TECHNISCHE UNIVERSITÄT WIEN

ICEBE IMAGINEERING NATURE

Bio-Acetate production via dual fluidized bed syngas fermentation

IEA Task 33 Workshop Gasification and Chemicals

Alexander Bartik, 12th June 2024

The circular carbon bioeconomy based on biomass

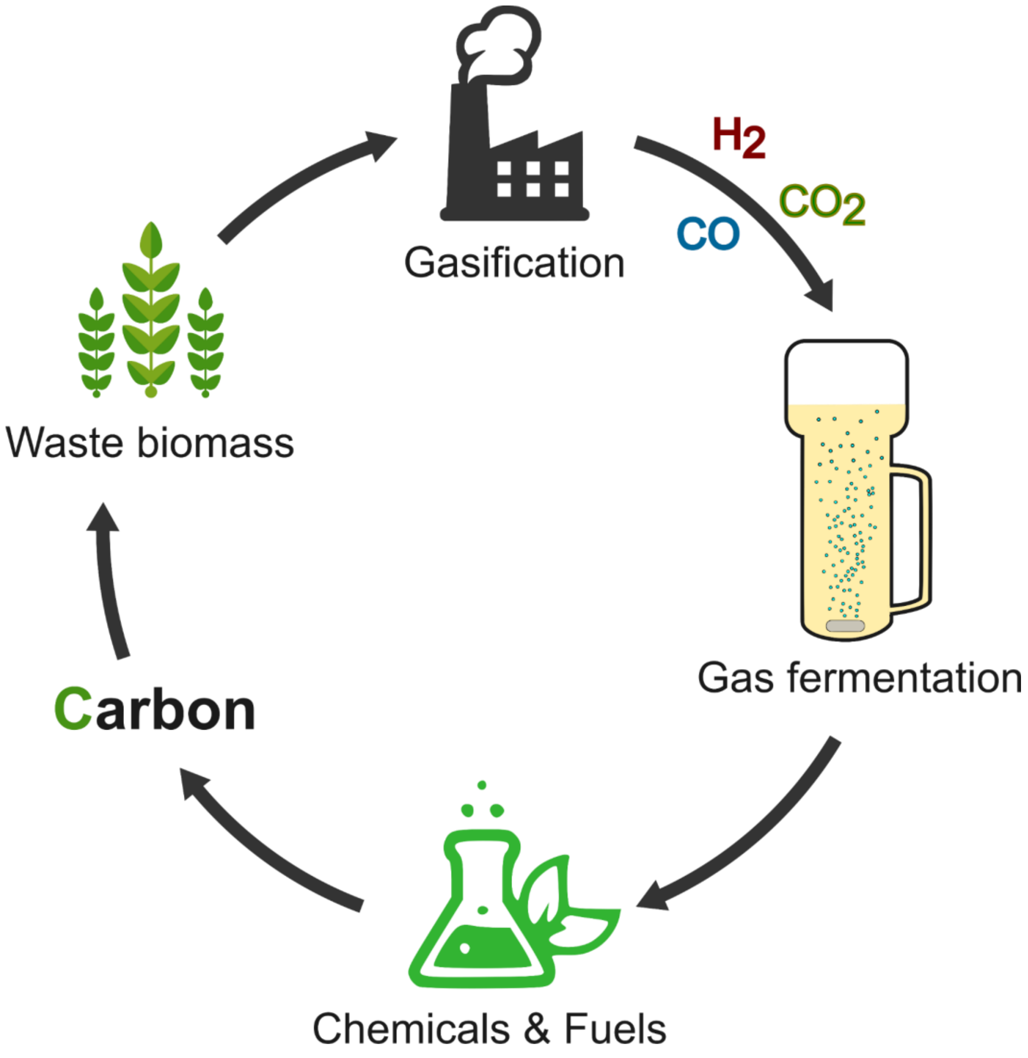
- **Gasification** of lignocellulosic (waste) biomass

  → Dual fluidized bed (DFB) gasification to produce product gas/syngas

- **Gas fermentation** to produce chemicals & fuels

  → Bubble column reactor with *Thermoanaerobacter* kivui to produce **acetate** (lactate*)

