SEMPRE-BIO

EUBCE 2025

# Design of a Novel Process for Biomethane Production via Thermochemical Conversion of Woody Biomass

## EUBCE 2025 (Valencia, Spain)

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SINTEF

Funded by the European Union

# Introduction – 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**

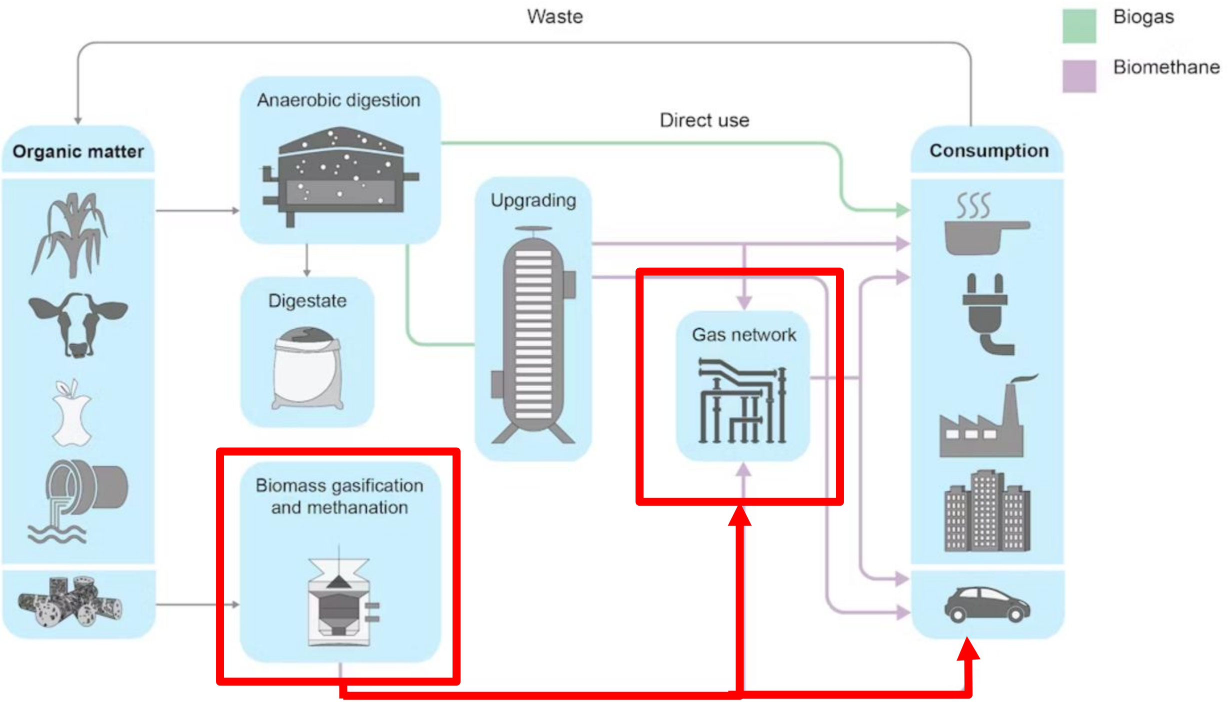

[1] European Biogas Association. Accessed: Jul. 09, 2024. [Online]. Available: https://www.europeanbiogas.eu/
[2] An introduction to biogas and biomethane – Outlook for biogas and biomethane: Prospects for organic growth – Analysis, IEA. Accessed: Jul. 09, 2024. [Online]. Available: https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-orga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

# Novel pathways to biomethane

**Diversifying feedstock** is crucial to:

- increase the biomass availability
- address waste management issues
- **enhance circular economy** in **different geographical contexts**.

