Electromethanogenesis pilot

Geoffrey Karakachian, ENGIE

lab CRIGEN

Thessaloniki

20/06/2024

Co-funded by
the European Union

innovations in the BIOMETHAne uniVERSE

Demo Site in France

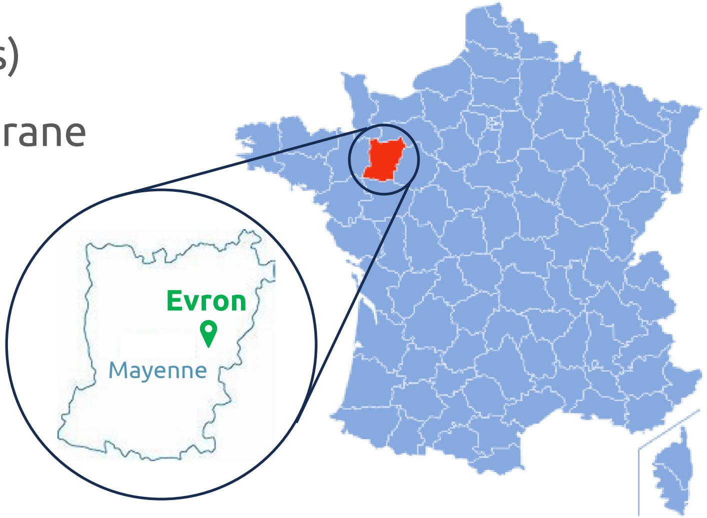
Demonstration site: EVRON , MAYENNE

Feedstock: 30 000t/y (70% agro-industrial residues +30% agricultural residues)

Type : Continuously Stirred Tank Reactor // Mesophilic // Upgrading via membrane

The unit injected its first m^3 of biomethane in November 2021

Several solid and liquid feed lanes, adapted to the type of input.



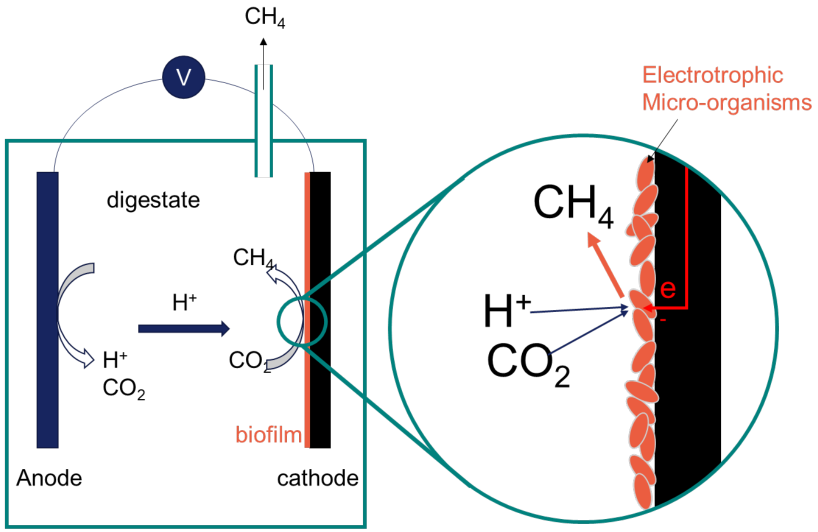
Main numbers:

- **21 GWh /y** of biomethane production
- **Up to 220Nm³/h** injected into NG grid
- **9 000 m³** digestion volume (HRT> 50 d) :
    - 2 Main digesters of 4 500 m³
- **21,000 m³** of liquid digestate storage
- 1 800 m³ of solid digestate storage
    - Valorization of digestate by land spreading
- (**3 000 ha**, **21** farms).

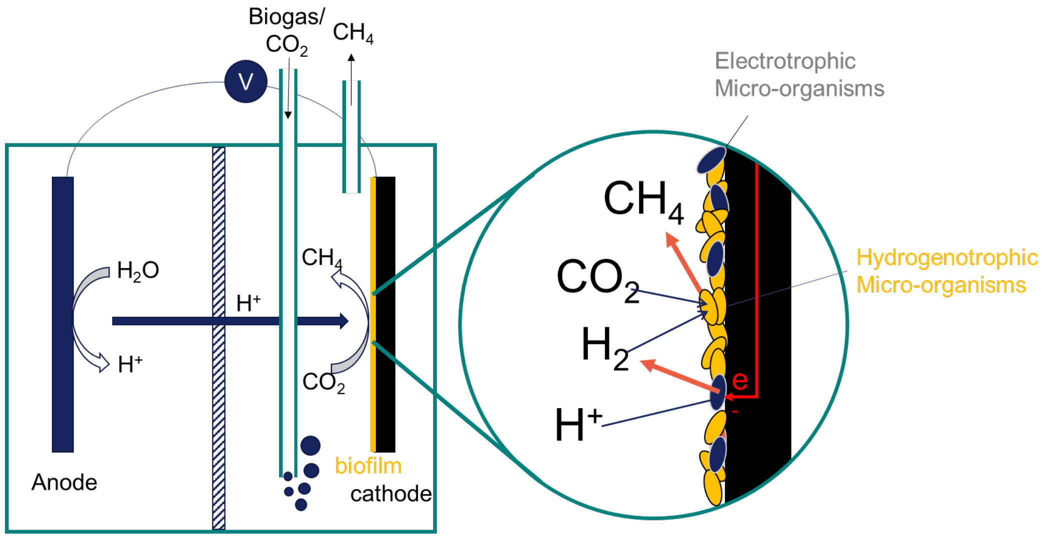
Co-funded by the European Union

Technology description

1 chamber reactor :
Boost of biogas production rate



2 chamber reactor :
Biogas upgrading towards high CH_4 %



- Electromethanogenesis is at the **frontier between electrolysis** (H_2 production in-situ) **and biological methanation** (H_2 + CO_2 conversion into CH_4).
- The technology relies on the use of **electrodes inserted into digestate or given medium** . Under voltage, the micro-organism activity within the biofilm attached to the electrodes is boosted and leads to higher biogas production and/or quality.
- Fine tuning of electrochemistry and biochemistry favorize the production of CH_4.
- Technology aiming at increasing the biomethane production of AD unit and gas quality.

Co-funded by
the European Union

Ambition and progress beyond the state of the art

Ambition : Increase biomethane production on the AD unit **using the effluent digestate, biogas of the main digestor and external green electricity** from solar and wind.

