Electromethanogenesis pilot

Gaspard Bouteau, ENGIE

lab CRIGEN

Milano

01/12/2023

Co-funded by
the European Union

innovations in the BIOMETHAne uniVERSE

Demo Site in France

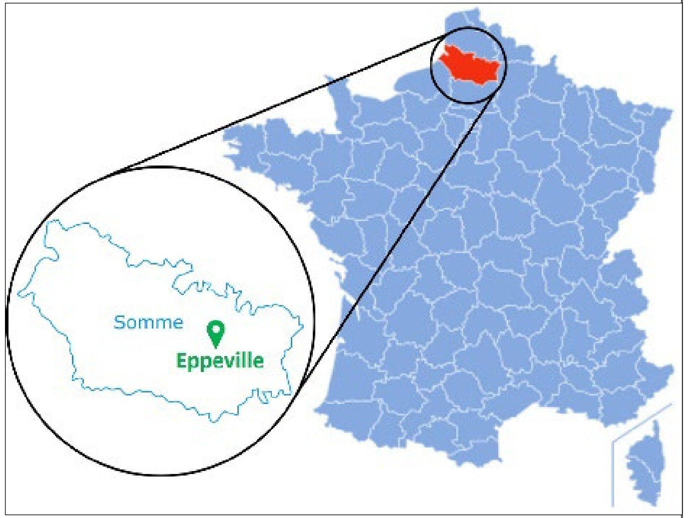
Demonstration site: EPPEVILLE, HAUT DE FRANCE REGION

Feedstock: 50 940 t/y agro-industrial residues

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

The unit injected its first m^3 of biomethane in December 2016.

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

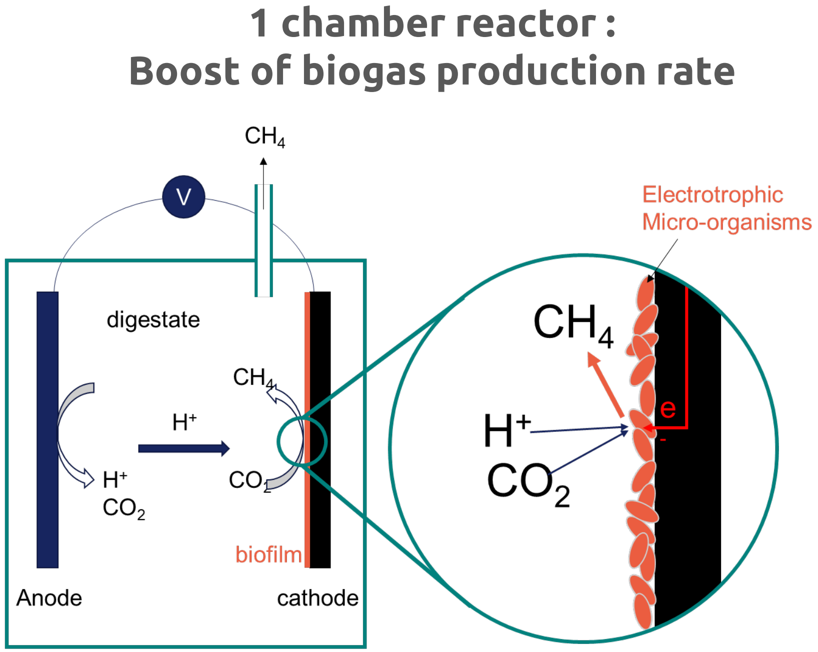


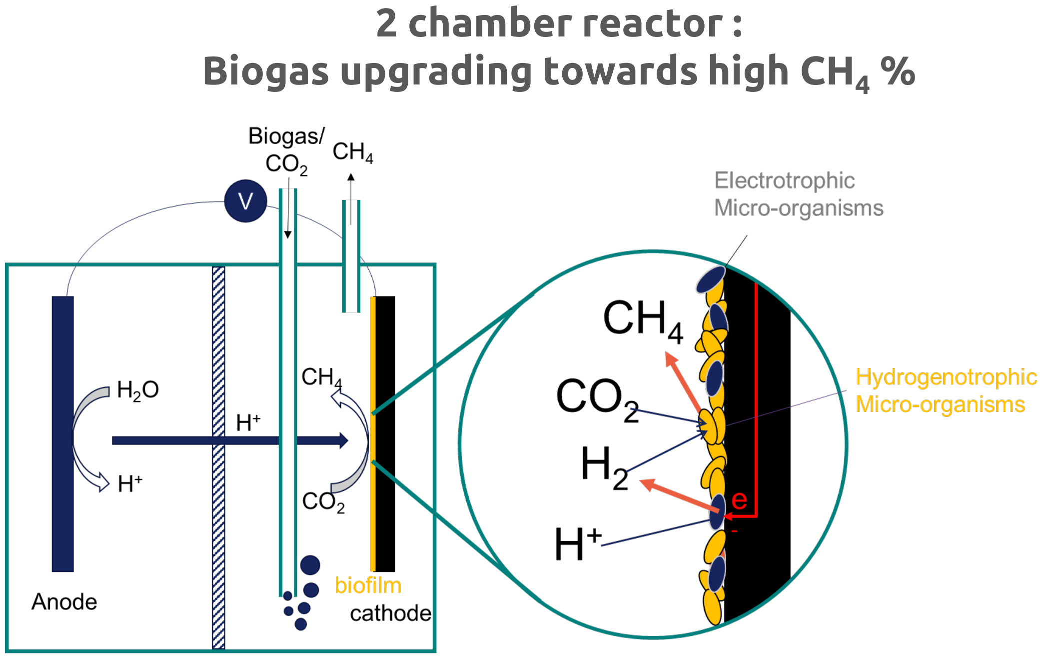
Main numbers:

