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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

Lead Partner:



CRONUS Functional Prototype 1 successfully demonstrated the integration of carbon capture, algae cultivation, and bioenergy production within an existing waste biorefinery at the NTUA pilot facilities in Lavrion, Greece. The prototype captured biogenic CO₂ emitted from biomass combustion, ethanol fermentation, and anaerobic digestion and converted it into valuable algal biomass through outdoor cultivation in four raceway ponds. The harvested algae were subsequently valorised through anaerobic co-digestion with food waste stillage, creating a closed carbon cycle that increased renewable energy production without generating additional waste. This integrated approach demonstrates how existing biorefineries can be upgraded with carbon capture and utilisation technologies while improving overall resource efficiency.

During the demonstration campaign, more than 85% of the incoming CO₂ was successfully captured using an innovative scrubbing system based on potassium carbonate, digestate, and hybrid absorbent solutions. The hybrid absorbent achieved the highest carbon capture efficiency while producing a nutrient-rich stream suitable for direct algae cultivation, eliminating the need for additional processing. The algae cultivation system remained stable throughout the six-month outdoor operation despite seasonal weather variations, demonstrating that captured inorganic carbon remained bioavailable and was efficiently converted into biomass through photosynthesis. The highest biomass productivity, reaching

Aim:

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

Location:

Lavrion Technological & Cultural Park

approximately 7.2 g dry biomass m⁻² day⁻¹, was achieved using the hybrid CO₂-loaded absorbent, confirming the successful integration of carbon capture with biological utilisation.

Laboratory optimisation performed earlier in the project identified anaerobic digestion of fresh algal biomass as the most efficient valorisation route within the existing biorefinery, avoiding the need for energy-intensive harvesting and drying operations. This strategy was successfully demonstrated during FP1 operation, where the harvested algae were used as a co-substrate in the anaerobic digestion process. The addition of algae increased biogas production while maintaining stable digester performance, demonstrating an effective pathway for recovering the captured carbon as renewable energy. At the same time, the existing biorefinery continued producing bioethanol, bio-oil, and biogas from organic waste streams, illustrating how CO₂ capture can be integrated into existing waste-to-biofuel facilities without disrupting their primary production processes.

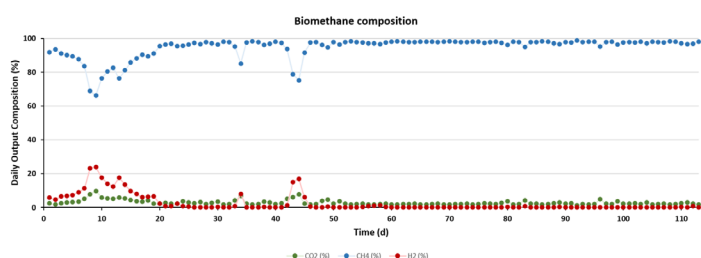
The integrated system delivered significant environmental benefits. It was demonstrated that the combination of CO₂ capture, algae cultivation, and anaerobic co-digestion represents a technically feasible and scalable solution for transforming conventional waste biorefineries into circular carbon utilisation systems that simultaneously produce renewable fuels, recover nutrients, and reduce greenhouse gas emissions.

Progress of FP2

Lead Partner:



Having already demonstrated reliable performance under variable, industrially representative feedstock conditions, FP2 entered a new operational phase in which the biomethanation reactor was operated at a fixed Gas Retention Time (GRT) of 1 hour. During this phase, the biogas reactor was fed exclusively with cattle manure, ensuring a stable and predictable biogas profile. However, the biogas generated by the digester alone was insufficient to achieve the targeted GRT. Therefore, an external CO₂ supply was introduced into the system to supplement the gas stream and maintain the total gas flow required for reactor operation.