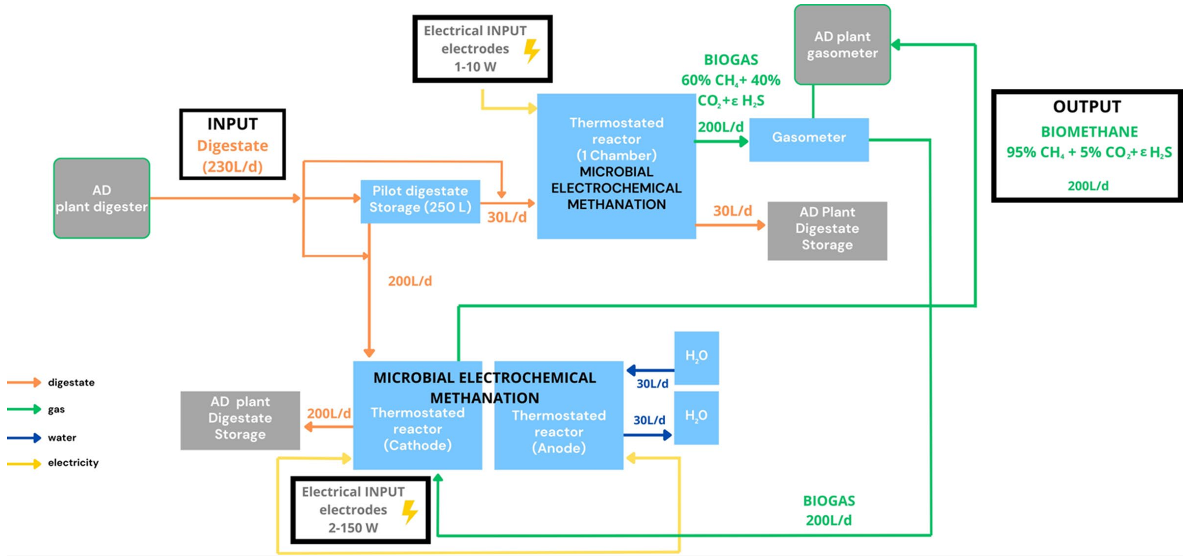
TRL Objective : 4 → 6/7

Single chamber reactor (1c-AD-BES)

- Electrodes directly immerged in the digestate.
- **Planned pilot is a reactor of 1 m³** reactor working at the same mesophilic temperature of the main AD plant.
- **Electrical power source < 2 V** driven by a renewable energy mix from local wind and photovoltaic electricity generators.
- **Enhancement of the bioelectrode geometry and electron transfer properties by prior surface treatment**
- Coupling the 1c-AD-BES downstream the main digester, the **aim is to have a surplus production of 100 L-CH_4/m³/d to the already existing production.**

Double chamber reactor (2c-AD-BES)

- Electrodes separated by a membrane, water oxidation (anodic part) and CO_2 (–biogas) reduction (cathodic part).
- **Planned pilot is a reactor of 1 m³**
- Injection of **biogas (from the main digestor first and then from 1c-AD-BES reactor)**, enabling an efficient power-to-gas process in a H_2O/CO_2 electrosynthesis cell
- **2c-AD-BES is an upgrading step towards maximum biomethane purity output**. At lab scale, the **current two-chamber system can produce 200-1000 L CH_4 per day per m3 reactor volume**



INPUT		OUTPUT
Digestate 230 L/d Electrical power (balance of plant) 13,2 kW (64.5 kWh/d) *(Thermal energy 4,2 kWh/d)* Electrical power (electrodes) 3-160 W (0.072- 3.84 kWh/d)	→	Biomethane 200 L (95% CH_4 +5% CO_2) *Thermal energy 1.7kWh/d*

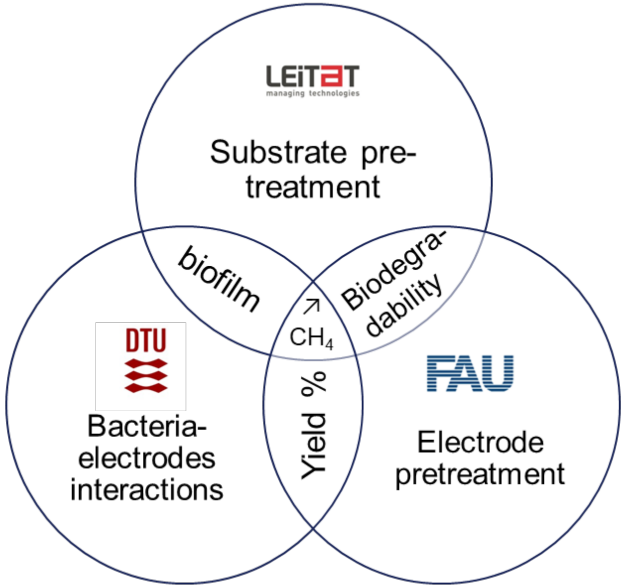
Co-funded by the European Union

Challenges

Performances challenges :

Previous lab experiences showed that **two main parameters contribute to increase biogas/biomethane production in AD-BES:**

- Available surface for biofilm growth, due to electrodes presence
- Application of an optimal voltage for the stimulation of electro-active microbes.
  - ➢ **Labscale trials (2023)** : (**LEITAT-DTU-FAU**)
    1. Pretreatment of electrode materials → maximizing the bioelectrochemical performances
    2. Pretreatment of the substrate (AD digestate) → facilitating the substrate degradation



Operational challenges :

- Feeding conditions at upscaled level : continuous feeding investigation
- Inoculation of anode and cathode with proper electro-active biofilms
  - ➢ **Pre-pilot testing at 10/15 L scale (2023-2024) (LEITAT-DTU)**

Safety challenges :

- Safe usage of the pilot on an operational demo-site
  - ➢ SAFETY Studies (ENGIE-AERIS) :
    - ➢ **HAZID study (Sept. 2023) :**
      Hazard identification considering the pilot in its environment
    - ➢ **ATEX study (2023) :**
      Identification of the ATEX zoning of the pilot and setting-up of mitigation measure → input for the future pilot localisation
    - ➢ **HAZOP study (Jan. 2024)** :
      Operational hazard identificaton on the pilot usage

Pre-pilot operation
- Overcoming of operational challenges on performances

Safety studies
- Ensuring the safe usage of the pilot without impacting AD unit operation

Pilot Operation
- 1 year testing 2025-2026

Co-funded by the European Union

Digestate characterization and pretreatment

Sieving

Figure 1 – Sieved post-digestate with 2 mm mesh (Source: Leitat)