- **30 GWh /y** of biomethane production
- **Up to 350 Nm^3/h** injected into NG grid
- **6,840 m^3** digestion volume (HRT> 50 d) :
    - 2 Main digesters of 2280 m^3
    - 1 Post-digester of 2280 m^3
- **27,000 m^3** of digestate storage / Valorization of digestate by land spreading
- (**6,000 ha**, **31** farms).

Co-funded by the European Union

Technology description





- 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

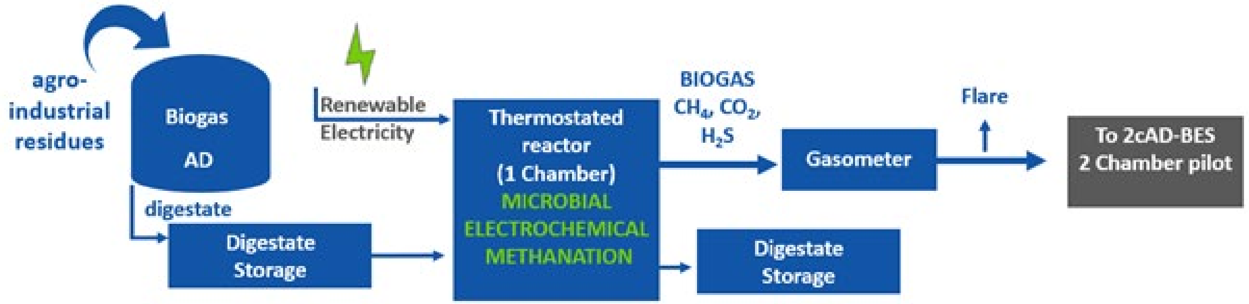
Ambition and progress beyond the state of the art

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

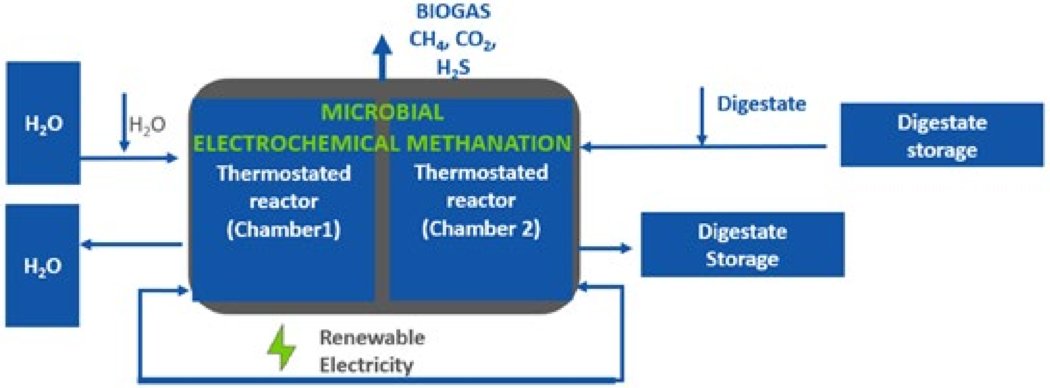
Single chamber reactor (1c-AD-BES)

- 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**



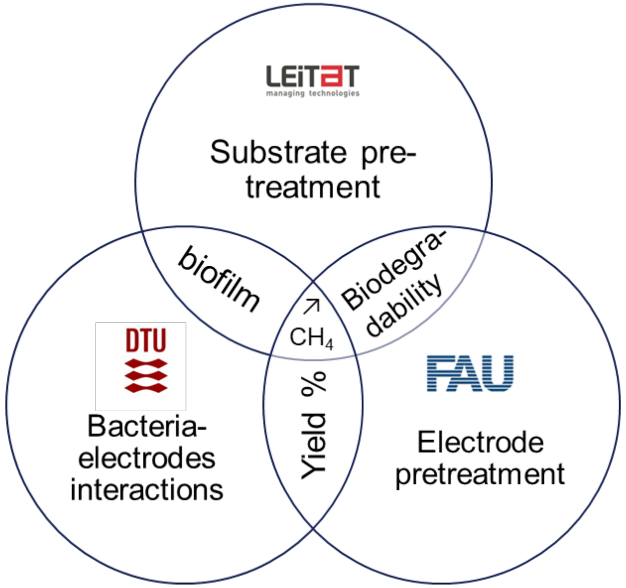
Co-funded by the European Union

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.
  - ➢ **trials ongoing (2023)** : (**LEITAT-DTU-FAU**)
    1. Pretreatment of electrode materials → maximizing the bioelectrochemical performances
    2. Pretreatment of the substrate (AD digestate) → facilitating the substrate degradation

