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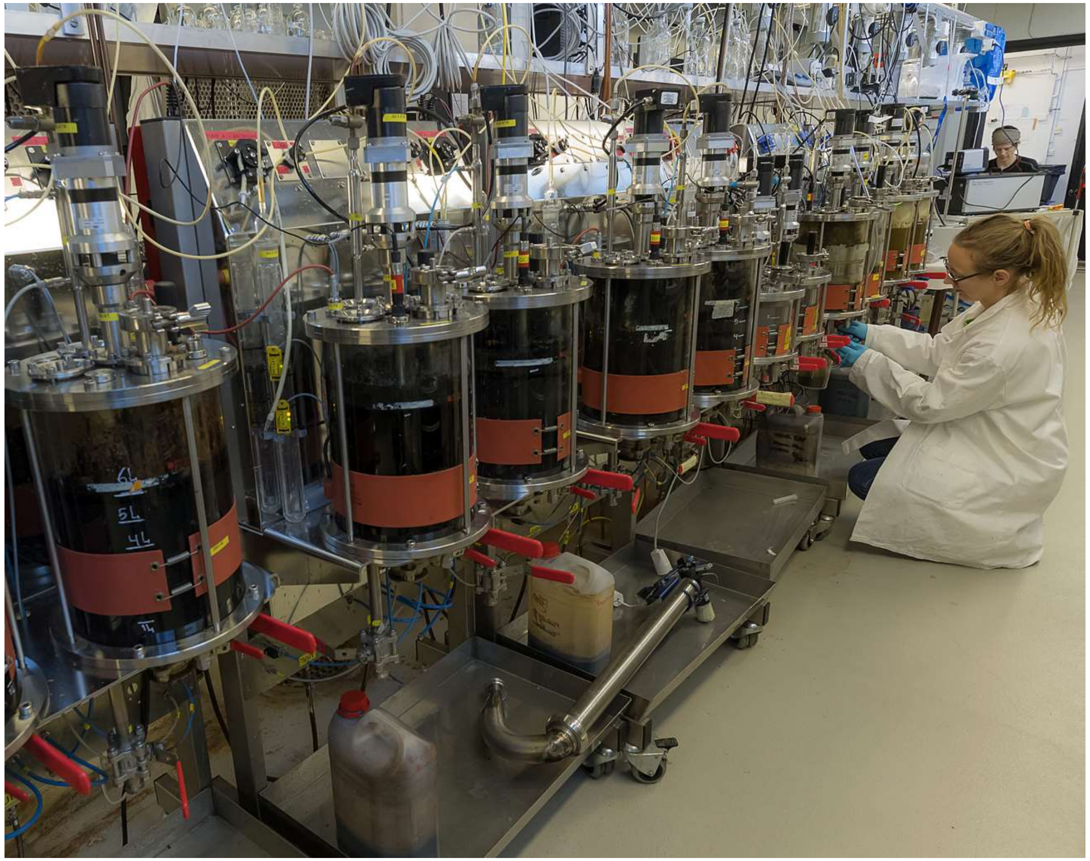
BIO4FUELS

