Utilisation of CO_2 and H_2 for the production of liquid biofuels

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Bioenergy 2020+

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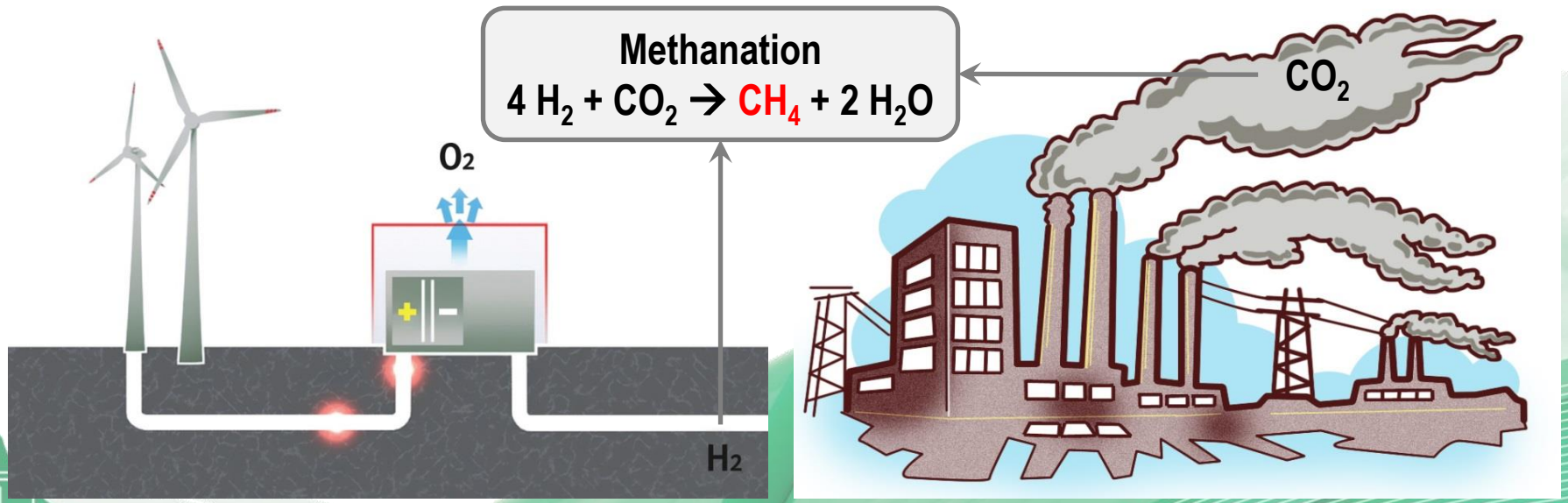
Power to gas

- H_2 from water hydrolysis using peak electricity
- CO_2 from power plants or factories

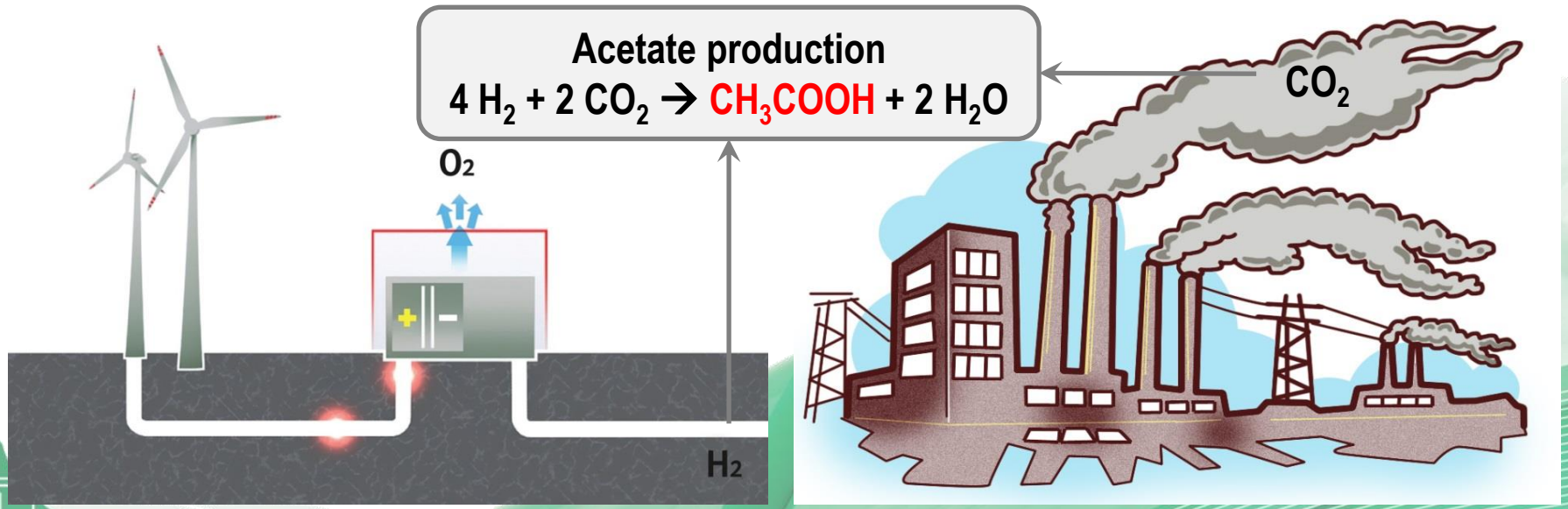
  - Hydrogenotrophic Archaea
  - Sabatier process



Alternative to Power to gas - PtL

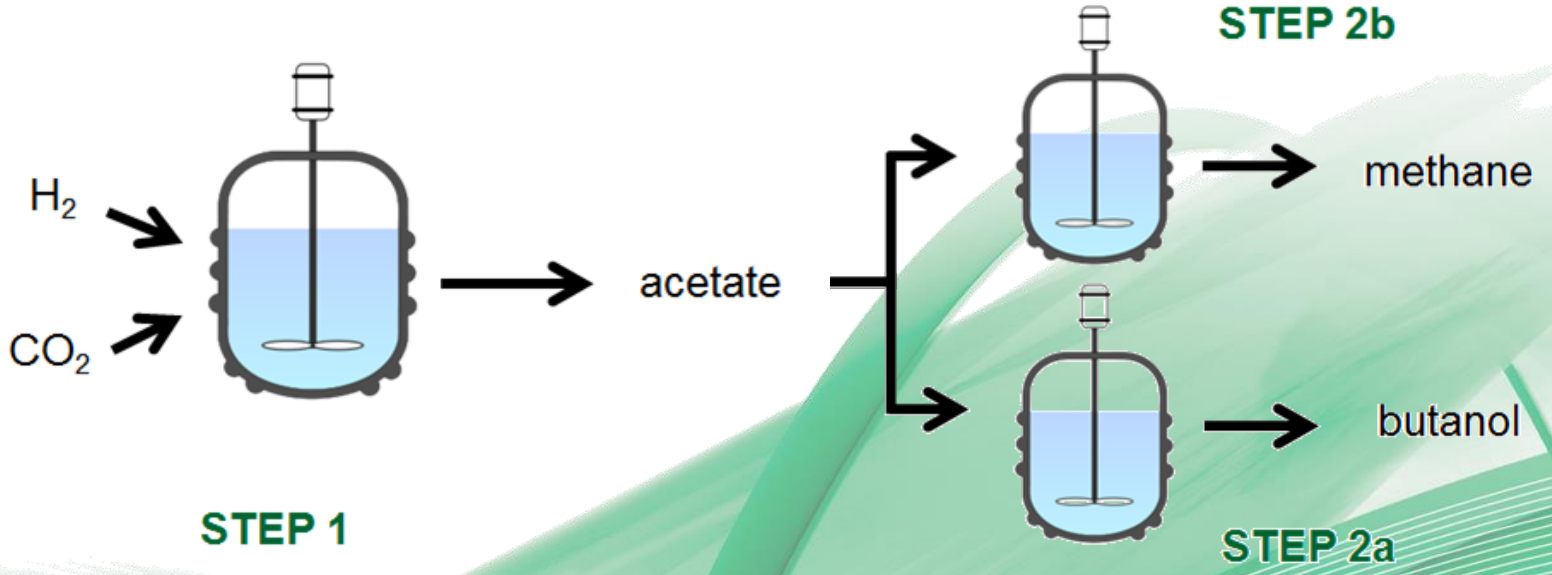
- Acetate as (intermediate) product…
  - Bulk chemical
  - Converted to other fuels