*currently investigated

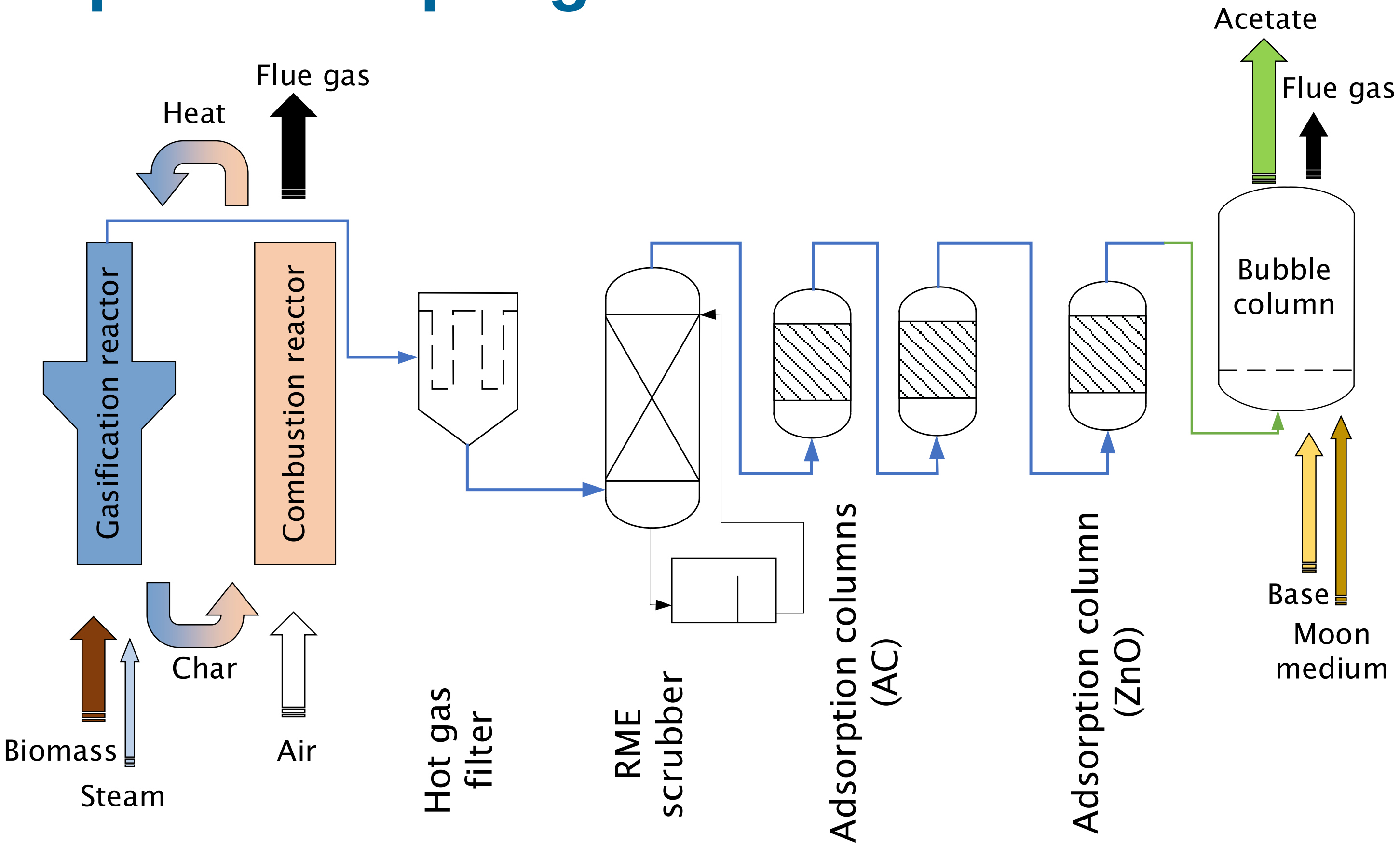


Goals

Proof of concept: coupling “real” DFB product gas with gas fermentation to produce acetate

- Characterize *T. kivui* physiology/metabolism
- (Re)adaptation of *T. kivui* to CO
- Show acetate production with synthetic gas and parameter testing
- Show resilience to product gas impurities and integration possibilities

Concept for coupling

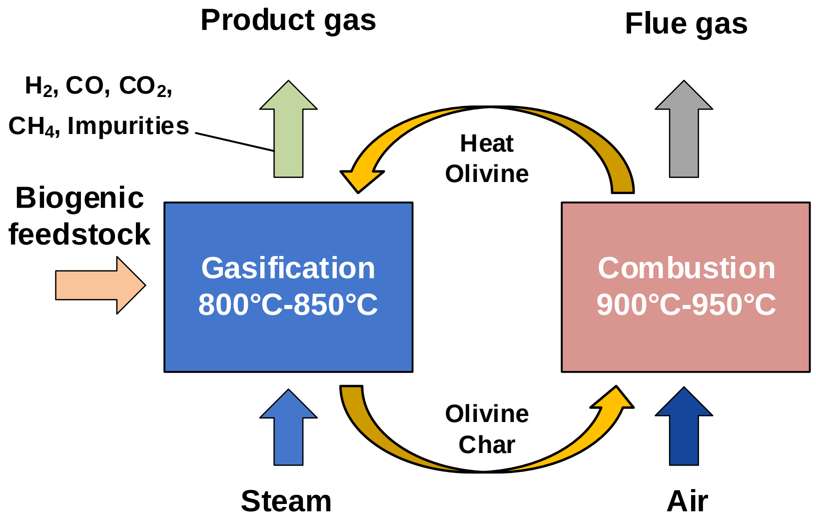


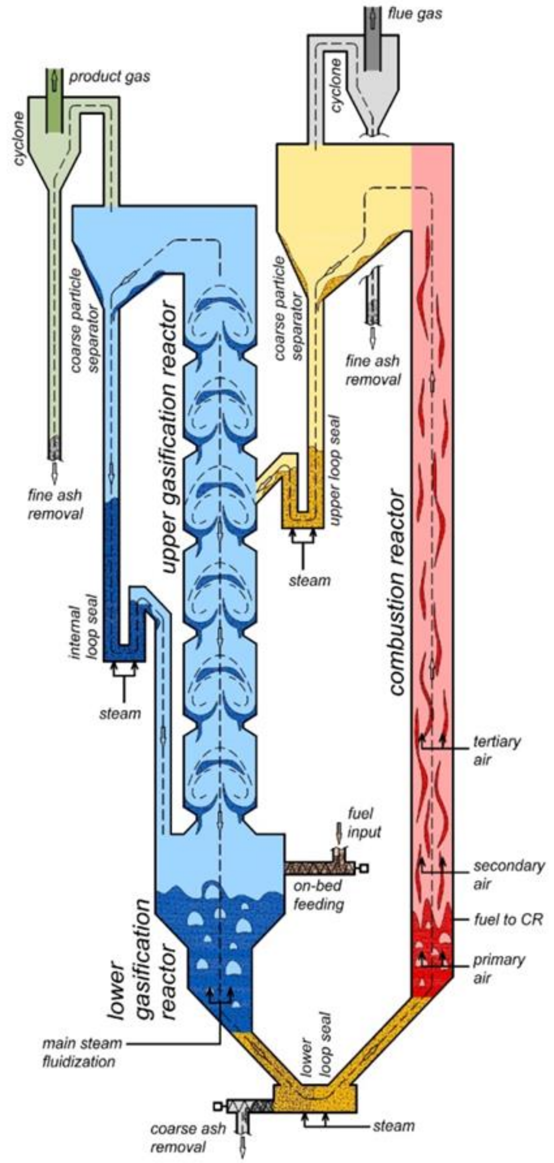
DFB steam gasification → Gas cleaning → Fermentation