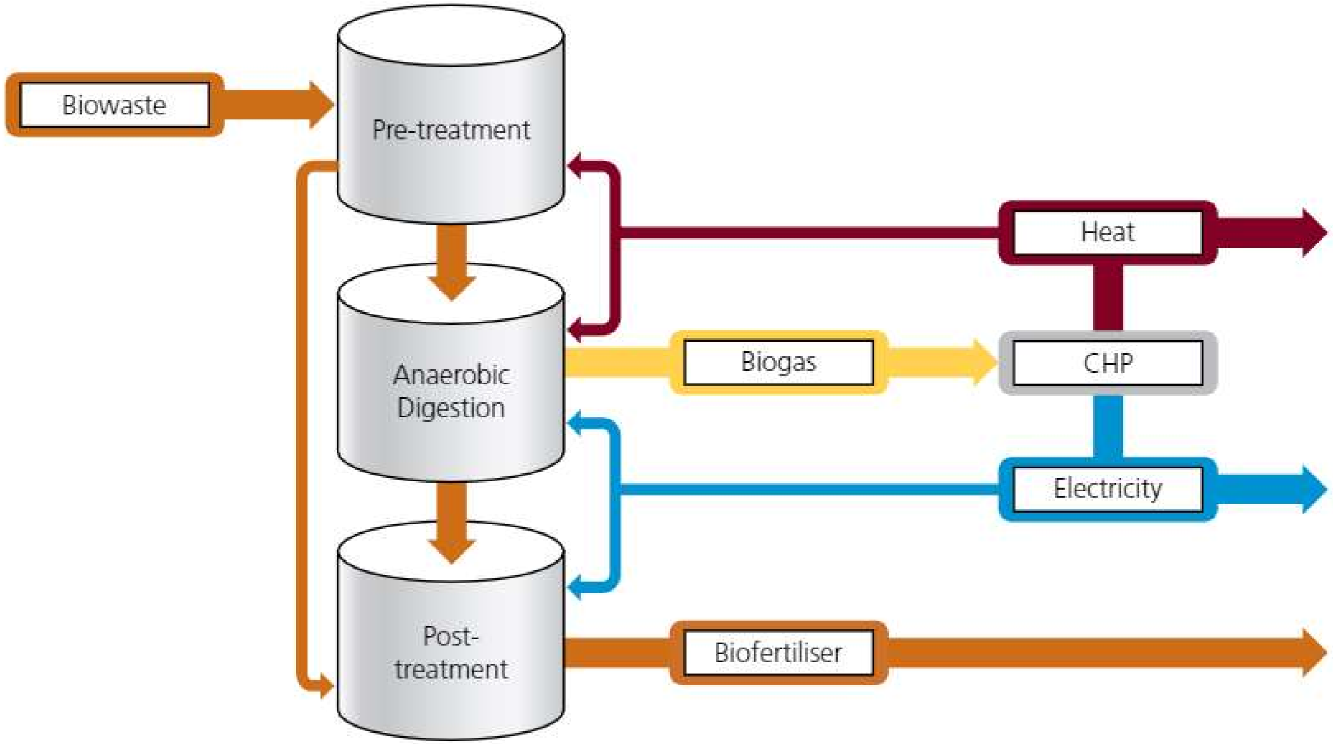
The recent trends in biological biogas upgrading

Bio4Fuels Days • Michal Sposob • 19.11.2020



Background

Biogas - a mixture of methane (CH_4) and carbon dioxide (CO_2) generated during the anaerobic digestion process in which biodegradable organic matter is converted where dissolved oxygen and nitrate-N are excluded.



www.gov.uk/government/publications/anaerobic-digestion-strategy-and-action-plan

Background

Biogas = 20-25 MJ/m^3

(Bio)Methane = 50.4 MJ/m^3

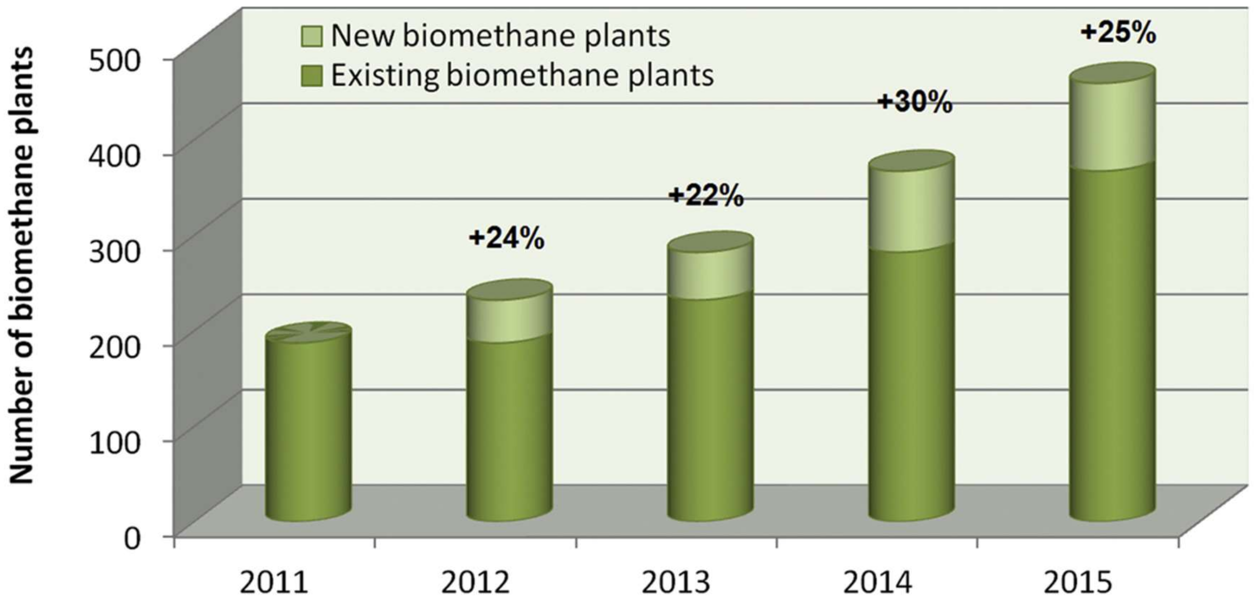
Upgraded biogas (biomethane) can be used in various applications:

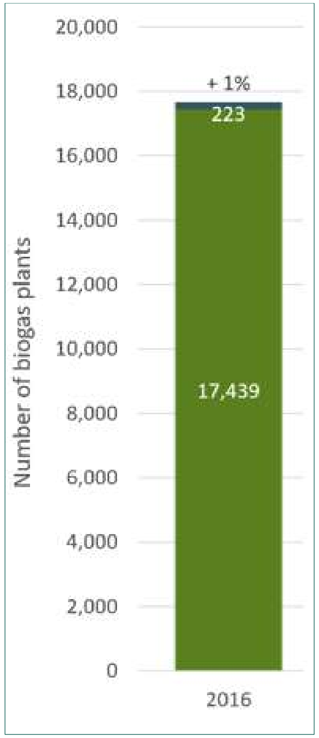
- electricity, heat or steam generation
- household and industry
- injection into natural gas grid
- fuel for vehicles

Compound	Unit	AD gas
CH_4	%	50-80
CO_2		15-50
N_2		0-5
O_2		0-1
H_2S	ppm	100-20000
NH_3		0-100
Total chlorine		0-100
Total fluorine		0-100

Chen, X. Y., Vinh-Thang, H., Ramirez, A. A., Rodrigue, D., & Kaliaguine, S. (2015). *RSC Advances*, *5*(31), 24399-24448.