➢ Homoacetogenic bacteria



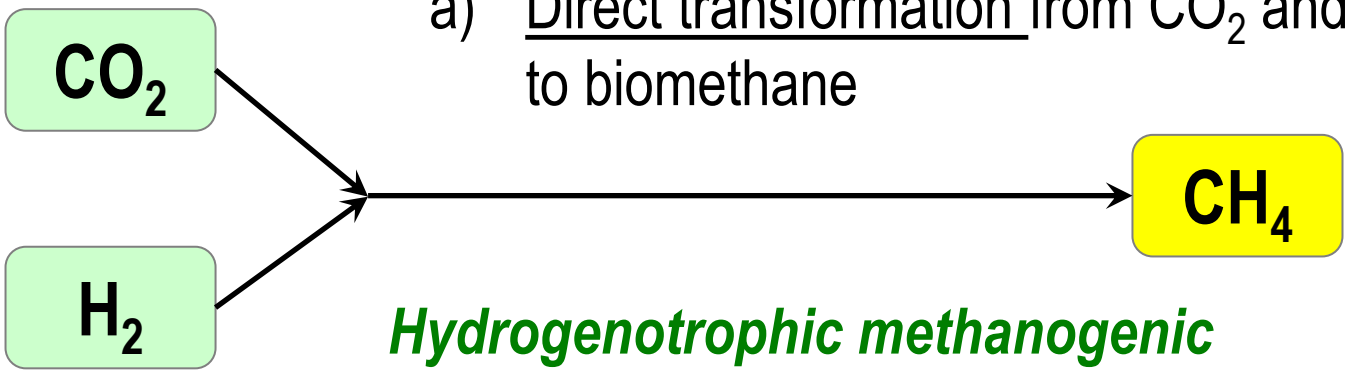
The „Hydrofinery“ project

- Gas fermentation of CO_2 and H_2
- Produce Acetate as intermediate for…
  - Acetone, butanol, ethanol (ABE) fermentation
  - Biomethane production



Hydrofinery – next generation biofuels from CO_2 and H_2

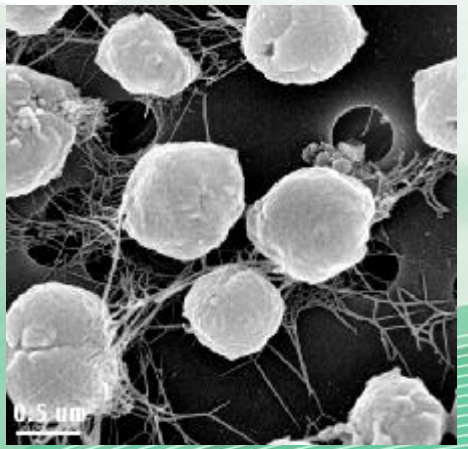
a) Direct transformation from CO_2 and H_2 to biomethane



Hydrogenotrophic methanogenic Archaea

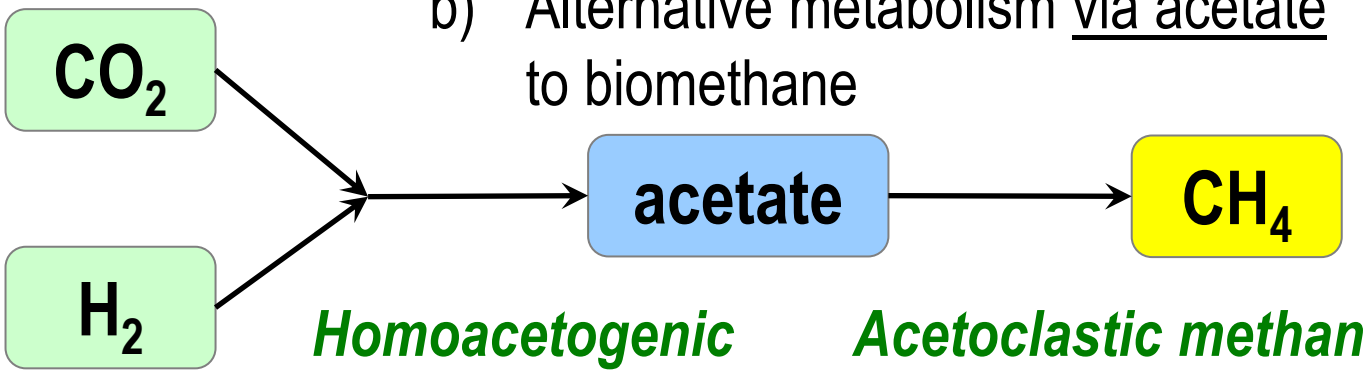
Methanococcus jannaschii

Source:http://microbewiki.kenyon.edu/index.php/Methanococcus_jannaschii



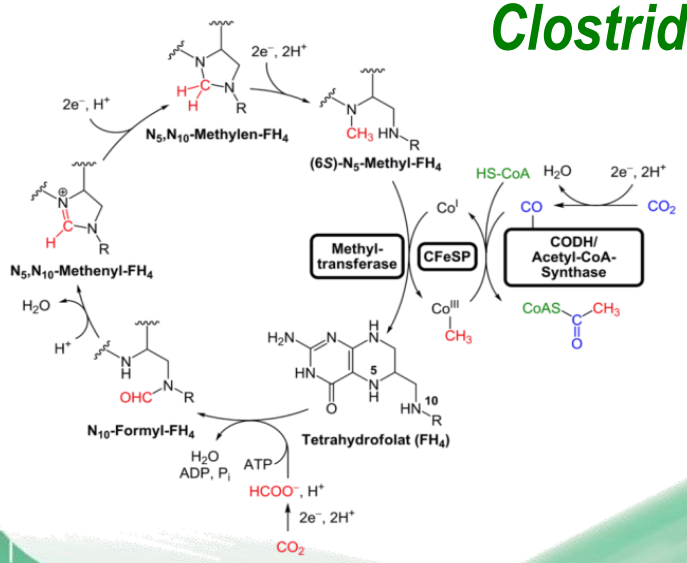
Hydrofinery – next generation biofuels from CO_2 and H_2

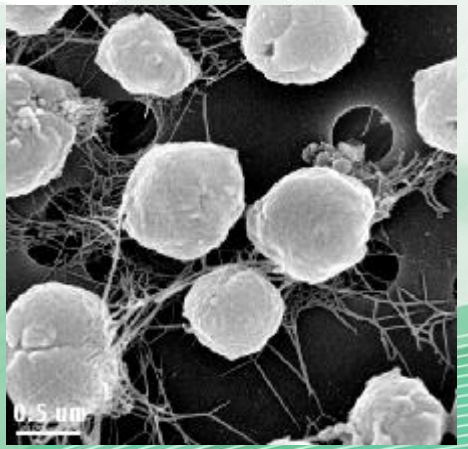
b) Alternative metabolism via acetate to biomethane



