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CRONUS

CAPTURE AND REUSE OF BIOGENIC GASES FOR NEGATIVE-EMISSION – SUSTAINABLE BIOFUELS

The overall ambition of the CRONUS project is to significantly advance the current state of the art in the area of biofuels production and the utilisation of biogenic effluent gases. CRONUS will introduce effective technologies with high- potential innovations (techno-economic feasible solutions), thus accelerating the green transition and associated transformation of our economy, industry and society with a view to achieving climate neutrality in Europe by 2050. CRONUS aims to accelerate on the path to sustainable bioenergy and play an important and constructive role in achieving the United Nations Sustainable Development Goals, by incorporating in the biofuels production lines Carbon Capture, Utilisation and Storage (CCUS) techniques. CUS can stand as a solution to meet the 2021 Glasgow agreement on climate change's aim of less than 1,5°C and contribute to the phase-out of fossil fuels and the decarbonisation of the EU economy in accordance to European Green Deal goals.

TECHNICAL PROGRESS

Progress of FP1

Integrated System

Location:
Lavrion Technological & Cultural Park

Lead Partner: NTUA

AIM:
Capture and utilise carbon dioxide produced from a biofuels biorefinery that include biomass combustion, ethanolic fermentation and anaerobic digestion via autotrophic algae growth

Following several months of continuous operation, the FP1 pilot system at NTUA's Lavrion Technological and Cultural Park (LCTP) has demonstrated stable and reliable performance. The integrated configuration, combining the CO_2 scrubbing unit with the algal cultivation ponds, has operated smoothly under real and varying conditions, enabling the capture and utilization of biogenic CO_2 streams originating from the biorefinery processes. Throughout this operational period, the system has successfully achieved key quantitative targets, including the production of microalgal biomass under varying carbon and nutrient sources, and the effective valorization of digestate streams. These results further confirm the robustness of the process integration approach implemented within the CRONUS project.

The encouraging operational performance has been reflected in consistent algal growth and sustained biomass productivity across the cultivation ponds. Regular monitoring and analytical measurements indicate that the system is effectively coupling CO_2 capture with biological conversion into valuable biomass, while simultaneously contributing to the circular utilization of process streams such as digestate. The data collected during this period provide important insights into the system's efficiency and operational stability, supporting ongoing optimization efforts. These achievements represent a significant step toward demonstrating the feasibility of integrating carbon capture, nutrient recovery, and microalgal biomass production within a low-carbon biorefinery framework.

PLACE	PARTNERS	BIOGENIC GAS	BIOGENIC GAS CAPACITY
Athens, Greece	**ALGEN**	**CO_2**	**2000 L/Day**
RESPONSIBLE	PRODUCTION LINE	END-PRODUCT	TECHNOLOGIES
NTUA	**Ethanol Fermentation, Biodiesel Production, Anaerobic Digestion**	**Bioethanol, Biodiesel, Biomass**	**Enzymatic Capture Of CO_2, Autotropic Algae Cultivation**

Progress of FP2

Location:
ELGO-DIMITRA's
Thermi-Thessaloniki campus

Lead Partner: ELGO

ELGO - DIMITRA
HELLENIC AGRICULTURAL ORGANIZATION - DIMITRA

AIM:
Utilize CO2 from biogas and hydrogen generated through water electrolysis for the production of biomethane as the final product.