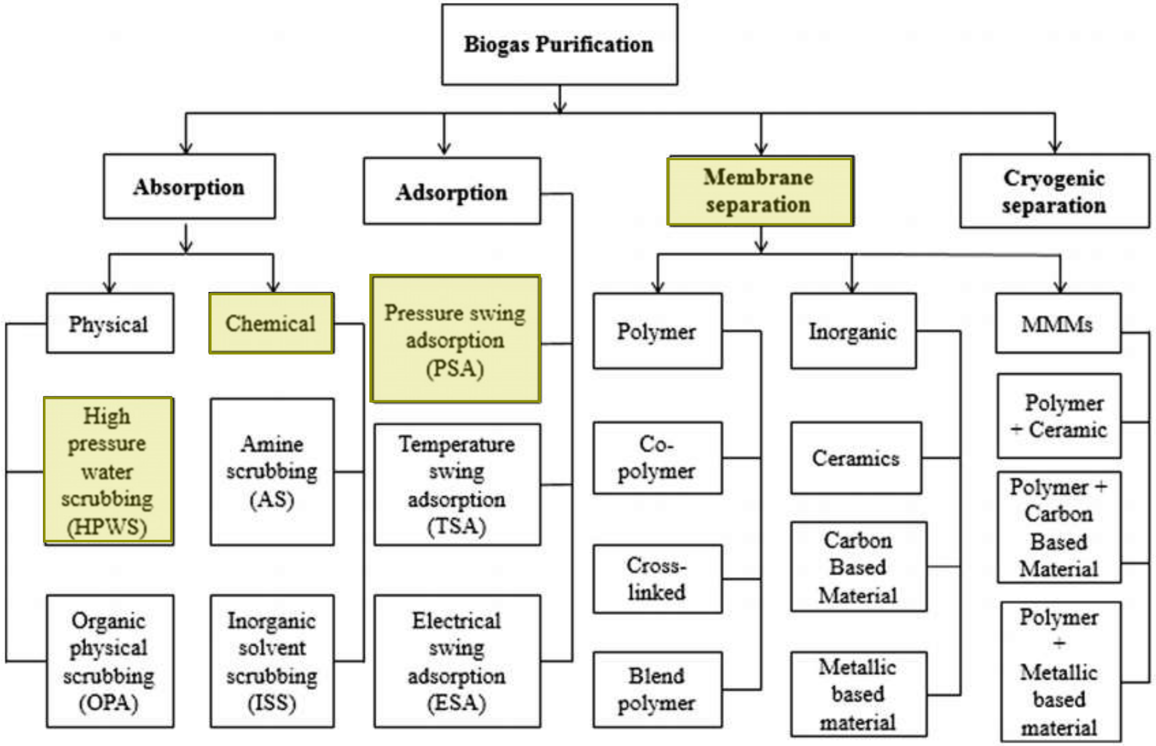
Background

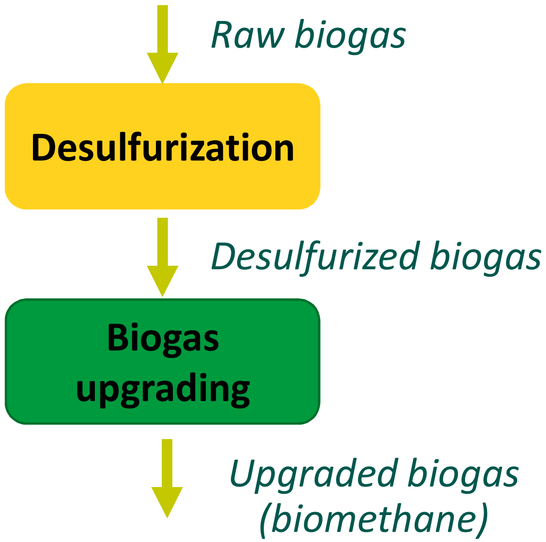




Angelidaki, I., Treu, L., Tsapekos, P., Luo, G., Campanaro, S., Wenzel, H., & Kougias, P. G. (2018). *Biotechnology Advances, 36*, 452-466.
EBA Statistical Report 2017

Background





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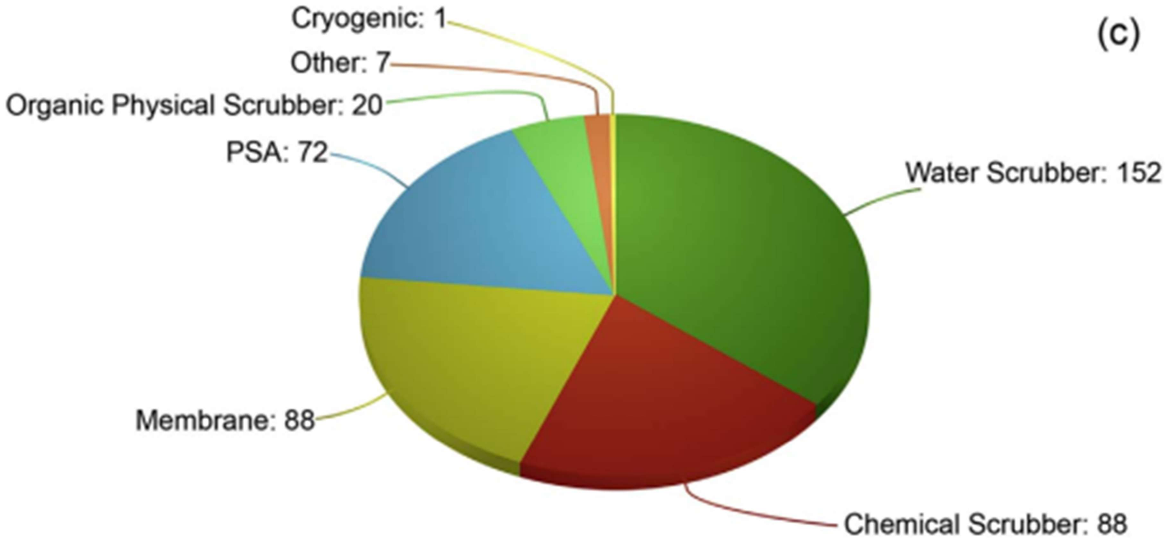
Background

Currently upgrading methods are costly and energy intensive (pressure, chemicals or membranes).

Economically and energetically feasible if plant operational capacity exceeds c. 100-200 m^3/h.

Upgrading for small and medium scale facilities is not economically feasible.

Losses of CO_2 and CH_4.



