Chair of Energy Systems
School of Engineering and Design
Technical University of Munich

(Bio)Process Engineering - a Key to Sustainable Development

Decontamination of polluted soils: a gas fermentation model for SynFuel production and techno-economic estimation

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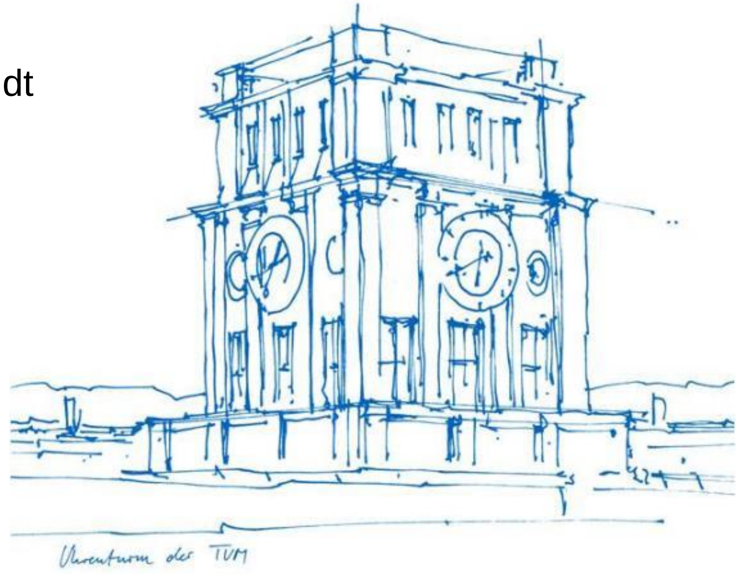
Aachen, 14th September 2022