Grinding

Figure 2 – Grinded post-digestate for 1 min at 1500 rpm (Source: Leitat)

2 approaches were investigated at LEITAT :

- Sieving (gave the best results)
- Grinding

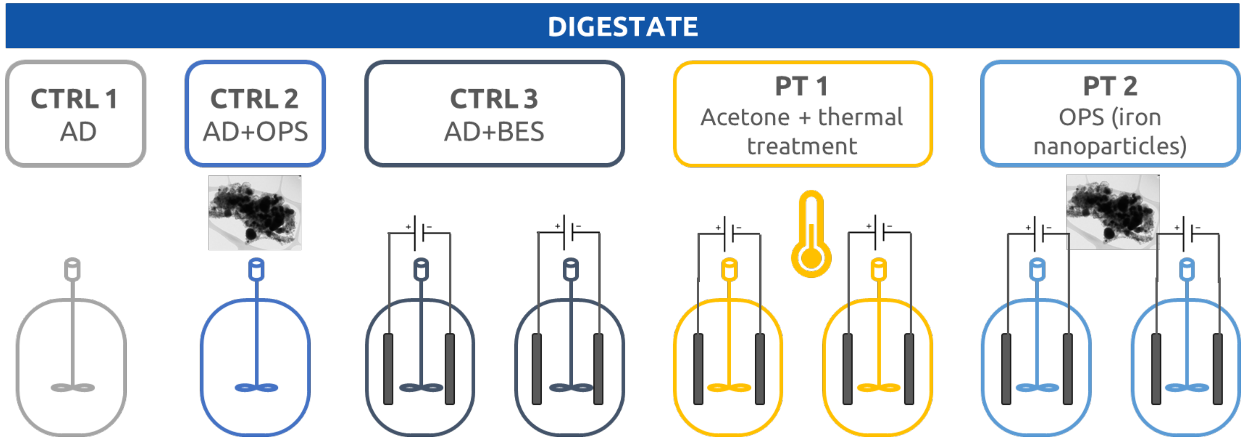
Liquid digestate produced at AD site was sent and used for characterization and labscale work.

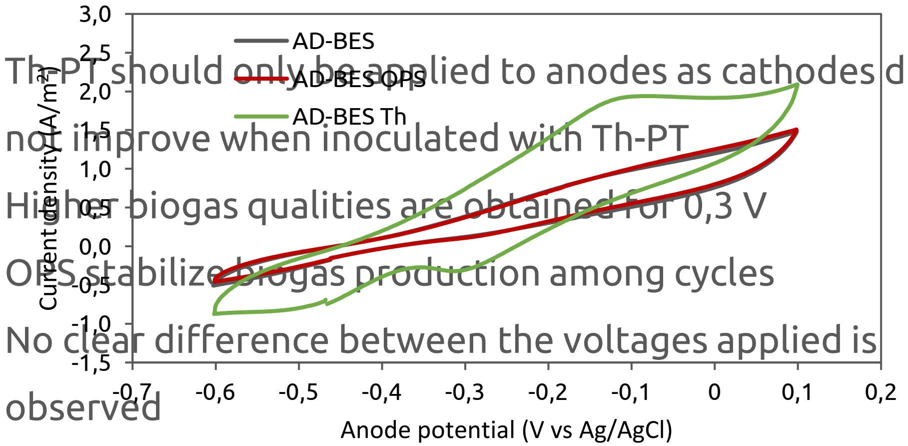
Parameter	Post-digester (2023)	Sieving	Liquid digestate
pH (-)	8,17±0,04	8,86±0,06	8,39±0,01
Cond. (mS/cm)	16,51±0,16	13,02±0,01	29,2±0,08
COD_{tot} (g/L)	79,33±3,09	64,07±0,61	61,03±0,82
COD_{sol} (g/L)	45,37±0,56	31,67±0,31	33±8,31
COD_{sol}/COD_{tot} (%)	57,26%	49,44%	53,90%
$BOD_{5,tot}$ (g/L)	10,482±1,05	8,546±0,23	5,644±0,116
$BOD_{5,sol}$ (g/L)	2,1±0,21	2,21±0,15	2,15±0,394
TN (g/L)	6,51±0,21	3,62±0,17	8,18±0,89
TAN (g/L)	2,98±0,03	0,93±0	5,03±0,12
Nitrates (NO_3^- N g/L)	0,319±0,02	0,288±0,039	0,242±0,004
COD_{sol}/TN ratio (-)	6,98±0,29	8,76±0,47	7,55±0,83
PO_4^{3-}-P (g/L)	0,573±0,01	0,505±0,01	0,49±0,01
K (g/L)	3,52±0,03	3,61±0,24	4,13±0,12
TS (g/L)	92,1±0,6	99,3±1,6	69,8±0,4
VS (g/L)	64,6±0,7	66,4±1,1	47,1±3,3
Alkalinity (mg/L)	4,436±0,255	5,248±0,056	4,569±0,086
FOS/TAC	0,249±0,02	0,479±0,01	0,192±0
Viscosity (Pa s)	8,39±0,63	3,89±0,64	0,84±0,07

Conclusions : Solid part in the digestate might cause operative issue → **Decision to go for liquid digestate directly produced at demo site**