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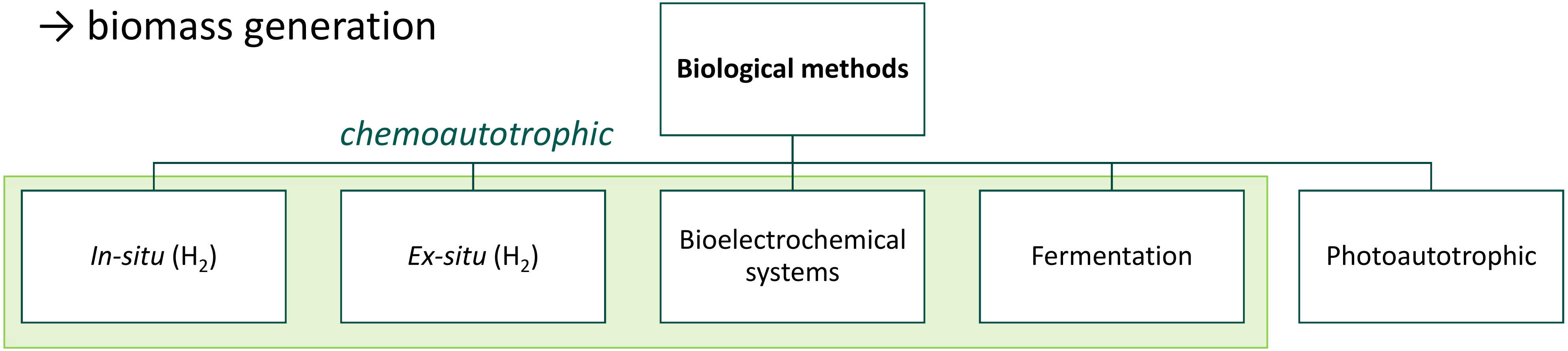
The recent trends

The new methods are focused on CO_2 use instead of removal

→ methanation (hydrogenotrophic methanogenesis)/acetogenesis

→ biomass generation



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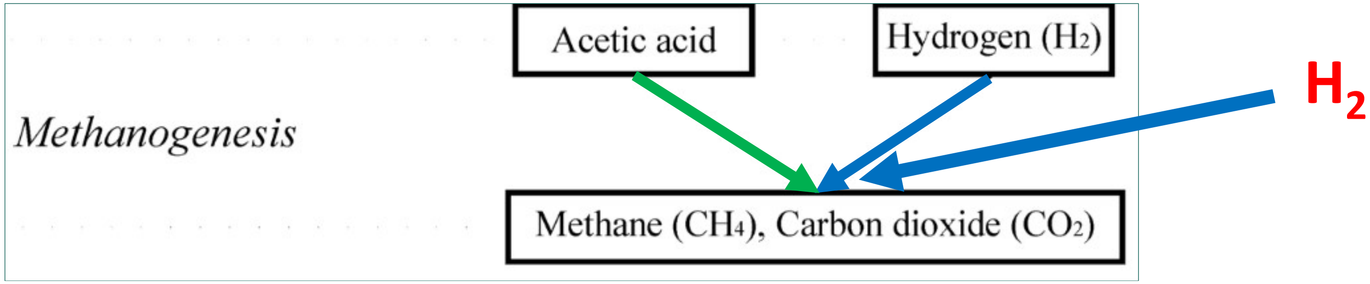
The recent trends
Chemoautotrophic

$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$ $\Delta G^0 = -130.7$ kJ/mol (*hydrogenotrophic methanogenesis*)



$CH_3CH_2COO^- + 3H_2O \rightarrow CH_3COO^- + HCO_3^- + H^+ + 3H_2$ $\Delta G_r^0 = 76.1$ kJ/reaction

$3H_2 + 3/4HCO_3^- + 3/4H^+ \rightarrow 3/4CH_4 + 9/4H_2O$ $\Delta G_r^0 = -101.7$ kJ/reaction

