Anaerobic digestion (AD)

– two additional routes for increasing production of renewable methane

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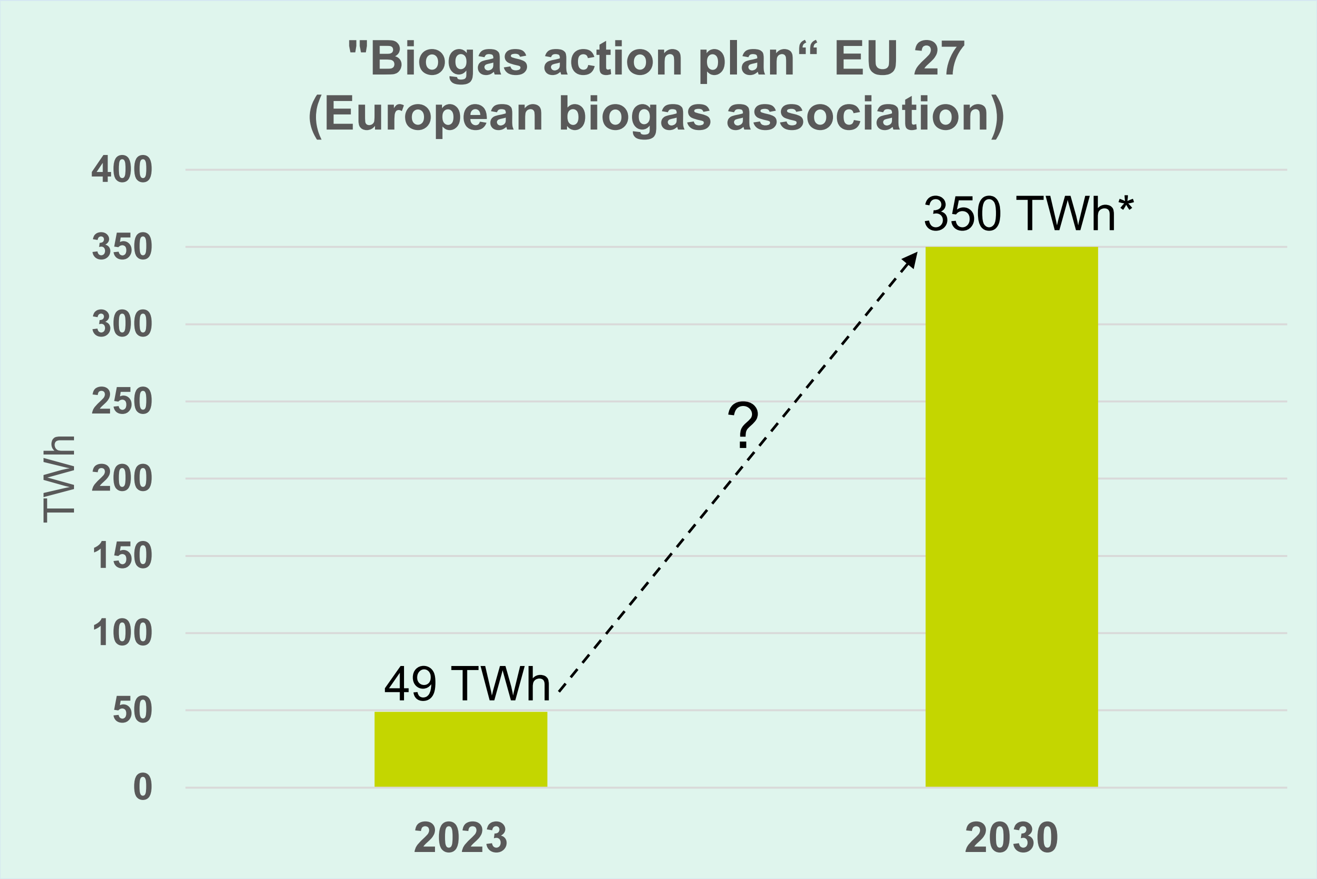
Biomethane: Europe and Sweden

