SEMPRE-BIO

EUBCE
33rd European Biomass Conference & Exhibition

Design and Assessment of a Novel Hybrid Low-Temperature Process for The Upgrading of Biogas

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Session code 3BO.9 – Biogas in biorefineries, Tuesday, June 10th 2025

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Outlines

1 **Introduction**

Role of biogas in the EU decarbonization strategy

2 **Process overview**

Process description and model assumption

3 **Results**

Main KPIs and other comments

4 **Conclusions**

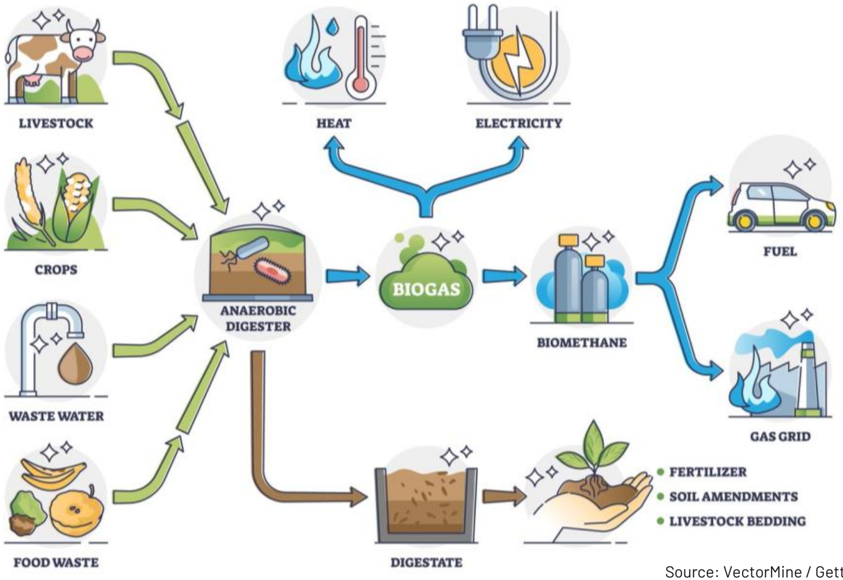
Achievements & future works

1.Introduction

Biogas production

- Mainly produced via **anaerobic digestion**
- **CH_4** content variable from **45 to 75 vol%**
- The remaining is **wet CO_2** with **traces of NH_3 and H_2S**
- **Upgrading** is necessary for applications of bio-CH_4 as **fuel** or **transport** (either gas o liquid)

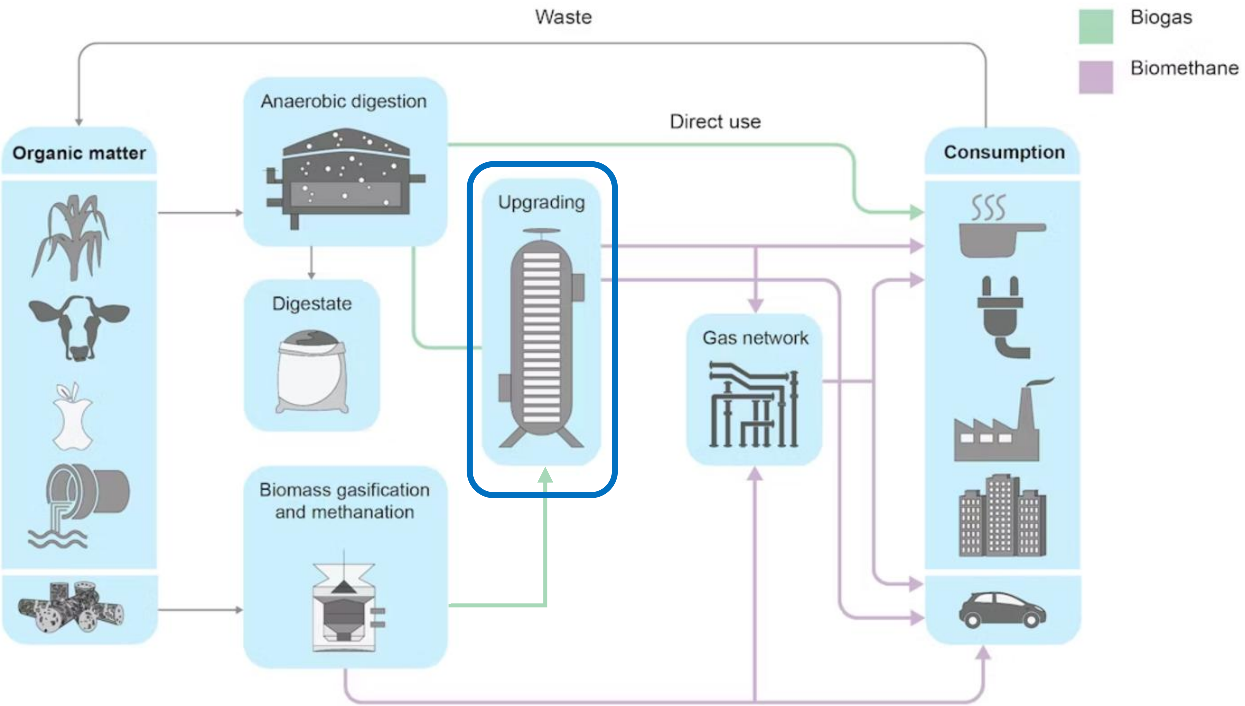
European Biogas Association - https://www.europeanbiogas.eu/
IEA - https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane