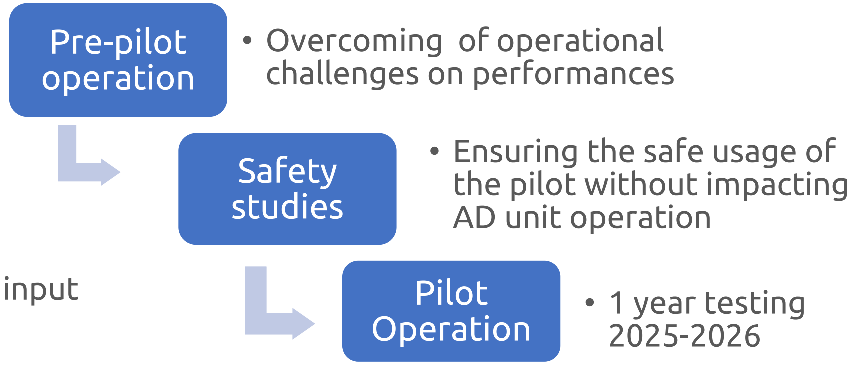


Operational challenges :

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

Safety challenges :

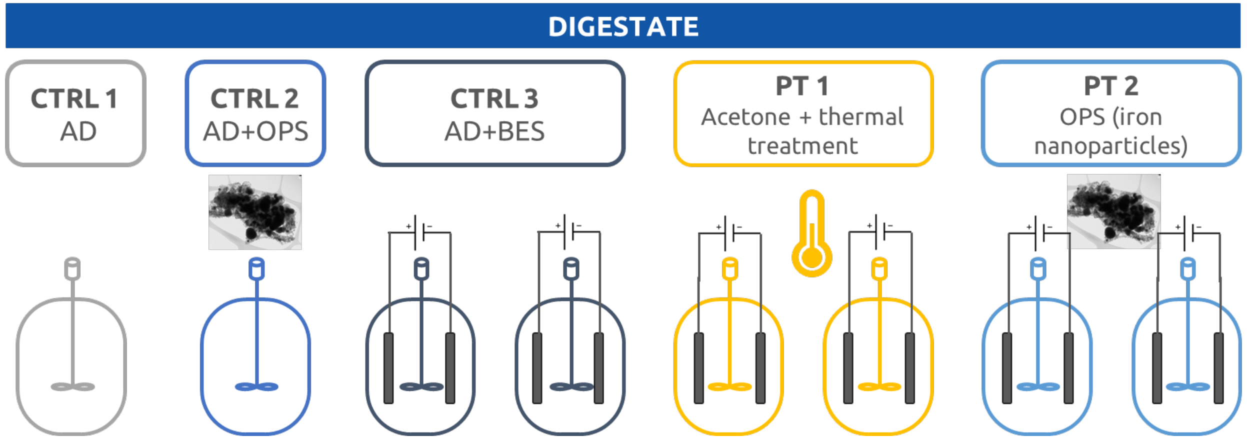
- Safe usage of the pilot on an operational demo-site
  - ➢ SAFETY Studies (ENGIE-AERIS) :
    - ➢ **HAZID study (Sept. 2023) :**
      Hazard identification considering the pilot in its environment
    - ➢ **ATEX study (2023) :**
      Identification of the ATEX zoning of the pilot and setting-up of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



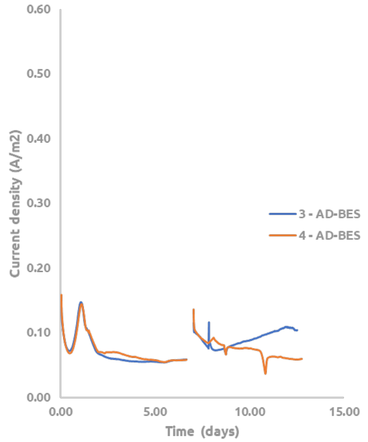
Co-funded by the European Union

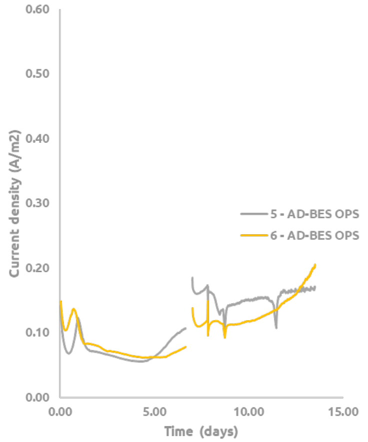
Single chamber reactor (1c-AD-BES)

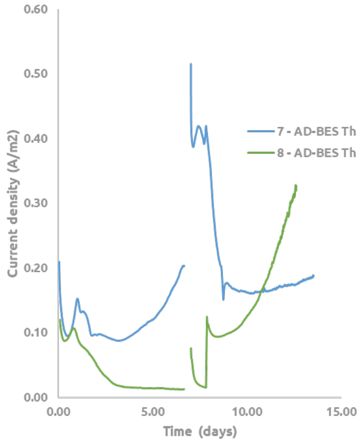
Electrodes characterization and pretreatment



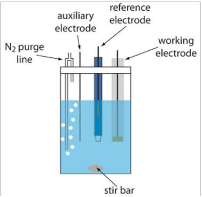
2 weeks of **inoculation** done – expected to last 4-6 weeks







