ALGAE CULTIVATION ON BIOLOGICALLY CAPTURED CO_2

a functional prototype of CRONUS - CAPTURE AND REUSE OF BIOGENIC GASES FOR NEGATIVE-EMISSION - SUSTAINABLE BIOFUELS

CRONUS

Overview

Functional prototype 1 called FP1 integrates enzymatic CO_2 capture with autotrophic algae cultivation to transform biogenic emissions from biowaste into valuable bio-products.
The system produces algae biomass, enzymes, and fuels while achieving high CO_2 utilisation efficiency and supporting circular, carbon-negative value chains.

Goals and Objectives

Environmental

FP1 creates a fully carbon-negative loop by recycling all biogenic CO_2 through a clean, enzyme-based system that requires no synthetic chemicals and transforms algae residues and digestate into valuable biofertilisers.

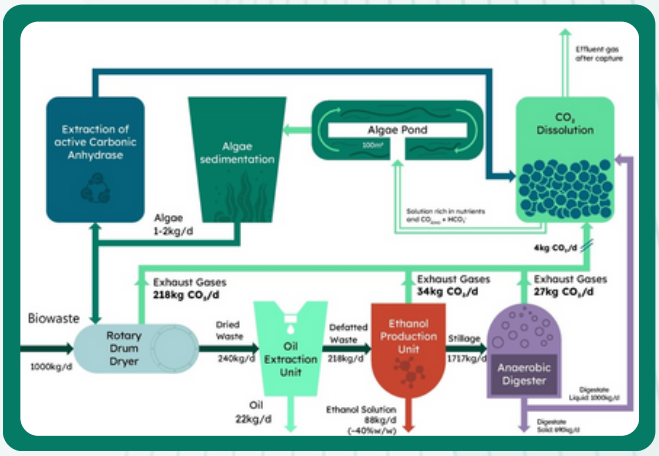
Economic

Economically, FP1 maximises biowaste value through multiple high-value outputs: algae, enzymes, biofuel precursors, , boosting revenue per tonne by 20-35% while reducing operating costs via enzyme reuse.

Operational

Operationally, FP1 is a modular, low-maintenance solution that retrofits easily onto existing biogas, AD or bioethanol facilities and has been reliably demonstrated in continuous TRL5 operation.

System description



FP1 captures biogenic CO_2 and reintegrates it into a closed-loop system combining enzymatic absorption and algae cultivation. By transforming emissions into valuable bio-based outputs, the system reduces costs, increases resource efficiency, and enables carbon-negative biofuel production.

Key numbers

- Payback period of **<10** years
- Funding coverage up to **70%**
- CO_2 capture efficiency up to **90%**
- OPEX reduction about **-40%**
- Biomass utilisation of **+22,01%**

Co-funded by the European Union

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CRONUS

Financial elements

Capital Expenditures:

- Approx. €100K for a 100 m² FPI module
- Includes CO_2 capture unit, algae ponds, sedimentation tank & integration
- CAPEX decreases by 30-40% at larger scale (≥500 m²)

Operating Expenditures:

- Low energy demand: 5-15 Wh/m² thanks to shallow pond design
- Enzyme regeneration lowers chemical costs by 25-40%
- Maintenance: ~1% of CAPEX/year

Revenue Streams:

- Algae biomass sales (feed, fertiliser, biofuel precursors)
- Carbonic Anhydrase enzyme (high-value biocatalyst)
- Carbon credits from biogenic CO_2 recycling

Funding schemes

European funds

- EBRD – InvestEU: loans covering 20–40% CAPEX
- Just Transition Fund: grants 40-60% CAPEX
- Innovation Fund: 30-60% of CAPEX/OPEX

National funds

- National Bank of Greece: green loans 30-50% CAPEX
- HDBI: co-investment up to 30% (≈€0,5–5M)

Private investment

- Sporos Platform: €100K–1,5M
- NEP: €500K–3M

Business case Highlights

- Transforms **biogenic CO_2** into **new revenue streams,** creating value instead of treating CO_2 as waste.
- Opens access to **fast-growing markets** such as **biofertilisers, aquaculture feed**, **enzymes,** and **bio-based chemicals.**
- Provides an **immediate decarbonisation pathway** for existing plants **without major** infrastructure changes.
- Strengthens **ESG performance** by enabling **carbon-negative operations** and **circular resource** use.
- Ensures **low technical risk**, thanks to a **simple, robust open-pond configuration** with proven **TRL5 results**.
- **Fully compatible** with multiple industrial sectors, increasing its **deployability across Europe.**
- Supports **regulatory compliance** under RED II, the EU Green Deal, and future carbon accounting requirements.