Steiner et al. 2024, in preparation

Dual fluidized bed gasification

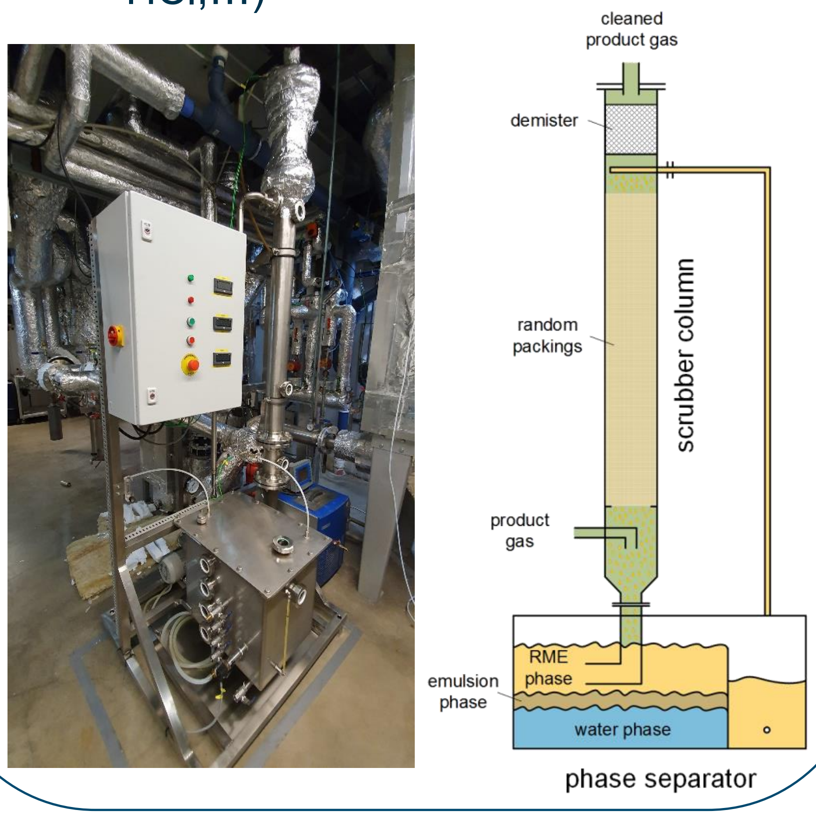
- 100 kW_{th} advanced DFB pilot plant at TU Wien
- Two inter-connected fluidized beds
- Bed material circulation provides heat
- Nearly N_2-free product gas (PG)
- Advanced design for enhanced gas-solid contact & soft bed materials





Gas cleaning

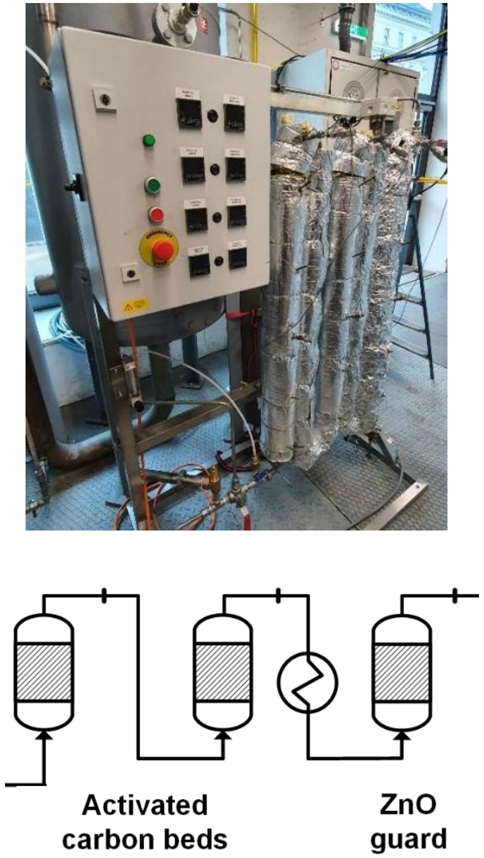
Absorption & condensation of
- Tar compounds
- Water-soluble substances (NH_3, HCl,…)



Biodiesel scrubber

Activated carbon beds & zinc oxide

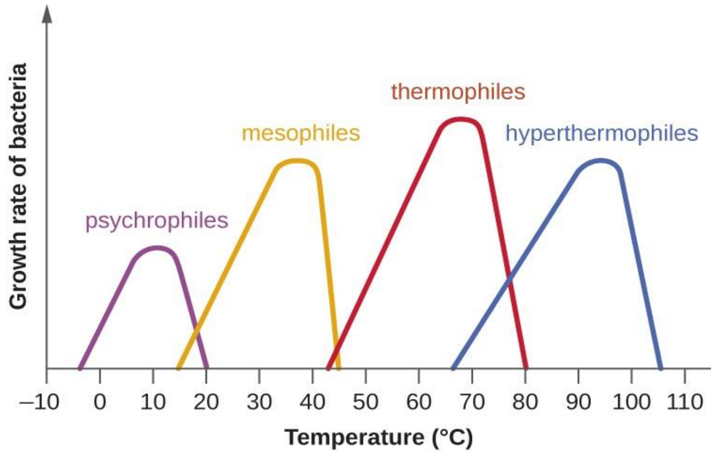
Adsorption of
- Hydrocarbons & tar compounds (BTX, naphthalene)
- Sulfur compounds



Gas fermentation

- „Emerging“ technology
- Mass transfer critical for an economic operation of gas fermentation
- Anaerobic bacteria (acetogenes) suitable for syngas fermentation
- Robust biocatalysts with high tolerance
- High carbon and energy efficiency

- *T. kivui* is a thermophilic acetogenic bacteria
  - → growth at ~70°C
  - → low cooling costs
  - → high growth rates