Homoacetogenic Clostridia

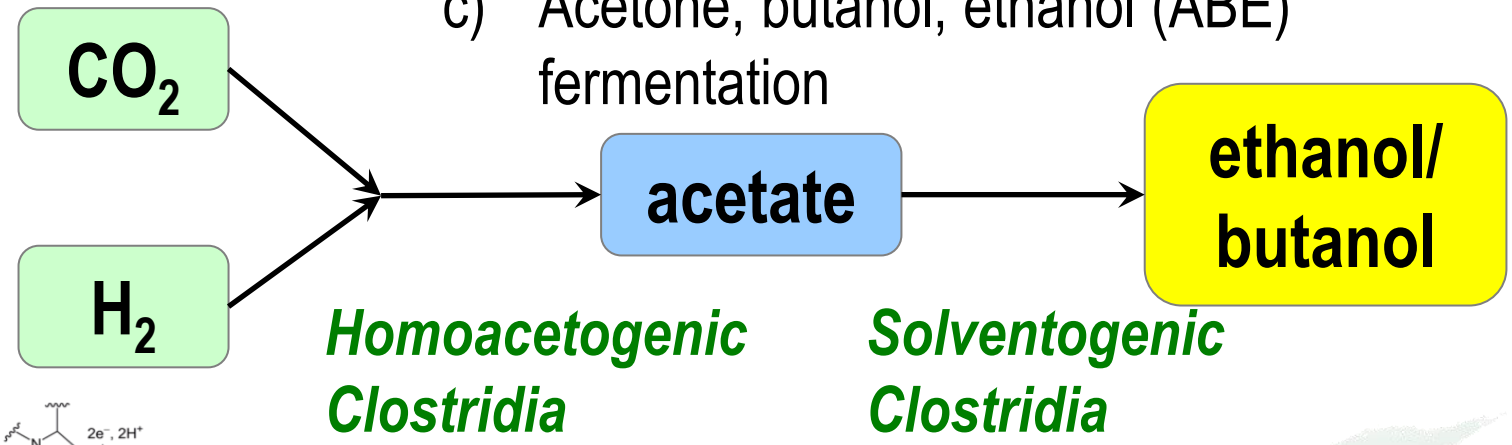
Acetoclastic methanogenic Archaea

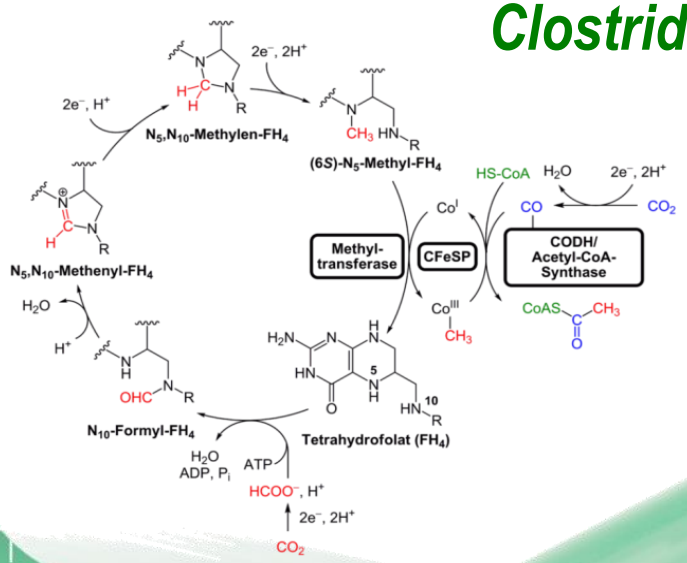




Hydrofinery – next generation biofuels from CO_2 and H_2

c) Acetone, butanol, ethanol (ABE) fermentation

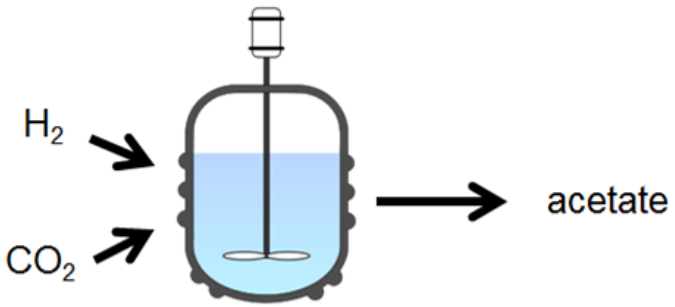


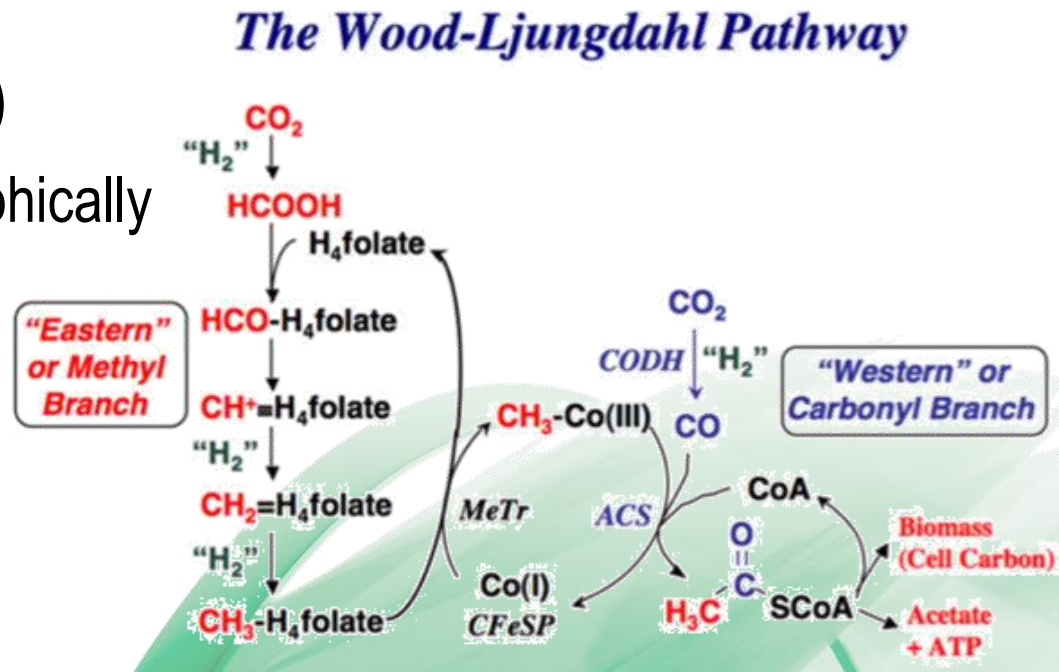


Homoacetogenic fermentation

Homoacetogenic Clostridia

- *Morella thermoacetica (55°C)*
- *Acetobacterium woodii (30°C)*
  - Grow auto- and heterotrophically
  - Strictly anaerobic