Co-funded by the European Union

Lab-scale trials on EMG for 1c AD-BES

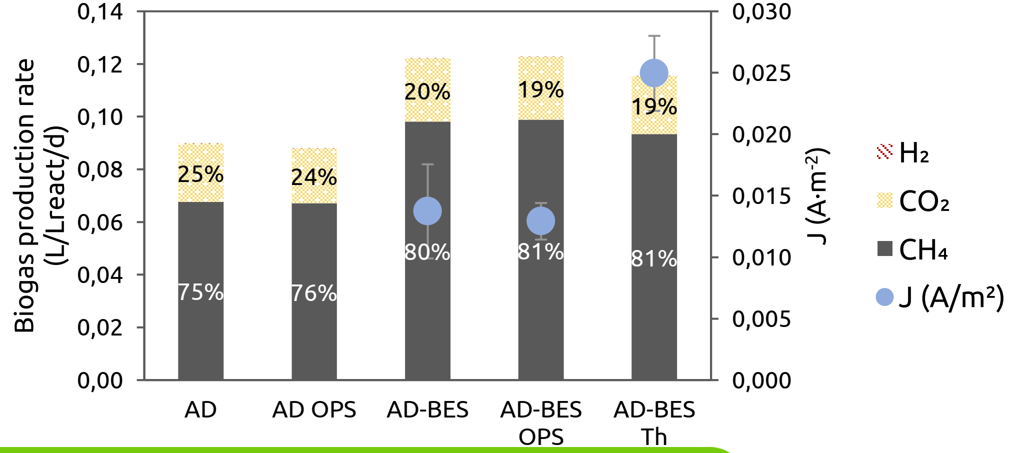




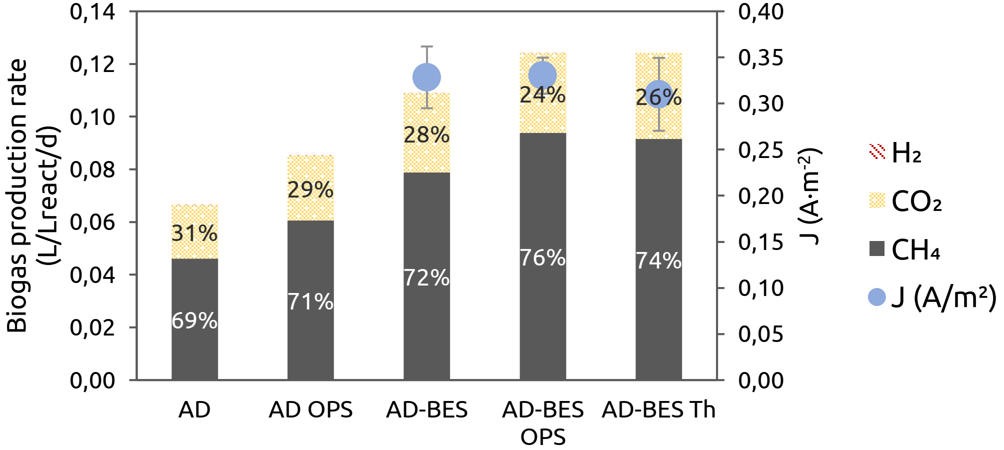
- Th-PT should only be applied to anodes as cathodes do not improve when inoculated with Th-PT
- Higher biogas qualities are obtained for 0,3 V
- OPS stabilize biogas production among cycles
- No clear difference between the voltages applied is observed

→No electrode pretreatment will be applied for the pilot

For an applied voltage of 0,3 V



For an applied voltage of 0,7 V



Co-funded by the European Union

Reactor engineering, pre-pilot scale (M4-M27)

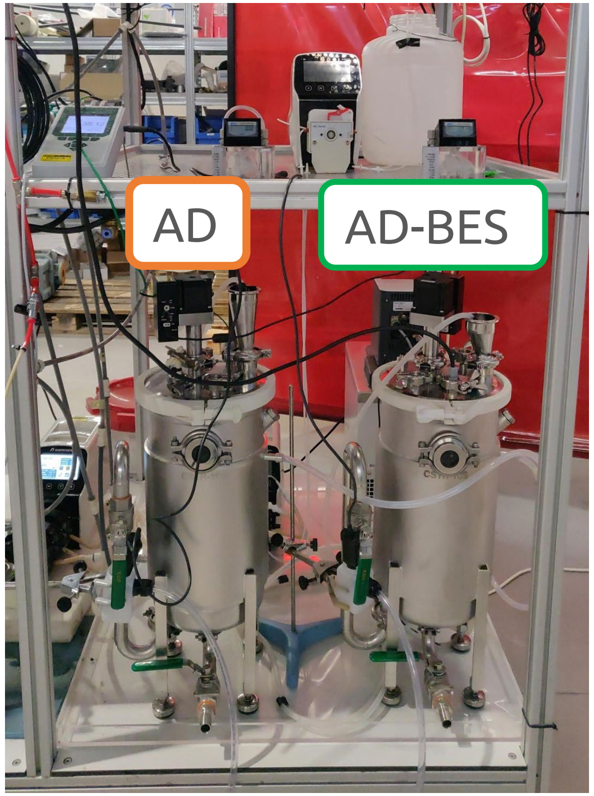
Reactors:

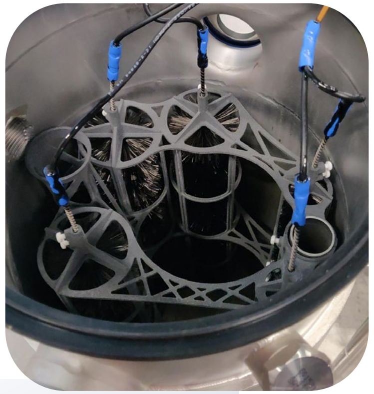
- AD useful volume: 10 L
- AD-BES useful volume: 9,57 L

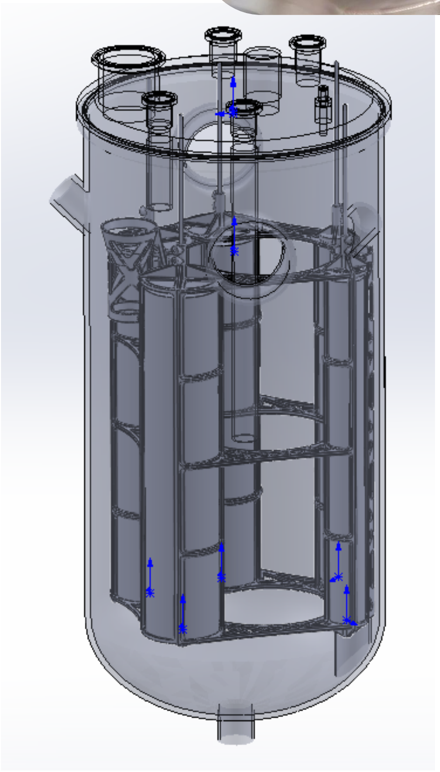
Electrodes:

- 3 cathodes and 2 anodes → ratio CAT/AN 3
- S/V= 13 m^2/m^3

Parameters	Periodicity
pH, electrode potentials	Twice per week
Temperature, voltage, current density	Continuous
Gas production rate	Once per day
Gas composition, COD, FOS/TAC, TS, VS, NH_4^+	Once per week
Organic acid profile	Once per phase