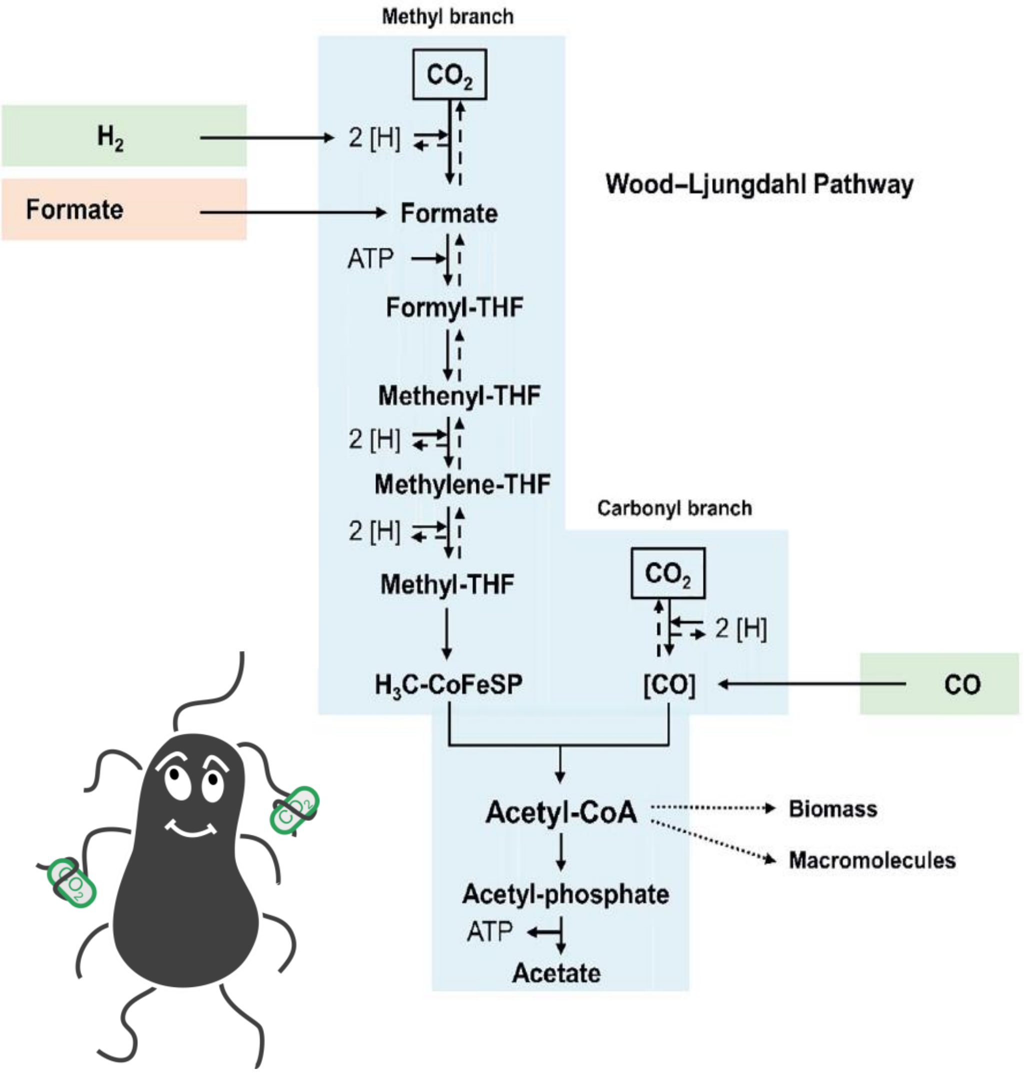
20 liter bubble column gas fermentation reactor at TU Wien

Thermoanaerobacter kivui

- Thermophilic acetogen (T_{opt}= 66 °C)
- Fast growth on H_2/CO_2 [1]
- Sole CO utilization as carbon and energy source after adaptation [2]
- CO energetically more favorable than CO_2
- Syngas: co-utilization of CO_2, H_2 and CO
- Mineral medium without yeast extract or vitamins [1]
- Wood-Ljungdahl pathway

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

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



[1] Leigh et al., 1981, Archives of Microbiology, https://doi.org/10.1007/BF00414697
[2] Weghoff and Müller, 2016, Applied and Environmental Microbiology, https://doi.org/10.1128/AEM.00122-16

Modified from: Müller, 2019, Trends in Biotechnology, https://doi.org/10.1016/j.tibtech.2019.05.008

Approach

1 Bottled gas + Serum bottle

→ Fundamental survival
→ Adaptation

2 Bottled gas + continuous culture

→ Acetate production
→ Parameter testing

3 100 kW DFB pilot plant +
20 l bubble column reactor

→ Coupling with “real” product gas
→ proof of concept

4 Bottled gas + Serum bottle

→ Impurity tests

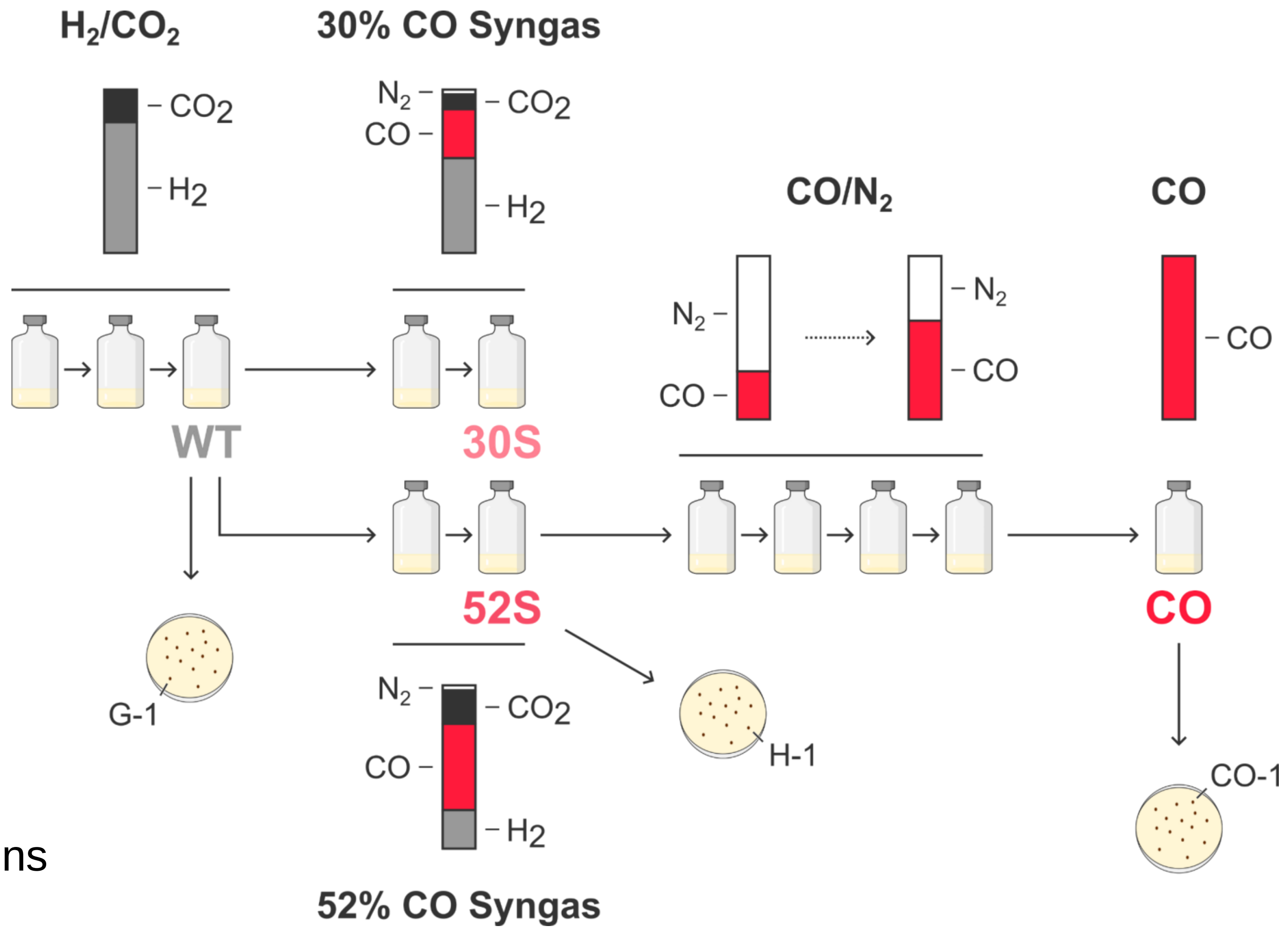
Adaptation of *T. kivui* to CO utilization