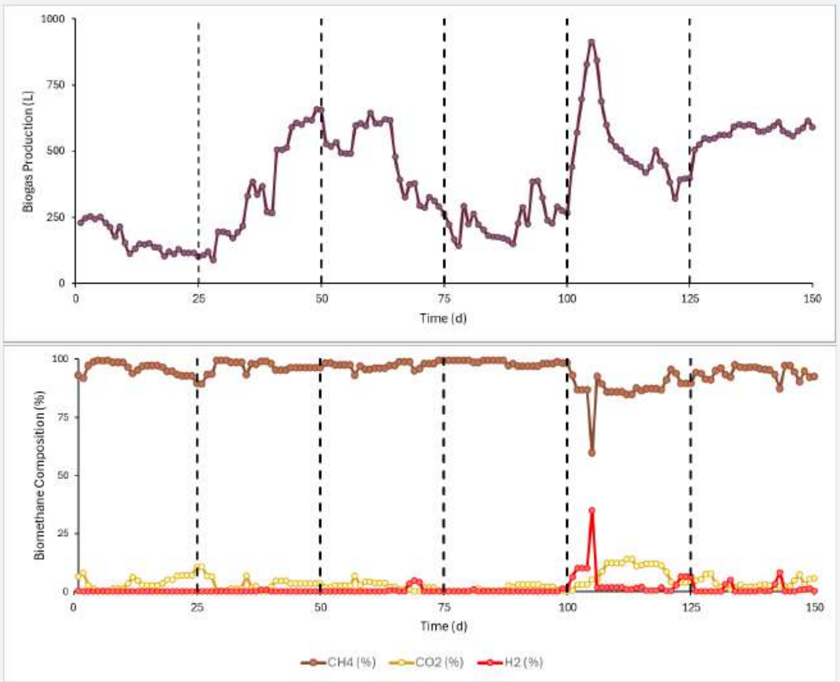
A central objective of the current research phase was to evaluate the FP2 under conditions representative of real industrial biogas operations. This experimental design was intended to replicate the dynamic conditions of real-world biogas production, where substrate availability shifts with seasonal cycles and processing schedules. The anaerobic digester was fed with a mixture of three substrates drawn from two broad waste categories: livestock waste (cattle manure) and agro-industrial by-products (olive mill wastewater and sweet brine from a pepper processing facility). These substrates were selected because they reflect the heterogeneous feedstock composition typically encountered in agricultural biogas plants, where input materials vary considerably in organic load, pH, and nutrient content. This experimental design was intended to replicate the dynamic, variable conditions of real-world biogas production, where substrate availability shifts with seasonal cycles and processing schedules.

The biogas produced by the anaerobic digester was continuously fed into the biomethanation reactor, where an automated monitoring system measured the incoming biogas flow and regulated the hydrogen (H2) supply accordingly. Under stable operating conditions, the biomethanation unit performed reliably, consistently producing biomethane with a methane (CH4) content exceeding 95% in the output gas.This high-purity output confirms the effectiveness of the biological upgrading process under realistic operational conditions. The only notable exception occurred during periods when the biogas reactor produced unexpectedly high gas volumes that exceeded the biomethanation unit's processing capacity. Under these transient overloading conditions, unconsumed H2 accumulated within the system, triggering a shift toward homoacetogenesis, which is a competing biological pathway in which homoacetogenic bacteria utilise H_2 to produce acetic acid rather than methane.

PLACE **Thessaloniki, Greece**	PARTNERS **DTU, UNIPD**	BIOGENIC GAS **CO_2**	BIOGENIC GAS CAPACITY **330 L/Day**
RESPONSIBLE **ELGO**	PRODUCTION LINE **Anaerobic Digestion**	END-PRODUCT **Biomethane**	TECHNOLOGIES **Biological CO_2 Hydrogenation**

The presence of acetic acid in the reactor during these episodes confirmed this metabolic shift, underscoring the sensitivity of TBR performance to fluctuations in upstream biogas supply. Notably, once biogas production returned to normal levels, the system recovered quickly and efficiently, restoring high-purity biomethane output without any lasting impact on process performance. This resilience underscores both the sensitivity of TBR performance to fluctuations in upstream biogas supply and the robustness of the microbial community to self-correct under more stable conditions.

The system operated continuously for 150 days across six successive experimental phases, and despite the challenges encountered, it demonstrated a strong capacity for recovery following periods of process disturbance. These findings confirm that biological biogas upgrading can perform reliably under variable, industrially relevant conditions, provided that H2 supply and upstream biogas production remain within stable operating ranges. This has important implications for the design and operation of integrated biogas upgrading systems, particularly in the context of Power-to-Gas applications, where consistent biomethane quality and process stability are essential requirements.