- Need to diversify supply and reduce dependence on external gas providers.
- ”RePowerEU” plan launced by the European Commission (2022)



Swedish biogas production: ca 2.3 TWh

Swedish import: ca 2 TWh

Industrial demand: 10 TWh

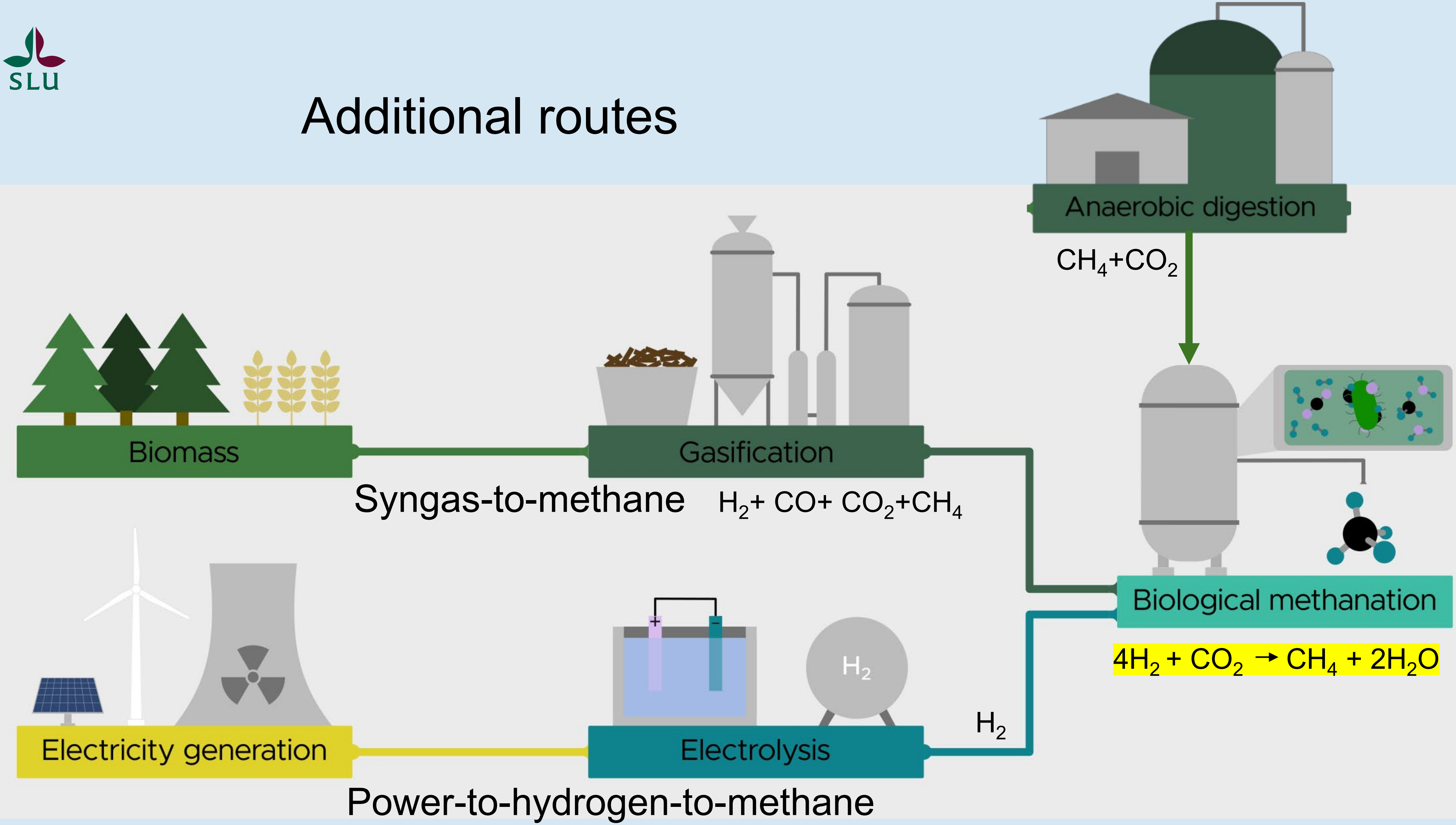
(Industry biogas commission)