Agenda

Project GOLD

Project ReGasFerm

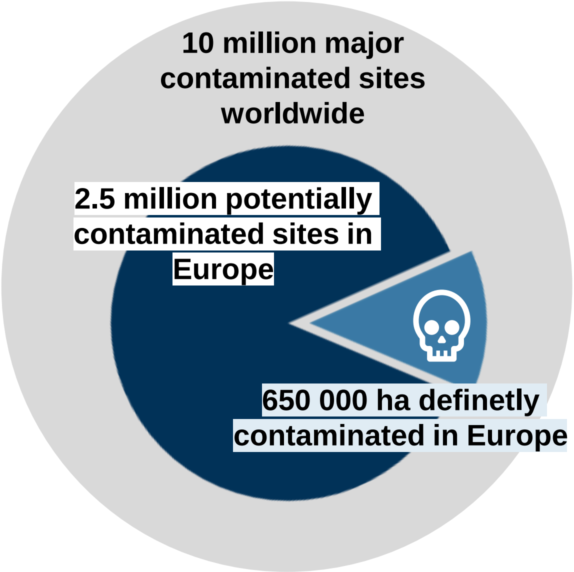
Modelling Clean SynFuel Production

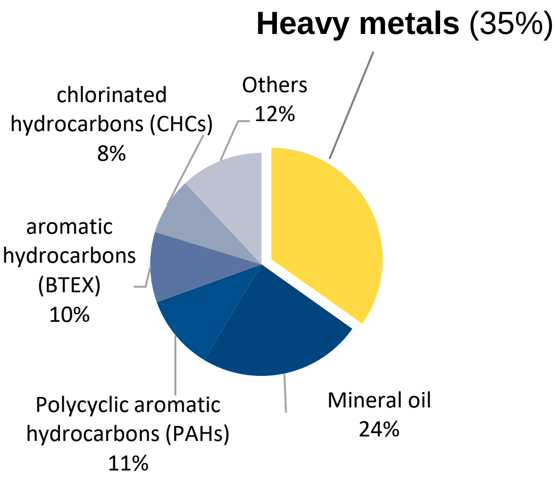
Techno-Economic Estimation

Summary and Outlook

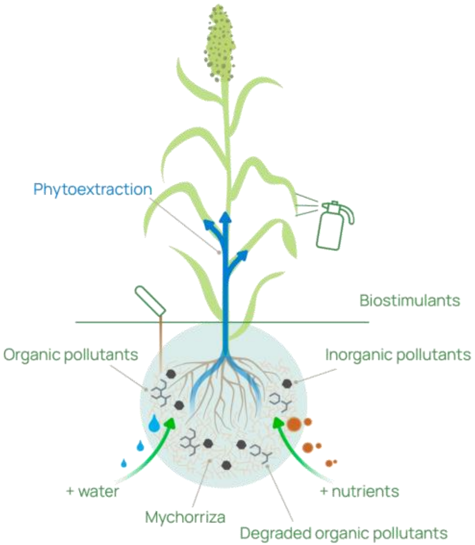
Contaminated soils and phytoremediation

Motivation and GOLD project Idea





Phytoextraction

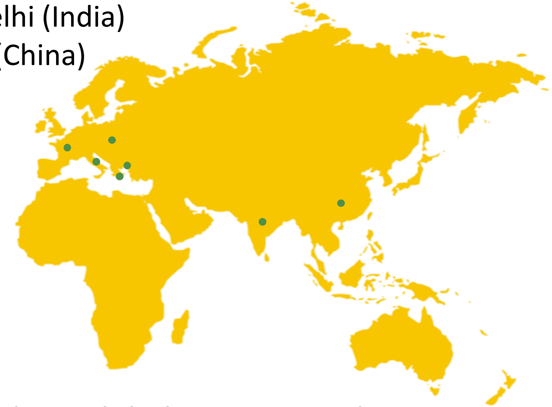


Project GOLD

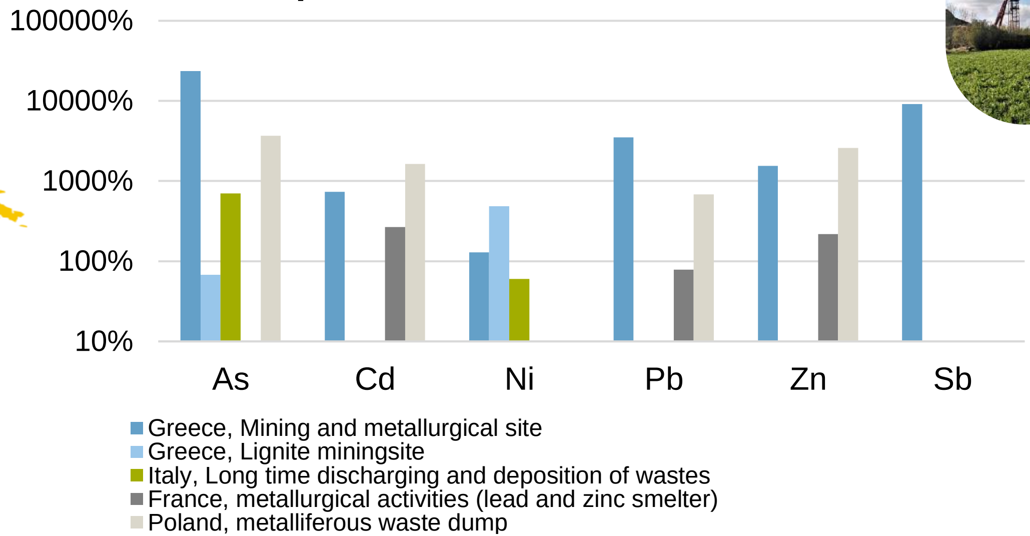
Bridging the gap between phytoremediation solutions on Growing energy crOps on contaminated LanDs and clean SynFuel production

Field trials at seven sites:

- Metaleurop Nord (France)
- Bologna (Italy)
- Silesia (Poland)
- Lavreotiki and Kozani(Greece)
- New Delhi (India)
- Hunan (China)



Soil contamination at EU field sites compared to uncontaminated soils



Project GOLD

Conversion processes for clean SynFuel production

TorWash® *TNO* / Torrefaction *TNO* / Pyroloysis *RE-CORD* → **EF Gasification** *TUM-CES* → **Gas Cleaning** *TUM-CES* → **Syngas Fermentation** *TUM-CBE* → Mixed alcohols