①

→ **Quick adaptation**:
from H_2/CO_2 to 100% CO in ~31 generations

→ **Fast growth on CO**:
growth rates of 0.20-0.25 h^{-1} of *T. kivui* CO-1

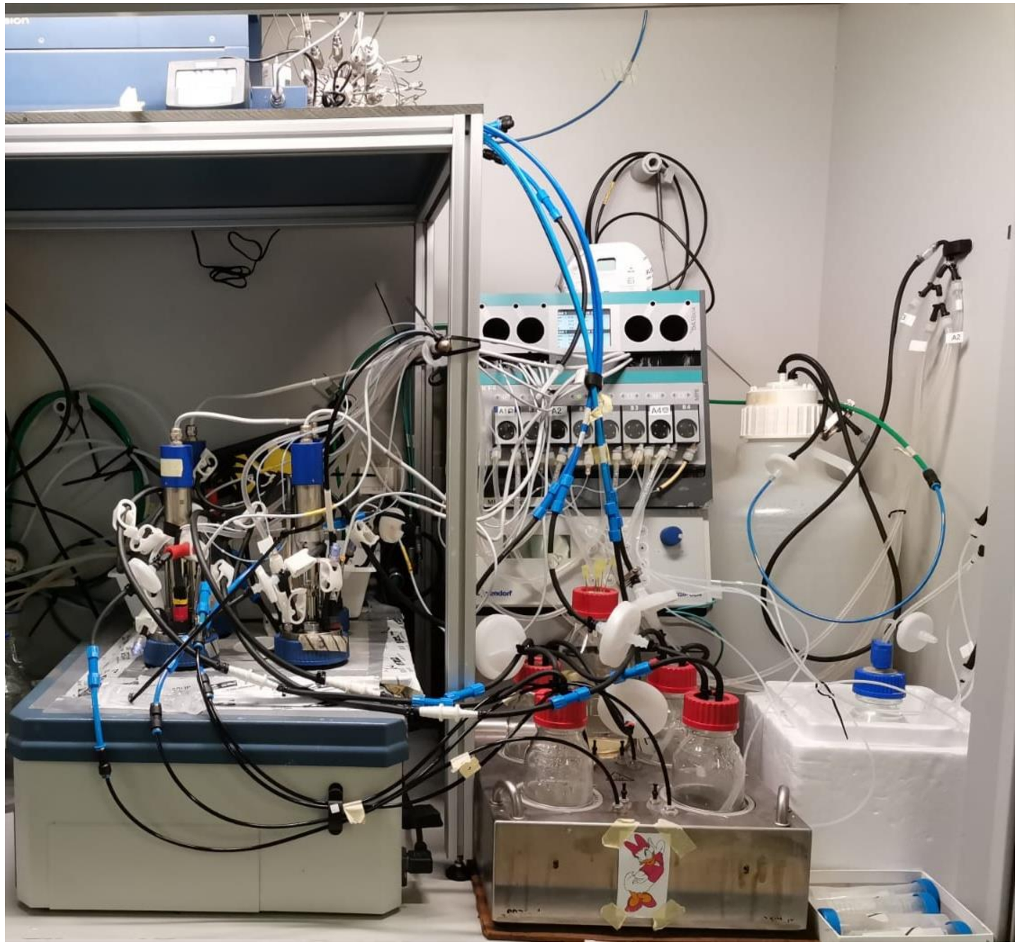
adaptable to various syngas compositions



