SEMPRE-BIO

Design of a novel process for biomethane production via thermochemical conversion of woody biomass

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Introduction

Biomethane production protects the environment by **recycling organic waste streams into renewable energy**, while simultaneously **reducing GHG emissions**.

The main **challenges** are:

1) **decrease** investment and operational **costs**
2) **optimize feedstock supply** and use
3) identify alternative and **cheaper feedstocks**
4) **improve** plant **efficiency** and operations
5) **monetize co-benefits from** the commercialization of **side-products**.

Biomethane production

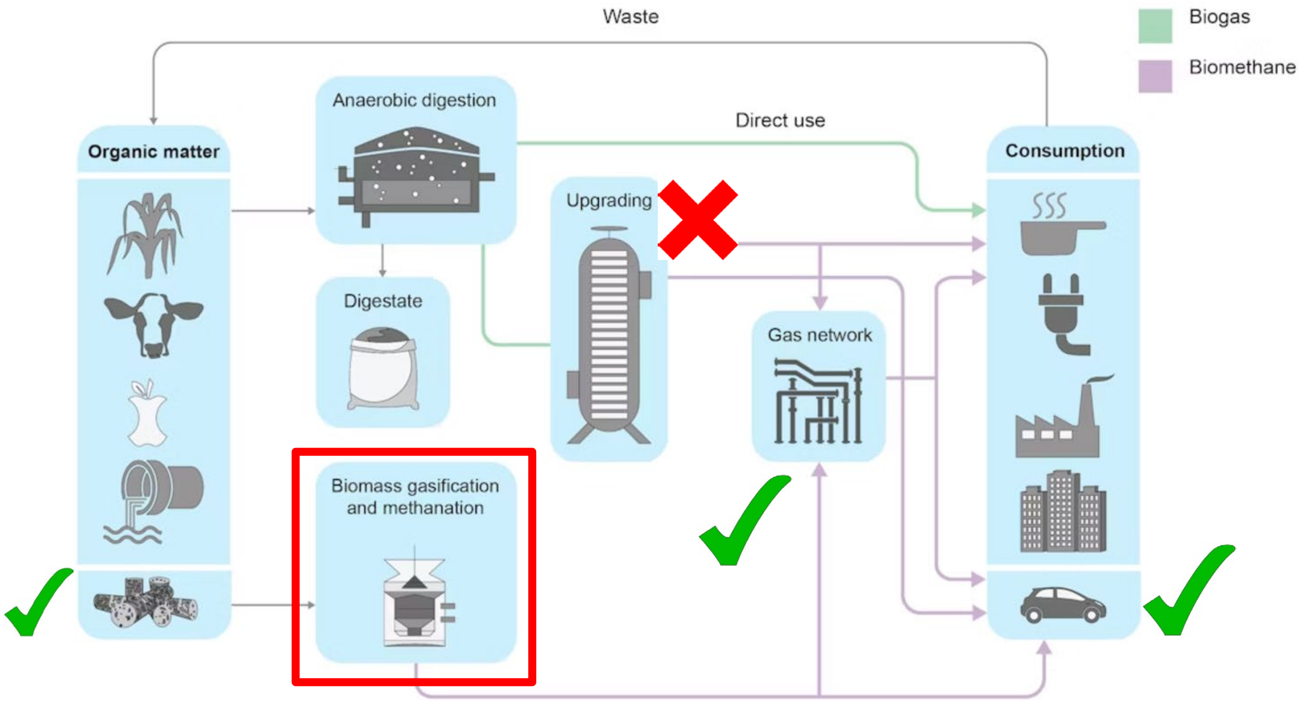
- **Over 95% of biomethane** is currently produced via **anaerobic digestion** of organic matter/waste [1].
- **Raw biogas** methane content ranges from 45% to maximum 75% [2], the remaining part is mainly CO_2
- Biogas must undergo **upgrading (CO_2 removal)** to meet the target purity and heating value.
- The **upgrading** step is **highly-energy intensive**

[1] European Biogas Association. Accessed: Jul. 09, 2024. [Online]. Available: https://www.europeanbiogas.eu/
[2] An introduction to biogas and biomethane – Outlook for biogas and biomethane: Prospects for organic growth – Analysis, IEA. Accessed: Jul. 09, 2024. [Online]. Available: https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane

Novel pathways to biomethane

- **Diversifying feedstock** is crucial to increase the biomass availability, address waste management issues, and **enhance the circular economy** in **different geographical contexts**.