Feedstock potential: 5-15 TWh

Potential of forestry residues: 4-12 TWh/y

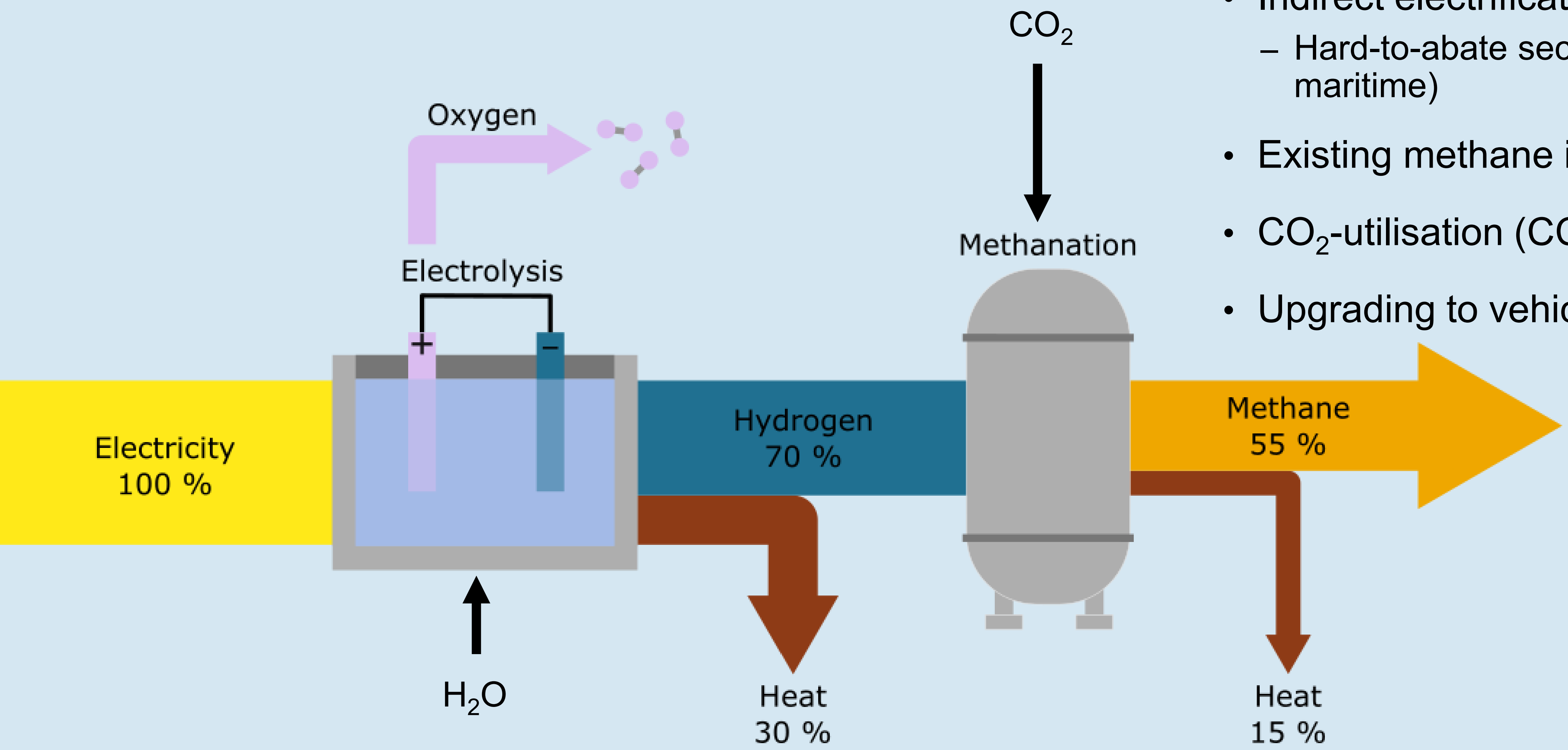
* represents 20% of gas imports from Russia 2021