Concentrated contaminant removal

Slag containing heavy elements in vitrified form (Cu, Ni)

Reaction engineering analysis of acetogens in lab-scale bioreactors (stirred-tank reactor) to produce biofuels like ethanol and butanol

- **Identification of critical impurities and concentrations**
- Investigation of **conversion of synthesis gas** with selected MOs
- Establishment of a (continuous) **lab-scale gas fermentation process** at well-defined reaction conditions for **efficient production of biofuels from syngas** Providing process-engineering data for **further scale-up**

Syngas fermentation lab @TUM-CBE

ReGas Ferm

Project ReGasFerm

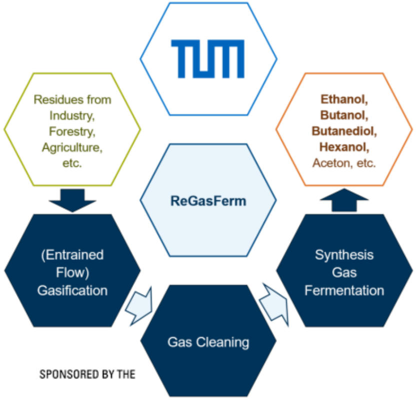
Utilization of biogenic residues to produce SynFuel

Motivation:

Continuous production of mixed alcohols from purified synthesis gases produced via entrained flow gasification of biogenic residues with oxygen

Research focus:

- Gasification behavior of biogenic residues
- Formation and degradation of trace substances
- Syngas purification system for the fermentation process
- Trace analysis of impurities in purified synthesis gases



Project:

- Funded by BMBF (PtJ)
- Project partners: TU-CBE, Florafuel AG

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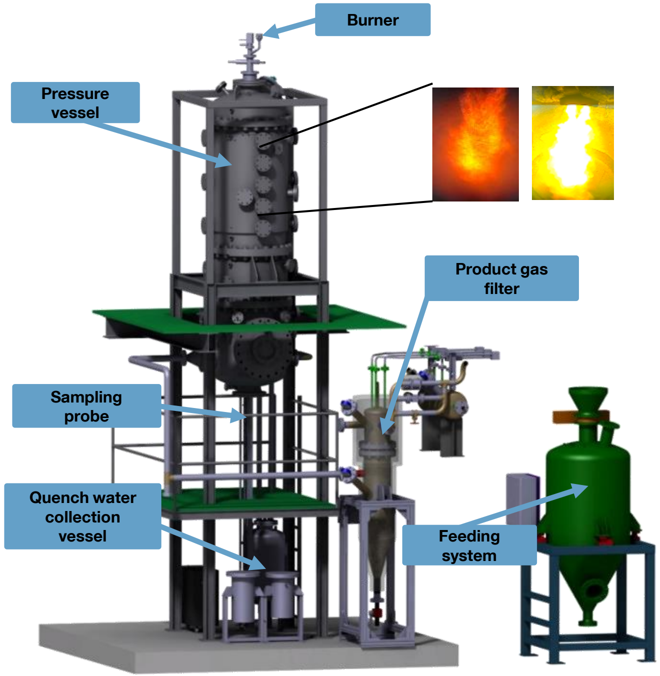
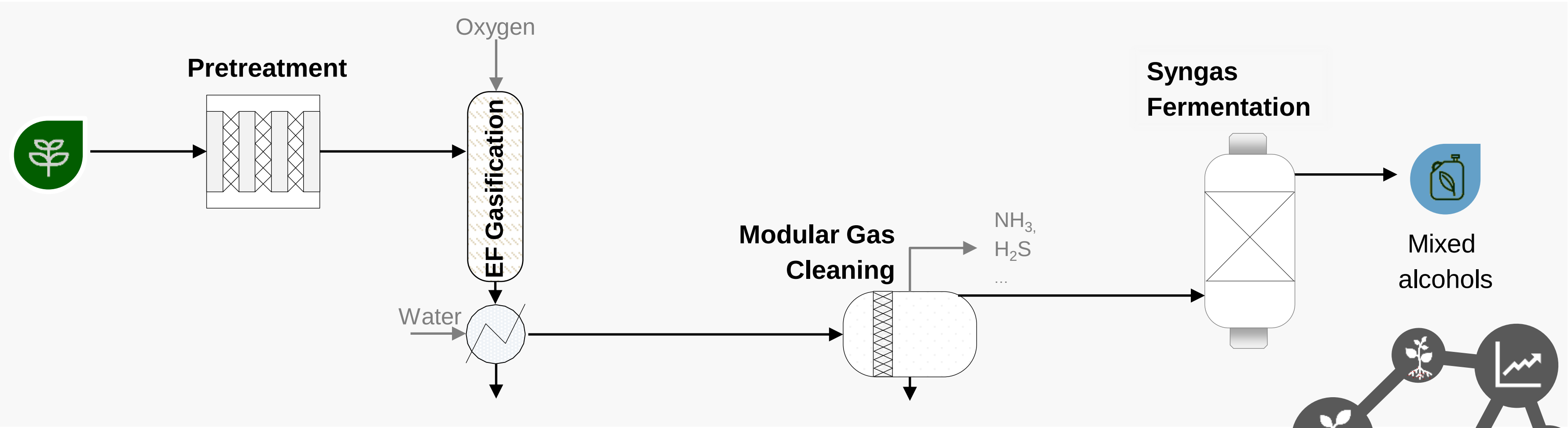