Electrode characterization and pre-treatment tests for 1c-ADBES are ongoing

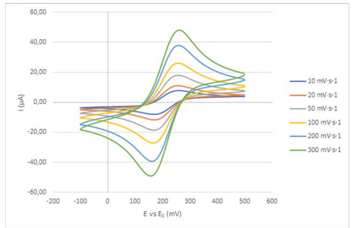


Working electrode	Counter electrode	Reference electrode
Carbon fibre brush	Titanium 3D electrode	Ag/AgCl/NaCl 3M

For **ECSA calculations** with abiotic electrode:

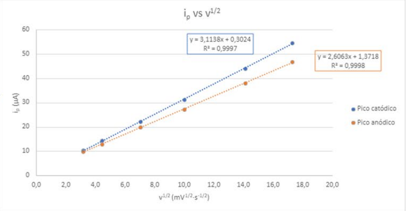
- Potassium hexacyanoferrate(III) 10mM
- KCl 0,5 M as support electrolyte
- Scan rate of 20, 50, 100 and 200 mV/s

Titanium wire that acts as current collector will be masked



Randles-Sevcik equation

$$I_p = (2{,}69 \cdot 10^5) n^{\frac{3}{2}} A C D^{\frac{1}{2}} v^{\frac{1}{2}}$$

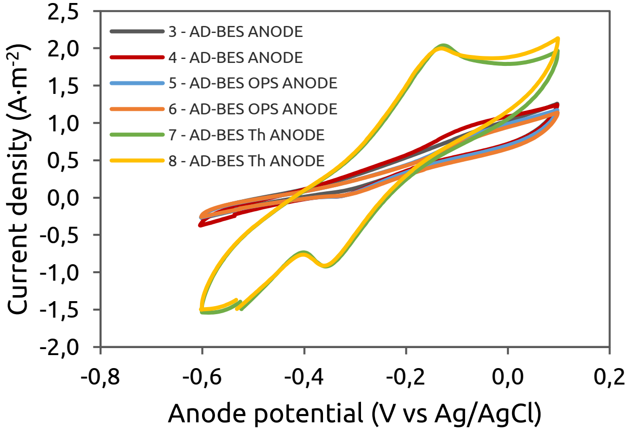


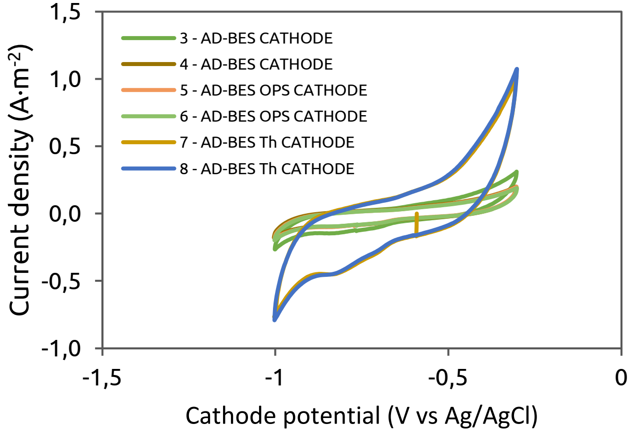
→ **Study of the electrochemical performances of the chosen electrodes with pre-treatment using liquid digestate (pilot conditions) from Eppeville AD plant**

Co-funded by the European Union

Single chamber reactor (1c-AD-BES)

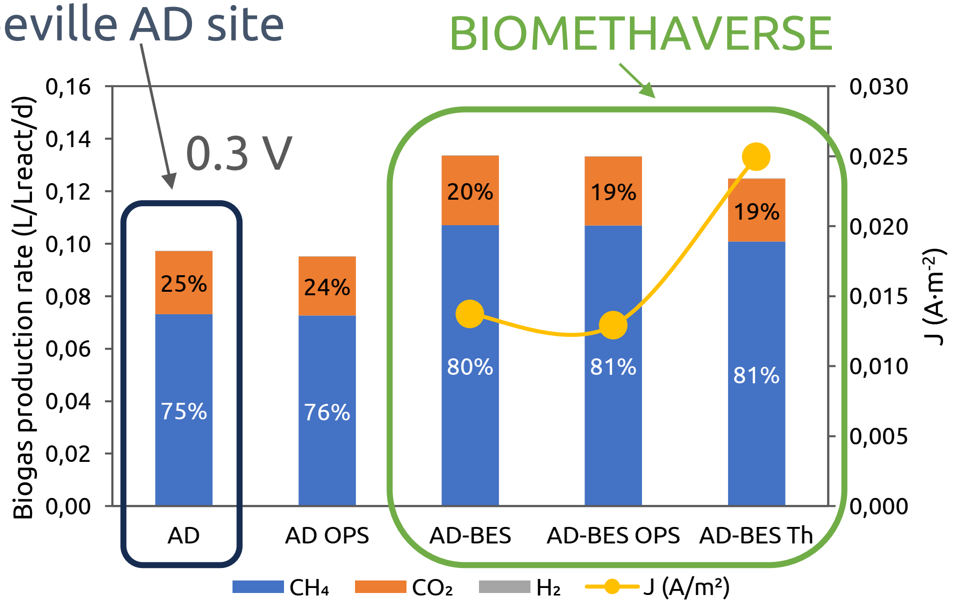
Electrodes characterization and pretreatment