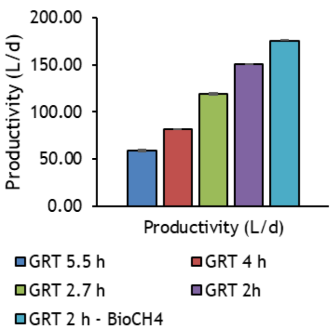
Progress of FP3

Location:
Copenhagen, Denmark

Lead Partner: BTPRO

AIM:
Generate additional value by improving the waste conversion efficiency and biogas production of conventional biogas plants through the syngas biomethanation process contemplated

Following the installation of Functional Prototype 3 in September 2025, BTPRO and DTU have optimized the performance of a syngas biomethanation unit designed to upgrade syngas and pyrolysis gas into biomethane. Functional Prototype 3 features a 100 L trickle bed reactor, which is a type of packed-bed reactor filled with high-surface area packing material that supports growth of methanogenic biofilms while maximizing the transfer of gaseous syngas molecules into the liquid phase. The unit is located at DTU Chemical Engineering in Kongens Lyngby, Denmark.



The primary objective of FP3 is to demonstrate a scalable and efficient technology for upgrading syngas or pyrolysis gas into biomethane.

The unit has been in operation since September 2025. Since then, key aspects of the performance of the syngas biomethanation process have been evaluated and optimized.
The optimization of the gas residence time resulted in stable biomethane production at a minimum gas residence time of 2 h, which translates into a production capacity of 176 LCH_4/d with a CH_4 content of 92% in the gaseous output. Investigating the potential for intermittent operation of the unit also demonstrated that the performance of the process is sustained after variable shutdown periods, ranging from 3 weeks to repeated 12 h shutdown intervals. Neither the productivity nor the biomethane quality in the gaseous output were compromised under the entire shutdown period range evaluated.

The next experimental campaign will focus on evaluating process instabilities derived from high tar loading into the reactor, with the aim of defining the minimum gaseous feedstock quality requirements for the syngas biomethanation process. This will contribute to determining the technical feasibility of coupling syngas biomethanation with gasification or pyrolysis processes.

PLACE
Copenhagen, Denmark

RESPONSIBLE
DTU

PARTNERS
BTPRO, CIRAD

PRODUCTION LINE
Pyrolysis

BIOGENIC GAS
CO_2, CO, H_2

END-PRODUCT
Biomethane

BIOGENIC GAS CAPACITY
300 L/Day

TECHNOLOGIES
Syngas Biomethanation

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Progress of FP4

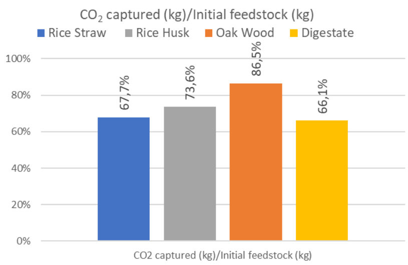
Location:
Energy Platform of Cirad, Montpellier – France

Lead Partner: CIRAD

cirad

Aim:
to convert biomass, agroresidues and digestates into (i) biochar (solid carbon product) for agronomic and carbon sink applications, and (ii) gaseous co-products for energy applications

CO₂ Capture Performance

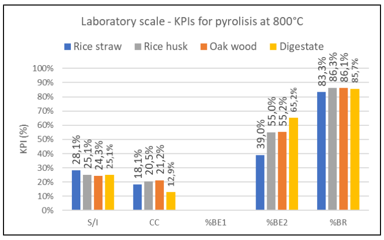


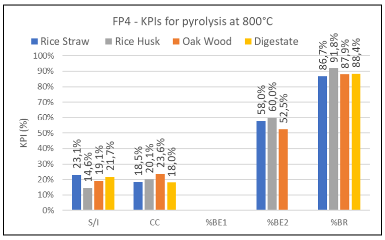
The biochar production process demonstrated significant carbon sequestration potential across all feedstocks evaluated. CO_2 capture ranged from approximately 66% to 86% of the initial feedstock mass, highlighting the effectiveness of pyrolysis as a carbon removal pathway. Among the feedstocks tested, oak wood achieved the highest CO_2 capture rate (85.8%), followed by rice husk (73.6%) and rice straw (67.1%), while digestate captured 66.1% of the initial carbon input.

Laboratory-Scale KPI Results (Pyrolysis at 800°C)

At laboratory scale, pyrolysis at 800°C delivered favorable environmental performance indicators.

