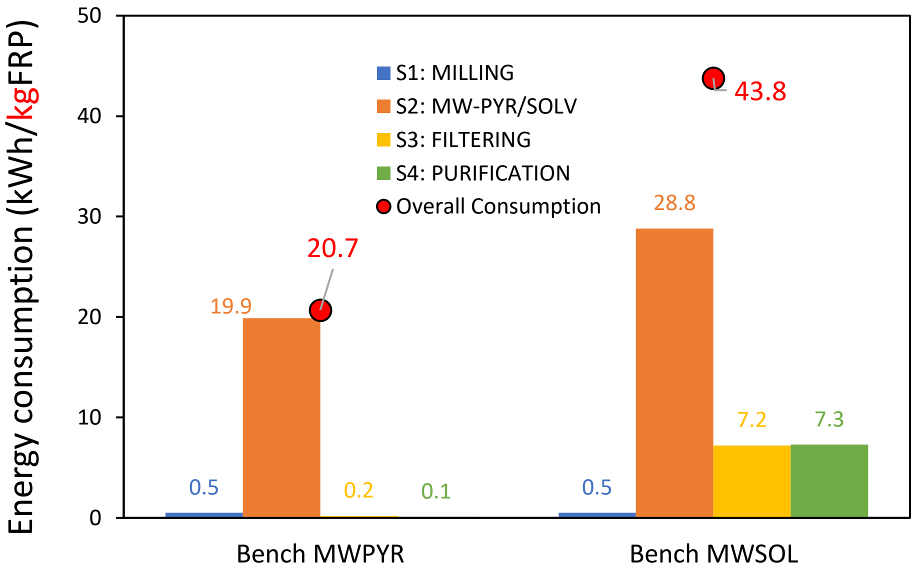
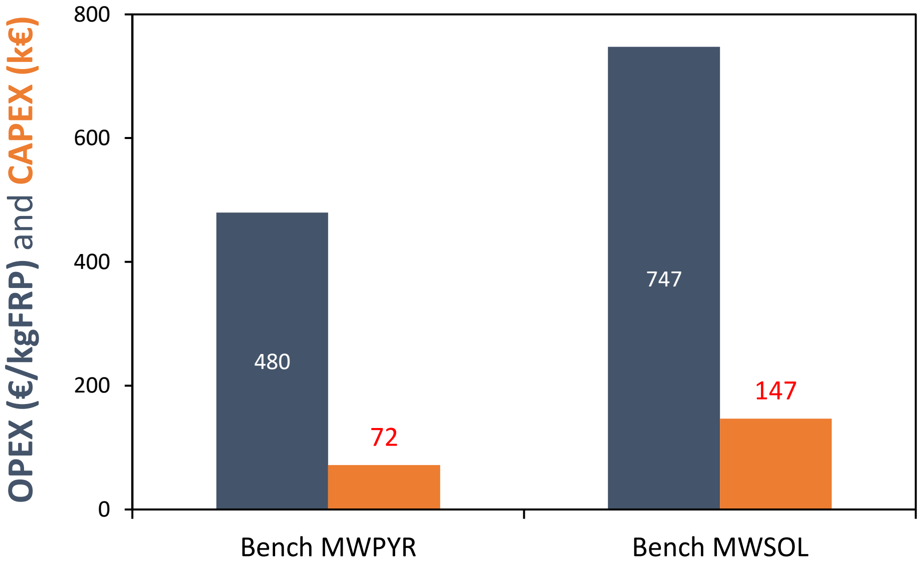
1 MW-assisted WTB recycling technologies comparison





This analysis suggest that **MWPYR outperforms MWSOL** in terms of CAPEX, OPEX and, specifically, process energy consumption. The analysis excludes the **Cost/Benefit** assessment derived from the recycled products' quality and potential selling price.

FAQ

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1 Which is the most appropriate Technology, among the evaluated ones, from a techno-economic point of view?