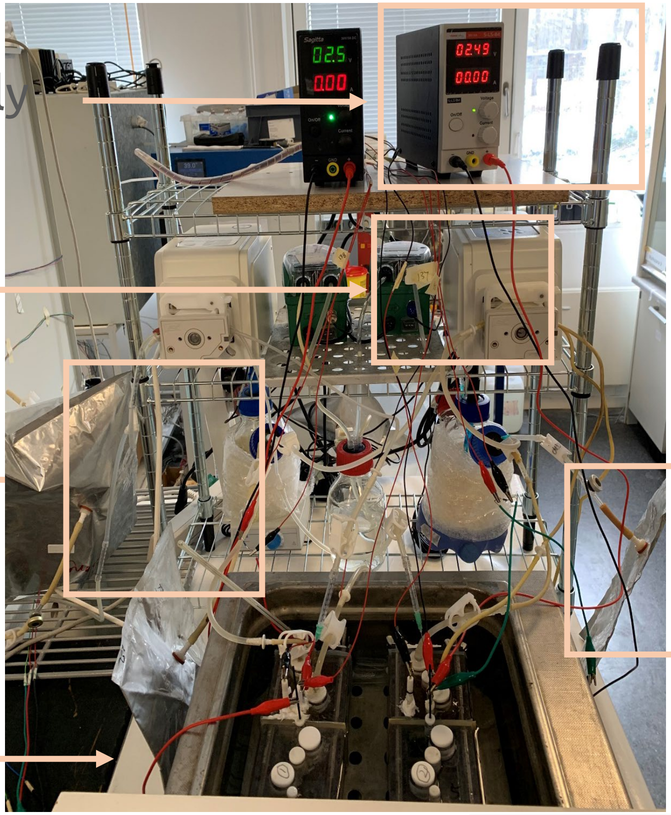


Plan of experiments:

- 8 weeks inoculation + 4 weeks operation
- 4 weeks of voltage testing
- 4 weeks of intermittent voltage testing
- 12 weeks of HRT testing
- XX weeks of organic overloading testing

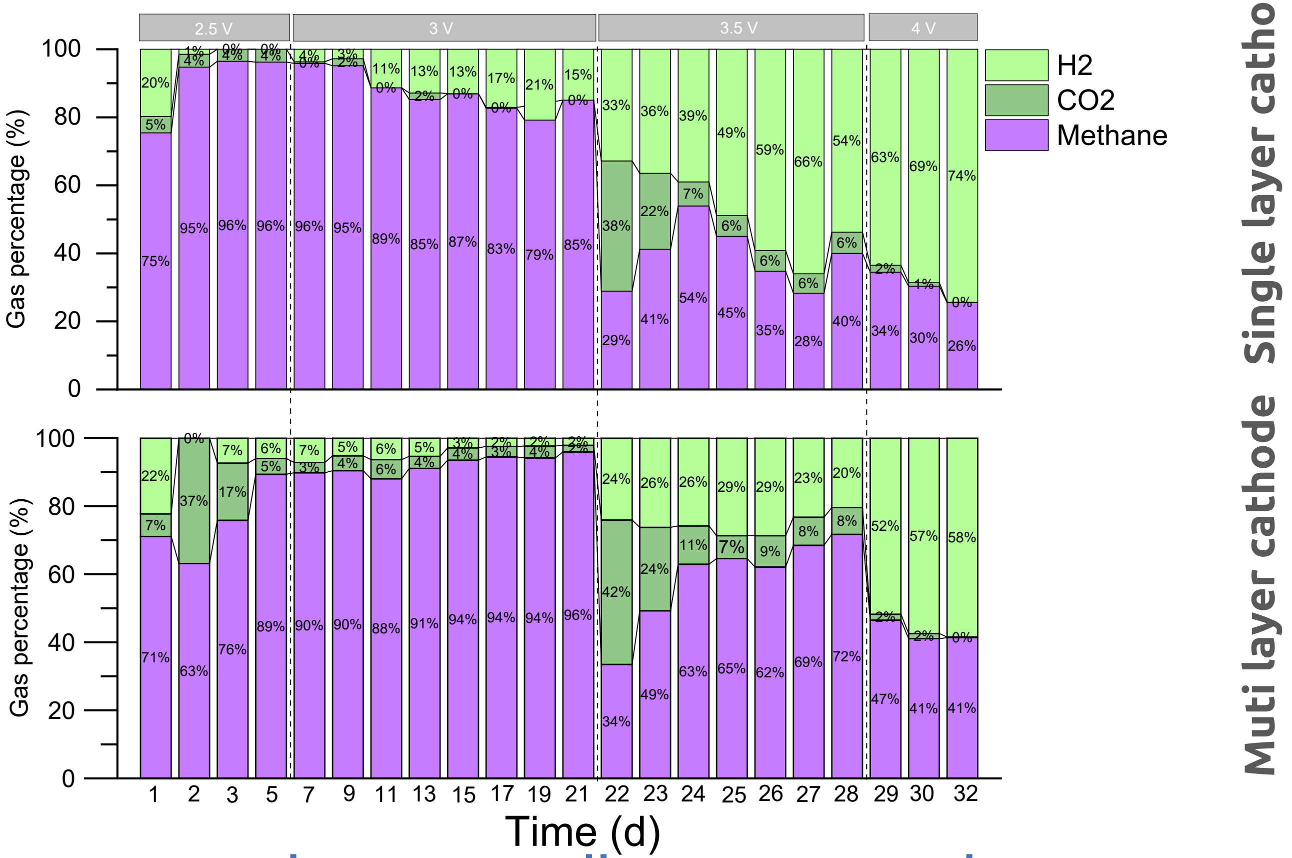
Co-funded by the European Union

Double chamber reactor (2c-ADBES) : voltage optimization



Different Voltage to supply the water splitting

High voltage supplies a higher amount of H_2, which supports a higher biogas treatment ability.