PLACE: Athens, Greece

RESPONSIBLE: NTUA

PARTNERS: ALGEN

PRODUCTION LINE: Ethanol Fermentation, Biodiesel Production, Anaerobic Digestion

END-PRODUCT: Bioethanol, Biodiesel, Biomass

TECHNOLOGIES: Enzymatic Capture Of CO_2, Autotropic Algae Cultivation

BIOGENIC GAS: CO_2

BIOGENIC GAS CAPACITY: 2000 L/Day

Co-funded by the European Union

BIOLOGICAL CO_2 HYDROGENATION FOR BIOMETHANE PRODUCTION

a functional prototype of CRONUS - CAPTURE AND REUSE OF BIOGENIC GASES FOR NEGATIVE-EMISSION - SUSTAINABLE BIOFUELS

CRONUS

Overview

Functional prototype 2 - FP2 - upgrades biogenic CO_2 into methane-rich renewable gas using a biological methanation process. Integrated directly into anaerobic digestion units, FP2 increases methane output, enhances plant energy efficiency, and provides a circular, carbon-negative pathway with high industrial relevance.

Goals and Objectives

Environmental

FP2 transforms biogenic CO_2 into renewable methane, enabling circular carbon loops and reducing net emissions from anaerobic digestion.

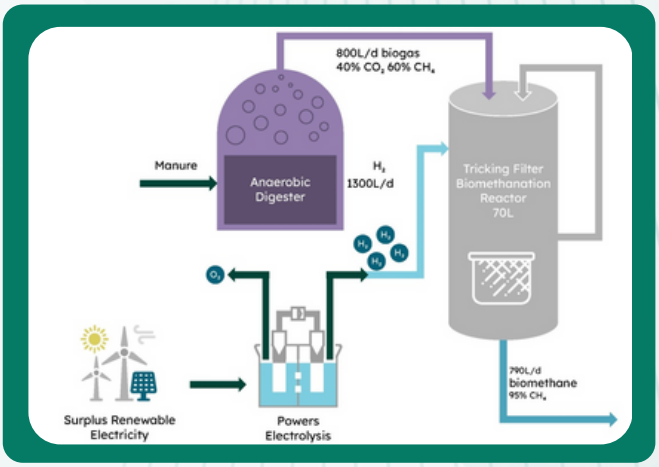
Economic

FP2 increases methane yield and creates new revenue streams through upgraded biomethane suitable for grid injection, heat, electricity, or transport fuel markets.

Operational

FP2 integrates seamlessly with existing AD infrastructures, offering a low-maintenance, biologically robust solution with proven TRL5 performance.

System description



FP2 upgrades biogas by biologically converting CO_2 into methane through the integration of renewable hydrogen. By increasing methane concentration and energy efficiency, the system enhances biogas quality and enables flexible power-to-gas integration.

Key numbers

- Payback period of **<10** years
- Funding coverage up to **70%**
- CO_2 capture efficiency up to **90%**
- OPEX reduction about **-40%**
- CH_4 enrichment **+25%**

Co-funded by the European Union

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CRONUS

Financial elements

Capital Expenditures:

- Approx. €120K for a fully integrated FP2 module.
- Includes methanation bioreactor, gas upgrading interfaces, automation & sensors.
- CAPEX reduces by 20-30% at larger scale (>250 kW plants)

Operating Expenditures:

- Bioreactor operation: low energy demand (no high-pressure catalysts)
- O&M cost: 0,5–1,5% of CAPEX/year
- Requires limited nutrients & no expensive chemicals

Revenue Streams:

- Upgraded biomethane sales (grid injection or on-site CHP)
- Transport-grade biofuel (Bio-CNG / Bio-LNG)
- Carbon credits for CO_2 conversion
- Additional heat/electricity value from increased methane yield
- Revenue potential increases +10-25% with biological methanation integrated