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



# The SEMPRE-BIO project

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

**3 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.

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# Aim of the work

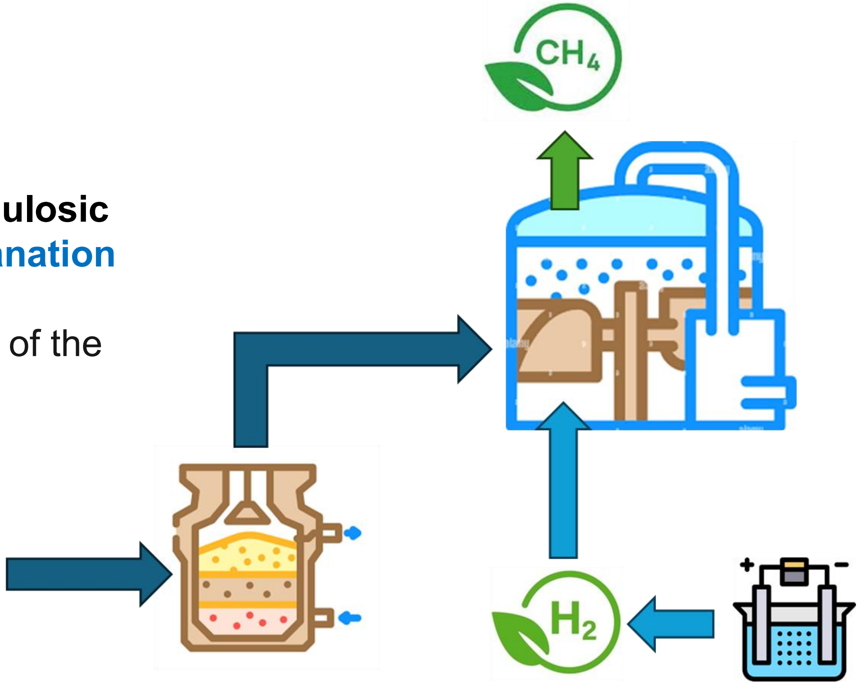
This work deals with
**(1) process design and modelling**
**(2) evaluation of key Performance Indicators** (KPIs)

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

**Authothermal gasification** through **recirculation** of part of the produced **syngas**

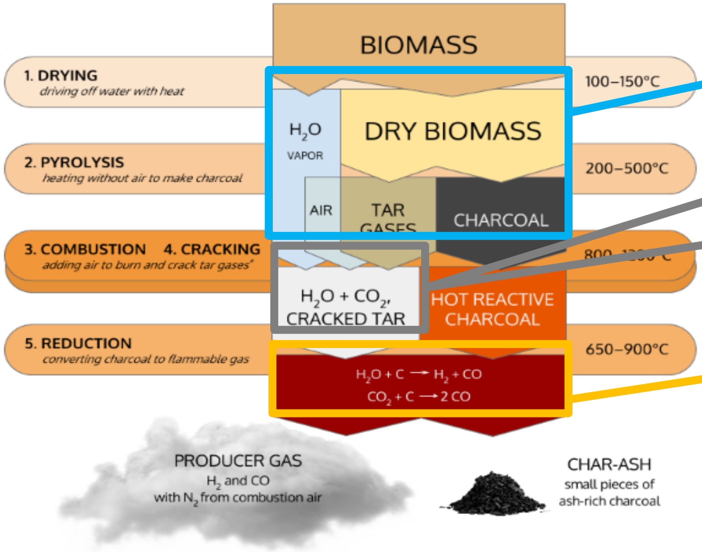
**External green $H_2$ is added** to improve the carbon conversion in the methanation reactor

Demo-plant **capacity**: **150 kg/h** of green waste **feedstock**



# Model for biomass gasification

**Gasification is a multi-step process !**




1. **Pyrolysis** (lumped kinetic model by Ranzi et al., 2017)[3]
2. **Tar cracking** reactions (kinetic model by Chen et al., 2021)[4]
3. **Steam reforming of intermediates** (Gibbs reactor)
4. **Gas-phase secondary reactions** (kinetic model by Chaurasia, Groeneweld, Gomez-Barea et al. )[5-7]

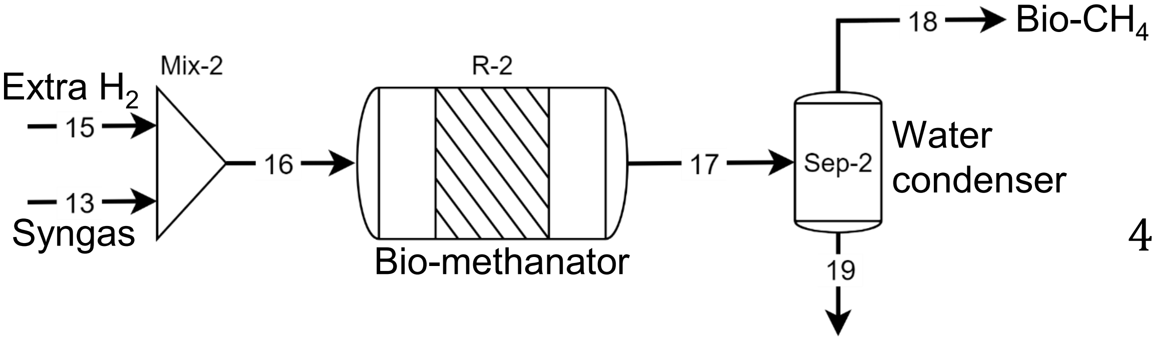
Only **rigorous models** allow for:

- **Handling a change** in **feedstock** and/or **operating conditions**
- **Sizing** the units


[3] Ranzi E., Debiagi, P.E.A., Frassoldati, A., 2017. ACS Sustainable Chemistry & Engineering 5, 4, 2867–2881. https://doi.org/10.1021/acssuschemeng.6b03096
[4] Chen, T., Ku, X., Li, T., Karlsson, B.S.A.,, Sjöblom, J., Ström, H., 2021. Chemical Engineering Journal, 417, 127923. https://doi.org/10.1016/j.cej.2020.127923
[5] Chaurasia, A., 2016. Energy, 116, 1, 1065-1076. https://doi.org/10.1016/j.energy.2016.10.037
[6] Groeneveld, M.J., van Swaaij, W.P.M., 1980. Chemical Engineering Science, 35, 1-2, 307-313. https://doi.org/10.1016/0009-2509(80)80101-1
[7] Gómez-Barea, A., Leckner, B., 2010. Progress in Energy and Combustion Science, 36, 4, 444-509. https://doi.org/10.1016/j.pecs.2009.12.002

# Bio-methanation reactor model

- **Bio-methanation of CO and $CO_2$** is modelled using a **soft model retrieved from the literature** [1].
- **Validation using in-house project data** to be performed in Q3 2025.




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

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

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

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].

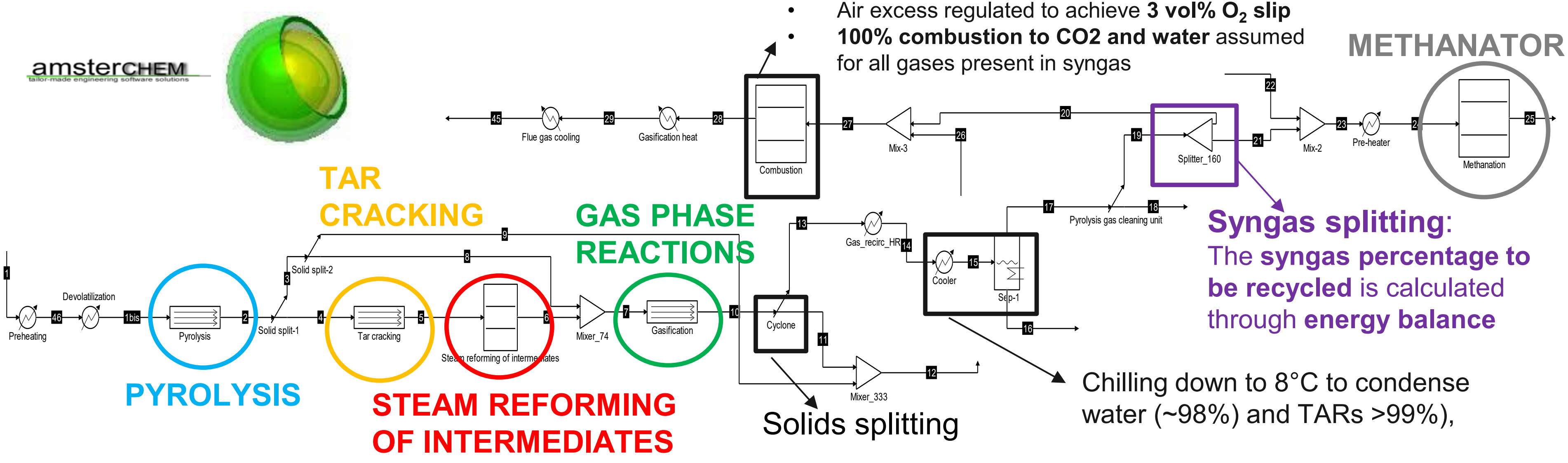
[1] https://doi.org/10.1016/j.biortech.2020.123739

# Model for biomass gasification

- **Pyrolysis chamber**, **tar cracking**, and **gas phase reactors** modelled as **PFR** → reactors **sizing** is **available**
- **Steam reforming** modelled as **Gibbs reactor** → TDM equilibrium assumed
- **Biomethanator** modelled as a **conversion reactor**

**Combustion** chamber

- Air excess regulated to achieve **3 vol% $O_2$ slip**
- **100% combustion to CO2 and water** assumed for all gases present in syngas