Conversion process for clean liquid biofuel production

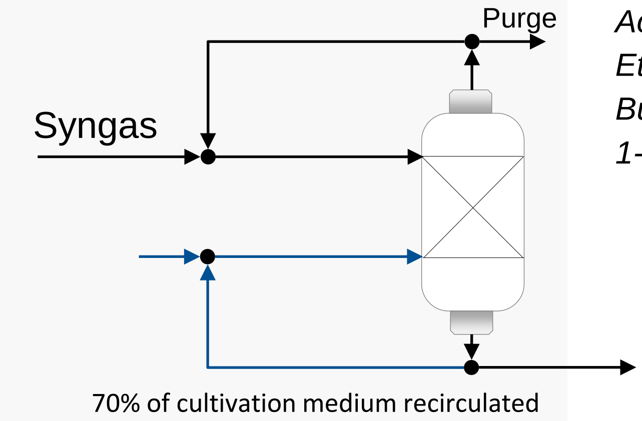
Process modelling approach



- Thermodynamic process modelling to evaluate overall carbon efficiency, potential integration options between process steps and feasibility
- Experimental data used to validate the steps among the process chain

Process modelling approach

Syngas fermentation thermodynamic reactor model



Mixed alcohols

C. carboxidivorans: reactions implemented in RStoic

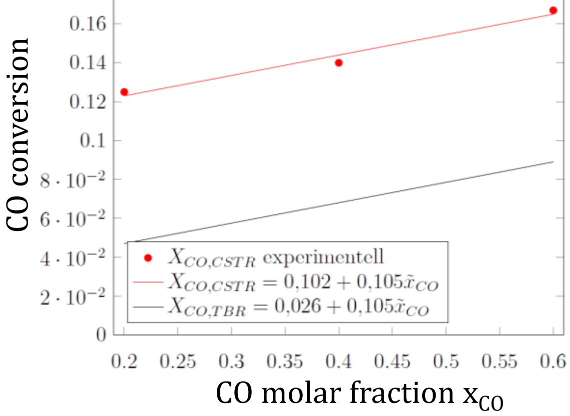
Acetic Acid: $4\ CO + 2\ H_2O \rightarrow CH_3COOH + 2CO_2$