Overall, ELGO-DIMITRA successfully designed, built and operated a fully integrated system that couples anaerobic digestion, biological biogas upgrading and water electrolysis. Throughout the project, the system captured and converted more than 61m³ of biogenic gas into high-purity biomethane. Across the entire experimental period, covering both variable and fixed gas flow conditions, the trickle-bed reactor (TBR)-based biomethanation process consistently

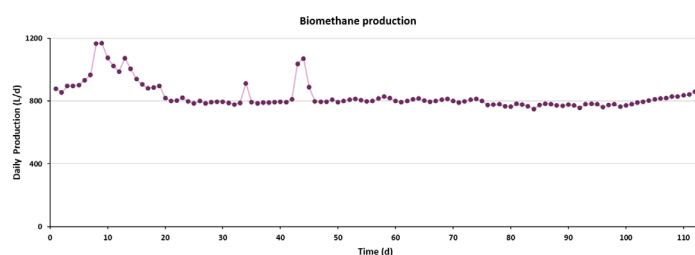
Aim:

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

Location:

ELGO-DIMITRA's Thessaloniki campus

Following a short adaptation period at the beginning of this phase, the methane content of the upgraded gas stabilized above 95%. In fact, from approximately the midpoint of the operational period onwards, the system achieved a mean methane content of 97.5% and a highly stable biomethane output of 770–805 L/d. Two brief performance declines, both linked to temporary equipment malfunctions rather than biological limitations, were followed by rapid recovery, confirming the resilience of the microbial community established within the reactor.



achieved methane purities exceeding 95% while exhibiting a strong ability to recover rapidly from operational disturbances without long-term effects on performance. These findings confirm the robustness, operational stability and scalability of biological biogas upgrading as a promising Power-to-Gas pathway, providing a strong technical basis for its further development and future exploitation of the technology beyond the lifetime of the project.

Progress of FP3

Lead Partner:



Functional Prototype 3 features a 100 L trickle bed reactor designed to deliver high rate biomethane production from pyrolysis gas. The reactor is filled with high surface area packing material to support growth of methanogenic biofilms. The unit is located at DTU Chemical Engineering in Kongens Lyngby, Denmark.

One year after the installation of Functional Prototype 3 in September 2025, BTPRO and DTU have just completed the optimization of the performance of bioreactor in terms of gas loading rate, reaching a minimum gas residence time (GRT) of 1 h and a maximum productivity of biomethane of 320 L/d. Following the optimization of the GRT, the last experimental campaign focused 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.

The results obtained so far show that FP3 can operate under low concentrations of pyrolysis-derived tars, corresponding to 250 mg/L of total tar, with no signs of process disturbance. However, increasing the total concentration of tars to 2.5 g/L led to immediate process failure. A preliminary analysis of the results suggests that the process failure derives from a combination of pH inhibition driven by the tar addition, and the high toxicity of certain tar compounds. A more

Aim:

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

Location:

Copenhagen, Denmark

formal analysis of the results will provide deeper insights into the inhibition mechanisms driving the process failure and will suggest optimal process configurations to couple biomass pyrolysis and syngas biomethanation processes efficiently.



Figure 1. Picture of Functional Prototype 3

Progress of FP4

Lead Partner:



Consistent pilot-scale pyrolysis and promising agronomic results

FP4 was operated according to the defined optimisation strategy, with work focusing on process performance, product quality and agronomic value. Four feedstocks were investigated: rice straw, rice husks, oak wood and digestate.

Uniform heating at pilot scale Biomass was loaded into four baskets stacked inside the reactor. Biochar yields were nearly identical across all four baskets, with standard deviations below 1.5%. This shows that the electric heating system kept the temperature uniform throughout the reactor, which is often hard to achieve at pilot scale. The yields also matched those from the WP4 laboratory experiments. This confirms that the feedstocks behave consistently when scaled up by two orders of magnitude and validates the reactor's thermal design.

Reproducible, high-quality biochar

Repeated runs at 800 °C gave stable average yields:

- Rice straw: 29.2%
- Rice husks: 35.2%
- Oak wood: 24.5%
- Digestate: 33.6%

The variability was within the range accepted for certified biochar production. Oak wood biochar had the highest carbon content (94.3%) and the lowest ash content (2.4%). All biochars had H/C ratios of 0.14–0.15, well below the 0.4 threshold, which indicates strong carbon sequestration potential.

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

Location:

Energy Platform of Cirad – Montpellier – France

Valuable gas and bio-oil streams



Gas: The pyrolysis gas contained 23–38% H₂, 22–30% CO, 25–32% CO₂ and 11–14% CH₄. Digestate gave the most hydrogen-rich gas (38.4% H₂), a promising result for biological methanation in FP3.



Bio-oils: GC-MS analysis of 84 compounds showed that oak wood bio-oils had the highest concentration of organic compounds. Digestate bio-oils had the lowest organic content but the highest PAH levels. These results will guide fuel applications and the gas cleaning needed before any coupling with biological processes.

