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TURNING WASTE INTO ENERGY: FLEXBY'S BREAKTHROUGHS IN THE QUEST FOR SUSTAINABLE BIOFUELS

Across Europe, scientists and engineers are giving waste a new purpose — transforming it into clean fuel for tomorrow's transport systems. The **EU-funded FLEXBY project** is at the forefront of this revolution, developing breakthrough technologies that convert industrial residues and microalgae into sustainable biofuels capable of powering planes, ships, and heavy vehicles.

What makes FLEXBY stand out is the combination of **microwave-assisted pyrolysis** with **hydrogen-free hydrodeoxygenation (HDO).** These technologies allow the recovery of energy from a variety of low-value waste streams without relying on fossil-based hydrogen. **The result is a flexible, cleaner, more efficient route to renewable fuels** — one that can process various feedstocks in one system, reuses water, valorises by-products, and cuts emissions across the production cycle.

Behind the technology is a strong European collaboration bringing together research teams from Portugal, Spain, Germany, and Italy. In Portugal, project partner **Algae for Future (A4F)** has been cultivating microalgae as a renewable feedstock; in Germany and Spain, engineers at **Fricke und Mallah** and **CSIC-INCAR** are developing and testing the project's innovative microwave reactor — a compact system that dries and converts biomass in a single step, ensuring precise temperature control and high energy efficiency.

Meanwhile, researchers at the **Universidad de Sevilla** are developing the **hydrogen-free hydrodeoxygenation and bio-hydrogen processes** and **catalytic materials** that upgrade the bio-oils and gases produced from the microwave pyrolysis into cleaner, more stable fuels using water instead of fossil hydrogen. Bringing it all together are the teams from **IDENER** in Spain and **Politecnico di Milano** who aim to optimise and help up-scale the FLEXBY process using state of the art digital tools and simulations.

Each of these innovations contributes to a common goal: **proving that waste can power Europe's clean energy transition.** FLEXBY's approach demonstrates how circular design — where every output has a new purpose — can reduce environmental impact while **creating value from materials once considered worthless.** It's a glimpse of a future where renewable fuel production no longer depends on scarce resources but instead thrives on the energy potential hidden in everyday waste.

FROM WASTEWATER TO BIOFUEL

A key part of the project's innovation lies in using **microalgae cultivated in wastewater** as a renewable feedstock. In Portugal, project partner **Algae for Future (A4F)** has shown that naturally occurring Scenedesmus species thrive in urban wastewater, achieving rapid growth and high lipid content — both essential for biofuel conversion.

The harvested biomass is now undergoing pyrolysis testing at **CSIC-INCAR**, where scientists are examining how its chemical composition influences conversion efficiency and fuel yield. This synergy between resource recovery from wastewater treatment and renewable energy exemplifies the circular economy principles at the heart of FLEXBY.

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SUSTAINABLE ENGINEERING AT THE CORE

Behind FLEXBY's technical achievements is an engineering effort led by **Fricke und Mallah** and **CSIC-INCAR**, who have developed a **simulation model for a microwave-assisted pyrolysis reactor** capable of converting algae-based and industrial sludges into bio-oils, biogas and biochar. Using advanced electromagnetic simulations, the team designed a compact system that combines microwave drying and pyrolysis within a single chamber. **The result is a highly efficient process** that ensures even heating, precise control, and reduced operational costs.

Fricke und Mallah´s reactor design includes a circularly polarised antenna, infrared sensors, automated temperature regulation, and a suite of safety mechanisms — including hydrogen detectors and pressure relief valves — to ensure both performance and reliability. **Its capacity to operate under variable pressures of up to three bar marks a breakthrough in reactor technology.** With the simulation phase complete, the consortium is now preparing to build and test the prototype, taking a decisive step toward pilot-scale operation.

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CATALYSTS FOR A CIRCULAR BIOECONOMY

Meanwhile, researchers at the **University of Seville** are advancing the chemical side of FLEXBY's innovation by developing **hybrid multifunctional catalysts** to upgrade the liquid and gaseous fractions produced by pyrolysis. These catalysts enable the conversion of bio-oil and pyro-gas into cleaner, more stable fuels through reactions that use water instead of fossil hydrogen. In a further step towards sustainability, FLEXBY is exploring the reuse of **biochar**, a solid carbon-rich by-product of pyrolysis, as a **catalyst support** — a strategy that reduces waste and integrates circularity directly into the fuel production chain.

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UNLOCKING THE POTENTIAL OF BIOCHAR

Biochar is a versatile product with multiple potential applications. Tests conducted at **CSIC-INCAR** have shown that process conditions can be tuned to control yields: lower temperatures (450–500°C) favour the production of bio-oil, while higher temperatures (up to 750°C) increase gas generation. At the same time, biochar yields of up to 58% have been achieved from macroalgae sludge at lower temperatures. Depending on its composition, this material can be used for **soil improvement, wastewater treatment, catalyst support, or even construction materials** — demonstrating FLEXBY's capacity to valorise all outputs from the process.

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MEASURABLE ENVIRONMENTAL GAINS

To verify the environmental benefits of these innovations, **GreenDelta** has carried out a **preliminary Life Cycle Assessment (LCA)** comparing FLEXBY's microwave-assisted pyrolysis process to conventional biofuel production methods. The results are encouraging: **the FLEXBY approach significantly reduces greenhouse gas emissions, acidification, and fossil resource use** while increasing overall energy efficiency.

Although drying wet biomass remains energy-intensive, the project's use of microwave technology allows part of the water content to contribute to the pyrolysis reaction itself, cutting energy demand. Plans are now underway for a comprehensive Life Cycle Sustainability Assessment (LCSA) that will evaluate the environmental, economic, and social impacts of FLEXBY's technology across its entire value chain.

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FROM LABORATORY TO MARKET

With its foundations now firmly established, FLEXBY is entering a critical new phase. The consortium aims to **validate and scale up its laboratory processes**, moving from **Technology Readiness Level (TRL) 4 to TRL 5** and demonstrating the full integration of microwave pyrolysis, hydrogen-free hydrodeoxygenation and bio-hydrogen production in a single operational system. These advances will bring FLEXBY closer to industrial validation and contribute directly to Europe's targets for clean energy and decarbonised transport.

A STRONG CONSORTIUM DRIVING INNOVATION

The FLEXBY consortium unites 10 partners from five countries, combining expertise in engineering, catalysis, sustainability, and communication. Partners include IDENER, A4F, CSIC-INCAR, Universidad de Sevilla, Politecnico di Milano, Fricke und Mallah, GreenDelta, GALP, CO_2 Value Europe, and KNEIA.

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