Source: VectorMine / Getty Images

Biogas production

- Upgrading is crucial to meet **specs for transport in the NG grid**
- Upgrading is also relevant for **liquefaction** and delivery (supply chain)



Source: IEA

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SEMPRE-BIO project

- SEMPRE-BIO aims at **demonstrating novel and cost-effective bio-CH_4 production solutions** to support the circular economy and **reduce dependence on fossil fuels**
- Biomethane production tested in **3 demo plants** across Europe accounting for **different feedstocks**

SEMPRE-BIO

SEcuring doMestic PRoduction of cost-Effective BIOmethane

Total funding € 9 926 450

HORIZON-IA

Case studies

Aigües de Barcelona, Barcelona, Spain

Terrawatt, Marmagne, France

Bio-CH_4 synthesis/production

De zwanebloem, De Panne, Belgium

Biogas upgrade and bio-CH_4 Liquefaction

Source: SEMPRE-BIO webpage

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2.Process

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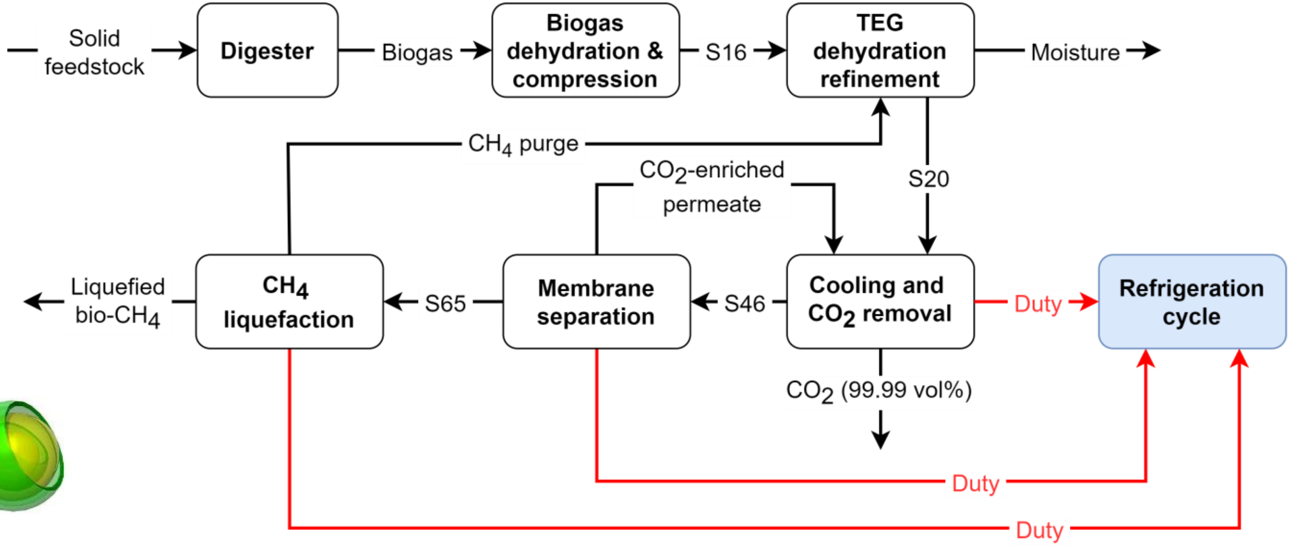
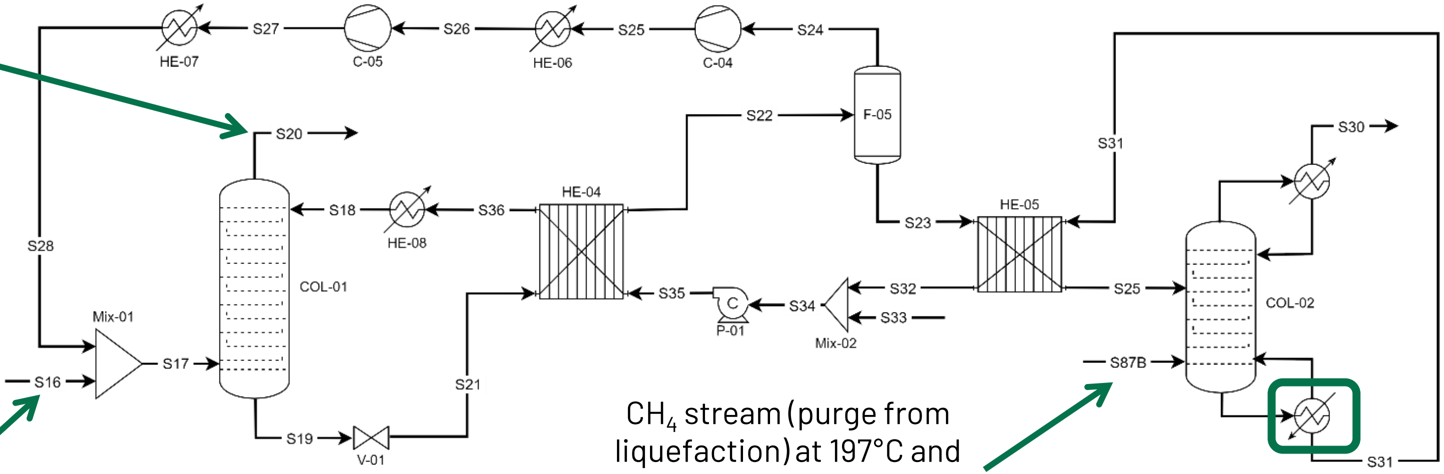
Block Flow Diagram

- **Upgrading** and **liquefaction** of bio-CH_4
- Application for transport of bio-CH_4 delivery in the absence of surrounding infrastructure (e.g., farms and remote biogas sites)
- Simulation in **COFE V3.6**, license-free simulation software by AmsterChem



