PRESS RELEASE
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ALGAESOL

Advancing Sustainable Aviation and Shipping Fuels through Microalgae and direct solar (bio)electrochemical systems

The ALGAESOL project is pioneering the development of sustainable aviation and shipping fuels using microalgae and direct solar (bio)electrochemical (BES) systems. These systems combine the biological conversion of carbon sources into energy-rich molecules with solar-driven electrochemical processes. Photoanodes capture sunlight to power oxidation reactions that support microbial activity and fuel production. BES have traditionally been used in wastewater treatment, energy production, and chemical synthesis - and now, ALGAESOL aims to use them, in combination with microalgae, to produce sustainable fuels (**Figure 1**)!

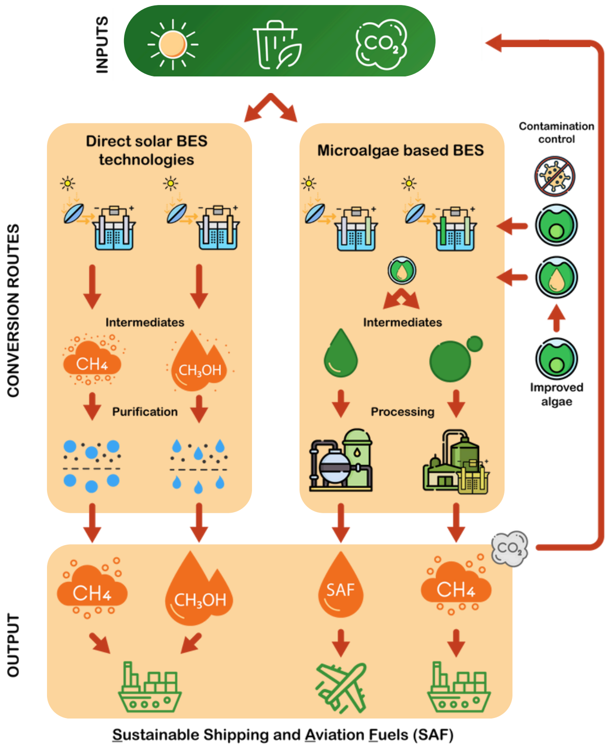

Figure 1. Overview of the ALGAEOSL project concept

The project's initial milestone was the definition of requirements and specifications for solar/algal biofuel production, completed in the first work package (WP1) by month 6.

At month 18, the consortium is focused on developing key components of the photo(bio)electrochemical system, such as cathodes, biocathodes, photoanodes, and a solar concentrator, and integrating them with microalgae cultivation.

Photoanode Development and Solar Concentrator

LEITAT is leading the design and fabrication of advanced scalable photoanodes and solar concentrator systems to maximize the utilization of sunlight in the photoelectrochemical process. The concentrator is engineered to enhance light intensity and spatial homogeneity over the photoactive surface, ensuring efficient and uniform illumination of the photoanode. Circular Fresnel lenses were selected for their ability to enhance light intensity and spatial uniformity across the reactor surface, enabling efficient sunlight harvesting. Scalable hematite (α-Fe_2O_3) photoanodes were fabricated using two cost-effective, industry-relevant techniques: screen printing (SP, **Figure 2a**) and large bath coating (LBC, **Figure 2b**).

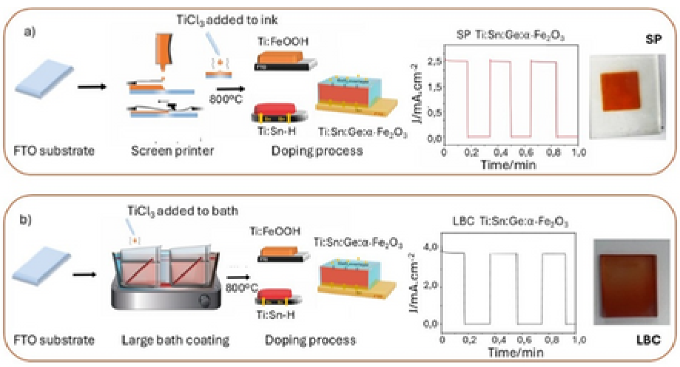

Figure 2. Scalable hematite (α-Fe_2O_3) photoanodes fabricated by screen printing (a) and Large Bath Coating (b)

The resulting photocurrents match the state of the art for LBC-prepared α-Fe_2O_3 photoanodes and set a new benchmark for screen-printed hematite photoanodes.