Greenhouse trials: matching biochar to soil.

Trials at CIRAD in Montpellier tested rice husk and oak wood biochars on sorghum. Two soils were used, one acidic and one alkaline, at application rates of 0–10 t/ha. The effects depended on biochar type, application rate and soil pH, rather than following a simple dose-response pattern:

- Rice husk biochar increased plant biomass in both soils at 5 t/ha. In the alkaline soil, it raised seed yield from 15.3 to 19.4 g/plant at 10 t/ha.
- Oak wood biochar increased seed yield in the acidic soil, from 13.9 to 15.9 g/plant.

The key message is that biochar delivers agronomic benefits when it is tailored to local soil conditions.

Progress of FP5

Lead Partner:



Over the course of CRONUS, FP5 has progressed from an integration concept to an operating TRL5 pilot at CARTIF in Boecillo, Valladolid. The prototype couples anaerobic digestion (AD) with a microbial electrolysis cell (MEC), enabling electroactive microorganisms and hydrogenotrophic methanogens to convert residual biogenic CO₂ into additional methane in situ.

FP5 at the finish line

FP5 retrofits one digester of an existing two-phase anaerobic-digestion pilot plant with a tailor-made MEC. The in-situ configuration is designed to intensify biomethane production, improve carbon utilisation and stabilise the biological process while preserving the host plant's core infrastructure.

LATEST OPERATING SNAPSHOT

- Up to +233% biogas production under optimised conditions
- Methane content around $63 \pm 3\%$, compared with $49 \pm 6\%$ for standard AD
- Shorter start-up and stronger stability across varying organic and nitrogen loads

Aim:

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

Location:

Cartif, Technology Park, Boecillo, Valladolid, Spain

The final campaigns demonstrated:



Stable operation under controlled conditions, with a hydraulic retention time of approximately 30 days and operating periods of 60–90 days.



Robust performance under changes in influent composition, including higher organic and nitrogen loads.



Continuous gas-chromatography monitoring to track biogas composition and support optimisation of methane yield and energy balance.



A practical pathway for in-situ biomethanation that can be added to existing AD assets rather than requiring a complete plant redesign.

The FP5 business model

The business-model discussion reframed residual CO₂ as recoverable value. Many AD plants already possess the digestion infrastructure and a steady supply of organic feedstock, yet a substantial fraction of the carbon in raw biogas remains as CO₂. FP5's proposition is to capture more value from those installed assets through a modular MEC retrofit.

Building block	FP5 proposition	Value created
Customer	AD and wastewater-treatment operators; agro-industries and cooperatives; renewable-gas developers; public authorities	Higher output from existing assets and a route to local renewable-gas production
Offer	Modular MEC retrofit, supported by equipment sales, licensing and a service contract	Minimal integration work compared with a new plant; adaptable deployment pathway
Revenue	Additional biomethane, Guarantees of Origin and carbon value; possible digestate valorisation	More revenue per unit of feedstock and diversified income streams
Cost base	MEC equipment dominates CAPEX; electricity dominates OPEX; low maintenance and no catalysts or chemical inputs	Clear optimisation priorities for engineering and commercial scale-up
Go-to-market	Demonstration at the FP5 pilot, joint feasibility assessment and partnerships with AD suppliers and regional cooperatives	Evidence-led adoption, de-risking and replication through trusted intermediaries

Indicative pilot-scale economics

The CoP presentation used the following estimates to structure discussion: CAPEX of €26,355; OPEX of €8,401 per year; and potential annual income above €2,946 at pilot scale from biomethane, digestate valorisation and Guarantees of Origin. It also explored how public co-financing could reduce the operator's initial net investment.

These are indicative pilot-scale assumptions, not a final investment case. Commercial bankability will depend on plant scale, electricity price, methane yield, integration requirements, certification rules, gas-market conditions and the availability of support schemes

From demonstration to deployment

The final Community of Practice translated FP5's results into a practical route forward. The immediate task is to move from a successful pilot to site-specific evidence and partnerships that can support replication.

Benefits extend across the value chain: more productive AD assets, new options for organic-

residue valorisation, traceable renewable gas, and opportunities for local decarbonisation and employment—provided that planning and participation are credible.

A concluding perspective

FP5 closes the CRONUS newsletter series with a shift from technical proof to deployment. The prototype showed that biological CO₂ conversion can intensify methane production and use carbon already circulating through an AD plant; the Community of Practice tested what is needed to turn that result into a credible offer.