Additional routes

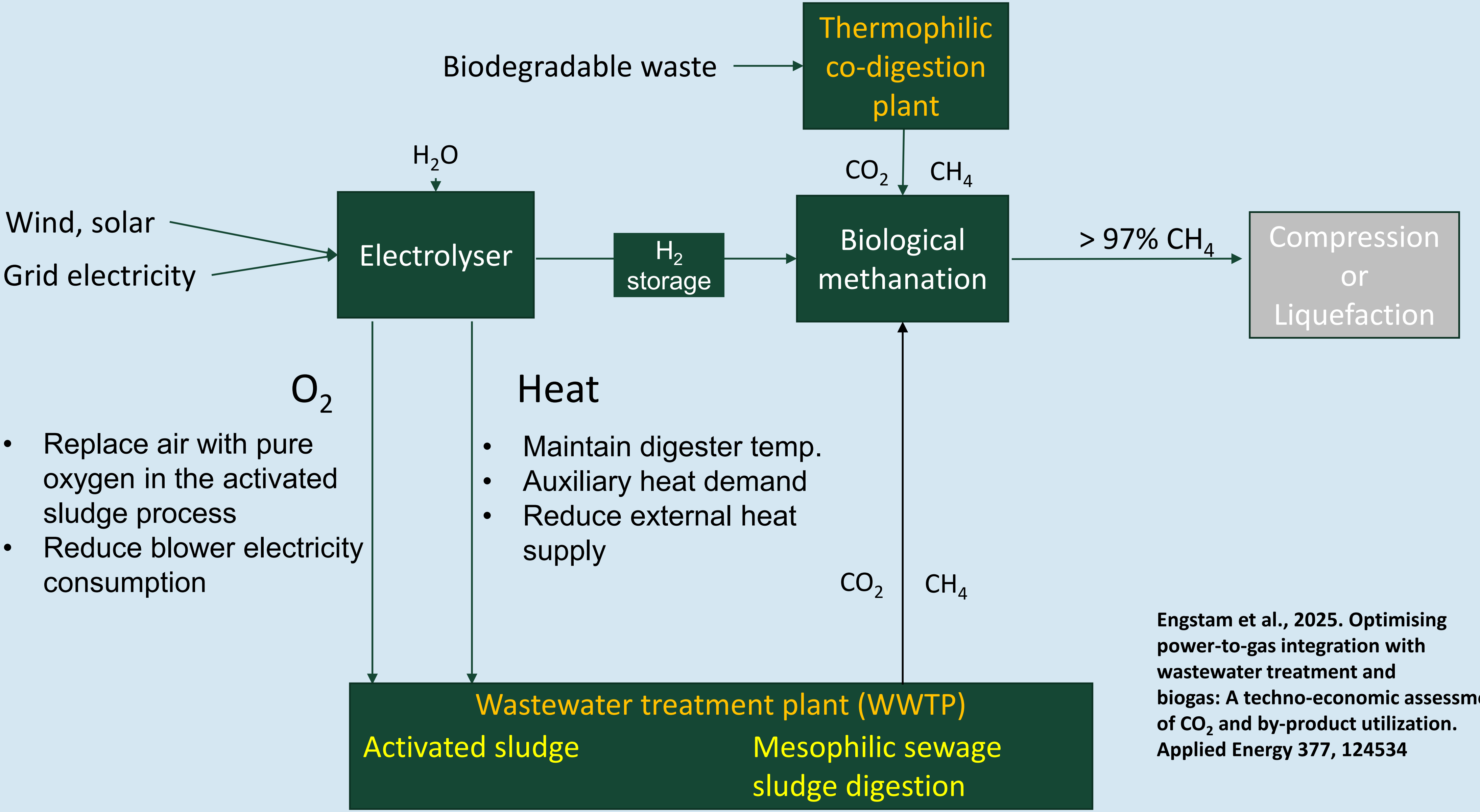


Power-to-hydrogen-to-methane

- Balance the grid
  - Flexible operation
  - Energy storage
- Indirect electrification
  - Hard-to-abate sectors (aviation, maritime)
- Existing methane infrastructure
- CO_2-utilisation (CCU)
- Upgrading to vehicle gas quality