Ethanol: $6\ CO + 3\ H_2O \rightarrow C_2H_5OH + 4CO_2$

Butyric Acid: $10CO + 4\ H_2O \rightarrow CH_3(CH_2)_2COOH + 6CO_2$

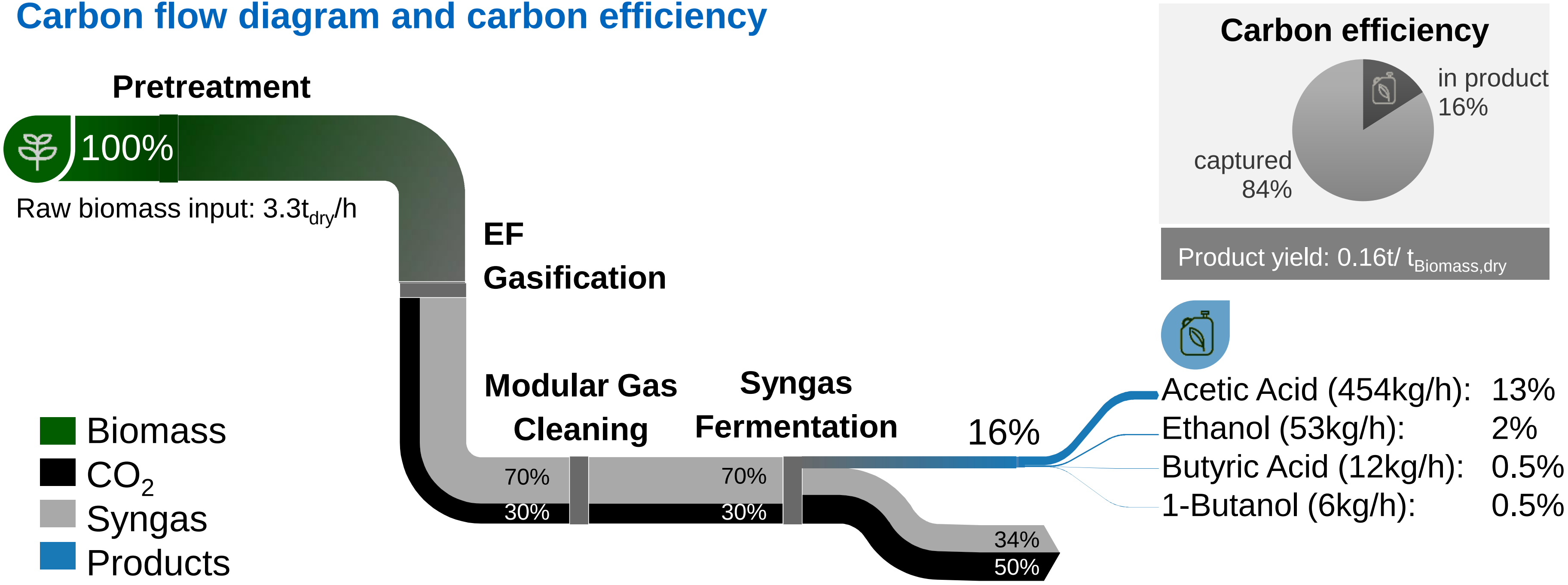
1-Butanol: $12CO + 5\ H_2O \rightarrow C_4H_9OH + 8CO_2$

Data from Doll 2018 and Riegler 2018



Process modelling results

Carbon flow diagram and carbon efficiency



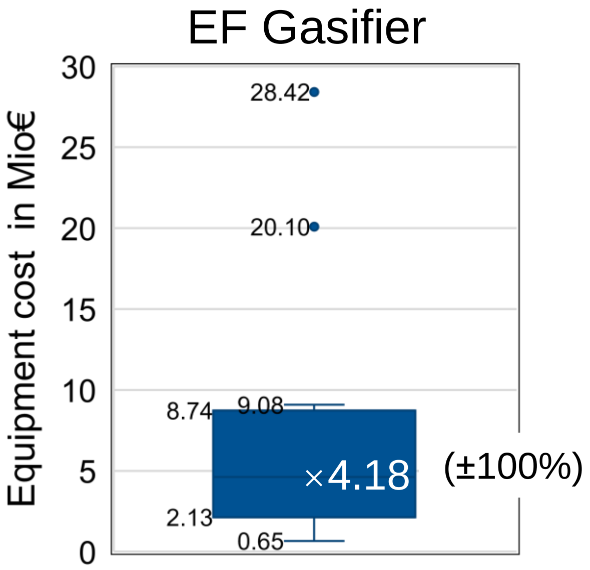
Techno-economic estimation

Total Capital Investment (TCI)