The next priorities are longer and larger-scale validation, lower electricity use, site-specific economics, robust certification, responsible digestate and logistics management, and early, transparent community involvement.

FP5's lasting contribution is both technological and commercial: a pathway to make anaerobic digestion more productive, circular and ready for the next stage of biomethane deployment.

Stakeholders' engagement & involvement

To facilitate stakeholder engagement and foster collaboration, Communities of Practice (CoPs) have been formed around each Functional Prototype (FP). These CoP meetings serve as platforms to bring together various stakeholders to discuss challenges, opportunities, and technological advancements in

the CRONUS project. Below is an overview of the CoP meetings organized for FP1 to FP5, including their objectives, processes, and outputs.

The third round of CoP meetings have taken place between May and June 2026.

3rd CoP Meeting for FP1

Date:

12 June 2026

Type:

In-person

Lead:

Dimitris Malamis (NTUA)

Location:

Lavrion Technological and Cultural Park, Greece

Objective

The meeting aimed to present the final outcomes of Functional Prototype 1 (FP1), showcasing its technical performance, techno-economic feasibility, social impact assessment, and business exploitation strategy. It also sought to engage stakeholders in discussing the opportunities and challenges associated with the large-scale deployment of biogenic CO₂ valorisation technologies and to strengthen collaboration between academia, industry, and public stakeholders.

Process

The meeting included presentations on the CRONUS project, the technical performance of FP1, its techno-economic and social assessments, and the business plan for future exploitation. An interactive discussion followed on technological maturity, economic viability, regulatory aspects, and large-scale implementation, concluding with a guided tour of the FP1 pilot facilities at NTUA's Lavrion site.

Outputs

The meeting successfully disseminated the final technical, socio-economic, and business results of Functional Prototype 1 (FP1) to a diverse group of stakeholders, increasing awareness of the CRONUS technology and its potential for industrial deployment. Participants gained a comprehensive understanding of the integrated CO₂ capture, microalgae cultivation, and anaerobic digestion system through both the technical presentations and the guided visit to the pilot installation.

The interactive discussion enabled stakeholders to exchange views on the technological readiness, economic feasibility, regulatory framework, and future market opportunities for biogenic CO₂ valorisation technologies. The feedback collected during the meeting confirmed a strong interest in the proposed solution, identified key considerations for its large-scale implementation, and provided valuable recommendations for future exploitation, replication, and stakeholder engagement activities.

The evaluation questionnaire further demonstrated a high level of participant satisfaction regarding the organisation of the event, the quality of the presentations, and the relevance of the topics discussed. Overall, the meeting strengthened collaboration between academia, industry, and public stakeholders while reinforcing the exploitation strategy and supporting the future uptake of the CRONUS technology.

3rd CoP Meeting for FP2

Date:

26th May 2026

Type:

In-person & Online

Lead:

Dr Panagiotis Kougias, Maria Gaspari (ELGO-DIMITRA)

Objective

The third and final CoP meeting was designed to present the final outcomes of FP2 to the community built over the past three years. Beyond reporting on progress, this closing meeting offered an opportunity to reflect collectively on what had been learned, to discuss the challenges that had emerged along the way, and to explore together the next steps for technology.

Process

The meeting started with the presentation of the technical results of FP2. The system's architecture and operating data were presented. The successful demonstration of the pilot were highlighted, since the system achieved methane purities exceeding 95% for most of the trial period. The overall conclusion was that the FP2 system had demonstrated stable, high-purity biomethane production under realistic and variable feeding conditions at TRL5, supporting its readiness for further demonstration.

It followed the presentations of the techno-economic, environmental and social assessments, and the business case for its commercial exploitation, with live audience polling used at several points to capture stakeholder views directly.

From the assessments presented, the biomethane selling price was identified as the most influential parameter affecting the economic performance of the system. Overall, the findings suggested that the technology has a strong economic foundation for large-scale deployment, provided

that the biomethane selling price is secured through a long-term agreement.

The life cycle assessment approach demonstrated that the system delivers an overall net environmental benefit. Although energy demand was identified as the primary contributor to environmental impacts, these were more than offset by the avoided emissions associated with biomethane production.

The social impact assessment showed that the most significant hotspots were associated with labor-related issues and grievance mechanisms while also highlighting positive findings in terms of local employment, economic benefits and consumers' perceptions of biomethane. Also, it was noted that the perceived gap between technology's environmental benefits and their fair distribution to host communities was the central social challenge to address going forward.