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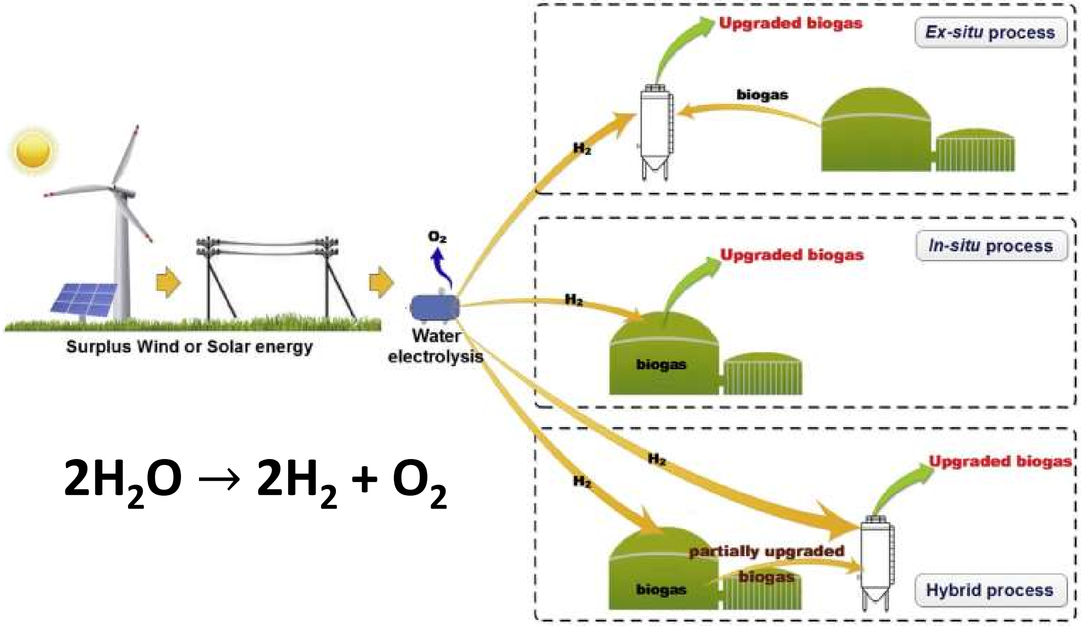
$CH_3CH_2COO^- + 3/4H_2O \rightarrow 3/4CH_4 + CH_3COO^- + 1/4HCO_3^- + 1/4H^+$ $\Delta G_r^0 = -24.6$ kJ/reaction

The recent trends
Chemoautotrophic

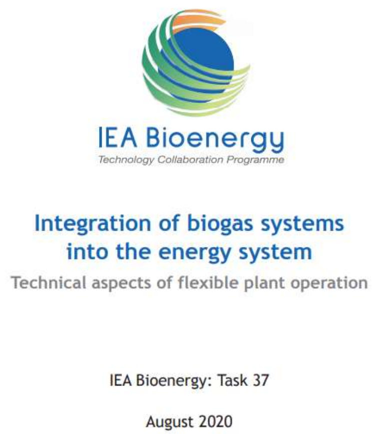
H_2 production using surplus electricity from windmills or solar panels (grid stabilization).

Power to gas (**P2G**).

EU countries → c. 26% of the electricity from wind is in a temporary surplus



$$2H_2O \rightarrow 2H_2 + O_2$$



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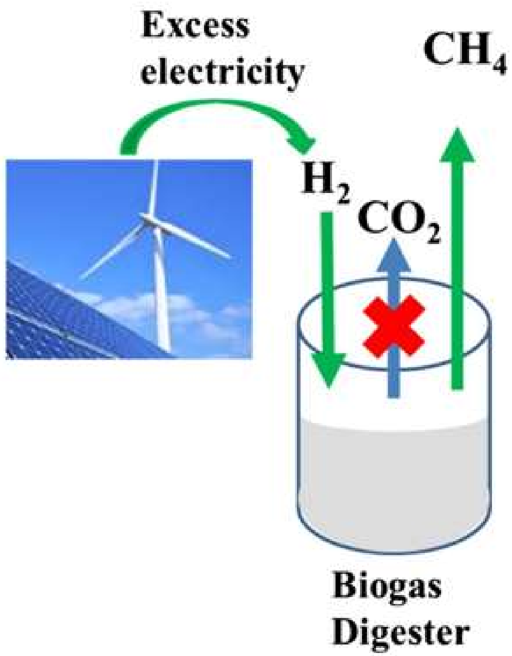
The recent trends
In-situ biomethanation

H_2 is injected continuously or by pulses inside the biogas reactor.

~89% of CH_4 can be reached if operational parameters are monitored and controlled (esp. pH).

It allows existing biogas plants to be utilized for H_2 addition.



H_2 solubility is low

gas-liquid mass transfer is limited

Anaerobic digesters are not designed to maximize the gas-liquid mass transfer.