TEG dehydration

Residue moisture in biogas **< 3 ppmv**

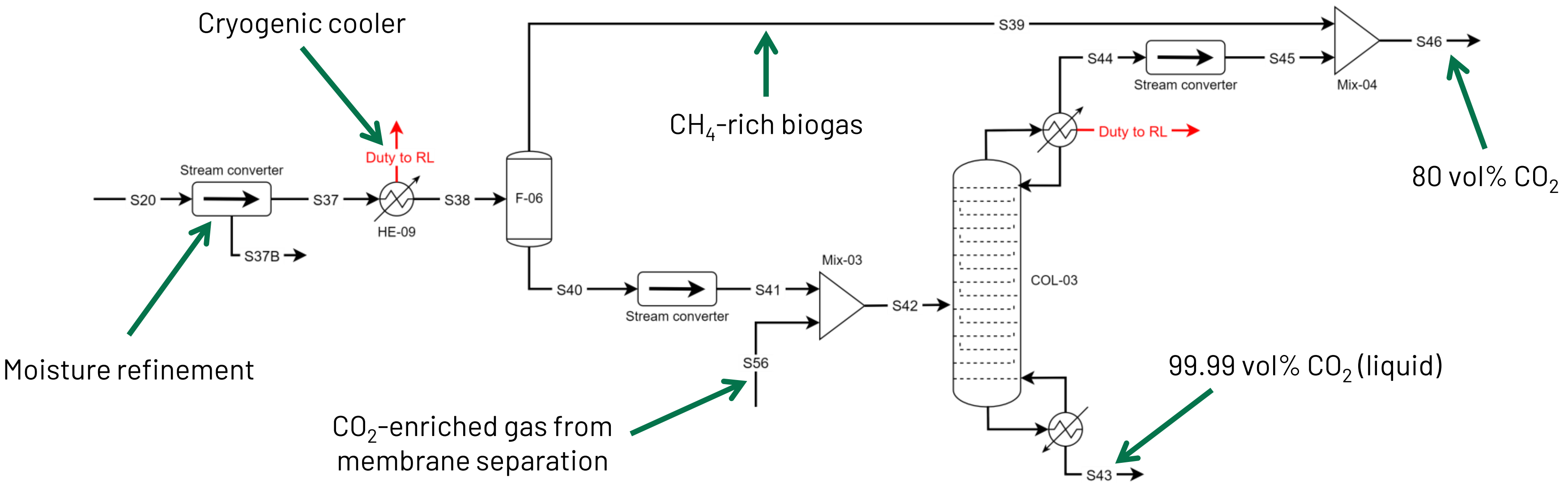


Compressed and purified biogas

CH_4 stream (purge from liquefaction) at 197°C and 5 bar as **stripping gas to lower the duty**

T < 210°C to prevent TEG degradation

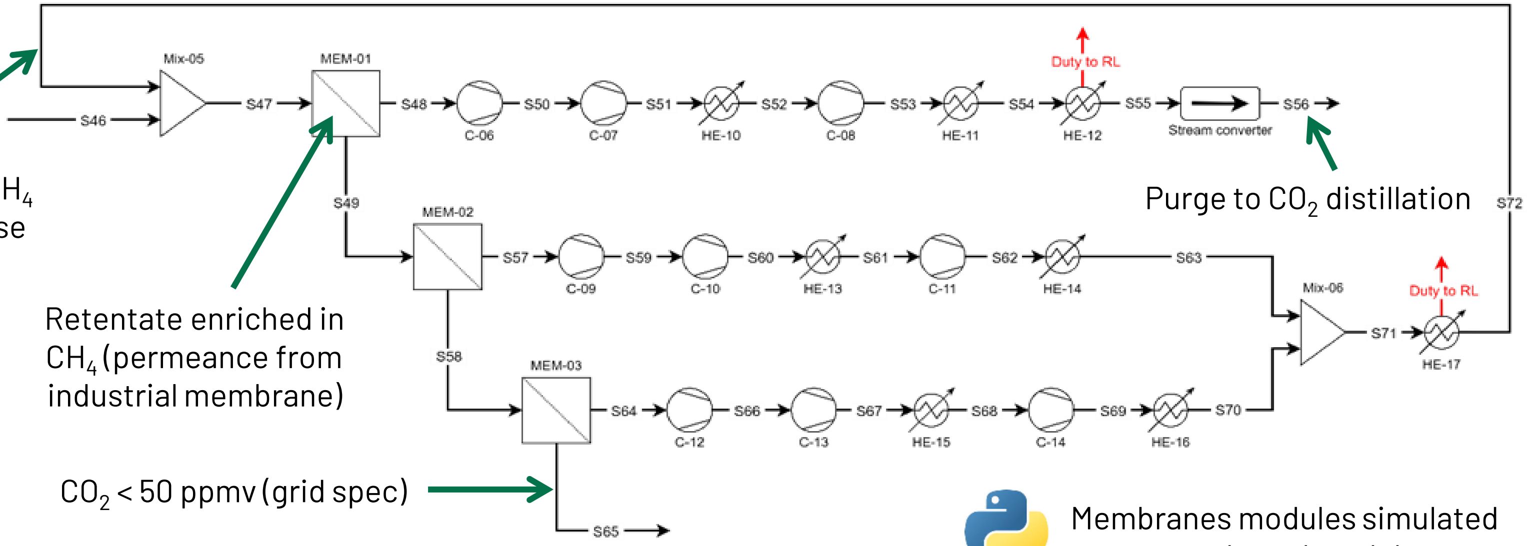
CO_2 removal



Cryogenic cooler
S39
S46
S44
S45
Stream converter
Mix-04
CH4-rich biogas
Duty to RL
Duty to RL
80 vol% CO2
Stream converter
S20
S37
S38
F-06
HE-09
S37B
COL-03
Mix-03
S40
S41
S42
Stream converter
S56
Moisture refinement
99.99 vol% CO2 (liquid)
CO2-enriched gas from membrane separation
S43