Funding schemes

European funds

- EBRD – InvestEU: loans covering 20-40% CAPEX
- Just Transition Fund: grants 40-60% CAPEX
- Innovation Fund: 30-60% CAPEX/OPEX support

National funds

- National Bank of Greece: green loans 30–50% CAPEX
- HDBI: co-investment up to 30%

Private investment

- Sporos Platform: €100K–1,5M
- NEP: €500K–3M

Business case Highlights

- **Converts biogenic CO_2 into market-ready renewable methane,** increasing **plant energy autonomy.**
- **Opens access to high-demand biomethane markets,** including **grid injection, heat, electricity, CHP, and transport fuel.**
- **Requires minimal retrofitting,** integrating directly with **existing digesters.**
- **Enhances overall biogas plant profitability** by upgrading **CO_2 instead of venting it.**
- **Operates under mild biological conditions,** avoiding the **complexity and cost of catalytic methanation.**
- **Supports compliance with RED II, national biomethane quotas,** and **EU Green Gas targets.**
- **Offers strong replication potential** across **European biogas infrastructures.**

PLACE: Thessaloniki, Greece

RESPONSIBLE: ELGO

PARTNERS: DTU, UNIPD

PRODUCTION LINE: Anaerobic Digestion

END-PRODUCT: Biomethane

TECHNOLOGIES: Biological CO_2 Hydrogenation

BIOGENIC GAS: CO_2

BIOGENIC GAS CAPACITY: 330 L/Day

Co-funded by the European Union

SYNGAS BIOMETHANATION

a functional prototype of CRONUS - CAPTURE AND REUSE OF BIOGENIC GASES FOR NEGATIVE-EMISSION - SUSTAINABLE BIOFUELS

CRONUS

Overview

Functional prototype 3, called FP3, upgrades syngas from biomass pyrolysis into renewable biomethane through biological methanation, converting CO_2, CO and H_2 into CH_4 under mild, low-energy conditions.
This creates a fully circular and higher-value pathway, boosting carbon efficiency and producing decarbonised biomethane suitable for grid injection or on-site CHP.

Goals and Objectives

Environmental

Increase the carbon efficiency of pyrolysis by biologically converting CO_2- and CO-rich syngas into biomethane, reducing emissions and supporting carbon-negative pathways.

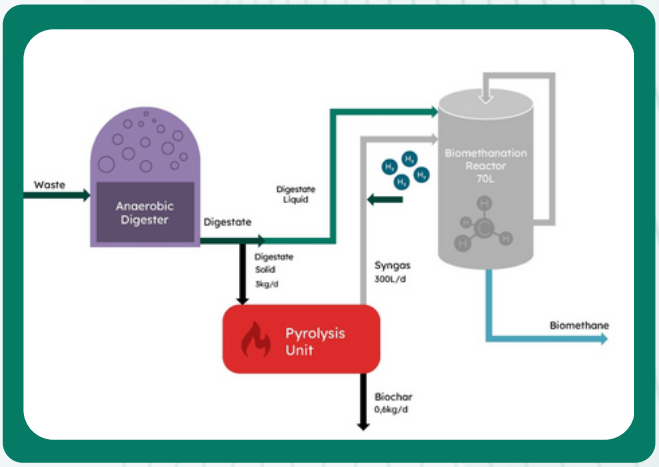
Economic

Boost the economic value of syngas streams by transforming them into market-ready biomethane, enabling access to grid, CHP, and transport fuel markets.

Operational

The system upgrades biogas by biologically converting carbon dioxide into methane using renewable hydrogen. By improving methane content and efficiency, it enhances gas quality and enables flexible power-to-gas integration.

System description



FP3 upgrades digestate by converting solid residues into syngas and biochar through pyrolysis and biomethanation. By increasing energy recovery and enabling long-term carbon storage, the system enhances biomethane production and overall resource efficiency.

Key numbers

- Payback period of **<10** years
- Funding coverage up to **70%**
- CO_2 capture efficiency up to **90%**
- OPEX reduction about **-40%**
- Syngas to CH_4 Conversion **70%**

Co-funded by the European Union

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CRONUS

Financial elements

Capital Expenditures:

- Approx. €130K–€160K for an FP3 module (biomethanation bioreactor + syngas conditioning + integration).
- Cost decreases 20–25% at scale (>250 kW)
- Lower CAPEX vs catalytic methanation due to ambient-pressure operation.