Improved electrochemical performances are observed with thermal pre-treatment of électrodes at 0.3 V. Gas production is however slightly reduced compred to AD-BES reference

→ To be investigated at 0.7V



J (A·m-2)	CB-VER	Sieved digestate	Liquid digestate
AD-BES	0,023	0,026	0,014
AD-BES OPS			0,013
AD-BES Th			0,025
Methane production rate (L/Lreact·d)	**CB-VER**	**Sieved digestate**	**Liquid digestate**
AD			0,073
AD OPS			0,073
AD-BES	0,104	0,100	0,107
AD-BES OPS			0,107
AD-BES Th			0,101

Co-funded by the European Union

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

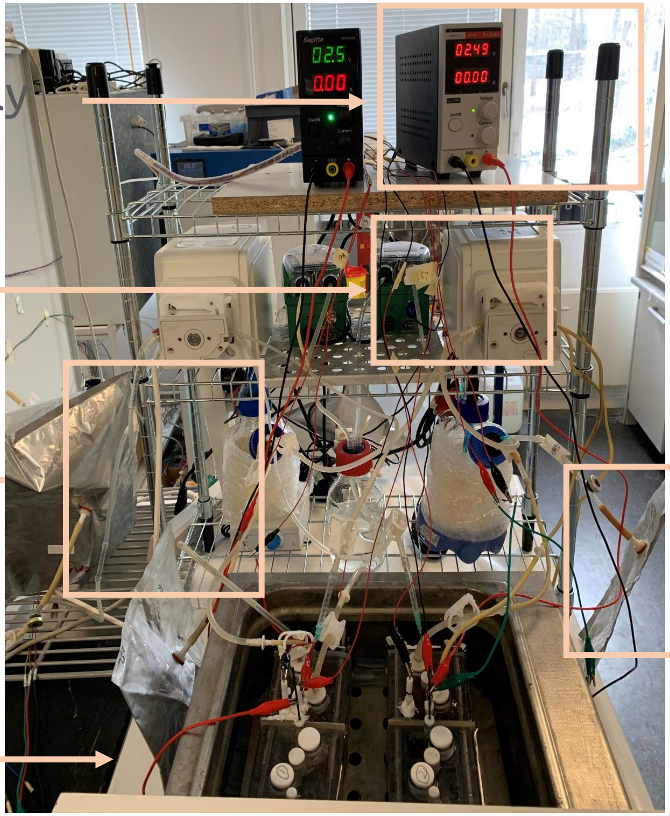
Power supply

pH Control

Raw biogas

60% CH_4, 40%

Water bath

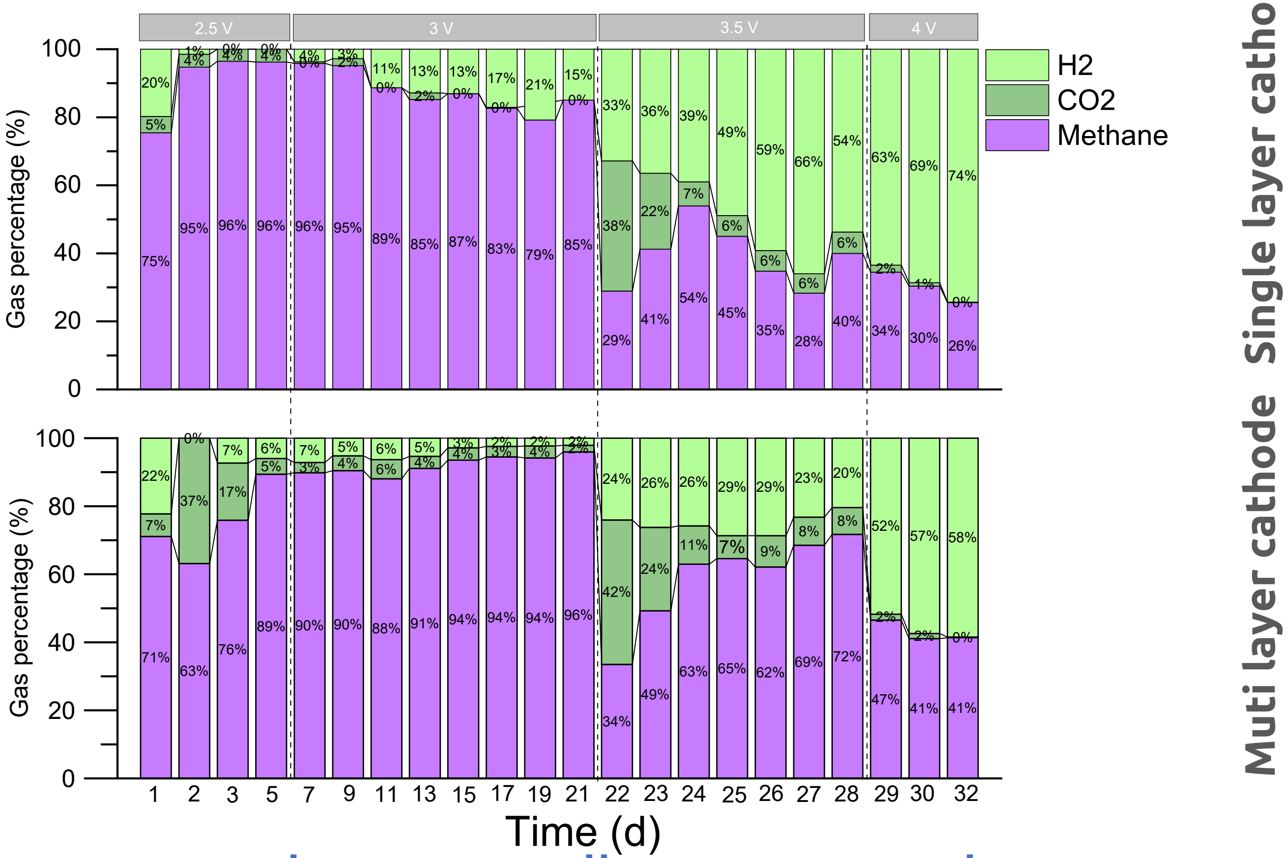


Upgraded biogas

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

Different Voltage to supply the water splitting

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



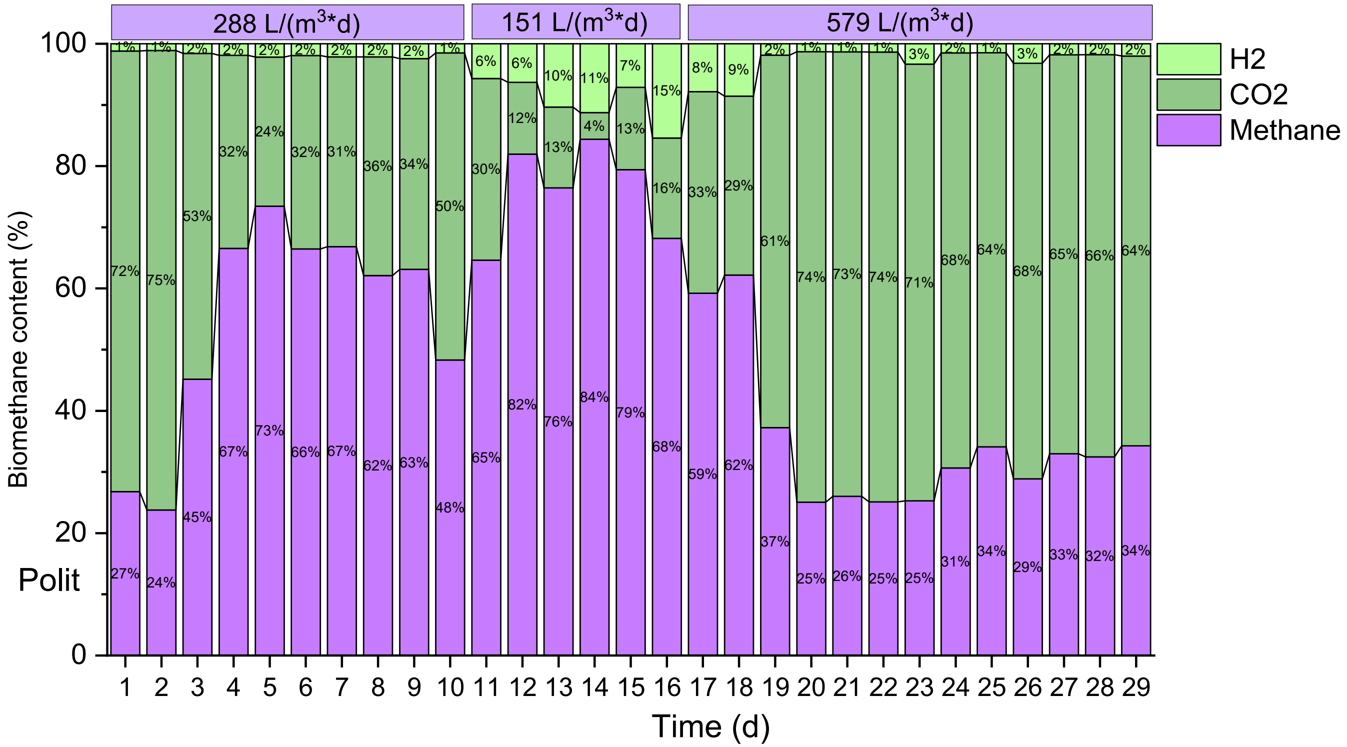
Optimized voltage for the size tested

Further biogas upgrading capability with higher voltage

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

Reactor engineering, pre-pilot (M4-M27)

Parameters optimization + control strategies:

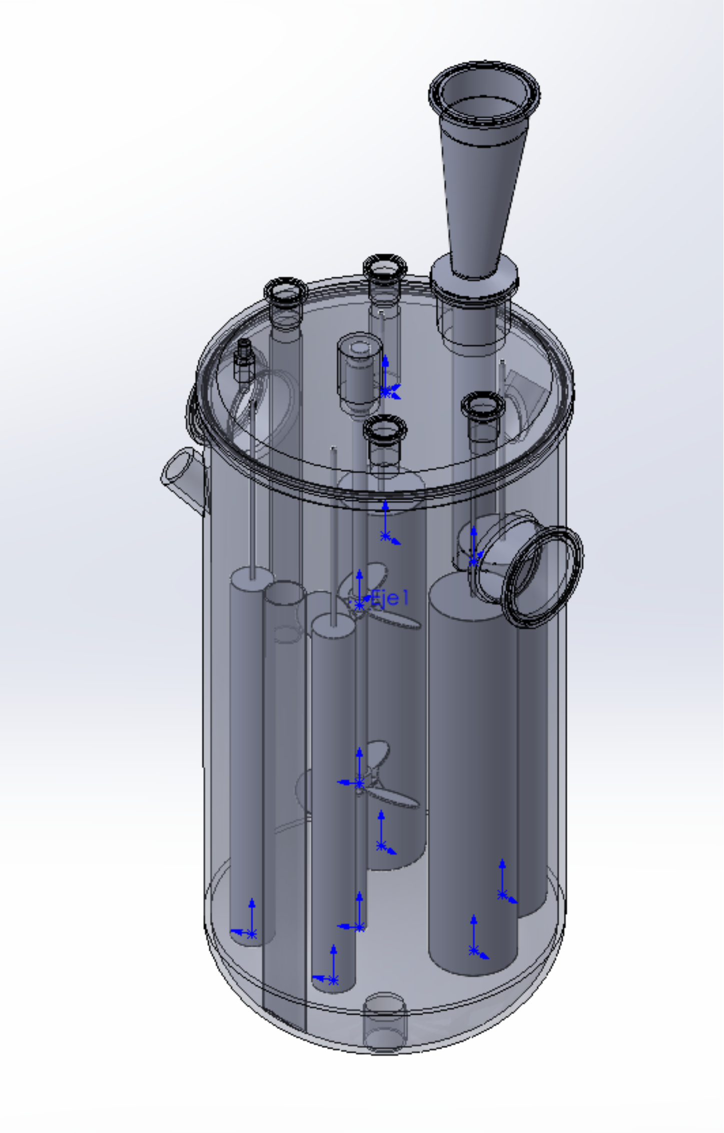
- Applied voltage with ON-OFF periods
- Switch ON/OFF the stirrer? Energy efficiency gained with it
- HRT to control ammonia inhibition[1]

Study of the response to perturbations:

- Organic overloading – difference between AD and AD-BES

Construction and start-up of pre-pilot

- Internal structure for the electrodes
  - Mesh around electrodes to avoid its contact with the reactor
  - Structure that joints all electrodes inside the reactor and goes out with two cables: anode and cathode



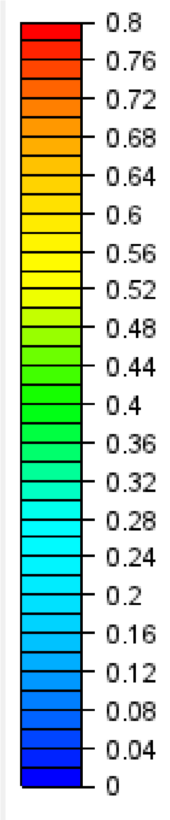
➢ **Reactor design under study at FAU side using CFD modelling** to better understand the influence of electrode presence on the flow dynamics of CSTR reactor (classicaly used for AD study)