Scaling-based CAPEX study estimate

$$I_i = I_{Basis,i} \cdot \left(\frac{CEPCI_{2019}}{CEPCI_{Basis}}\right) \cdot W_\$ \cdot \left(\frac{C_i}{C_{Basis,i}}\right)^d$$

balance of the capital costs are estimated by applying multiplying factors based on similar systems (Peters). Including Fixed Capital Investment (FCI) and Working Capital Investment (WC)



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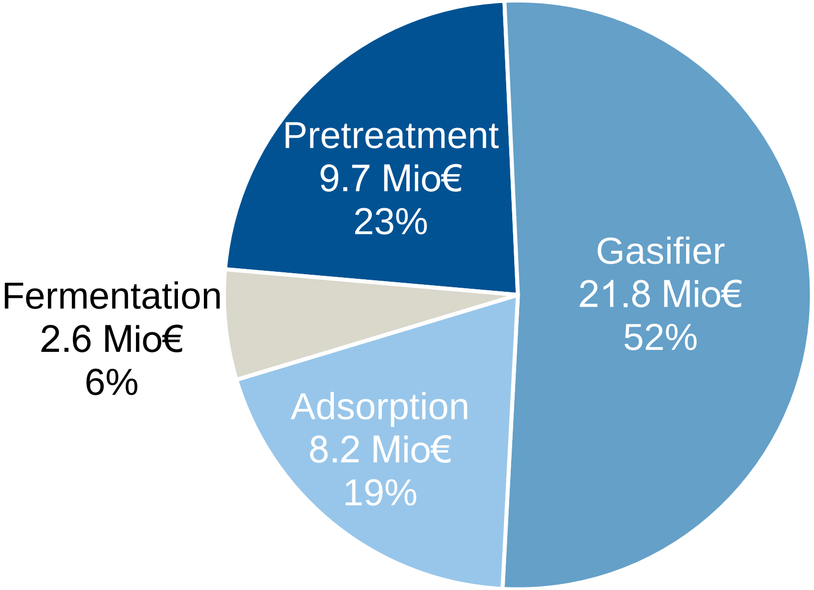
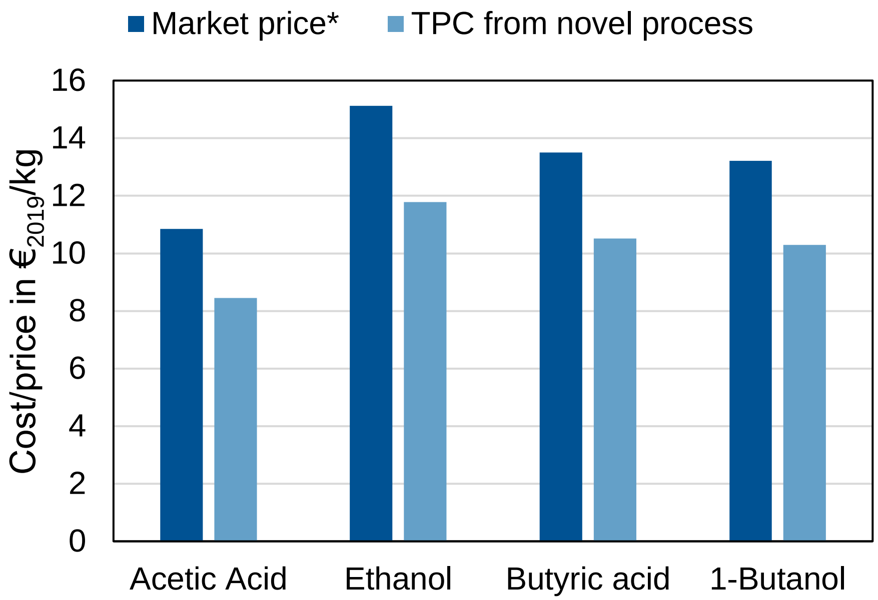
Total Capital Investment (TCI) : 42.3Mio€ (±30%)