From the market analysis, the biogenic CO₂ currently vented from Greek biogas and biorefinery installations is an increasingly costly missed opportunity under rising carbon pricing. The structural barriers to market uptake alongside the opportunities for commercialization were outlined, highlighting the large number of potential retrofit sites across Greece and the considerable market potential for the technology.

Outputs

The third and final Community of Practice meeting successfully fulfilled its objectives, bringing together participants to exchange knowledge and discuss the final results and future exploitation potential of FP2. The presentations of techno-economic, environmental and social evaluations, together with live interactive polling and open discussion, created a productive environment for knowledge exchange and stakeholder engagement. Furthermore, the live polls allowed the project team to capture participants' views in real time and on specific, targeted questions. Overall, the meeting reinforced the value of the Community of Practice as a space for dialogue and the feedback gathered will support the project's exploitation and dissemination efforts.

3rd CoP Meeting for FP3

Date:

26th May 2026

Type:

online

Lead:

DTU

Objective

The third and final CoP meeting was designed to present the final outcomes of FP3, as well as the results of the technoeconomic, environmental and social assessments, and the market analysis.

Process

The meeting started with the presentation of the latest research outcomes in syngas biomethanation and the pilot scale experimental results. It followed the technoeconomic, environmental and social assessments, and the market analysis.

Outputs

The main ideas and reflections that emerged from the discussion are the following:



The importance of the complexity of microbial culture. This calls to focus on the community rather than on specific microbes and the practical implications of it (e.g., nutrients requirements, production of synthetic consortia)



Development of a start-up protocol after shut-down periods (including information about H2 injection, start-up time, temperature) and for intermittent operation (online monitoring output gas) to work with green H2



Good environmental performance compared to natural gas. The transport of feedstock is one of the major contributors to negative environmental impacts.



H2 production is one of the main factors affecting economic performance.

3rd CoP Meeting for FP4

Date:

8th July 2026

Type:

online

Lead:

CIRAD

Objective

The third and final CoP meeting was designed to present the final outcomes of FP4, as well as the results of the technoeconomic, environmental and social assessments, and the market analysis.

Process

The meeting started with the presentation of the latest results of FP4's pilot. It followed the technoeconomic, environmental and social assessments, and the market analysis.

Outputs

After the presentation of the results of the project, the participants discussed about the potential uses of biochar. As biochar from wood or crop residues does not present much barriers, the discussion focused on the potential uses of biochar from digestate or sewage sludge. As this type of biochar may contain some pollutants from the feedstock (e.g., antibiotics, heavy metals), people proposed to use it as construction material, which would also serve as carbon storage mechanism.

3rd CoP Meeting for FP5

Date:

29th April 2026

Type:

In-person, in Boecillo

Lead:

CARTIF-UAB

Objective

The meeting was aimed at presenting the last advances of FP5, the results of the full-scale implementation study and the market analysis, as well as to visit the installations of the FP5 pilot.

Process

The meeting started with the presentation of the Centr@Tec program, which is aimed at promoting business R+D+I in Castile and Leon. It followed the presentation of the last advances of the FP5's pilot, the results of the full-scale implementation study and the business model

for FP5. Participants were split in groups to discuss and reflect about the prospects of biomethane development in Castile and Leon.

Outputs

Participants examined the latest prototype progress alongside the wider conditions for biomethane deployment in Castilla y León and Europe.

The final discussion moved beyond the question of whether AD-MEC can work and focused on the conditions under which it can create lasting value: modular integration, reliable operation, bankable economics, credible certification and strong territorial acceptance.

The session connected the technology with real implementation constraints: feedstock availability and transport distances; digestate handling and nutrient demand; greenhouse-gas performance, including supply-chain leakage; regional planning rules; and the social concerns that accompany new biogas and biomethane facilities.