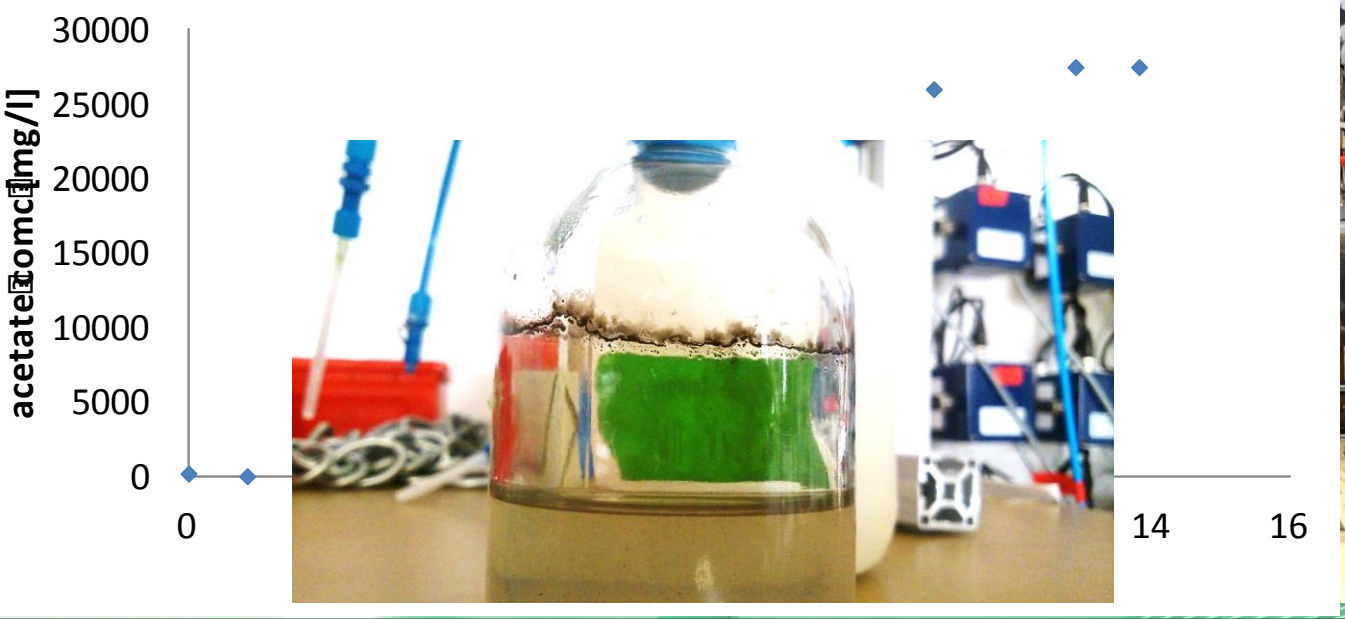


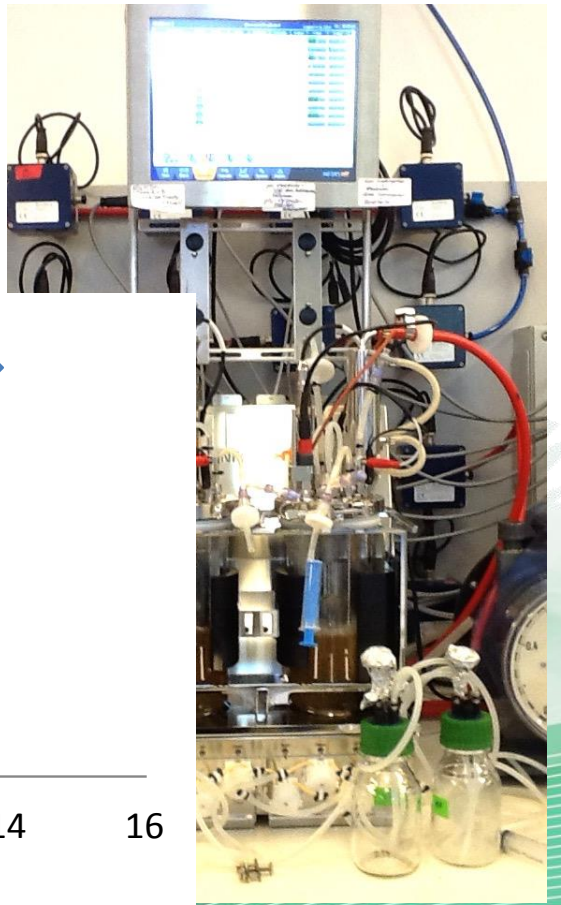
$4\ H_2 + 2\ CO_2 \rightarrow CH_3COOH + 2\ H_2O$

Source: Ragsdale & Pierce (2008)

Challenges

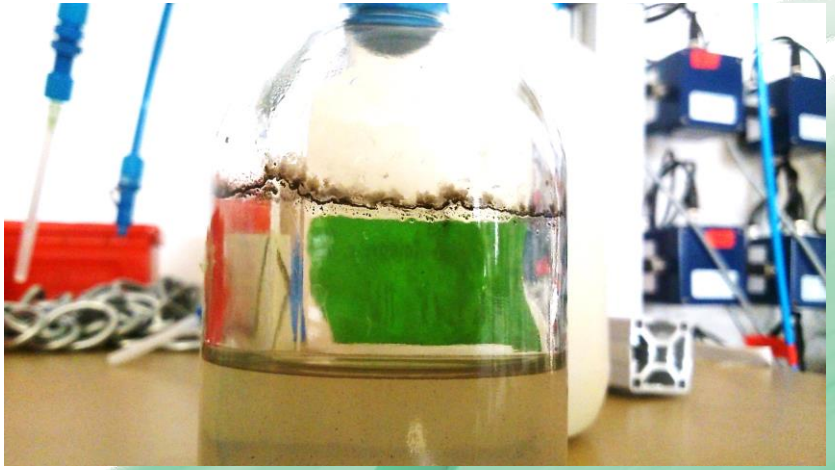
- Achieving a high acetate yield from H_2 and CO_2
- Slow growth rates, long lag phase
  - Difficult to obtain continuous growth
  - Cells are washed out when product is removed
  -





Challenges

- Achieving a high acetate yield from H_2 and CO_2
- Slow growth rates
  - Difficult to obtain continuous growth
  - Cells are washed out when product is removed
  - Need to retain the cells → Immobilisation



Selection of immobilisation materials

Consideration:

Charged bacteria should attach easier to a hydrophilic surface.

hydrophilic

Polyamide (Nylon)

Polysulphone (PSU)

Polyethersulphone (PES)

Polyethylene terephthalate (PET)

Polyethylene (PE)

Glass fibre

Polytetrafluoroethylene (PTFE, Teflon)

hydrophobic

Others:

Mixed cellulose ester

Linen

***A. woodii* on PET**

Selection of immobilisation materials

NOT STABLE

hydrophilic

Polyamide (Nylon)

Polysulphone (PSU)

Polyethersulphone (PES)

Polyethylene terephthalate (PET)

Polyethylene (PE)

~~Glass fibre~~

Polytetrafluoroethylene (PTFE, Teflon)

hydrophobic

Others:

~~Mixed cellulose ester~~

Linen

Selection of immobilisation materials

Others:
Linen

hydrophilic

Polyamide (Nylon)

Polysulphone (PSU)

Polyethersulphone (PES)

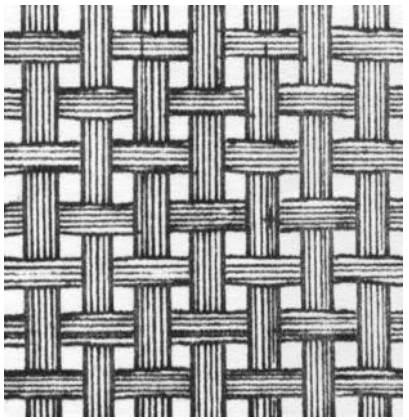
Polyethylene terephthalate (PET)

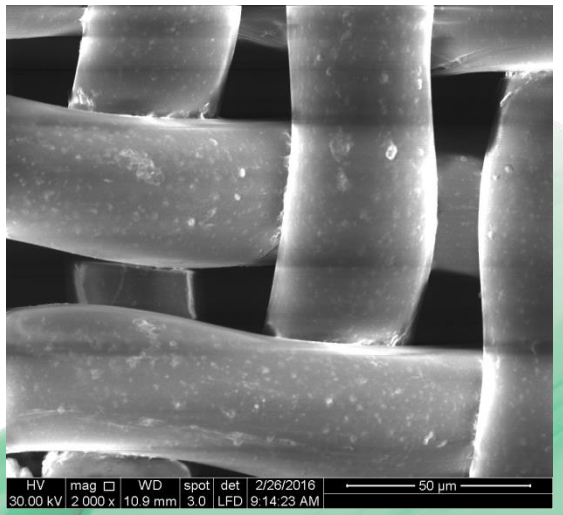
Polyethylene (PE)

Polytetrafluoroethylene (PTFE, Teflon)

hydrophobic

Woven membranes:





Nylon BLANK in SEM 2000x

Selection of immobilisation materials

Others:
Linen

hydrophilic

Polyamide (Nylon)

Polysulphone (PSU)

Polyethersulphone (PES)

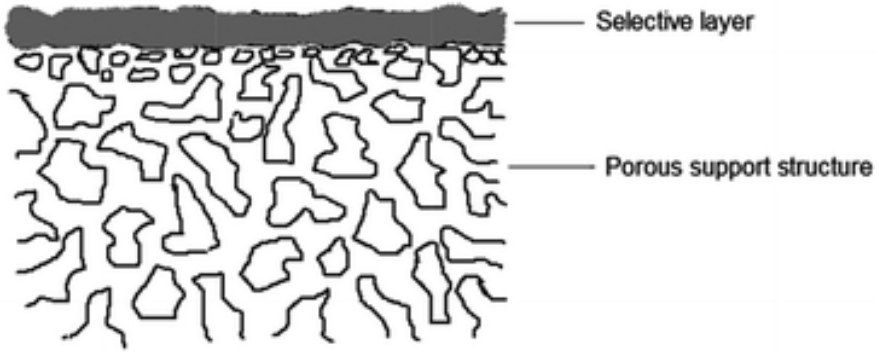
Polyethylene terephthalate (PET)