CO_2 refinement

Recycle: reduce CH_4 purity, but increase recovery



Retentate enriched in CH_4 (permeance from industrial membrane)

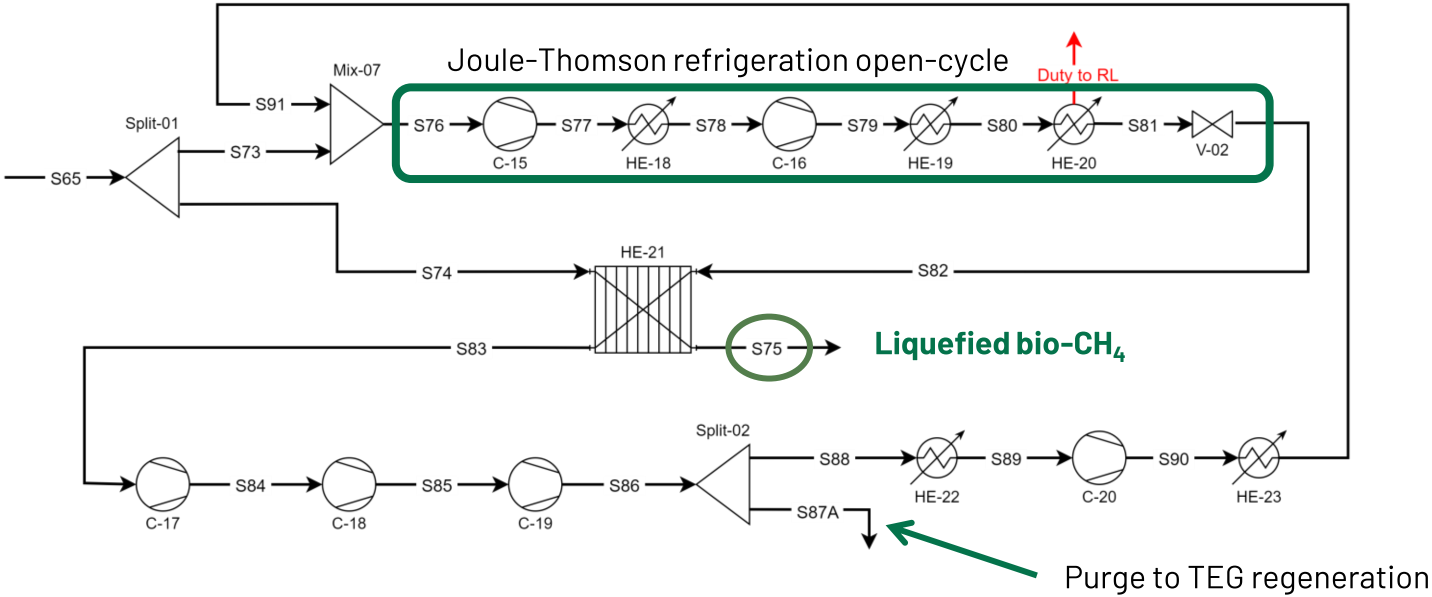
Purge to CO_2 distillation

CO_2 < 50 ppmv (grid spec)