The process achieved net carbon removal efficiencies ranging from approximately 66% to 86%, depending on the feedstock. Sustainability metrics showed relatively low impacts, with Specific Impact (SI) values between 24% and 30% and Carbon Cost (CC) values between 20% and 25%. In parallel, the process generated substantial climate benefits, with Net Environmental Benefits (NEB2) ranging from 39% to 69% and Net Benefit Ratios (NBR) reaching 88–90% across all feedstocks. Oak wood consistently exhibited the strongest overall performance, driven by its higher carbon capture potential and favorable benefit metrics.





KPIs – Comparison of Laboratory Scale and FP4

The FP4 assessment showed trends similar to those observed at laboratory scale, confirming the robustness of the pyrolysis process. While SI and CC values were generally lower in the FP4 case (13–20%), indicating reduced environmental burdens, NEB2 values ranged from 52% to 58% and NBR values remained high at approximately 88–91%. These results suggest that scaling the process maintains strong carbon removal performance while further improving overall sustainability outcomes.
Across both scenarios, the consistently high NBR values demonstrate the strong environmental and carbon management benefits of converting biomass residues into biochar through high-temperature pyrolysis.

PLACE	PARTNERS	BIOGENIC GAS	BIOGENIC GAS CAPACITY
Montpelier, France	**–**	**CO, H_2, CH_4,CnH_m**	**600 L/Day**
RESPONSIBLE	PRODUCTION LINE	END-PRODUCT	TECHNOLOGIES
CIRAD	**Pyrolysis**	**Biochar**	**Biogenic Carbon Storage Through Biochar Production**

Progress of FP5

Location:
Cartif, Technology Park, Boecillo, Valladolid, Spain

Lead Partner: CARTIF

Aim:
Design, construction and installation: An existing AD pilot plant will be retrofitted in terms of coupling a tailor-made MEC system in one of the digesters

The CRONUS project continues to advance the development and operation of Functional Prototype 5 (FP5), which integrates anaerobic digestion (AD) with a microbial electrolysis cell (MEC) to enhance biomethane production and improve carbon utilisation efficiency. The system is based on an **in-situ AD-MEC configuration**, allowing direct interaction between electroactive microorganisms and hydrogenotrophic methanogens, thereby facilitating the conversion of CO_2 into methane.

The pilot plant is currently operating under controlled conditions, with a hydraulic retention time of approximately 30 days and stable operation periods ranging between 60 and 90 days. Continuous monitoring and optimisation of operational parameters are being carried out to ensure stable performance and maximise methane production.

Initial and recent experimental results demonstrate **significant improvements compared to conventional anaerobic digestion systems**. Biogas production has shown substantial increases, with improvements of up to +233% under optimised conditions. In parallel, methane content has increased to approximately 63 ± 3%, compared to 49 ± 6% in standard AD processes. Furthermore, the AD-MEC system exhibits reduced start-up times and enhanced process stability.

Additional experiments under varying influent conditions, including higher organic and nitrogen loads, confirm the robustness and flexibility of the system, achieving higher production rates compared to standalone AD operation.

The system is continuously monitored through gas chromatography to analyse biogas composition, while operational conditions are adjusted to maximise methane yield and evaluate the overall energy balance of the process.

Future work will focus on long-term operation, further optimisation of system performance, evaluation of CO_2 conversion efficiency, and the execution of additional experimental campaigns. These activities aim to validate FP5 as a scalable and efficient solution for in-situ biomethanation within circular biofuel systems.

PLACE **Boecillo, Spain**	PARTNERS **–**	BIOGENIC GAS **CO_2**	BIOGENIC GAS CAPACITY **500 L/Day**
RESPONSIBLE **CARTIF**	PRODUCTION LINE **Anaerobic Digestion**	END-PRODUCT **Biomethane**	TECHNOLOGIES **In-Situ Biomethanation Using MEC**

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PROJECT EVENTS

MARKETING & EXPLOITATION ACTIVITITES

CRONUS at the BIO360 Europe 2026

SEMIDE took part in the recent BIO360 Europe 2026 (February 4–5), to present the CRONUS project and its pioneering advancements in carbon capture and utilisation (CCU) and biotransition.
This leading bioenergy and carbon management event attracted more than 5 500 participants from 45 countries and features over 400 exhibiting organisations with more than 200 prominent speakers. As part of the event, CRONUS and SEMIDE hosted a dedicated exhibition stand, providing an opportunity to present the project's five innovative functional prototypes and engage directly with researchers, industry representatives, investors and policymakers interested in carbon capture and utilisation solutions.