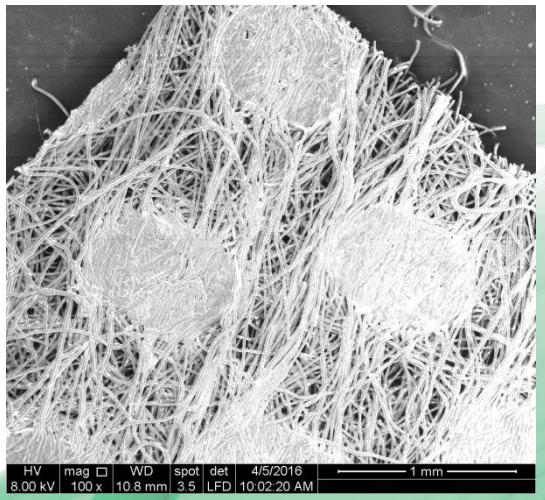
Polyethylene (PE)

Polytetrafluoroethylene (PTFE, Teflon)

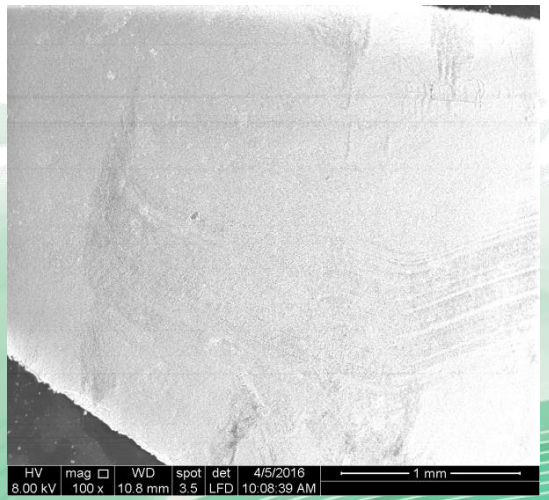
hydrophobic

Asymmetric membranes:





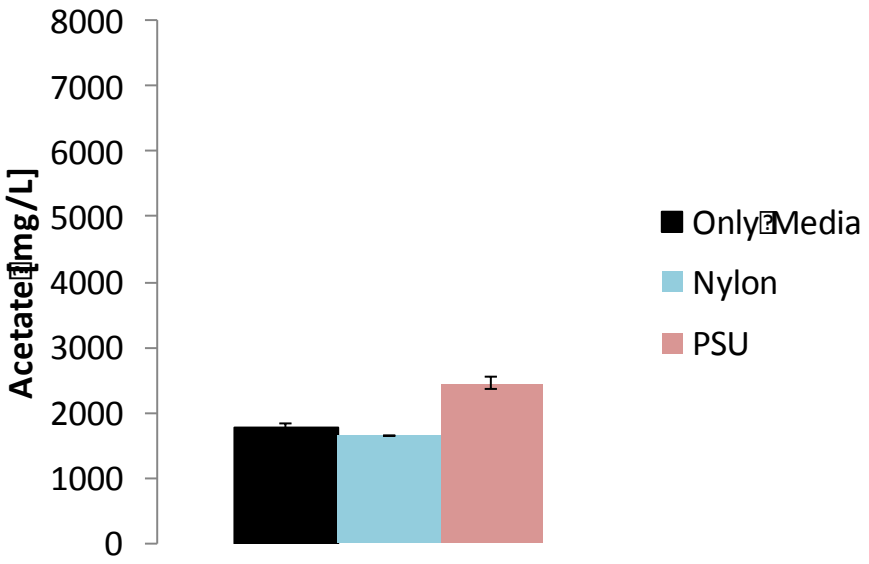
PET BLANK: porous structure in SEM 100x



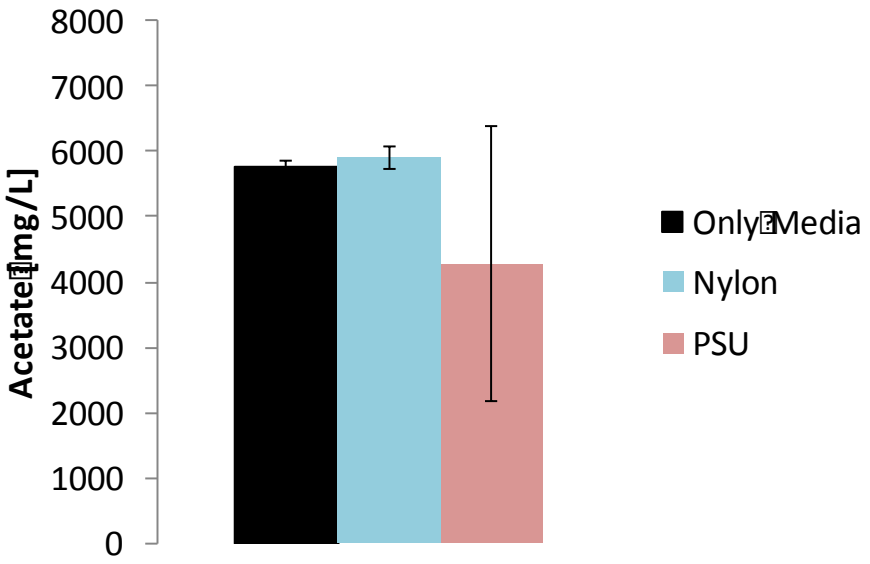
PET BLANK: selective layer in SEM 100x

Results: final acetate concentrations

- 1. experiment: Nylon, PSU



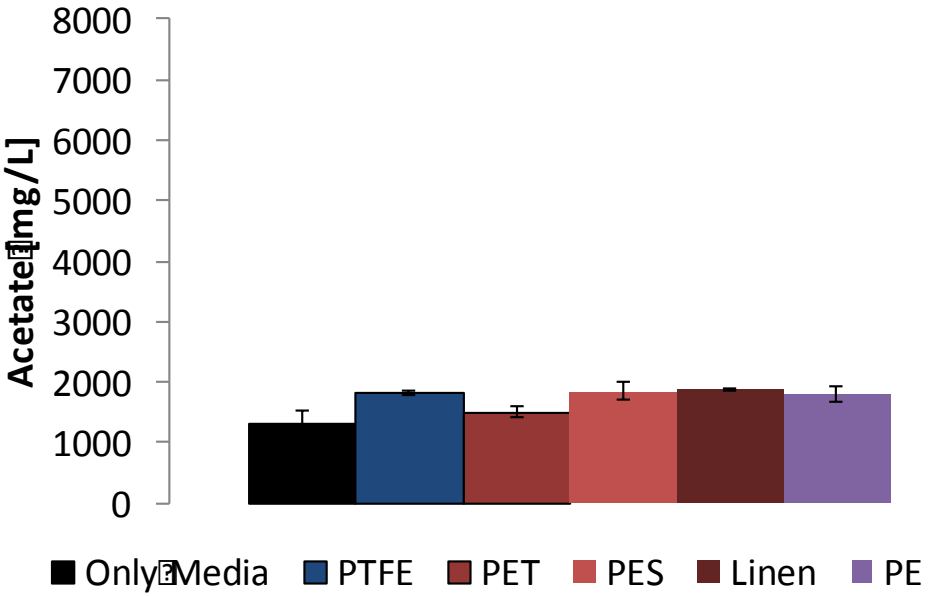
M. thermoacetica

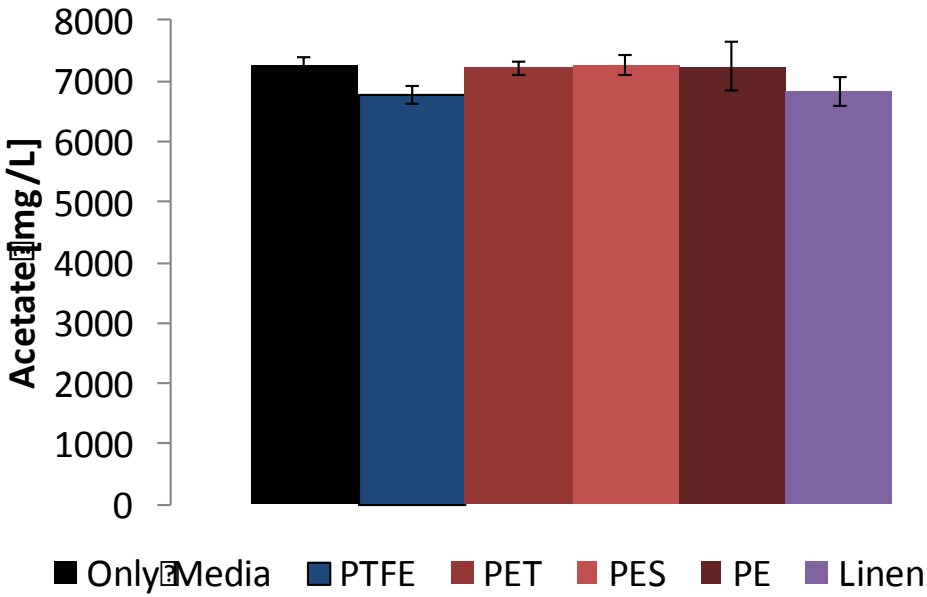


A. woodii

Results: final acetate concentrations

- 2. experiment: PTFE, PET, PES, PE, Linen



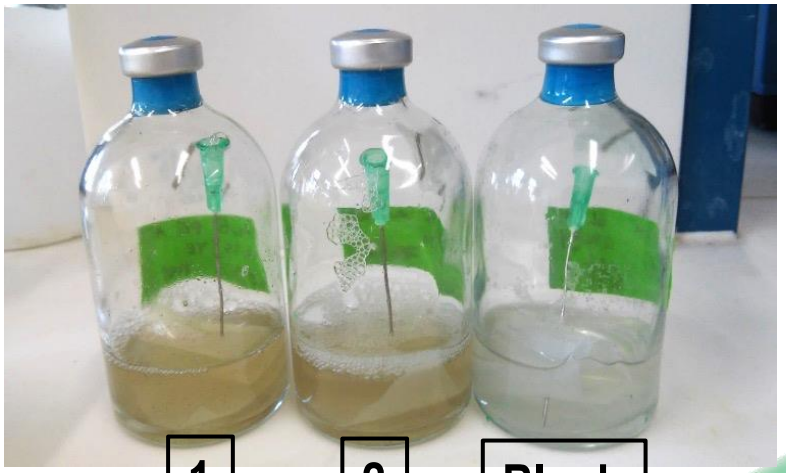


M. thermoacetica ***A. woodii***

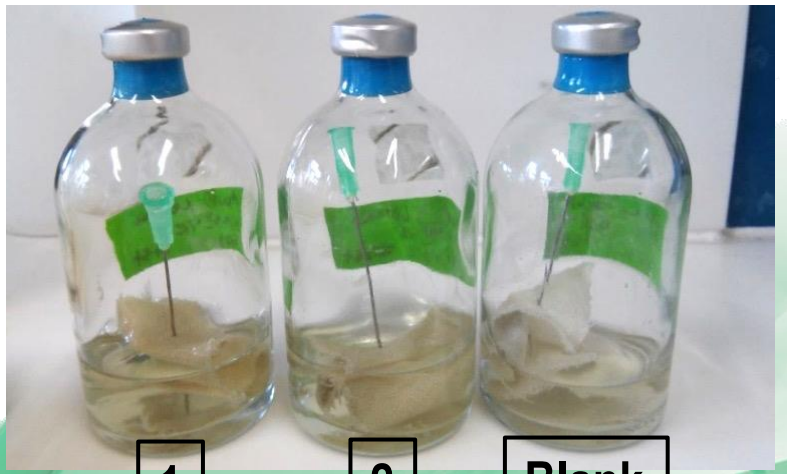
Results: optical evaluation

- PSU, Nylon, PES, PE → turbid suspension, not stable in experiment conditions (acetate)
- Linen, PET → stable in experiment conditions