1 S. Bhattacharya and G. F. Parkin, *Journal Water Pollution Control Federation*, 1989, **61**, 55–59.

Co-funded by the European Union

CFD simulations - 1c-AD-BES prepilot

Velocity – m s^{-1}

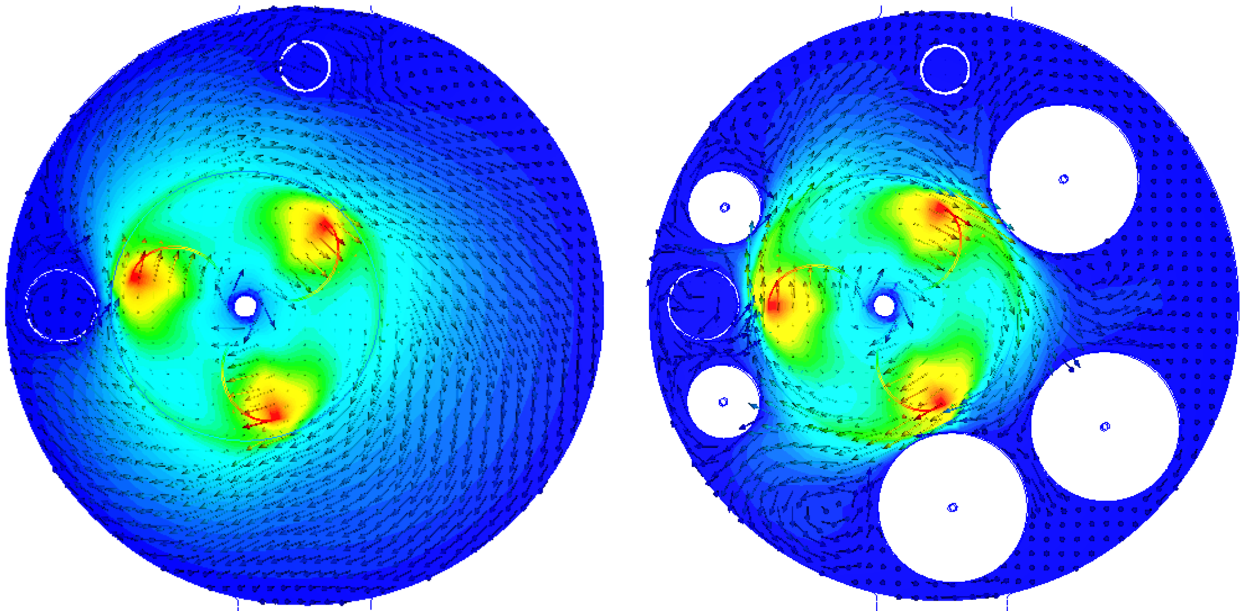


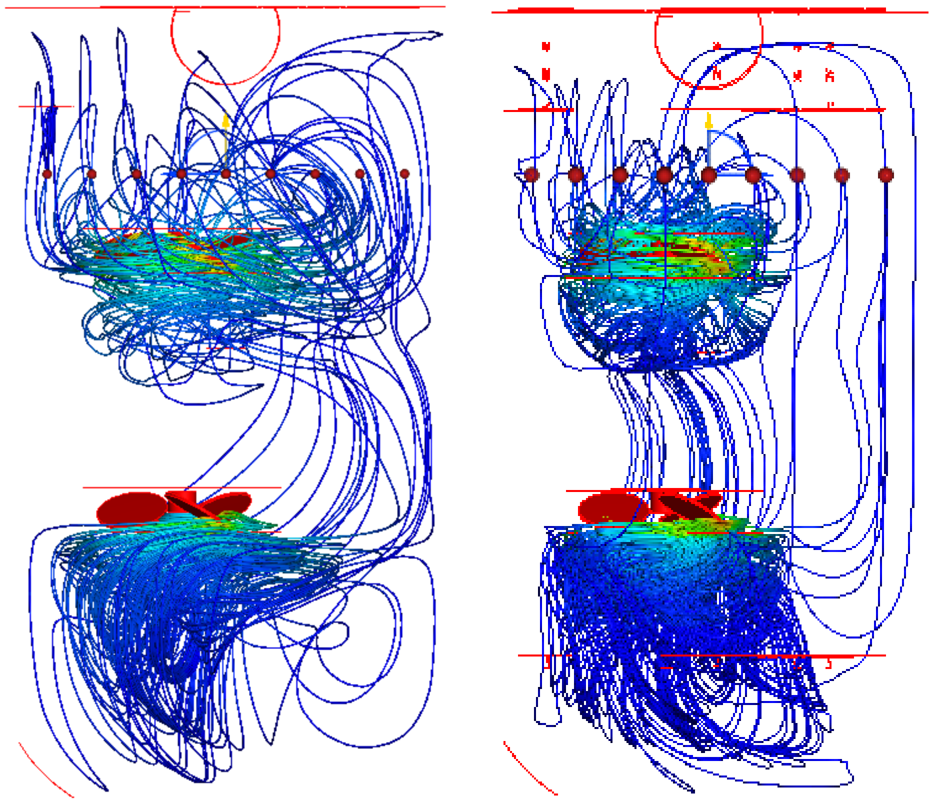
- Flow pattern
- Direction and magnitude of velocity of the fluid
- Visualization if the fluid flow in 2 and 2D

- Comparison of the reactor with and without the electrodes
- For determination of the influence of the electrodes

Without electrodes

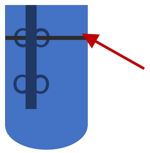
With electrodes





Without electrodes

With electrodes



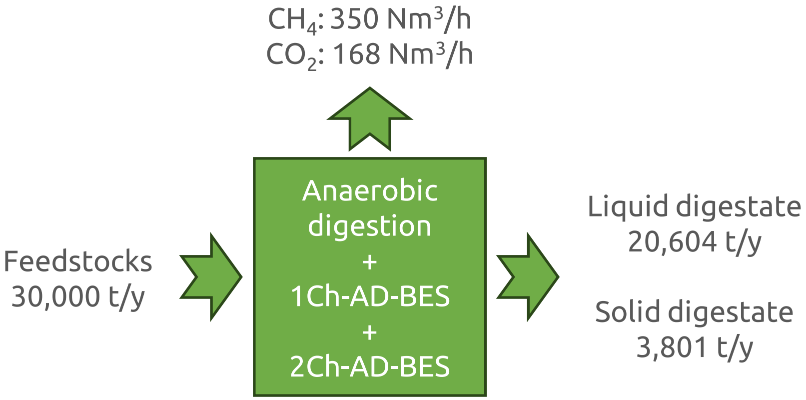
Location of the plane

Transient simulation
Turbulence model: k-epsilon model
Rotational speed: 200 rpm
Material data of water but with a higher viscosity of 0.84 Pas

AUTODESK CFD 2023

Co-funded by the European Union

Initial Business perspective



Scenario	AD reference case	+ 40% CH_4 production
CH_4 – Nm^3/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 :
- **Assessment and Optimisation** : *assessment of the demonstrators as built within the project, and of their potential optimised and upscaled configurations*
- **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: Gaspard Bouteau
Email: gaspard.bouteau@engie.com

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

Co-funded by the European Union