Optimized voltage for the size tested

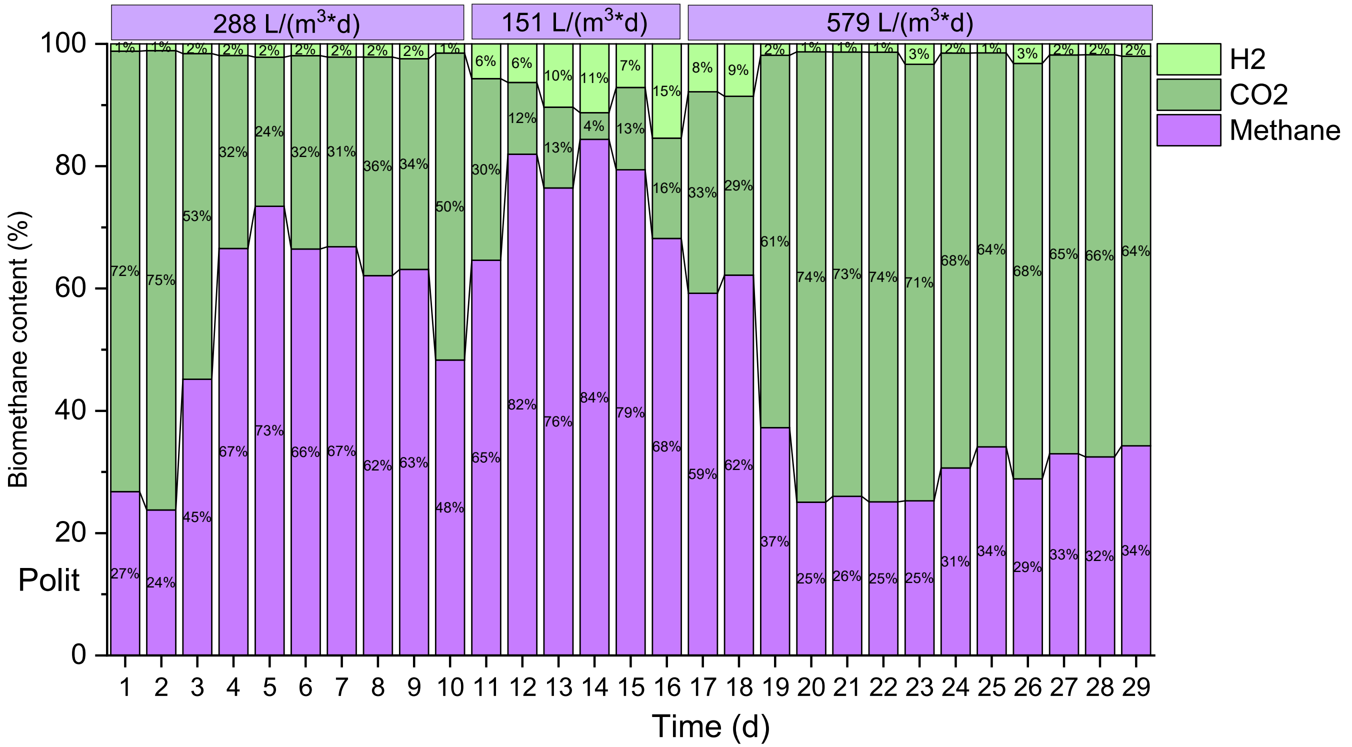
Further biogas upgrading capability with higher voltage

In optimized conditions the 2C-ADBES is able to upgrade biogas to biomethane specification in terms of CH_4 content

Co-funded by the European Union

Double chamber reactor (2c-ADBES) : pre-pilot system preparation

Feasibility verification pre-pilot using 20 L reactor,
Feed **pure CO_2** with different feed speeds, Voltage: 4V



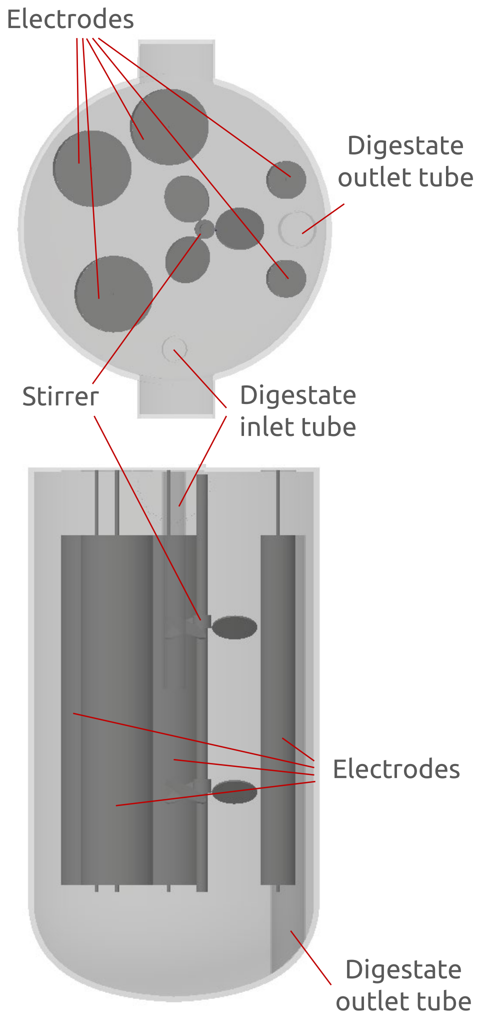
- Pre-pilot reactor worked with anaerobic granular sludge, higher than 70% CO2 was converted to CH4, with a feed speed of 151 $L/m^3_{reactor}$/day at 4 V.

<u>Next steps:</u>

- feed with **biogas,**
- **optimize** working parameters
- **increase feedrate** (target at 1000 $L/(m^3*d)$)