Cathode development for methanol production

Methanol, a widely used shipping fuel, can be produced through CO_2 reduction. In ALGAESOL's BES, this reaction occurs at the cathode. The consortium is optimizing materials for selective CO_2 reduction to methanol, identifying Cu_2O-based catalysts as promising candidates. These catalysts achieved Faradaic efficiencies* up to 47.5% and current densities of 10 mA/cm². Electrodes were fabricated by spray-coating Cu_2O and Cu_2O+ZnO inks onto carbon paper substrates. Analysis revealed that pure Cu_2O electrodes showed superior selectivity and activity, producing methanol concentrations up to 3 ppm in H-type cell tests. Electrochemical characterization confirmed methanol production at specific voltages, and work is ongoing to prevent product crossover between chambers.

Biocathode development for methane production

Electromethanogenesis is a BES technology converting carbon dioxide (CO_2) and electricity into methane (CH_4), using electroactive microorganisms growing on the biocathode of the cell. Optimization trials are being performed on a biocathode of stainless steel, working on three independent factors: the CO_2 injection strategy, the applied current density and the catholyte volume.

So far, a methane production rate of 1.1 L CH_4/L-cathode/day and a cathodic Faradaic efficiency of 67% were reached, at a current density of 12 A/m2. Additional trials are ongoing also to select a cathode material with a lower overpotential for electromethanogenesis, that could be more suitable for integration with the photoanode.

Integration all reactor components into modular PEC and PBEC

The integration of the cathode, anode, and light-harvesting system led to the development of two reactor architectures: Photoelectrochemical (PEC) and Photo-Bioelectrochemical (PBEC). Their design prioritizes scalability, sealing, and fluid management, with the goal of producing methane as a sustainable shipping fuel (**Figure 3**).

Microalgae Integration to BES for SAF production

To enable the production of sustainable aviation fuels (SAF) from microalgae lipids and intermediates, microalgae will be integrated into the system via the biocathode. Various materials are being inoculated with methanogenic biofilm and electrochemically characterized to identify the configuration with the lowest overpotentials, suitable for coupling with the photoanode.

Optimizing Microalgae Lipid Production

To maximize lipid production, different Chlorella sorokiniana mutants are being evaluated based on growth rate and lipid yield. Lipid extraction trials using Natural Deep Eutectic Solvents (NADES) have begun, exploring innovative technologies to optimize the process.

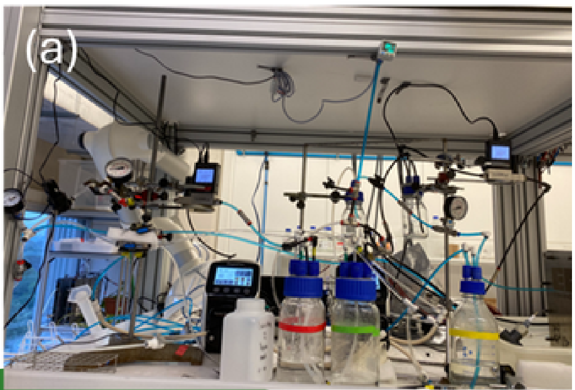

Figure 3. Laboratory setup with the assembled electrochemical reactor (a) and the set-up for methane production (b).

* Faradaic efficiencies: a measure of how efficiently an electrochemical reaction converts electrical charge into a specific product

Advanced pretreatment methods such as High-Pressure Homogenization (HPH, **Figure 4a**) and Ultrasound-Assisted Extraction (UAE, **Figure 4b**) are being tested, marking a significant step forward in green chemistry approaches for lipid recovery (**Figure 4c**).