- **Thermal gasification of solid biomass followed by methanation** is a promising alternative



The SEMPRE-BIO project

SEMPRE-BIO is an EU project targeting the **demonstration of** novel and **cost-effective biomethane production solutions** to support **circular economy** and **reduce dependence on fossil fuels**.

5 innovative biomethane production technologies will be **tested in 3 plants** through Europe.

International consortium with **partners from** research institutes, industry, academia, end-users and farmers.

SINTEF
DTU Technical University of Denmark
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SEMPRE-BIO

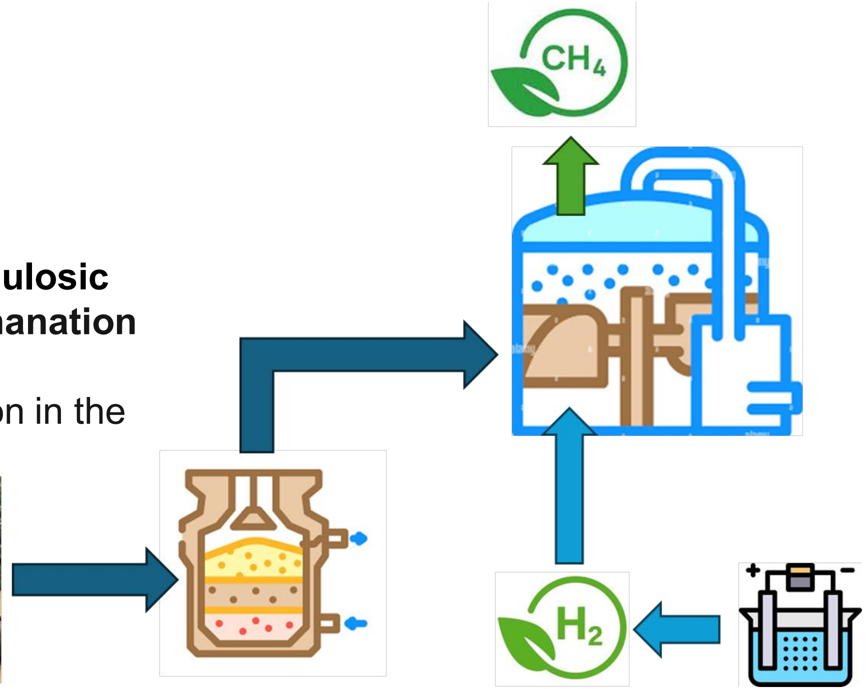
Aim of the work

This work deals with
(1) process design
(2) modelling
(3) evaluation of key Performance Indicators (KPIs)

for the **upgrading of syngas** obtained **through lignocellulosic biomass gasification** via **microorganisms-driven methanation**

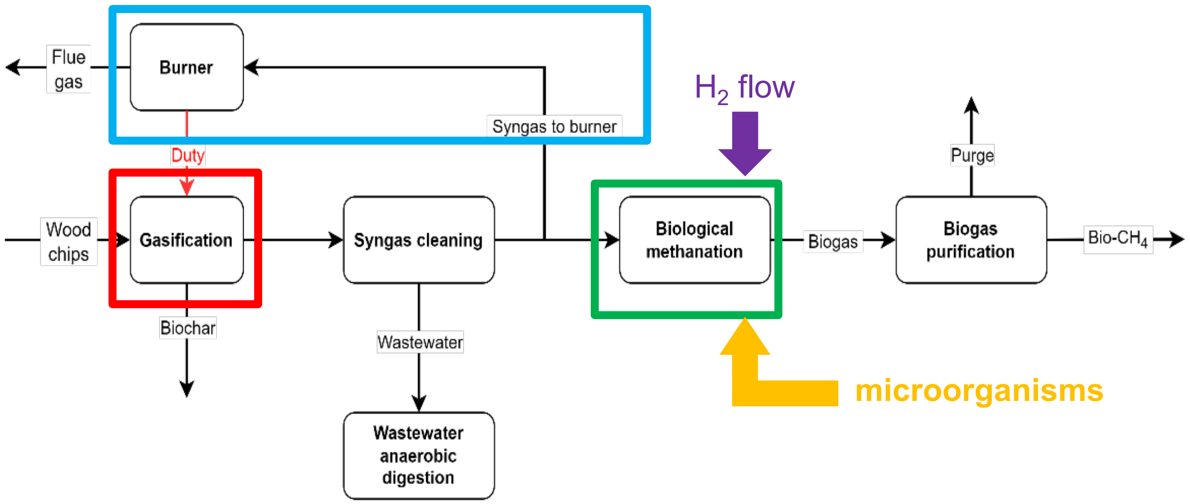
External green H_2 is added to improve carbon conversion in the methanation reactor