Continuous culture

2

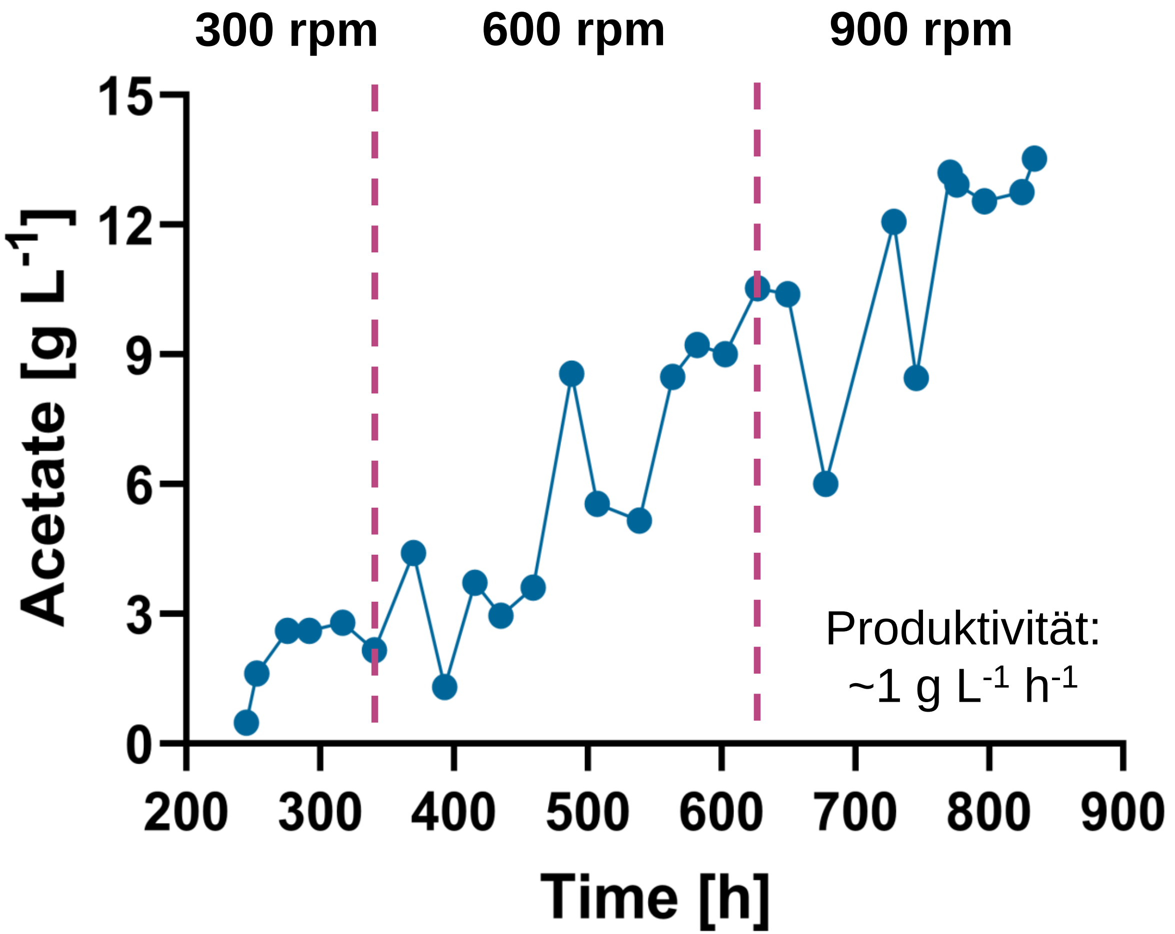
- 4x 200 mL parallel bioreactor system (DASBOX, Eppendorf)
- Continuous gas and liquid feeding (gas at 0.0633 vvm)
- Syngas composition: $CO:H_2:CO_2$ 52:24:21
- Dilution rate: 0.075 h^{-1}
- T = 66°C
- pH = 6.4



Continuous culture

- 4x 200 mL parallel bioreactor system (DASBOX, Eppendorf)
- Continuous gas and liquid feeding (gas at 0.0633 vvm)
- Syngas composition: $CO:H_2:CO_2$ 52:24:21
- Dilution rate: 0.075 h^{-1}
- T = 66°C
- pH = 6.4

- 818 h of continuous growth and acetate production
- Growth rate: 0.0766 h^{-1}
- Acetate productivity: 0.9527 g/l/h



Coupling with real DFB product gas

3

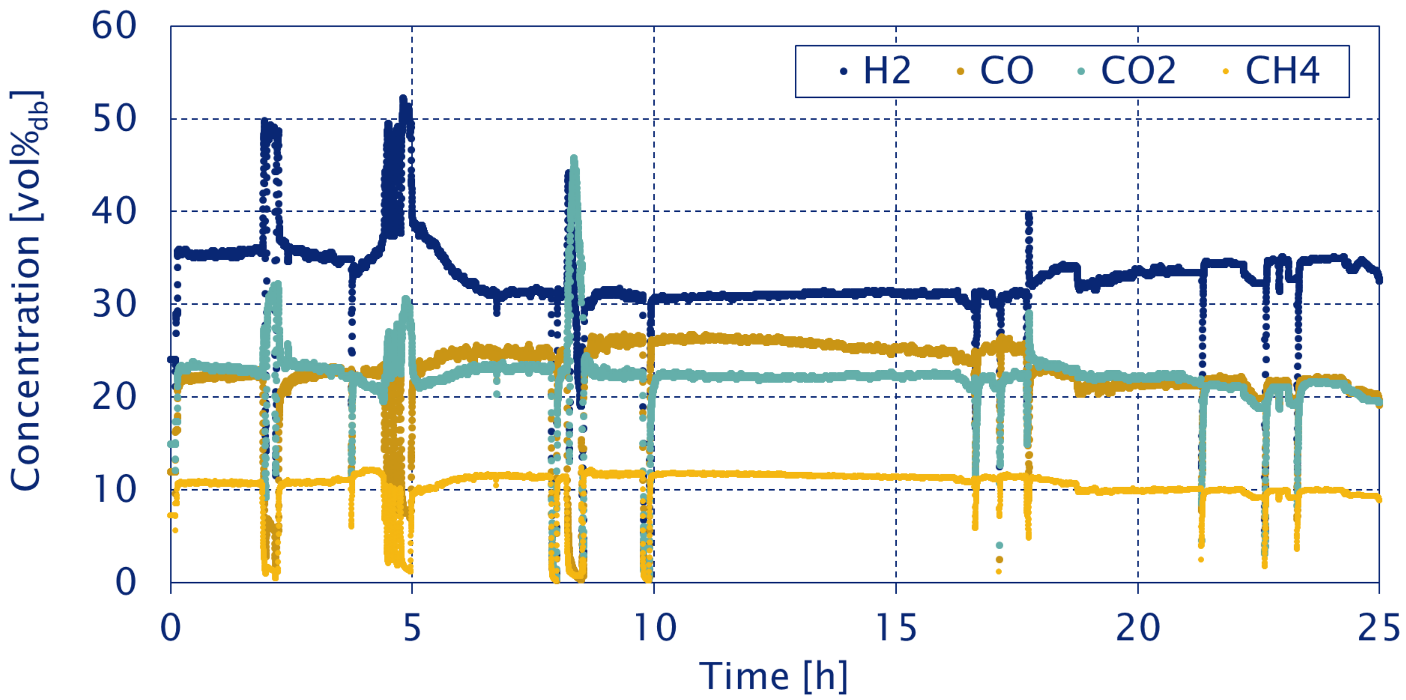
- Gasification of softwood pellets (~48 h)
- 25 h of coupled syngas fermentation