In addition, Dr. Najla Kamergi (SEMIDE) presented during the session of "Biogenic CO_2: Flue gas Capture to Industrial Valorisation" the latest work completed on CRONUS. The presentation focused on how CRONUS is developing a portfolio of five functional prototypes that are designed to capture CO_2 across the biofuels value chain. These innovative solutions demonstrate strong market potential with preliminary assessments of their techno-economic performance.

CRONUS at the 8th International Exhibition VERDE.TEC 2026

CRONUS was presented at UEST NTUA booth at the 8th International Exhibition VERDE.TEC 2026, the top meeting in Greece for Environment, Circular Economy, and Smart Cities which took place during February 27–28 and March 1, 2026 at the Mediterranean Exhibition Center (MEC) in Paiania, showcasing the present and future of Environmental Technologies in our country.

CRONUS at HELEXPO's Forward Green Expo 2026

NTUA & NEVIS participated in HELEXPO's Forward Green Expo 2026, a leading event for green transition and innovation. Project partners had the opportunity to engage with professionals in the fields of circular economy and smart, sustainable energy, through great discussions in a busy booth!

CRONUS collaborating with the EU Horizon Results Booster programme

In parallel, the CRONUS consortium has been advancing its exploitation strategy through the **Horizon Results Booster programme**, an initiative of the European Commission designed to support EU funded projects in preparing their results for market uptake. Through a series of structured workshops with project partners, the Booster process helped consolidate the positioning of three priority Key Exploitable Results, namely FP1, FP2 and FP5 of CRONUS.

The service aims at clarifying their potential pathways toward deployment and implementation at real-scale bioenergy plants.
The discussions focused on identifying relevant **market segments and early adopters**, defining appropriate exploitation routes such as **licensing, service-based models**, and assigning clear roles among partners for post project activities. Particular attention was also given to assessing key risks related to technical scale up, regulatory constraints and market adoption, ensuring **that mitigation measures can be integrated** into the exploitation roadmaps. Overall, this exploitation capacity-building support strengthens the strategic foundations needed to move the CRONUS technologies from pilot validation toward future industrial implementation and long-term impact.

FORTHCOMING EVENTS

3rd Annual Project Meeting

3 rd Annual Project Meeting scheduled to be held in Copenhagen, Denmark at DTU premises in May, 2026 along with a Joint Event with project FENIX.

CRONUS Final Meeting in Kos

Final Conference scheduled to take place within the 13th International Conference on Solid Waste Management, at Kos Island
https://kos2026.uest.gr/

PUBLICATIONS

New peer-reviewed research published!

Algen and NTUA researchers, partners in the Horizon Europe project Cronus, have published their work on utilisation of carbonic anhydrase enzyme. The enzyme, isolated from algae themselves, promoted algal growth in the cultures that were fed with anaerobic digestate from organic waste processing.

Based on the presented results, CRONUS functional prototype, developed by the partners, and demonstrated in Lavrion, Greece, will be able to capture more biogenic CO2 from the waste-processing systems.

Read the full paper at:
https://lnkd.in/dRyahNVq

Funded by the European Union

Project: 101084405 - CRONUS - HORIZON -CL5-2021-D3-03

Research on Sustainability Transitions

The overall approach is built on insights from research on 'sustainability transitions' that analyses innovation within socio-technical systems.

13 partners from 8 countries

The project will be delivered by 13 participant organisations representing 8 European countries

5 Functional Prototypes

Functional prototypes developed from optimised lab-scale technological processes will be designed, constructed and tested

Call: Sustainable, secure and competitive energy supply (HORIZON-CL5-2021-D3-03)
Project number: 101084405
Duration: 45 months

Starting date: 01/12/2022
End date: 31/08/2026
Budget (EU contribution): 4,390,894.50 €

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Coordinating Beneficiary

Associated Beneficiaries

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