Integrated biogas upgrading through power-to-gas with heat and oxygen valorization



Engstam et al., 2025. Optimising power-to-gas integration with wastewater treatment and biogas: A techno-economic assessment of CO_2 and by-product utilization. Applied Energy 377, 124534

Locally integrated power-to-gas: case details and methodology

Case: Uppsala, Sweden

Co-digestion plant

- Rated biogas production: 1200 Nm^3/h
- Gas composition: 63 $\%_{CH4}$, 37 $\%_{CO2}$
- Distance between co-digestion plant and WWTP: 1 km

WWTP (Wastewater treatment plant)

- Treated wastewater: 20 million m^3/yr
- Heat demand: ~500 kW
- Oxygen demand: ~4000 kg O_2/h

Methodology

- Hourly simulation of annual operation
  - Based on CO_2 availability + spot price, RES generation, and by-product demand
- Optimization of PtG configuration
  - Electrolyzer, methanation, H_2 storage
- Optimization of electricity supply
  - Wind and solar PV capacitiy vs grid

Engstam et al., 2025. Optimising power-to-gas integration with wastewater treatment and biogas: A techno-economic assessment of CO2 and by-product utilization. Applied Energy 377, 124534

Methane production and by-product utilisation

- 59% increase in methane production (ca 60 GWh/y to 95 GWh/y)
- 54% higher cost of e-methane compared to conventional upgrading (73 €/MWh to 113 €/MWh)
- Heat: 100% (4.5 GWh_{th}) of WWTP demand (only 25% of generated heat)
  - Heat integration reduced production costs of e-methane with 2%
  - Further use of heat:
    - Themophilic digestion of sewage sludge at the WWTP
    - Pasteurization at the co-digestion plant
- O_2: only 26% of WWTP demand (100% of generated) → 0.4 GWh_{el} avoided
  - O_2 integration increased production costs with 1%
  - The viability of oxygen utilization depends on local conditions:
    - Electricity consumption for aeration
    - Distance between power-to-hydrogen-to-methane plant and WWTP