Operating Expenditures:

- Low energy needs (ambient pressure, biological temperature range).
- No catalysts or precious metals required
- Annual O&M: ~1% of CAPEX.

Revenue Streams:

- Biomethane production from syngas upgrading
- Electricity & heat revenue (CHP).
- Bio-CNG / Bio-LNG markets.
- Carbon credits due to syngas carbon recycling
- Additional revenue from biochar valorisation when FP3 is paired with FP4.

Funding schemes

European funds

- EBRD – InvestEU: loans covering 20–40% CAPEX
- Just Transition Fund: grants 40-60% CAPEX
- Innovation Fund: 30-60% of CAPEX/OPEX

National funds

- Green Tax Reform schemes: support 20–30%
- Danish Energy Agency grants: up to 35% for renewable gas demo plants

Private investment

- Sporos Platform: €100K–1,5M
- NEP: €500K–3M

Business case Highlights

- Delivers high bioenergy efficiency with **64% BE1**, converting more of the **feedstock** energy into usable **biomethane.**
- Converts **CO_2** and **CO-rich syngas** into **renewable biomethane,** increasing **plant energy output** and **reducing emissions.**
- Unlocks **additional value** from **pyrolysis chains** by turning **low-value syngas** into a **premium energy product.**
- Creates **new revenue streams** through **biomethane sales**, **CHP integration**, **carbon credits**, **biochar** and **renewable gas markets.**
- Operates under **low-energy biological conditions**, **avoiding** high CAPEX/OPEX catalytic systems.
- Supports **circularity** by integrating **pyrolysis + biomethanation**, achieving better **carbon recovery** and improved **resource utilisation**.
- Strengthens **regulatory alignment** with **EU renewable gas targets, RED II,** and **national biomethane injection incentives.**

PLACE: Copenhagen, Denmark

RESPONSIBLE: DTU

PARTNERS: BTPRO, CIRAD

PRODUCTION LINE: Pyrolysis

END-PRODUCT: Biomethane

TECHNOLOGIES: Syngas Biomethanation

BIOGENIC GAS: CO_2, CO, H_2

BIOGENIC GAS CAPACITY: 300 L/Day

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BIOGENIC CARBON STORAGE THROUGH BIOCHAR PRODUCTION

a functional prototype of CRONUS - CAPTURE AND REUSE OF BIOGENIC GASES FOR NEGATIVE-EMISSION - SUSTAINABLE BIOFUELS

CRONUS

Overview

Functional prototype 4 - FP4 - demonstrates a thermochemical pyrolysis process that converts biomass residues into biochar, pyrolysis gas and bio-oil.
By stabilising carbon into biochar and producing energy-rich gases, FP4 enables carbon removal, renewable energy generation, and higher resource efficiency across agricultural and agro-industrial value chains.

Goals and Objectives

Environmental

FP4 locks carbon into stable biochar, enabling long-term carbon sequestration while reducing emissions from biomass disposal.

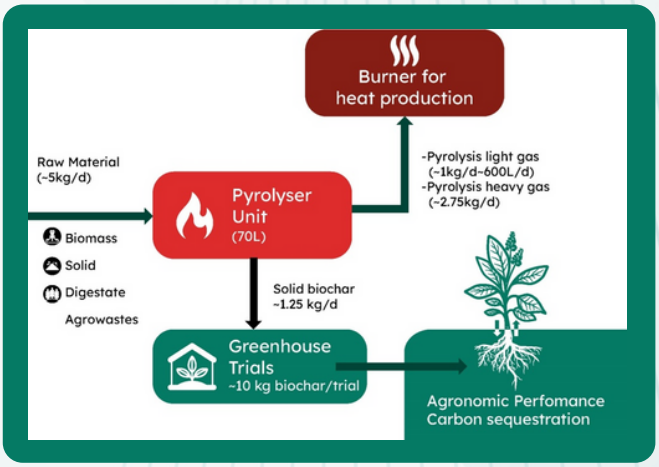
Economic

It generates multiple high-value products biochar, heat, gas and bio-oil diversifying revenue streams for biomass processors.