  → Bacteria growth rate: 0.102 h^{-1} (at 0.075 vvm)

  → Acetate productivity: 0.083 g/l/h (at 0.075 vvm)

- Survival of bacteria (low enough oxygen contamination)
- Successful acetate production
- Productivity limited due to mass transfer limitations ($k_L a$ value) of bubble column reactor

Product gas composition



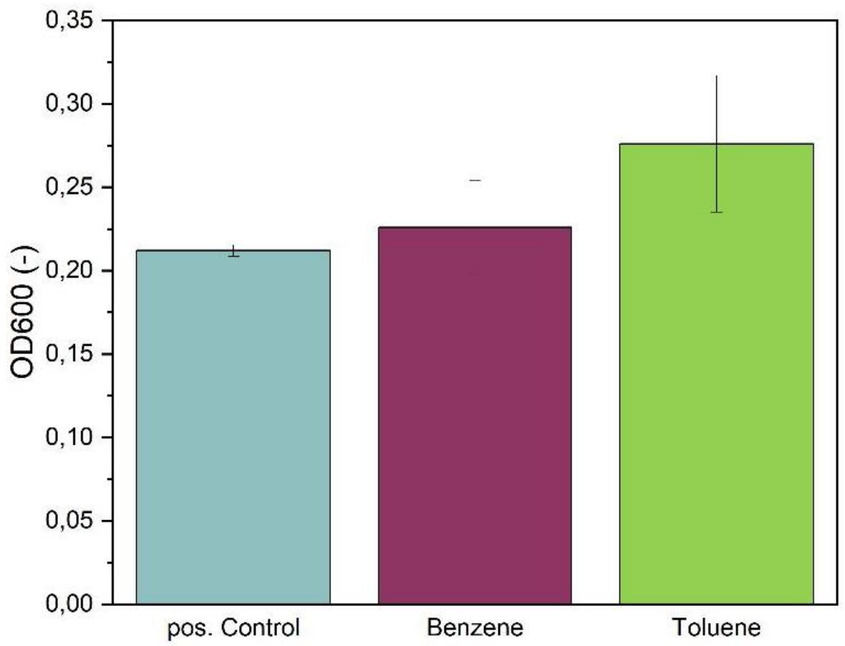
Testing of impurities

4

Could we use product gas downstream the biodiesel scrubber without activated carbon?

Typical impurities downstream of the biodiesel scrubber

Impurity	Concentration
Benzene	4000 ppm
Toluene	4000 ppm
H_2S	25 ppm



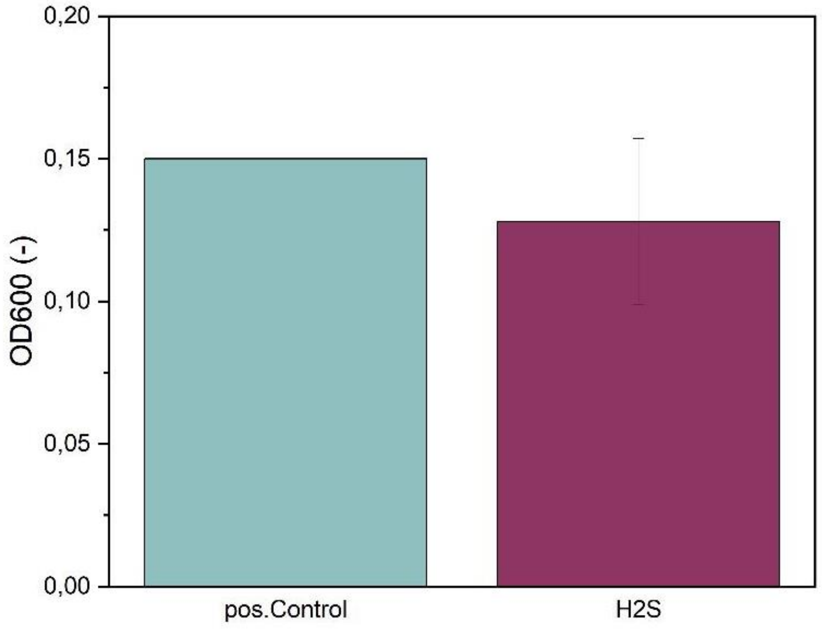
Testing of impurities

4

Could we use product gas downstream the biodiesel scrubber without activated carbon?