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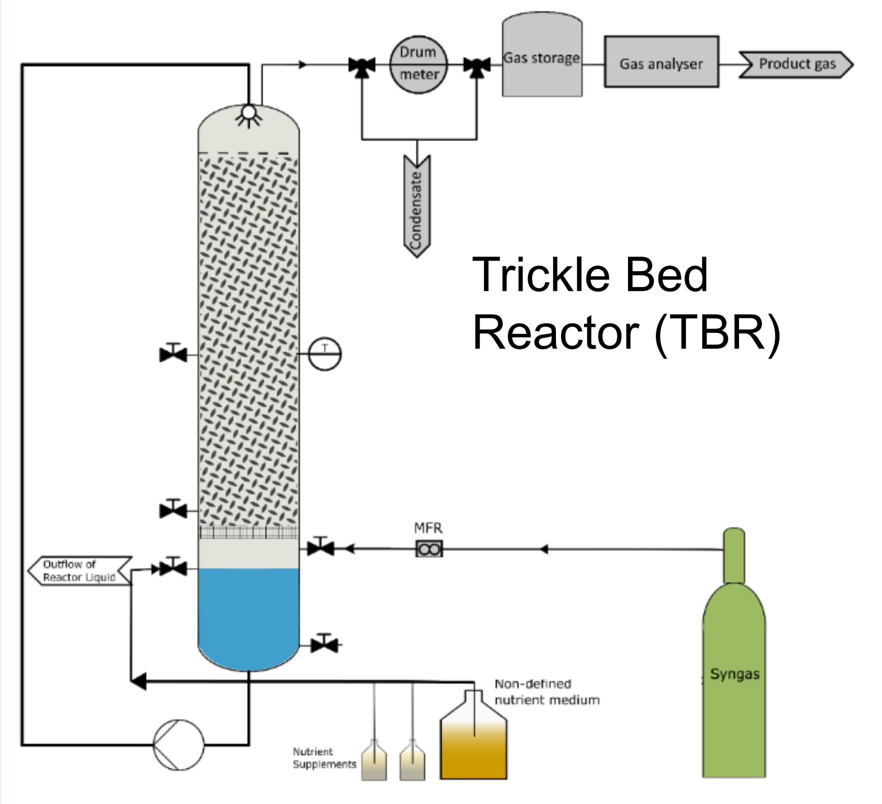
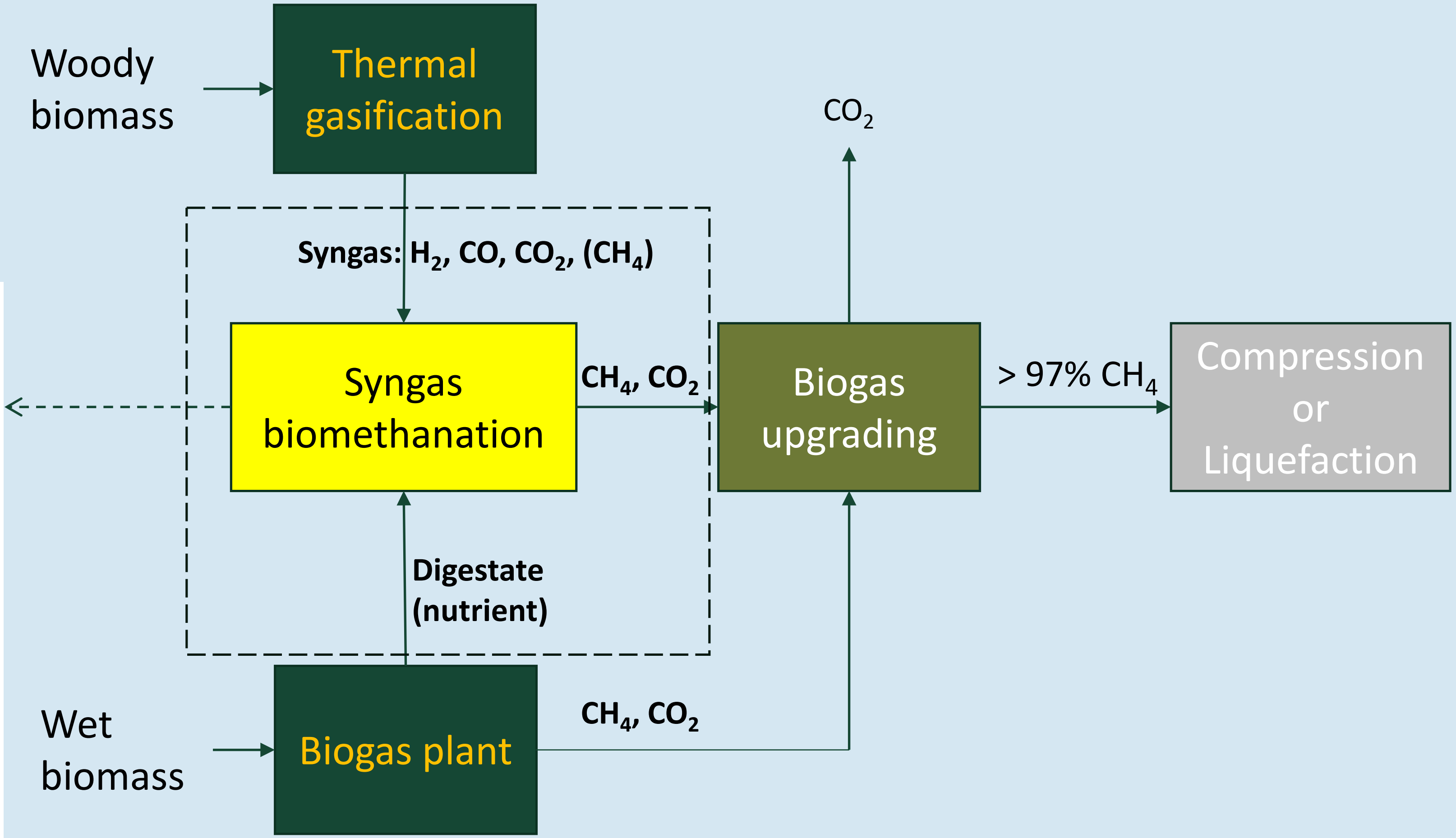
Syngas Biomethanation