# Results – gasification chamber sizing

| Gasifier section | Criteria for sizing | Estimated volume (liters) |
|---|---|---|
| Pyrolysis | 80% lignin conversion | 24 |
| Cracking | 95% conversion of species with medium-rate cracking (phenol) | 126 |
| Gas-phase reactions | Equilibrium approached – constant $CO/CO_2/H_2$ profiles | 63 |

- **120% increase** needed to obtain the **total gasifier volume**
- The **volume increase** accounts for **back mixing, heat-exchange areas**, and **char recovery**
- **Sizing reliability verified** with **TERRAWATT gasification pilot** (France)

# Gasification model results – mass balance

| Dry wt% composition | Model prediction |
|---|---|
| CO | 10.35% |
| $CO_2$ | 21.11% |
| $H_2$ | 40.45% |
| $CH_4$ | 6.00% |
| $C_2H_4$ | 2.28% |
| Humidity (%) | 19.87% |
| Char mass (kg/h) | 24.01 (0.23 kg/kg dry biom.) |

The **model** will be **validated to the experimental data** from a **pilot facility** owned by TERRAWATT to be commissioned in June 2025.

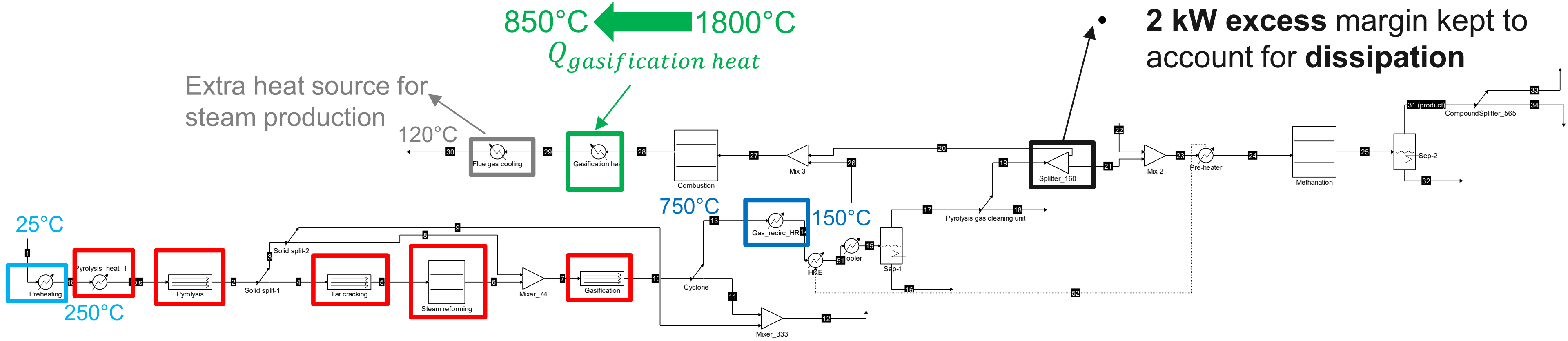
# Gasification model results – energy balance

**Autothermal** conditions → $Q_{gasification\ heat} = Q_{net,gasification\ chamber}$

$$Q_{net,gasification\ chamber} = Q_{devolatilization} + Q_{pyrolysis} + Q_{cracking} + Q_{reforming} + Q_{gas\ reactions}$$

**Heat recovery** → $Q_{preheating} = Q_{gas\ recirc\ HR}$

- Split ratio adjusted
- **64.5% of biogas is sent to methanation**
- **2 kW excess** margin kept to account for **dissipation**



# Bio-methanation – Key performance indicators

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| KPI | Value |
|---|---|
| Processed woody biomass [kg/h] | 150 (105 dry matter) |
| External $H_2$ demand [kg/h] | 5.61<br>(**0.19 kg/kg biomethane**) |
| Biomethane **productivity** [kg/h] | 28.90<br>(**0.28 kg/ kg dry feedstock**) |
| Biomethane **purity** | **96.5 vol%** |
| **Impurities** | ~3 vol% **ethylene**<br>3.2 vol% $\mathbf{CO_2}$<br>30 ppm CO |

# 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%)

- **Model verification to pilot data** from TERRAWATT (France) **planned** for Q3 2025

- **Results** from this preliminary study will be used to perform a detailed **comparative economic (TEA) and life-cycle assessment (LCA)**.

# Acknowledgements

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# Thank you!

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