Operational

FP4 provides a robust, modular pyrolysis unit compatible with heterogeneous feedstocks and adaptable to agricultural, forestry and agro-industry settings.

System description



FP4 converts biomass and digestate into biochar through controlled pyrolysis while recovering energy from pyrolysis gases. By producing stable biochar for agronomic use and carbon sequestration, the system enables long-term carbon storage and circular valorisation of biogenic residues.

Key numbers

- Payback period of **<10** years
- Funding coverage up to **70%**
- CO_2 capture efficiency up to **90%**
- OPEX reduction about **-40%**
- Energy positive process **100%**

Co-funded by the European Union

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CRONUS

Financial elements

Capital Expenditures:

- Approx. €180K–€250K for a modular FP4 pyrolysis unit (kiln, pre-drying, gas cleaning, biochar storage).
- CAPEX decreases 15–25% at larger capacity (≥ 500 kg/h).
- Lower equipment cost compared to gasification.

Operating Expenditures:

- Moderate energy demand for heating (can be partly met by pyrolysis gas).
- Annual maintenance ~2% of CAPEX.
- Labour and handling costs depend on biomass feedstock logistics.
- No expensive chemicals required.

Revenue Streams:

- Biochar sales (soil improvement, fertilisers, carbon removal credits).
- Heat & electricity from syngas combustion.
- Bio-oil for energy or upgrading routes.
- Strong revenue potential due to multi-product model and biochar premium pricing.

Funding schemes

European funds

- EBRD – InvestEU: loans covering 20–40% CAPEX
- Just Transition Fund: grants 40-60% CAPEX
- Innovation Fund: 30-60% of CAPEX/OPEX

National funds

- ADEME Fonds Chaleur: 30–45% for biomass/heat projects
- France Relance - Décarbonation: up to 30%

Private investment

- Sporos Platform: €100K–1,5M
- NEP: €500K–3M

Business case Highlights

- Enables **23 kg CO_2 sequestered per 100 kg feedstock**, delivering **measurable carbon-removal impact**.
- Produces **biochar, pyrolysis gas** and **bio-oil,** creating **multiple revenue pathways** instead of relying on a single output.
- **Converts low-value** agricultural residues into **premium carbon-negative products**, increasing overall resource value.
- Offers **access** to **fast-growing markets** for **biochar in soil improvement**, **carbon removal credits**, and speciality materials.
- Provides a **modular** pyrolysis **solution** that works with variable **biomass qualities** (wood chips, manure, residues).
- Supports **RED II, EU Carbon Removal Certification Framework**, and **national soil-carbon strategies.**
- **Creates synergy** with FP3, where pyrolysis gas can be upgraded to biomethane, further enhancing plant profitability.

PLACE: Montpelier, France

RESPONSIBLE: CIRAD

PARTNERS: -

PRODUCTION LINE: Pyrolysis

END-PRODUCT: Biochar

TECHNOLOGIES: Biogenic Carbon Storage Through Biochar Production

BIOGENIC GAS: CO, H_2, CH_4, CnHm

BIOGENIC GAS CAPACITY: 600 L/Day

Co-funded by the European Union

ANAEROBIC DIGESTION SYSTEM COUPLED WITH A MICROBIAL ELECTROLYSIS CELL (MEC)

a functional prototype of CRONUS - CAPTURE AND REUSE OF BIOGENIC GASES FOR NEGATIVE-EMISSION - SUSTAINABLE BIOFUELS

CRONUS

Overview

Functional prototype 5 - FP5 - retrofits a two-phase anaerobic digestion (AD) pilot plant with a Microbial Electrolysis Cell (MEC) to create in-situ biomethanation: the CO_2 produced during digestion reacts with H_2 generated by the MEC inside the reactor, enriching the biogas in methane.
This configuration increases bioenergy efficiency, improves carbon utilisation and delivers a more carbon-negative biomethane stream aligned with EU biomethane and decarbonisation targets.

Goals and Objectives

Environmental

FP5 enhances CO_2 utilisation in AD by converting part of the biogenic CO_2 into methane, contributing to the CRONUS 71–94% GHG emission reduction range.