Co-funded by the European Union

CFD simulations - 1c-AD-BES prepilot



CFD Simulations

- Uses numerical analysis to give insights into fluid flows

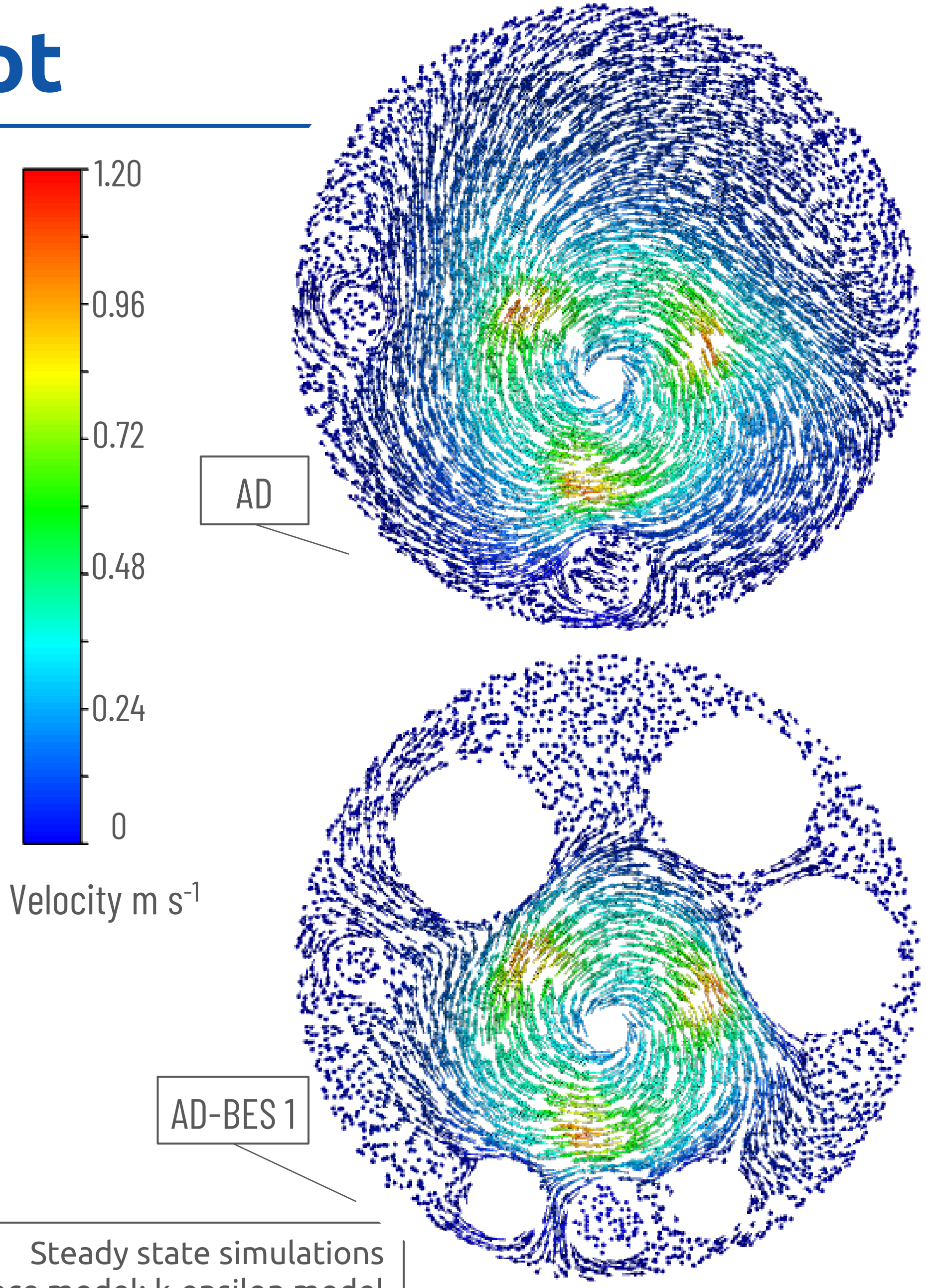
Simulation results already provide information about

- Flow pattern
- Mixing in the reactor
- Microscale of turbulence (Kolmogorov length), a parameter that allows estimation of possible damage to particulate components
- Turbulent kinetic energy
- Power input into the reactor

Simulation results will be provide information about

- Load variables (shear stress)
- Residence time distribution
- Bubble size distribution (gas-liquid systems)
- Bubble residence time prediction (gas-liquid systems)
- Reactions
- …

We can run multiple simulations and compare different setups and configurations

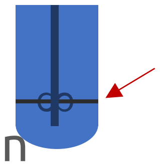


Steady state simulations
Turbulence model: k-epsilon model
Rotational speed: 300 rpm
Material data of water but with a higher viscosity of 840 mPas