Techno-economic estimation

Total Production Cost (TPC)



*merckmillipore.com

Some base case assumptions:

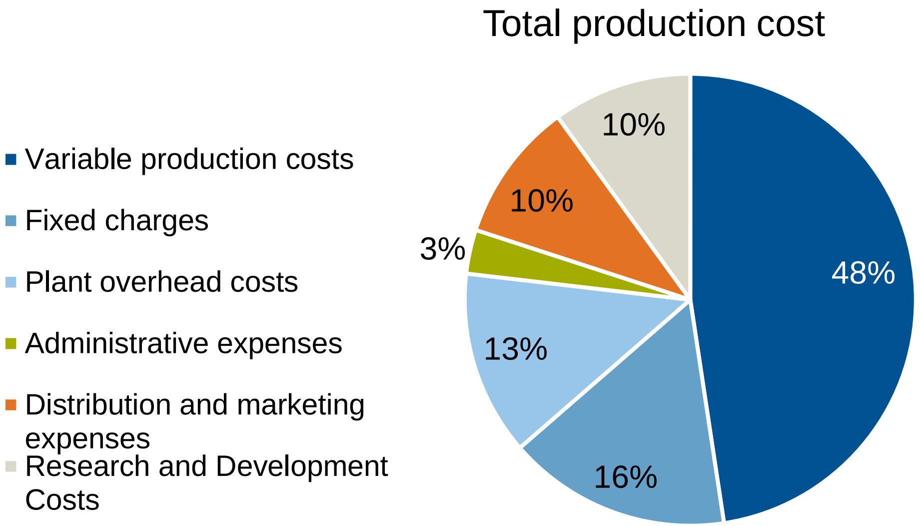
	Rate or quantity	Cost per rate or quantity
Raw materials		3.29€/t
Operating Labor	20Persona	6760€/month
Operating Supervision	15% of operating Labor	
Electricity	280kW	0.31€/kWh
Wastewater	3.15m³/hr	1.56€/Nm³
Water, quenching	1.58m³/hr	1.77€/Nm³
Water, fermentation	1.18m³/hr	1.77€/Nm³
Water, cooling	21.8m³/hr	1.77€/Nm³
Maintenance and repairs	5% of fixed capital invest	
Operating supplies	15% of maintenance and repairs	
Laboratory charges	15% of operating labor	
Royalties	3% of total product cost	
Adsorbent Packings	70kg/h	5€/kg
Nutrient Solution	1.8m³/hr	0.276€/l

Depreciation period: 7.5 years

(annuity and linear depreciation)

Techno-economic estimation

Total Production Cost (TPC)