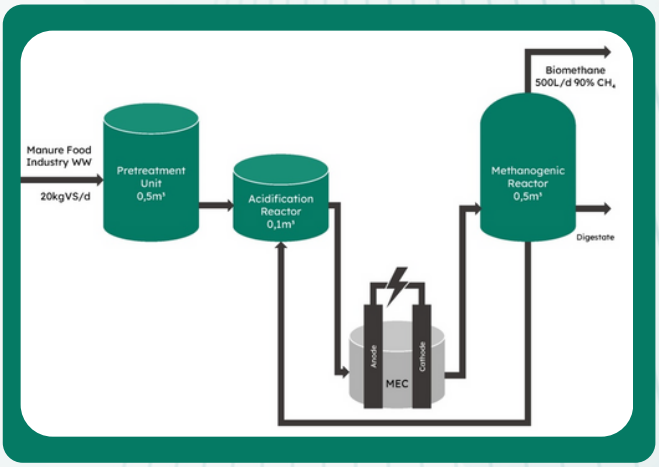
Economic

By enriching biogas in methane, FP5 increases the energy value and revenues of existing AD plants through higher biomethane output and potential access to premium biomethane markets.

Operational

FP5 demonstrates a MEC–AD hybrid reactor that can be retrofitted into existing digesters, operating under mild biological conditions with limited additional footprint and instrumentation.

System description



FP5 enhances anaerobic digestion by integrating microbial electrolysis to improve biomethane production. By stimulating in-situ H_2 generation & biological methanation, the system increases methane yield, improves process stability, and reduces residual carbon in the digestate.

Key numbers

- Payback period of **<10** years
- Funding coverage up to **70%**
- CO_2 capture efficiency up to **90%**
- OPEX reduction about **-40%**
- Biomass utilisation of **+22,01%**

Co-funded by the European Union

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CRONUS

Financial elements

Capital Expenditures:

- Approx. €100–150K for MEC unit + retrofit of an existing AD reactor.
- Includes: electrodes, power supply, control system, integration works.
- Modular and compact that lower CAPEX vs external methanation units.

Operating Expenditures:

- Main OPEX driver: electricity consumption for MEC operation.
- Limited reagents (biological process, no catalysts).
- Standard AD OPEX remains (mixing, heating), with incremental OPEX offset by increased methane production.
- Expected maintenance: ~1% of CAPEX/year.

Revenue Streams:

- Increased biomethane output from in-situ CO_2–H_2 methanation.
- CHP electricity & heat generation from richer methane biogas.
- Carbon credits / guarantees of origin for negative-emission biomethane.
- Gate fees from agro-food residues entering the two-phase AD system.

Funding schemes

European funds

- EBRD – InvestEU: loans covering 20–40% CAPEX
- Just Transition Fund: grants 40-60% CAPEX
- Innovation Fund: 30-60% of CAPEX/OPEX

National funds

- NextGenerationEU Biogas Programme: up to 40–50% CAPEX for biogas/biomethane upgrades.
- PERTE ERHA: large-scale national support for renewable gases and innovation.
- Regional incentives for biogas and renewable energy infrastructures.

Private investment

- Sporos Platform: €100K–1,5M.
- NEP: €500K–3M

Business case Highlights

- Improves bioenergy efficiency with **15% BE1 / 16% BE2**, showcasing **measurable performance gains**.
- **Enhances carbon utilisation** by upgrading **2-8 kg of biogenic carbon per 100 kg feedstock** into **biomethane.**
- **Boosts methane** content directly inside the digester, **avoiding external** hydrogen supply or catalytic reactors.
- **Increases the economic value** of AD plants through higher biomethane yield and **new revenue channels**.
- Operates **under low-temperature**, biological conditions, **reducing** technical complexity and **CAPEX/OPEX**.
- **Strengthens circularity** by combining bioelectrochemical processes (MEC) with AD, **improving** overall biomass resource **efficiency**.
- **Aligns** with Spanish and EU **biomethane strategies**, **supporting** large-scale **deployment** of renewable gases.

PLACE: Boecillo, Spain

RESPONSIBLE: CARTIF

PARTNERS: -

PRODUCTION LINE: Anaerobic Digestion

END-PRODUCT: Biomethane

BIOGENIC GAS: CO_2

TECHNOLOGIES: In-Situ Biomethanation Using MEC

BIOGENIC GAS CAPACITY: 500 L/Day

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