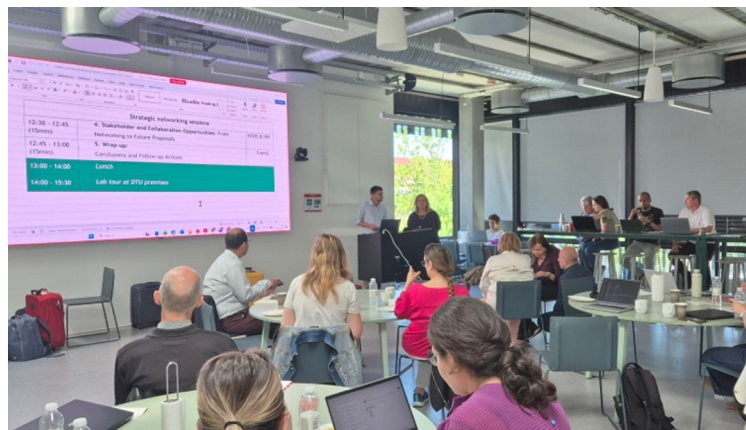
The central lesson throughout all 5FP Communities of Practice Meeting is that technical performance is necessary, however, scale-up also depends on logistics, regulation, transparent governance and a value proposition that works in a satisfactory way for both plant operators and host communities.

PROJECT EVENTS

3rd Project Meeting was held in Copenhagen, Denmark at DTU premises in May, 2026 – Networking session with FENIX Project

The 3rd Annual Project Meeting was held in Copenhagen on 28–29 May 2026, hosted by DTU at its premises in a hybrid format. Project partners shared key outcomes and progress across all CCUS pilots, as well as updates on business opportunities and the project's exploitation roadmap.

During this two-day event, the CRONUS consortium engaged with partners from the FENIX (<https://project-fenix.eu/>) project in a dedicated networking session organised around four core themes: Technical, Sustainability, System Integration and Deployment Perspectives, and Stakeholder Collaboration Opportunities. Each session was moderated by the respective Work Package leaders from the two projects. The networking event provided a valuable platform



for knowledge exchange, enabling participants to compare technical approaches, discuss common challenges, and identify complementary expertise. It also strengthened collaboration between the two consortia, fostering synergies, exploring future joint activities, and enhancing the potential for wider replication and impact of the innovative CCUS solutions developed by both projects.





FINAL – CLOSING CONFERENCE, JUNE 2026

During the 13th International Conference on Sustainable Waste Management (KOS 2026), the CRONUS project held its Final Conference on 24th June 2026, marking the successful completion of the project and showcasing its promising achievements.

As one of the leading events in the field, KOS2026 served as a vibrant hub for scientific exchange, collaboration, and innovation, bringing together researchers, technology providers, high-level EU officials, national and local authorities, policymakers, and other key stakeholders from the waste management sector.

This high-profile setting enabled CRONUS to maximize the visibility of its results, foster new collaborations, and contribute to shaping the future of sustainable waste management and the circular economy.

Dr. S. Mai (NTUA), Dr. P. Kougias (ELGO), Prof. I. Angelidaki (DTU), J. M. Commandre (CIRAD), and D. Hidalgo (CARTIF) presented the technologies developed and the key results achieved by each Functional Prototype on the capture, utilization, and storage of biogenic effluent gases within biofuel production lines. The

conference concluded with N. Kamergi (SEMIDE), who presented the financing mechanisms and business models supporting the deployment and uptake of these innovative solutions. The dedicated session was chaired by Prof. D. Malamis (Brunel University) and Prof. M. Loizidou (NTUA).

The event highlighted the project's significant scientific and technological advances, demonstrating the strong potential of the CRONUS solutions to contribute to the decarbonization and sustainability of the biofuels sector as well as outlined the commercial pathway required to scale CRONUS technologies from Technology Readiness Level 5 (TRL5) up to full market deployment at TRL9.



3rd Best Poster Award at the 13th International Conference on Sustainable Solid Waste Management, held from 24 to 26 June 2026 in Kos, Greece was awarded to CRONUS project poster.

The awarded poster created by Davide Sanguineti was developed by researchers from the University of Padua (UNIPD) and CARTIF Technology Center within the Horizon Europe CRONUS project. The award was accepted on behalf of all authors by Prof. Laura Treu (UNIPD).

The poster demonstrates the work carried out regarding the AD-MEC system, where the team

tried to infer the functioning of this complex and multi-compartment microbial community, from its structure and composition to the trophic chain leading to methane generation. We are especially proud that this work was recognized among so many remarkable poster presentations!

This achievement reflects the outstanding collaboration between UNIPD and CARTIF and is equally shared among all authors, with special recognition to the two task managers, Prof. Laura Treu and Dr. Rudolphus Antonius Timmers, whose guidance and dedication made this work possible.





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