Plant **capacity**: **150 kg/h** of green waste **feedstock**



Assumptions for gasification

- Biomass composition shared by TERRAWAT
- **Gasification** chamber operates at a constant temperature of **725°C**
- **Autothermal gasification** (temperature is maintained by **recycling and burning 1/3** of the produced **syngas**)
- The **remaining syngas flow** (2/3) is conveyed to **bio-methanation**
- **External H_2 is added** to achieve the optimal H:C ratio for methanation
- Methanation uses **thermophilic organisms** (operation at 55°C)

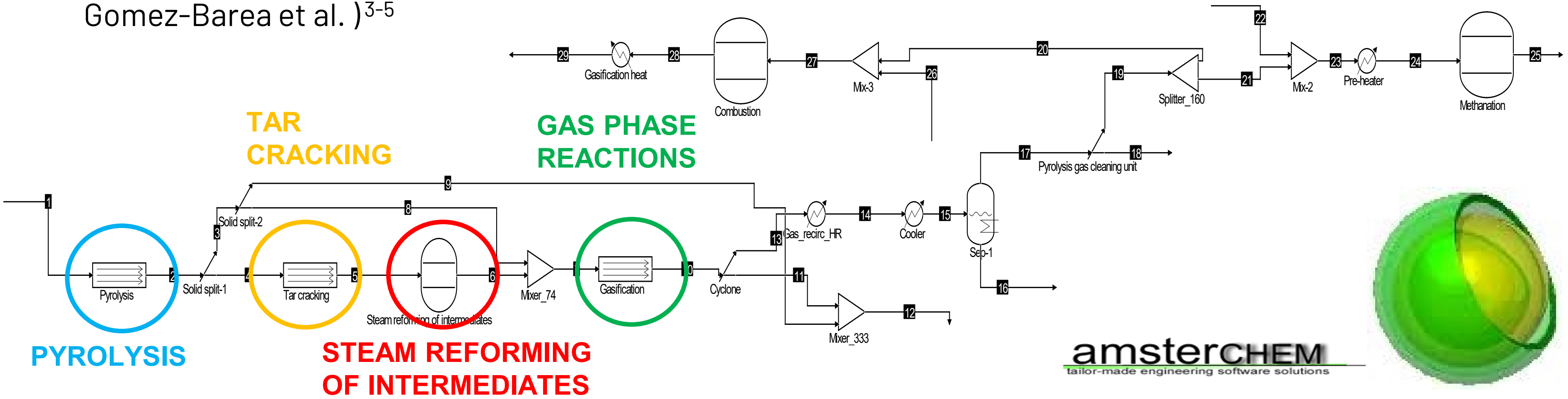


Modelling approach: gasification

Rigorous model for gasification implemented in **COCO-COFE** (license-free process simulator)

1. **Pyrolysis** (lumped kinetic model by Ranzi et al., 2017)[1]
2. **Tar cracking** reactions (kinetic model by Chen et al., 2021)[2]
3. **Steam reforming of intermediates** (conversion-based data-driven model)
4. **Gas-phase secondary reactions** (kinetic model by Chaurasia, Groeneweld, Gomez-Barea et al.)[3-5]