Co-funded by the European Union

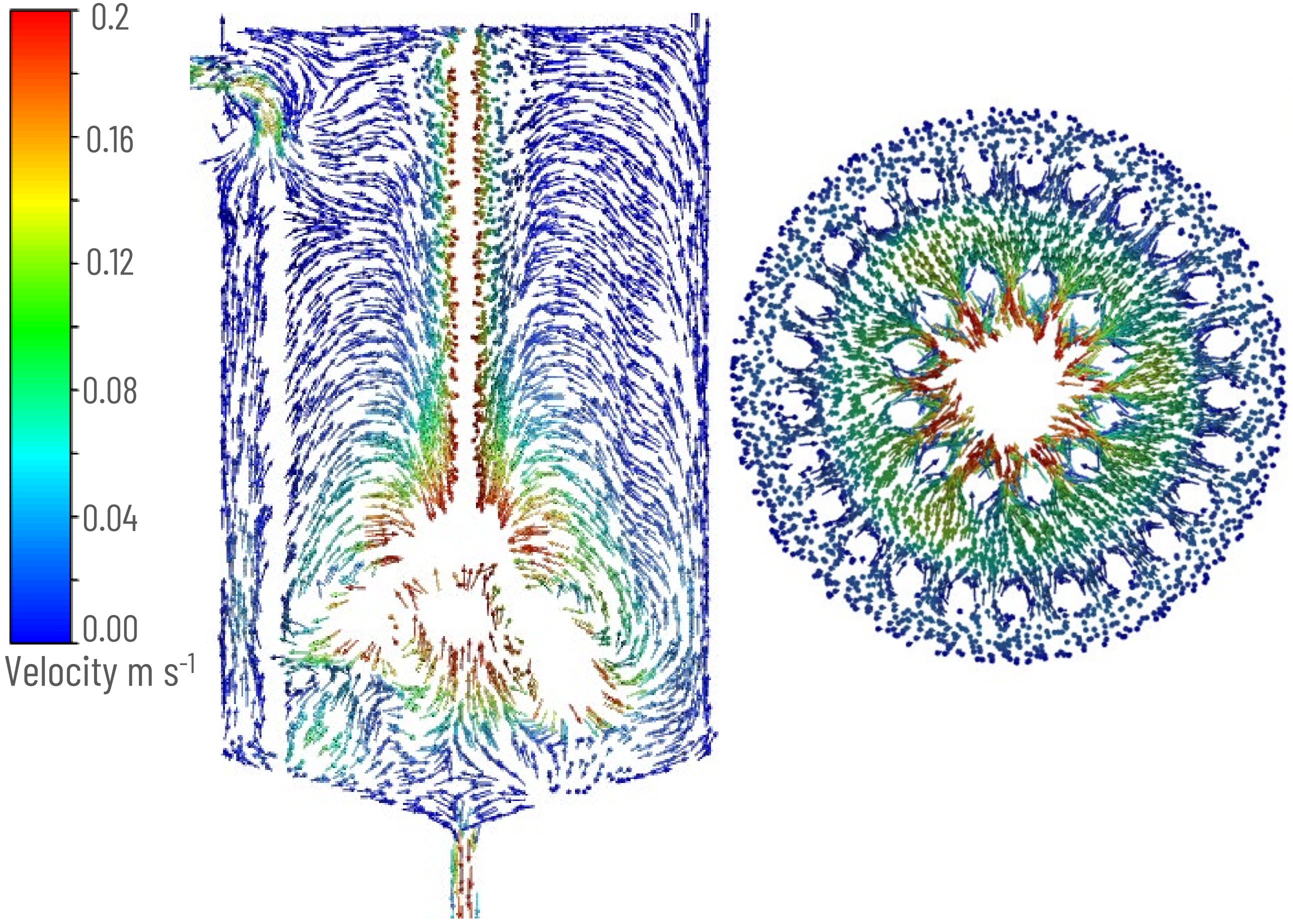
CFD simulations - 1c-AD-BES pilot

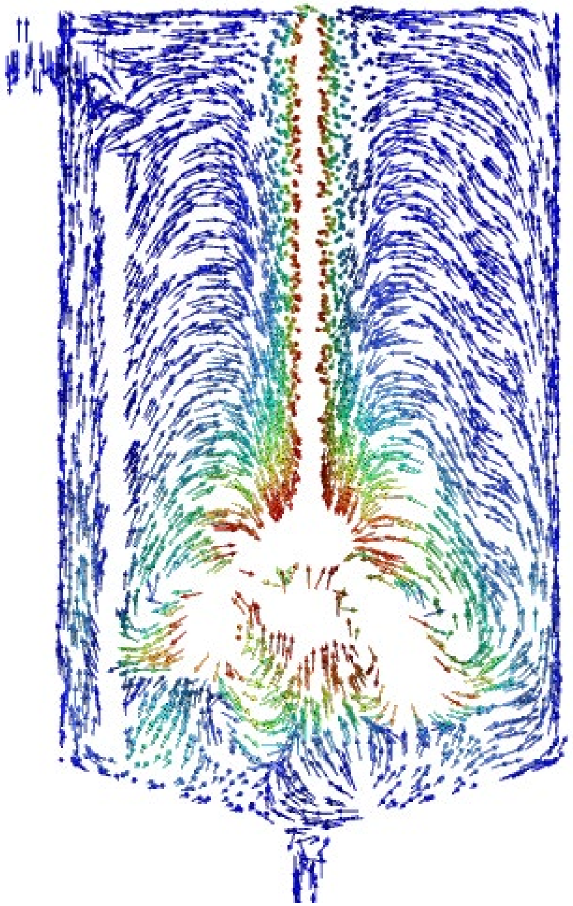
Comparison of operation with and without recirculation

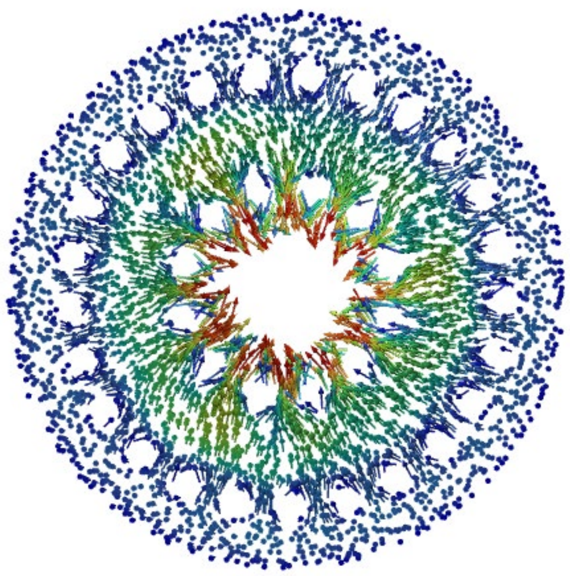


With recirculation

Without recirculation



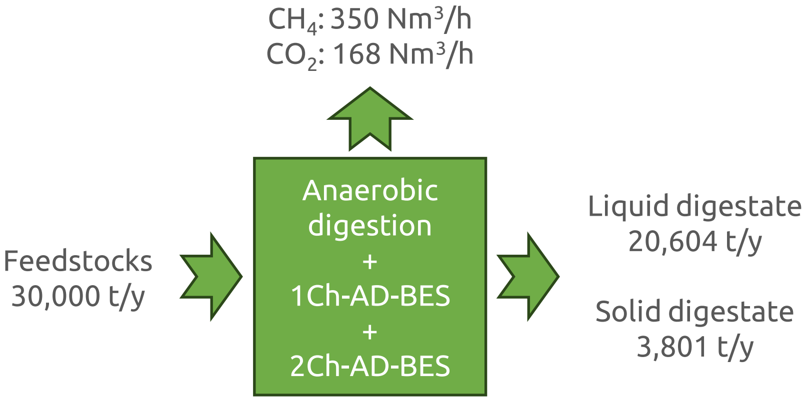




Steady state simulation
Turbulence model: k-epsilon model
Rotational speed: 400 rpm
Material data of water but with a higher viscosity of 840 mPas

Co-funded by the European Union

Initial Business perspective



Scenario	AD reference case	+ 40% CH_4 production
CH_4 – Nm³/h	250	350
CAPEX – k€	9,044	11,886
OPEX – k€/y	1,038	1,170
LCOE - €/MWh-HHV	87	71 (- 18%)

From first assessment of the technology with labscale data, a **+40% CH_4 production using EMG could lead to LCOE reduction of about 18%**

- **Policy :** discussion ongoing with (Direction Regional de l'Environnement et de l'Ammenagement et du Logement) : regulatory body in France.
  - **Actions :** realizing a legal document called (*Porté à connaissance*) → public document aiming at showing the full safety of a given installation (in here the EMG pilot) for people and goods. → integration of safety study oucomes (HAZID/HAZOP)
    - This action will help EMG to be recognized by as an innovative technology by regional decision makers (mayors, préfets…) and could favorize technology acceptation and development

- **Methodological analysis of the pilot :**
  - Costs (OPEX & CAPEX)
  - Operation (safety, usage, digestate quality)
  - Performances (biogas & biomethane production)
    - Pre-pilot and full-pilot scale for challenging the first economical perspectives
  - Mass and energy balance
  - Bill of material

Data provision all along the project for :
- **WP3 Assessment and Optimisation** : *assessment of the demonstrators as built within the project, and of their potential optimised and upscaled configurations*
- **WP4 Replicability :** *assessment of the replicability potential of technology pathways adopted and tested by demonstrators.*

→ Towards market penetration and stakeholder acceptation

Co-funded by the European Union

#Biomethaverse

Thank you!

Follow Biomethaverse:

www.biomethaverse.eu

@European_Biogas

@European Biogas Association

Contact: **Geoffrey Karakachian**

Email: **geoffrey.karakachain@engie.com**

Co-funded by the European Union