Membranes modules simulated as custom-based modules

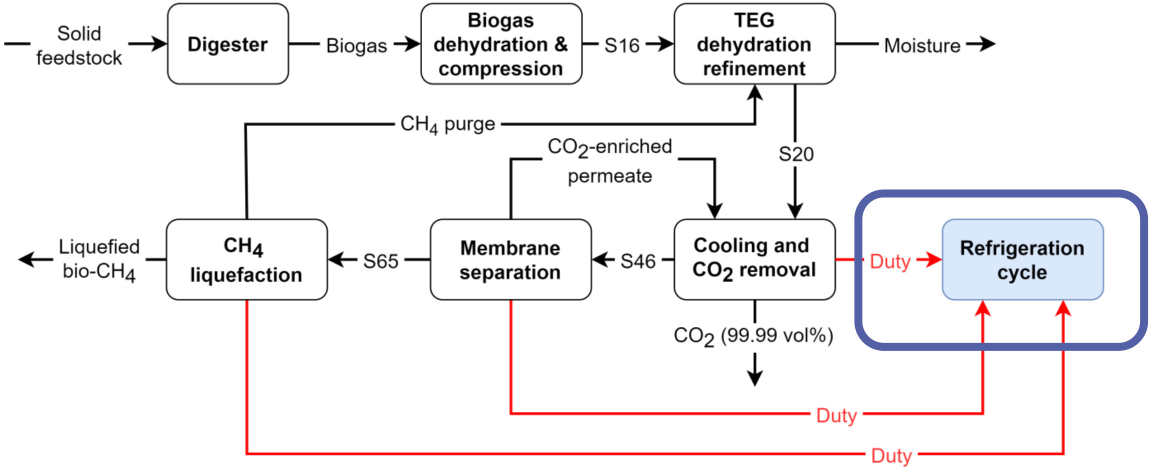
Nobandegani et al., Chemical Engineering Journal, 446, 4, 137223

CH_4 liquefaction



Cold box

- Cold box temperature is kept through an **external refrigeration loop** based on a **Joule-Thompson cycle**
- Working fluid is a mixture of C_2:C_3 hydrocarbon at 92:8 on a mass basis
- Pressure drop across the lamination valve is 45 bar

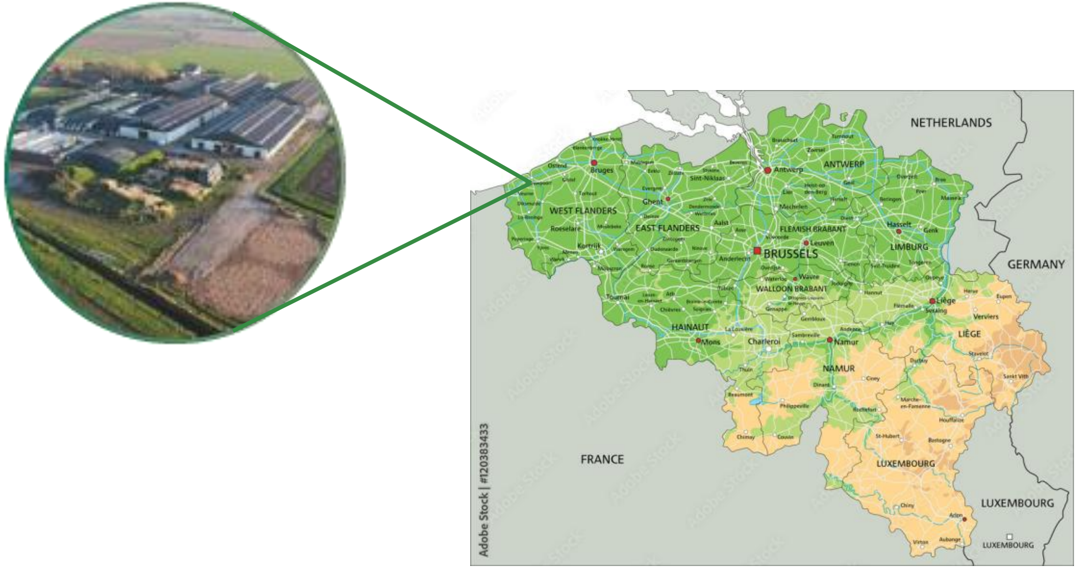


3.Results

Input data

- Manure is the solid feedstock
- Produced biogas is a sensitive info
- Biogas composition (used for the simulation)

CH_4	57.5 vol%
CO_2	39.5 vol%
Moisture	~ 3.0 vol%
H_2S/NH_3	~ 200 ppmv



Utilities

Electricity
Compressors
Pumps
Refrigeration loop
Air cooler

Cooling water
Heat exchanger
(interstage cooling)
Top condenser chiller
Reboiler of CO_2 distillation

Heat (steam)
TEG regeneration

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Results (KPIs)