[3] https://doi.org/10.1021/acssuschemeng.6b03096
[4] https://doi.org/10.1016/j.cej.2020.127923
[5] https://doi.org/10.1016/j.energy.2016.10.037
[6] https://doi.org/10.1016/0009-2509(80)80101-1
[7] https://doi.org/10.1016/j.pecs.2009.12.002



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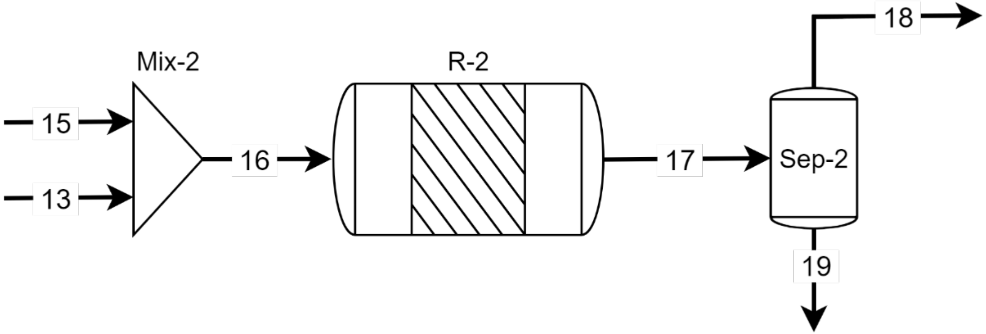
Gasification model validation

The **model** is **validated to the experimental data** shared from a **pilot facility** owned by AEnergy.

Dry wt% composition	Deviation
CO	3.79%
CO_2	3.43%
H_2	3.06%
CH_4	53.5%
C1+C2 hydrocarbons	13.7%
Humidity	4.28%
Char	0.01%

CS2: bio methanation reactor model

- **Bio-methanation** of CO and CO_2 is modelled using a **soft model retrieved from the literature** [1].
- No validation to in-house project data has been performed so far.



$$CO + 3\ H_2 \rightarrow CH_4 + H_2O$$

$$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$$

$$4\ CO + 2\ H_2O \rightarrow CH_3COOH + 2\ CO_2$$

The degree of advancement of the three reactions has been tuned to meet the following targets:

- all the CO is consumed (limiting reactant);
- the **purity** of the produced **biomethane** is **95 vol%** on a dry basis [1];
- the acetic acid accumulating in the product stream is 1.5 dry vol% (stoichiometric $H_2/CO/CO_2$ ratio) [1].

[1] https://doi.org/10.1016/j.biortech.2020.123739

Results

KPI	Value
Thermal energy for gasification [kW]	113 (3.8 MJ/kg dry feedstock)
External H_2 demand [kg/h]	5.92 (**60 g/ kg dry feedstock**)
Biomethane **productivity** [kg/h]	21.2 (**210 g/ kg dry feedstock**)
Biomethane **purity**	**96.5 vol%**
Impurities	3 vol% CO_2 0.2 vol% ethane and ethylene ppm vol% of CO and H_2

Innovation and relevance

INNOVATION

- **Autothermal process** via syngas recycling
- Non-fermentable **green waste valorization**
- **No catalyst** needed
- Substantial **lowering of operating temperature** (from >300°C down to **55°C**)
- Improvement of **circularity**

IMPACT

- **Accelerate** commercial-scale **development across Europe**
- **Decentralized energy** source for **local communities**
- **Cooking fuel** for **developing countries**
- Make **EU energy self-sustained**
- Side **production** of **bio-char**, (energy supply from green origin)

Conclusions and future developments

- Key **milestones** in **conceptual development and preliminary feasibility assessment** (modelling, KPIs estimation) **achieved for a novel biomethane production pathway**.

- The novel **process** does not require **any external heat source**

- **Hydrogen** is the main raw material input – the **main expected OPEX** for the plant

- The **residual CO_2 content** (3 vol%) in the produced biomethane **reaches the limit** allowed in **natural gas grids** (typically 2-3 vol%)

- **Results** from this preliminary study will be used as a **basis** to perform a detailed **comparative economic and life-cycle assessment**.

Acknowledgements

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Thank you!

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