MBES Optimization and Circularity

At the LEQUIA lab in Girona, efforts to maximize acetate production in BES continue. Acetate is an important organic carbon source that enhances both biomass growth and lipid yield. Current production levels have reached up to 100 $g \cdot m^{-2} cat \cdot d^{-1}$.

To ensure circularity within the ALGAESOL system, microalgae are being cultivated using BES effluent (**Figure 5**).

This approach has achieved biomass growth rates of up to 1.23 ± 0.15 $g \cdot L^{-1} \cdot d^{-1}$ under mixotrophic conditions, and up to 2.94 ± 0.02 $g \cdot L^{-1} \cdot d^{-1}$ in heterotrophic cultivation.

Towards Scalable and Sustainable Fuel Production

ALGAESOL's technology development spans TRL 2-4. To support sustainable scale-up, WP5 focuses on simulations, sustainability analysis, and scale-up strategies. SIMTECH has developed customized Process Component Models to compose the ALGAESOL Model Library and simulate fuel conversion pathways. Additional simulations are underway to determine current generation in the photoanode, with parameters calibrated to match experimental data.

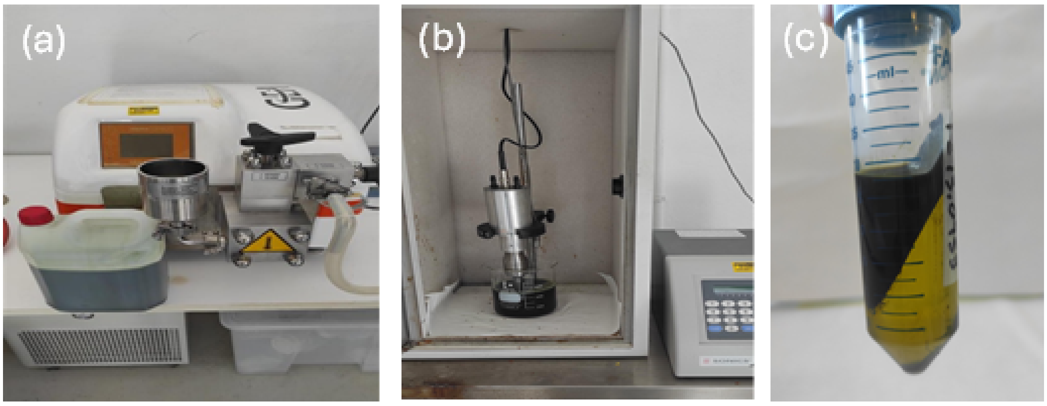

Figure 4. Lipid extraction using High-Pressure Homogenization (HPH, a) and Ultrasound-Assisted Extraction (UAE, b). Two-phase algal lipid extract (c).

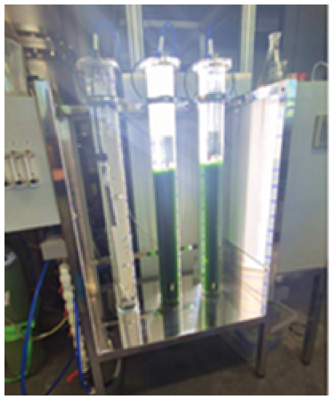

Figure 5. Microalgae cultivation unit at UdG lab

With 18 months completed and 18 months to go, the ALGAESOL consortium is making significant progress toward establishing BES as a viable and sustainable technology for SAF and shipping fuel production.

About ALGAESOL "Sustainable aviation and shipping fuels from microalgae and direct solar BES technologies":

ALGAESOL consortium consist of 6 European partners including research organisation, universities, and private companies: NORCE Norwegian Research Centre AS, LEITAT -Acondicionamiento Tarrasense Associacion, UdG -Universitat de Girona, DTI - Danish Technological Institute, SIMTECH GMBH, SOCAR Petroleum SA and AMIRES SRO.

The project started on May 1st, 2024, and will run for 36 months under NORCE's coordination.

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