2 **Is this Technology scalable?**

Answers (III)

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2

Shredded FRP waste

up to 30 kg/h

9 kW MW power

6 kW cooling power

Sorted/cleaned fiber

Pyrolysis oil

Answers (IV)

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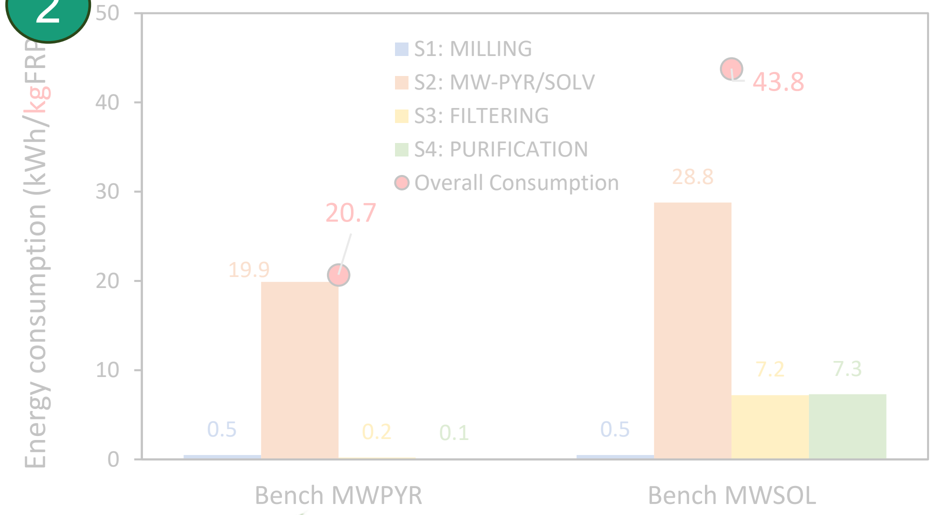
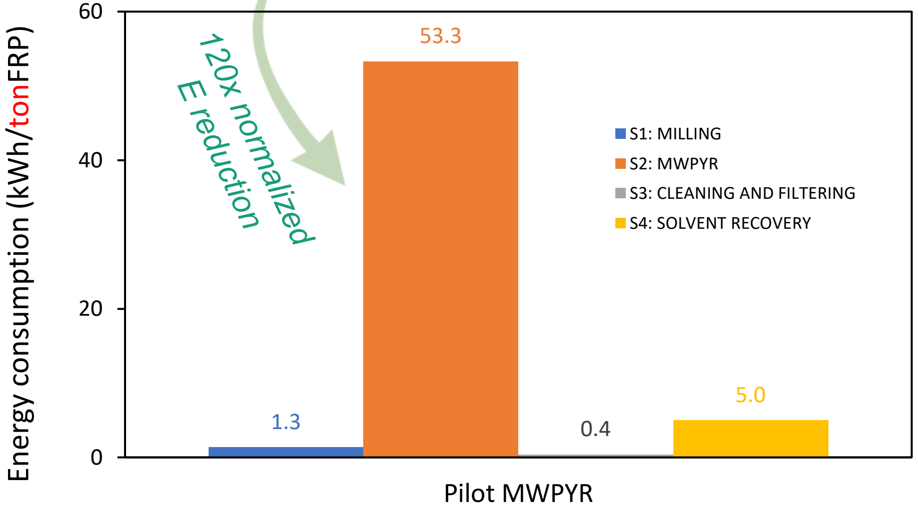
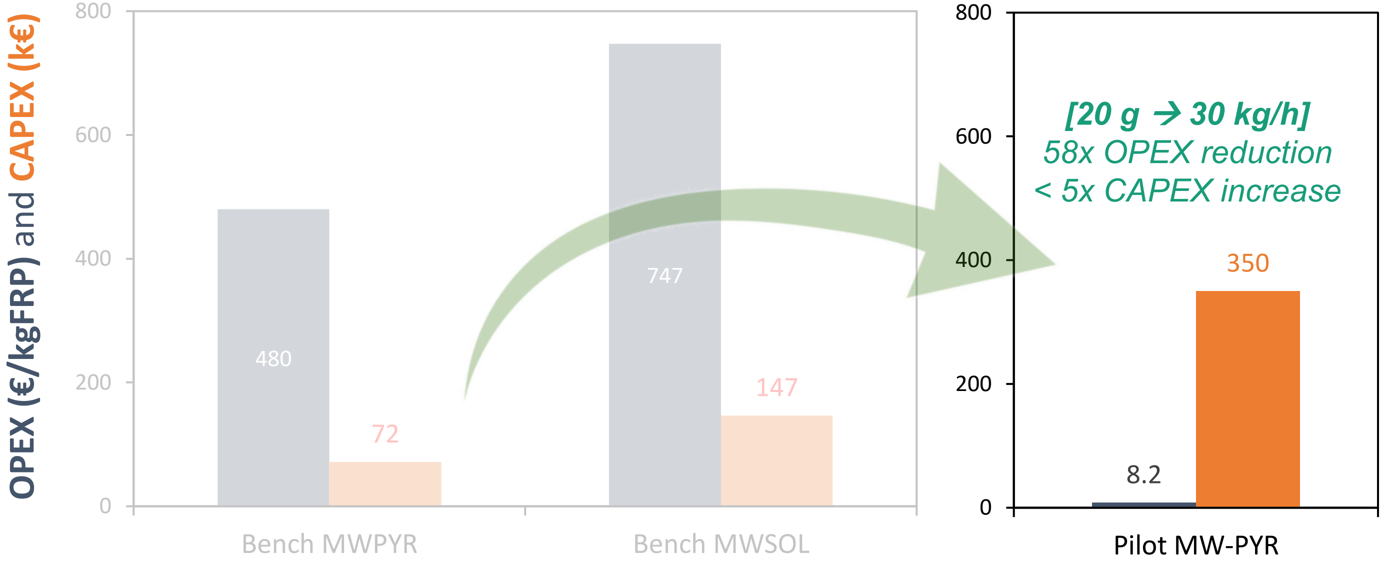
2