Trickle Bed Reactor (TBR)



Theoretical biomethanation of syngas

40% H_2, 30% CO, 20% CO_2, 10% N_2*

$$4\ H_2 + 3\ CO + 2\ CO_2 + 1\ CH_4 \rightarrow 2.75\ CH_4 + 3.25\ CO_2 + 0.5\ H_2O$$

45.83% CH_4 (dry gas)
54.17% CO_2

Need to add supplementary H_2 to achieve higher CH_4-concentration!

$$7.391\ H_2 + 1.305\ CO + 0.870\ CO_2 + 0.435\ CH_4 \rightarrow$$
$$\rightarrow 2.610\ CH_4 + 0.001\ CO_2 + 3.044\ H_2O$$

99.97% CH_4 (dry gas)
0.03% CO_2

73.91% H_2, 13.05% CO, 8.70% CO_2, 4.35% N_2*

So, what was achieved experimentally?

*N_2 considered as placeholder for CH_4

What was achieved experimentally?

- Theory: 73.91% H_2, 13.05% CO, 8.70% CO_2, 4.35% N_2*
- Experiment:**71.00% H_2, 14.50% CO, 9.67% CO_2, 4.83% N_2***

→ **ca 90% CH_4**

Why?

- High H_2 partial pressure inhibit CO conversion

- Reduced gas-liquid mass transfer due to low gas retention time

*N_2 considered as placeholder for CH_4

RFNBO
Renewable fuels of non-biological origin

- Renewable Energy Directive (RED) ((EU) 2018/2001)

  – Delegated Regulation (EU) 2023/1185 [Eligible CO_2 sources and calculation methods]

  – Delegated Regulation (EU) 2023/1184 [requirements for electricity supply]

    - **Additionality** – new or capacity-expanded installations
    - **Temporal** – electricity used alignes on a monthly basis (2030). Thereafter on an hourly basis
    - **Geographically** – generated in the same bidding zone
    - Biomass-derived and nuclear electricity excluded
    - PPA required

Exemptions! (Do not have to meet critera above)
> 90% renewable electricity generation in the grid of the bidding zone
< 18 g CO_2-ekv/MJ in the grid of the bidding zone

Take home messages

- More expensive with e-methane than biomethane
- Integrated biogas upgrading through power-to-gas with heat and oxygen valorization can increase energy efficiency
- Supplementary H_2 is needed to achieve high CH_4-concentrations for biomethanation of syngas
- CO conversion can be challenging for biomethanation of syngas
- Regulatory framework for e-fuels (RFNBOs) allows electricity from the Swedish grid

Thank you for your attention

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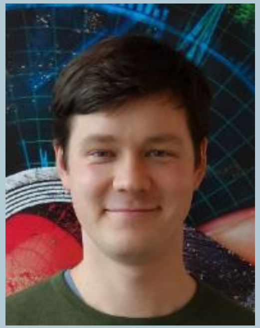

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