Key Performance Indicator	Value	Note
CH_4 recovery (before liquefaction)	96.0%	Basis: mass flow bio-CH_4 in biogas from anaerobic digester Purity 99.99+ vol%
CH_4 liquefied	91.2%	After liquefaction cycle
CO_2 recovery	80.6%	Basis: bio-CO_2 in biogas from anaerobic digestor As liquid at 99.99 vol% purity

Results (KPIs)

Key Performance Indicator	Value	Note
Electricity demand	3.10 $kWh_{el}/kg_{CH4\ liq}$ 1.19 kWh_{el}/Nm^3_{biogas}	Normal condition: 1 bar and 0°C
Heat demand	0.38 $kWh_{th}/kg_{CH4\ liq}$ 0.15 kWh_{th}/Nm^3_{biogas}	
Steam demand	0.76 $kg/kg_{CH4\ liq}$ 0.29 kg/Nm^3_{biogas}	Saturated steam at 225°C (25 bar)
Cooling water demand	196.2 $kg/kg_{CH4\ liq}$ 75.6 kg/Nm^3_{biogas}	Assuming CW at 20°C and max discharge temperature 30°C

Comparison

KPI	Study work (no liquefaction)	MDEA 50 wt%	Optimised MDEA
CH_4 purity	99.99+ vol%	98 vol%	98 vol%
CO_2 purity	99.99 vol%	Off specs	Off specs
Pressure (bar)	Sensitive	2	2
Impurities in CH_4 and CO_2	Negligible	Moisture Volatile amine (limit 10 mg/Nm^3)	Moisture Volatile amine (limit 10 mg/Nm^3)
Electricity demand	0.80 kWh_{el}/Nm^3_{biogas}	0.10 kWh_{el}/Nm^3_{biogas}	0.10 kWh_{el}/Nm^3_{biogas}
Heat demand	0.15 kWh_{th}/Nm^3_{biogas}	0.30 kWh_{th}/Nm^3_{biogas}	0.26 kWh_{th}/Nm^3_{biogas}

MDEA 50 wt%: Pellegrini et al., Chemical Engineering Transaction, 43, 409-414   Optimised MDEA: Capra et al., Energy Procedia, 148, 970-977

Comments

- Cryogenic process delivers far purer CH_4 and CO_2 without moisture and potential corrosive amines
- Amine scrubbing studies limit their analysis to CO_2 and acid gas removal, but **further purification is disregarded**
- **Energy demand exponentially increases** as purity specs becomes strict and imposes limitations on which pollutants (and how much is tolerated)

KPI	Study work	MDEA 50 wt%	Optimised MDEA
CH_4 purity	99.99+ vol%	98 vol%	98 vol%
CO_2 purity	99.99 vol%	Off specs	Off specs
Impurities in CH_4 and CO_2	Negligible	Moisture Volatile amine	Moisture Volatile amine
Electricity demand (kWh_{el}/Nm^3_{biogas})	0.80	0.10	0.10
Heat demand (kWh_{th}/Nm^3_{biogas})	0.15	0.30	0.26

Comments

Amine scrubbing studies limit their analysis to CO_2 and acid gas removal, but further **post-processing is disregarded**

- Compression of bio-CH_4
- Amine and moisture removal
- CO_2 purification and compression

KPI	Study work	MDEA 50 wt%	Optimised MDEA
CH_4 purity	99.99+ vol%	98 vol%	98 vol%
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Impurities in CH_4 and CO_2	Negligible	Moisture Volatile amine	Moisture Volatile amine
Electricity demand (kWh_{el}/Nm^3_{biogas})	0.80	0.10	0.10
Heat demand (kWh_{th}/Nm^3_{biogas})	0.15	0.30	0.26

4.Conclusions

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To wrap up

- Biogas upgrading is a necessary step to **meet specs for biomethane transport** as liquid or in the natural gas grid
- Liquefaction (**cryogenic process**) is an alternative to **valorise biogas whenever the direct injection into the NG grid is not possible**
- Cryogenic purification has significant electricity consumption; however, delivers **both pure CO_2 and CH_4** (and pressurized)

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Acknowledgements

This project received funding from the EU's Horizon Europe programme under grant agreement Nº 101084297

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Thank you for your kind attention!

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