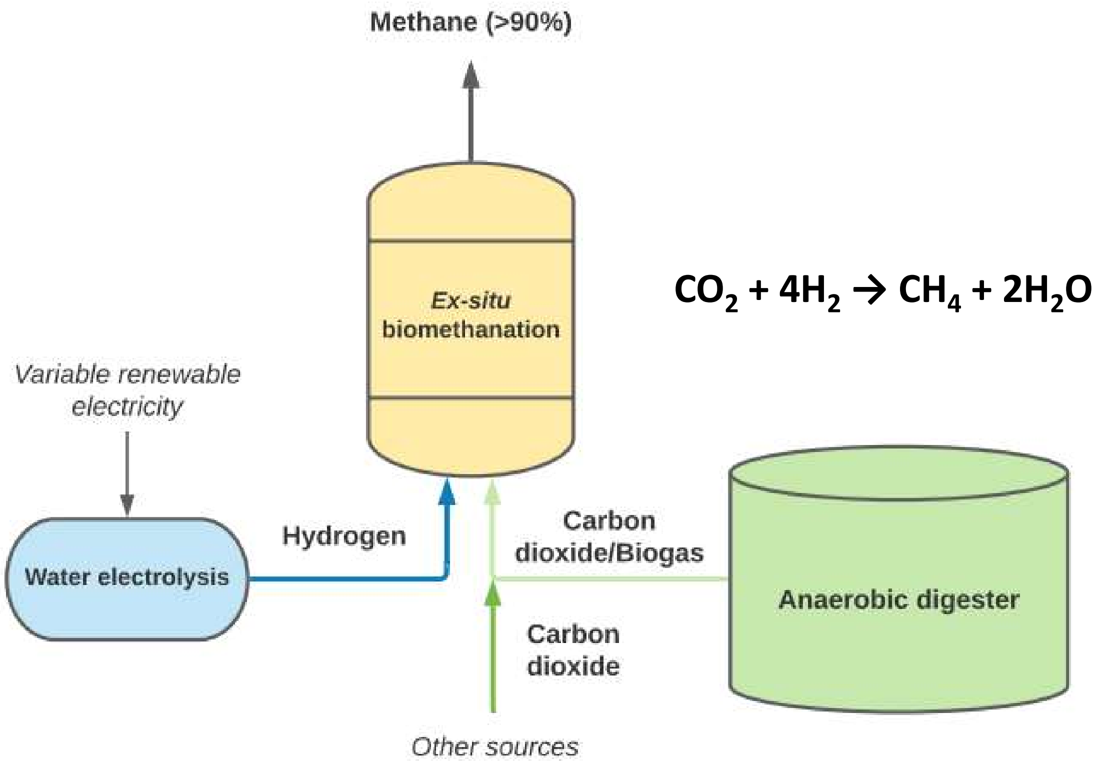
Mulat, D. G., Mosbæk, F., Ward, A. J., Polag, D., Greule, M., Keppler, F., ... & Feilberg, A. (2017). *Waste Management*, *68*, 146-156.

The recent trends
Ex-situ biomethanation

Biogas/CO_2 and H_2 are introduced into an anaerobic reactor containing a mixed hydrogenotrophic culture.

This method has several advantages compared to the *in-situ* process:

- secures the stability of the conventional biogas process
- biochemical process is simpler (no degradation of organic matter)
- higher flexibility (another source of waste CO_2 can be supplied)
- Better resistance to impurities (e.g., H_2S, NH_3)



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

The recent trends

Bioelectrochemical systems (BES)