  → clear suspension ⇒ immobilised cells

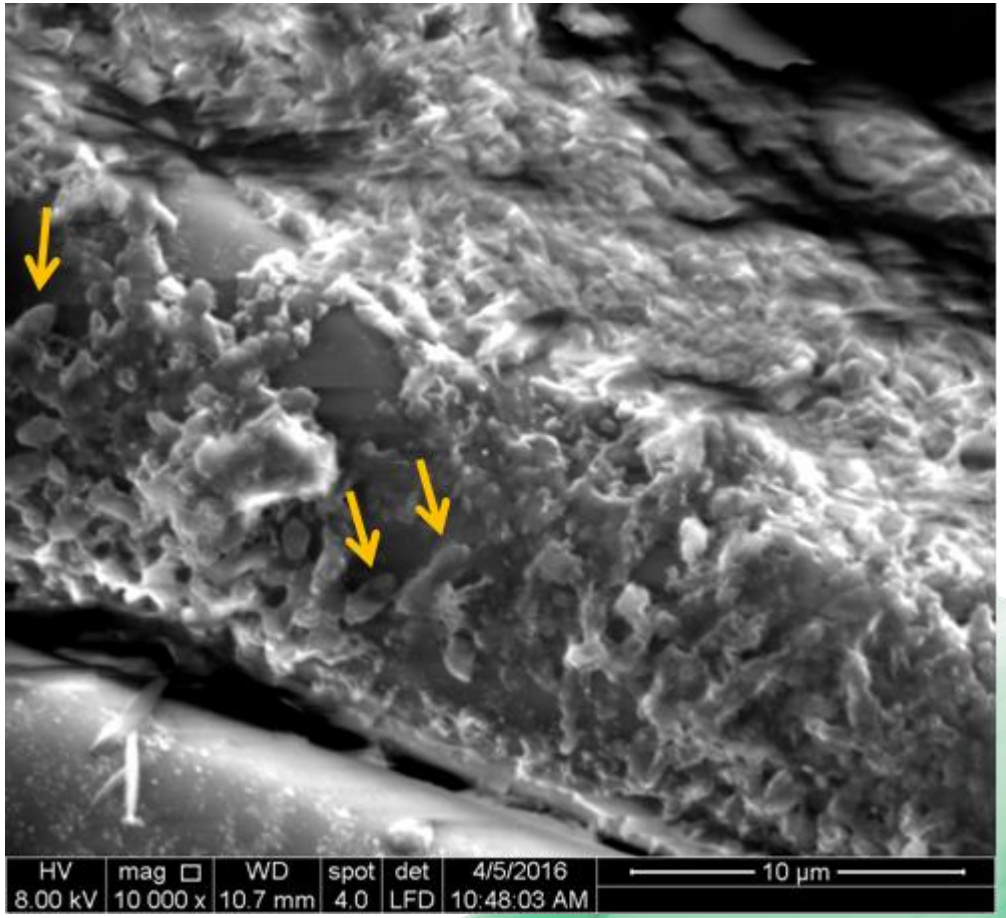


***A. woodii* on PE**



***A. woodii* on Linen**

Results for *A.woodii* - SEM

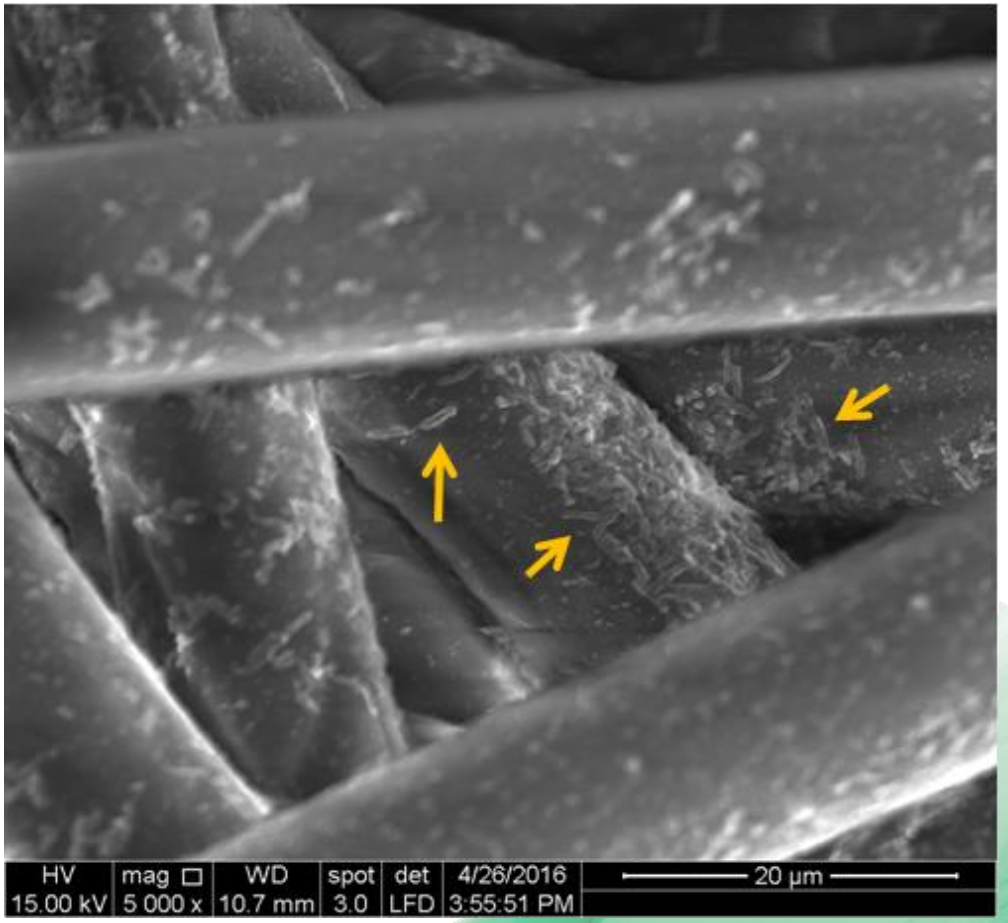


***A.woodii* on PET – in SEM 10 000x**

Results for *A.woodii* - SEM

***A.woodii* on Linen – in SEM 10 000x**

Results for *M.thermoacetica* - SEM



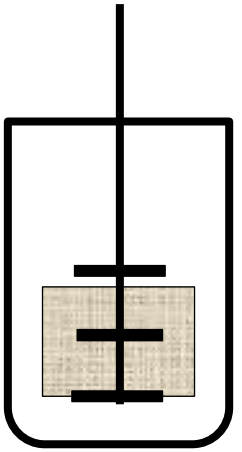
***M.thermoacetica* on PET – in SEM 5 000x**

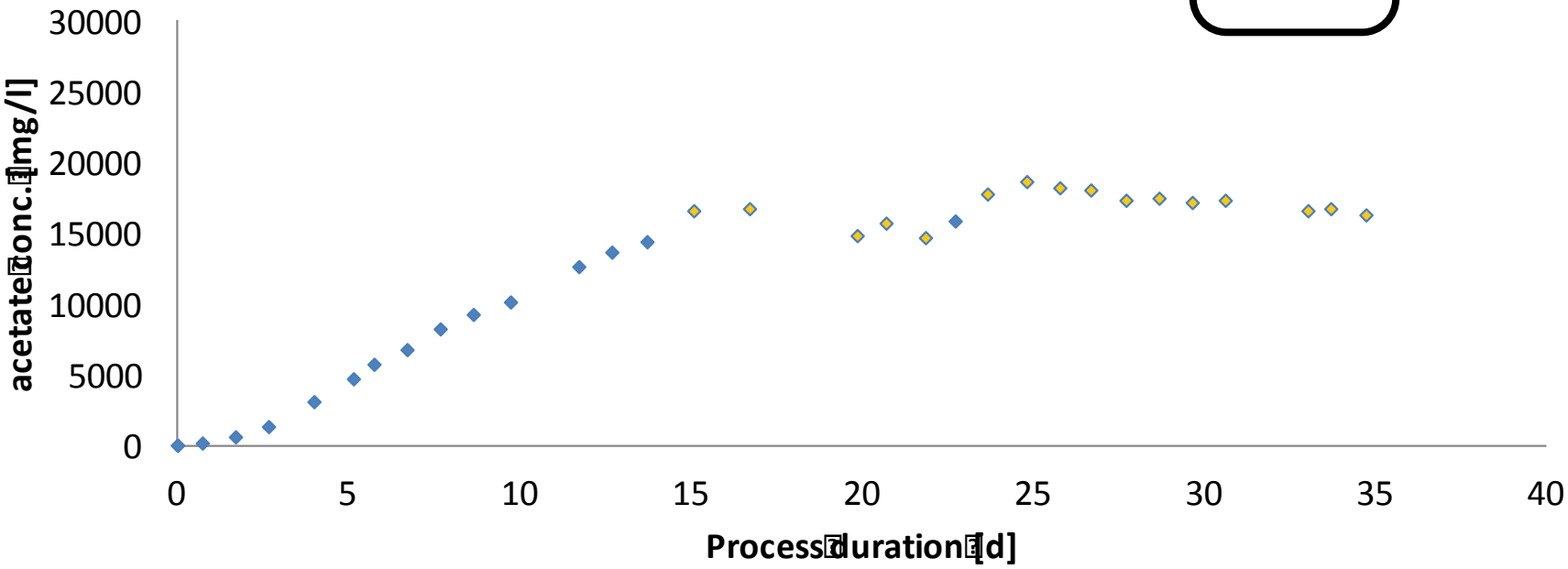
Summary

- PET and Linen are the favorable immobilisation materials due to stability, optical evaluation and acetate concentration
- Final acetate concentrations:
  - *A.woodii*
    - PET: 7.2 g/L
    - Linen: 6.8 g/L
  - *M.thermoacetica*
    - PET: 1.5 g/L
    - Linen: 1.9 g/L
- Due to easier handling and environmental reasons linen was chosen for further experiments in batch and continuous fermentation

Linen in the bioreactor

- Sewed a linen cylinder
  - Hangs in the fermenter
- 15 days batch growth
  - then acetate removal with media feeding