MWPYR process upscaling (continuous operation regime) drastically **increases energy efficiency** and **reduces OPEX**, thus, improving the technology prospects towards industrialization

Conclusions and outlook

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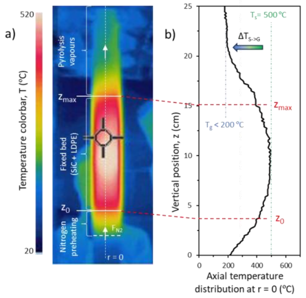
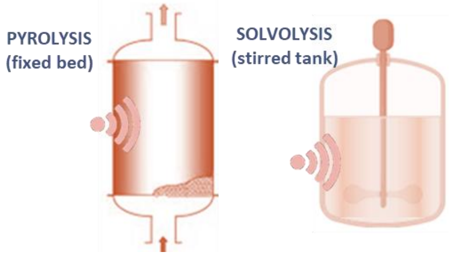
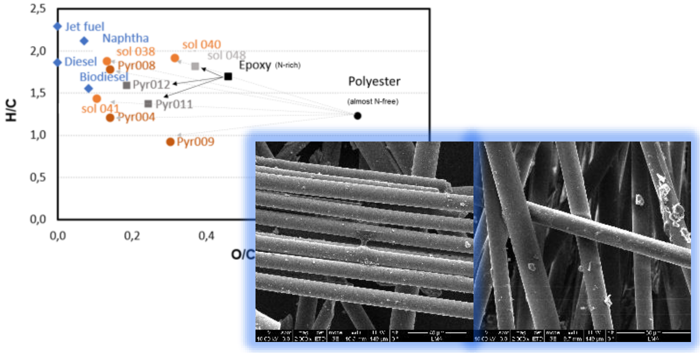
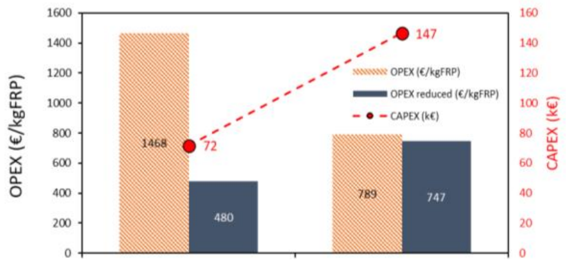


Microwave heating boosts **energy-efficiency** of WTB recycling (down to 3x lower consumption per kg_{FRP}), **process controllability** (oil products distribution) and **reclaimed fibers quality** (keeping up to 80% of original mechanical performance)

MW-PYR and MW-SOL technologies were experimentally assessed for the thermochemical recycling of FRP from WTB. Both may provide clean GF and/or CF plus complex oils that could be used either as fuels or chemical building blocks







The techno-economic assessment revealed that the **overall cost (CAPEX + OPEX) of MW-PYR is roughly 2x lower than that of MW-SOL.** The quality of the fibers are comparable and pyroils seem more interesting for end-use point of view

A new MW-PYR pilot unit is being commissioned at CIRCE's premises to assess the process scalability and energy efficiency at larger scale under continuous operation. Its maximum (shredded FRP) processing capacity will be ca. 30 kg/h and will be available for bench trials for potential investors

Thank you for your attention!

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Creating together

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