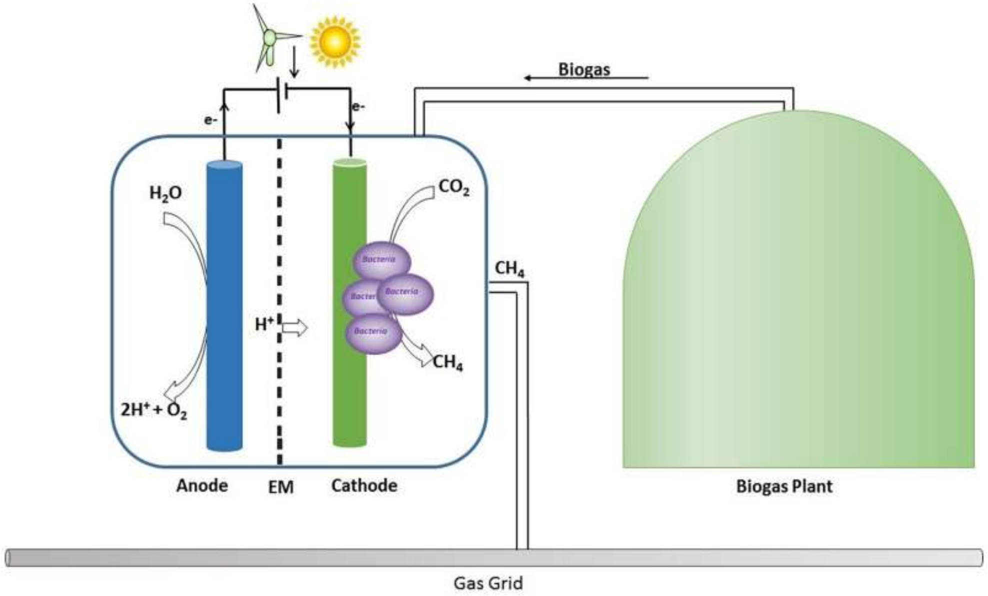
CO_2 can be metabolically reduced to CH_4 by using:

- electrons
- H_2 derived from cathode

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

$$CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$$

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



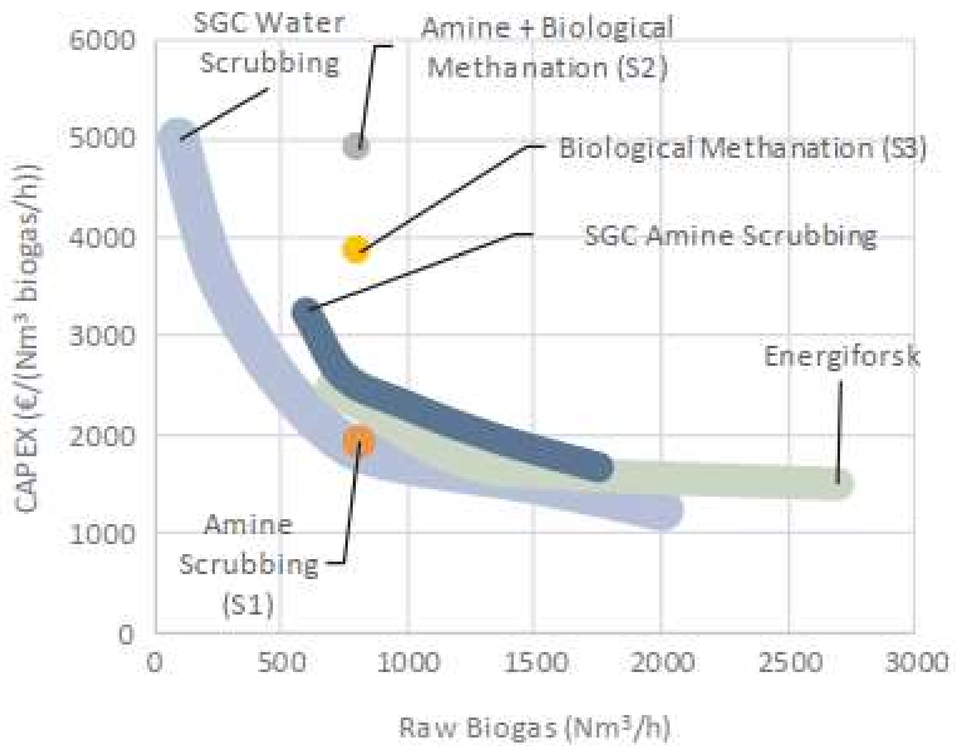
Aryal, N., Kvist, T., Ammam, F., Pant, D., & Ottosen, L. D. (2018). *Bioresource Technology*, *264*, 359-369

Costs

Information about the costs of the new upgrading methods is limited.

The cost of the biological methanation is believed to be similar to chemical upgrading.

From an environmental/sustainability perspective, biological methanation is more sustainable than amine scrubbing.



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Conclusions and remarks

The new methods for biogas upgrading:

- convert CO_2 rather than remove
- give a high CH_4 final volume
- convert surplus electricity
- have lower technical requirements

However:

- mass transfer limitations (CO_2 and H_2)
- stability of BES and *in-situ*
- capital and operational costs

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