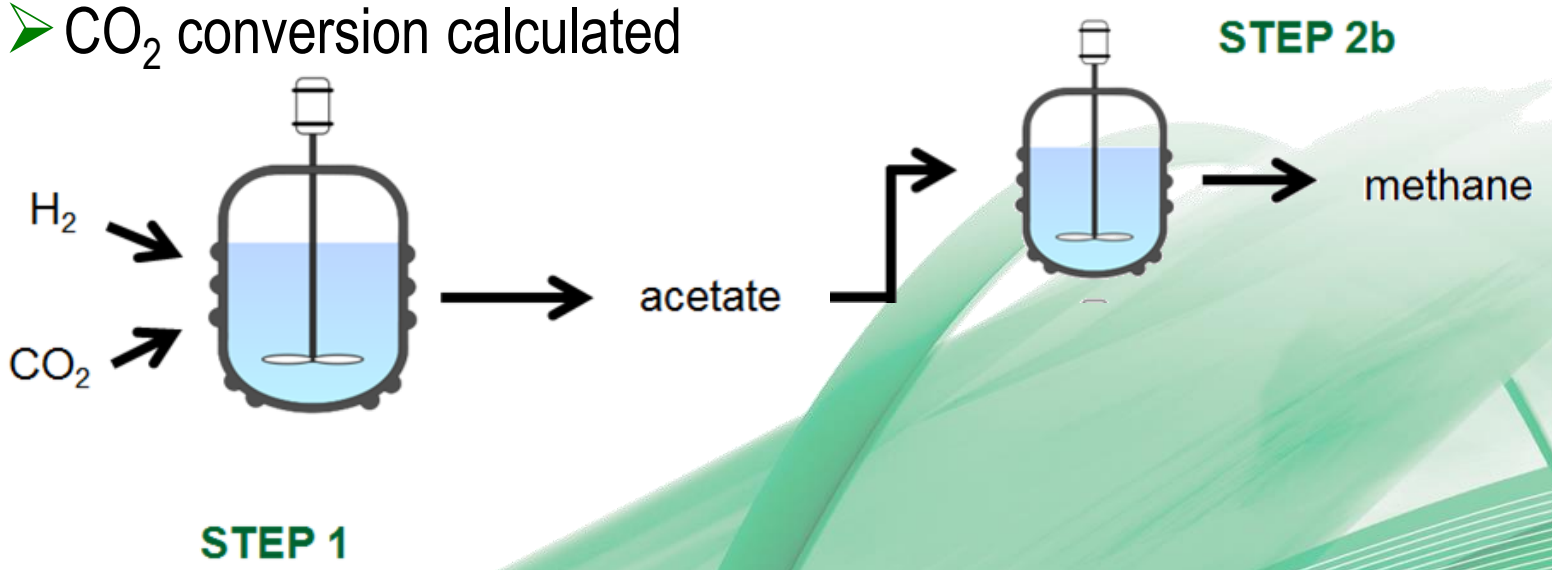




Hydrogenotrophic methanogenesis

- Evaluate the effect of acetate on hydrogenotrophic methanogenesis

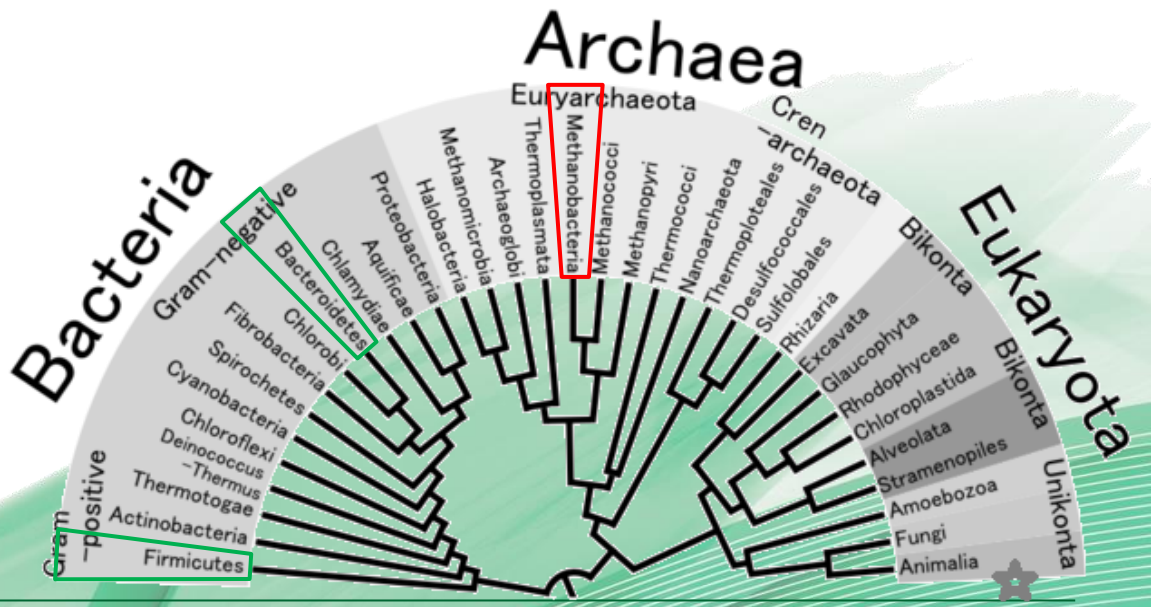
  - Hydrogenotrophic enrichment culture from sewedge sludge
  - 16 SrDNA analysis
  - CO_2 conversion calculated



Results: Consortium analysis

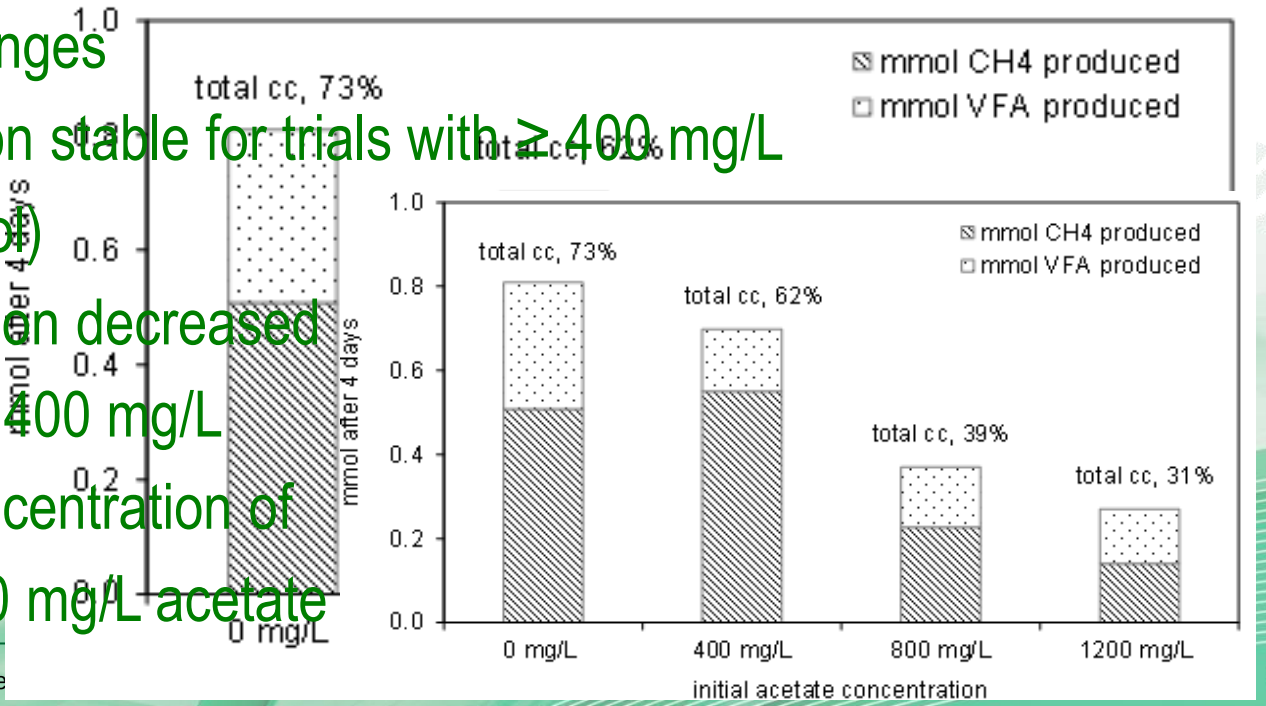
16 SrDNA analysis of adapted hydrogenotrophic consortium

- Proved a balanced mix of methanogenic Archaea species and acetogenic bacteria
- Acetogenic Bacteria (Bacetiodetes and Firmicutes):
  - Bacteroidales 23%
  - Clostridiales 17%
- Methanogenic Archaea:
  - Methanobacteriales 49%



Results

- Total carbon conversion (cc)
  - ➢ Reduces with increasing acetate conc.
- Product amounts of methane and volatile fatty acids (VFA) at increasing acetate supplementation
  - ➢ Product ratio changes
  - ➢ Acetate production stable for trials with ≥ 400 mg/L (0.14 ± 0.01 mmol)
  - ➢ Methane production decreased from 79% CH_4 at 400 mg/L initial acetate concentration of 52% CH_4 at 1.200 mg/L acetate



Outlook

Plan to:

- Optimise fermentation with linen
  - mixing speed, gas flow rate, media removal rate
  - for both strains
- Compare to other immobilisation systems
  - hollow fibre membrane fermentation system
- Test CO_2 / acetate conversion rates for methanogenic strains in pure culture
- Evaluate ABE-fermentation from acetate

Thank you for your attention

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https://www.researchgate.net/project/Hydrofinery-the-use-of-CO2-and-H2-in-fermentation-to-produce-liquid-and-gaseous-fuels

Franziska Steger, Matthias Windhagauer, Lydia Rachbauer, Günther Bochmann, Lucy Montgomery

Thank you for your attention

Save the date:
Workshop on gas fermentation & ABE
10th & 11th November 2016
Vienna

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