Typical impurities downstream of the biodiesel scrubber

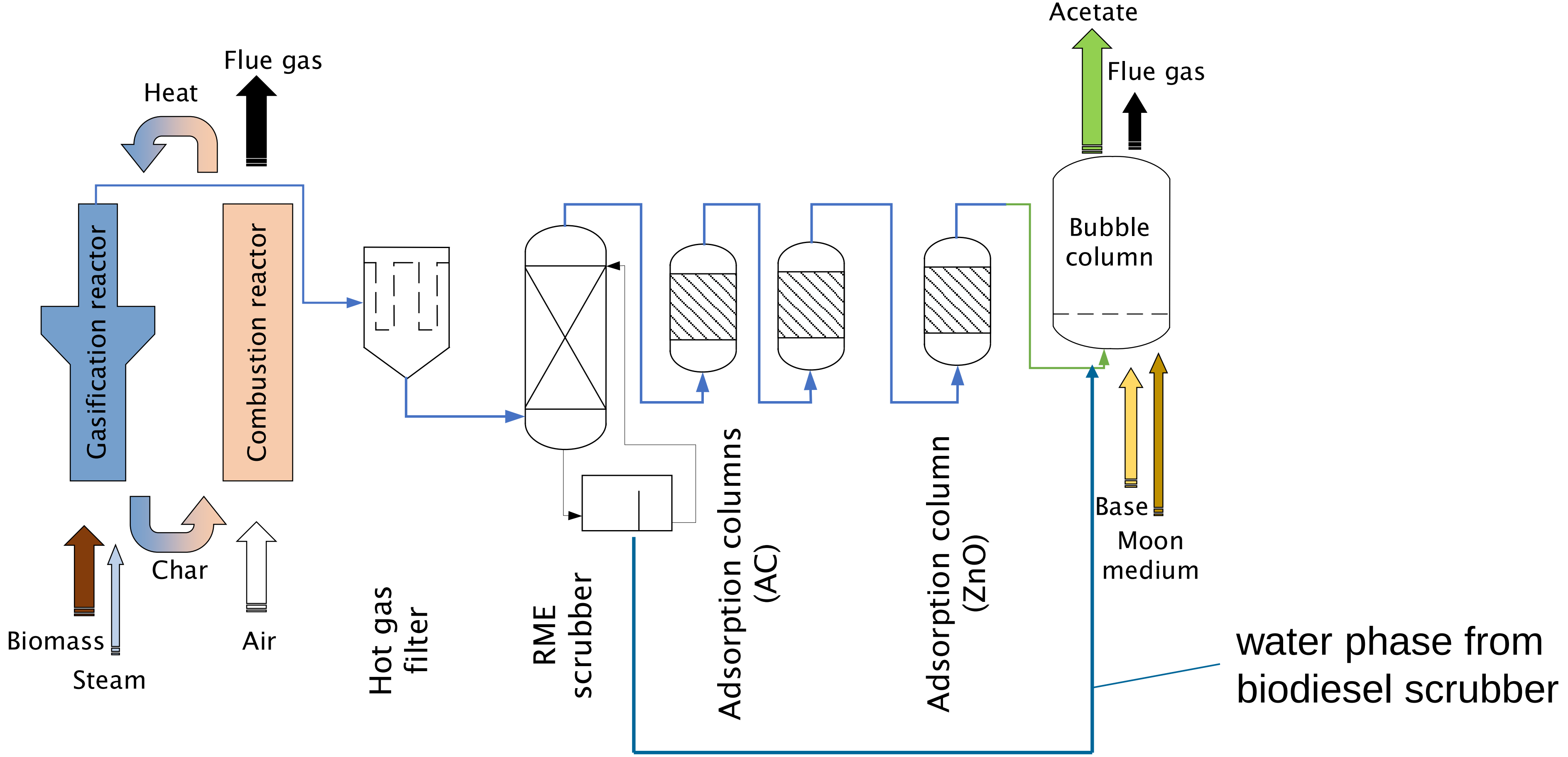
Impurity	Concentration
Benzene	4000 ppm
Toluene	4000 ppm
H_2S	25 ppm



→ Use of product gas after RME scrubber conceivable

Integration possibility using scrubber water phase

4



DFB steam gasification → Gas cleaning → Fermentation

Steiner et al. 2024, in preparation

Integration possibility using scrubber water phase

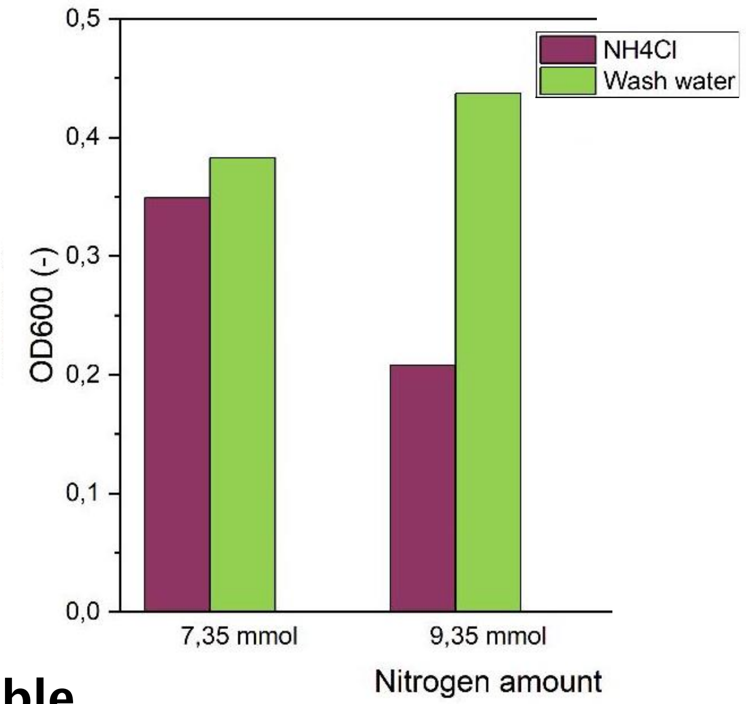
4

Could we use product gas downstream the biodiesel scrubber without activated carbon?

Typical impurities downstream of the biodiesel scrubber

Impurity	Concentration
Benzene	4000 ppm
Toluene	4000 ppm
H_2S	25 ppm
Condensate*	unknown

*From phase separator; Contains NH_3, Phenol, Cyanate, Cyanide…



→ **Use of water phase from biodiesel scrubber conceivable**

Already tested and published for yeast production as well: https:\\doi.org\10.3389/fbioe.2023.1179269

Acknowledgements

Biotechnology

Dr. Stefan Pflügl
Dr. Rémi Hocq
Josef Horvath
Julia Reichebner
Maja Stumptner
Marlies Müller
Angeliki Sitara
Klara Wögerbauer
Renaud Eynard
Dr. Eugenio Pettinato

Funding

Christian Doppler Forschungsgesellschaft

CIRCE

Acknowledgements

Lena Steiner
Dr. Florian Benedikt
Dr. Alexander Bartik
Hans Zeitlhofer
Dr. Josef Fuchs
Tom Popov
Veronica Gubin
David Kadlez
Ferdinand Thelen

Fuel and Energy System Engineering

Funding

Christian Doppler Forschungsgesellschaft

CIRCE