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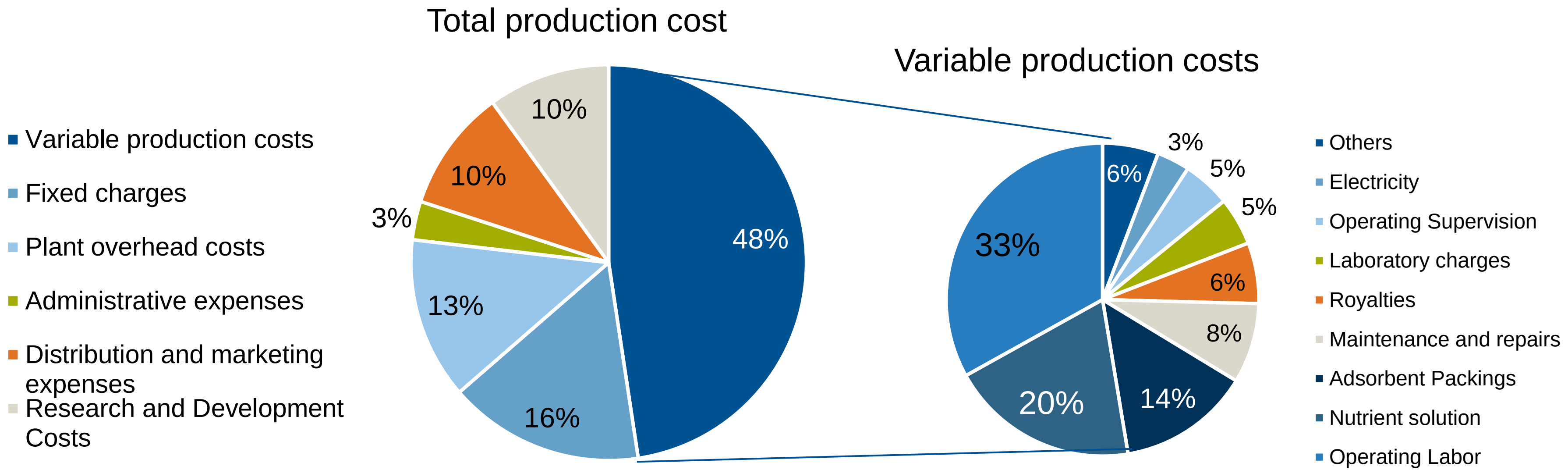
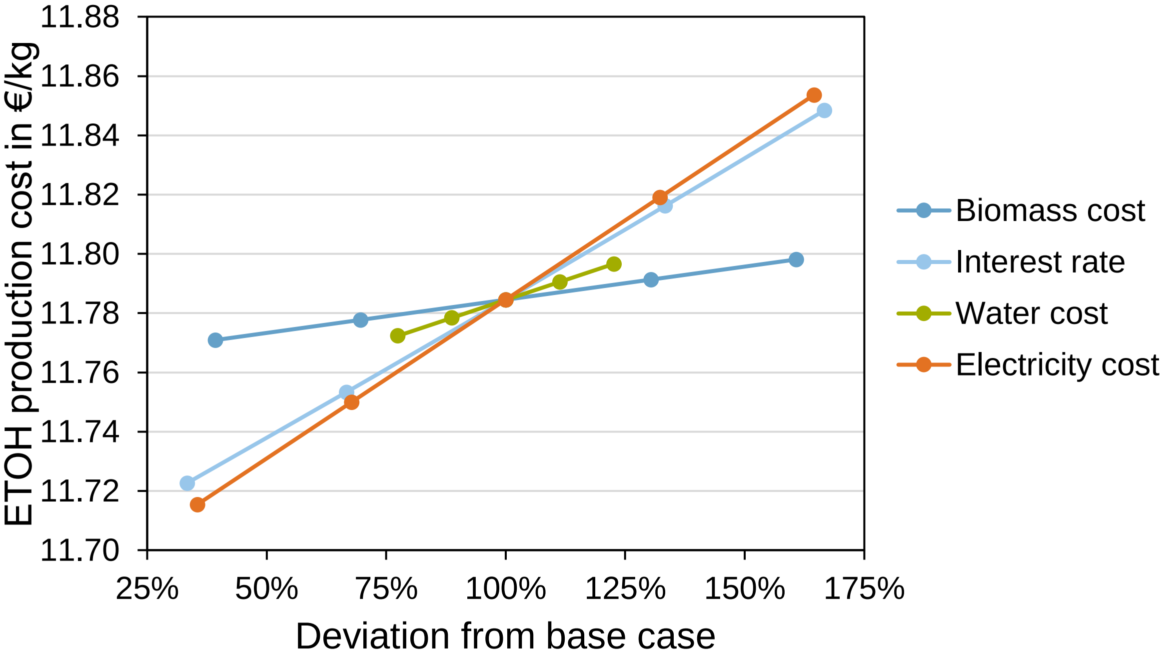
Techno-economic estimation

Total Production Cost (TPC)



Techno-economic estimation

Sensitivity analysis Ethanol TPC



Base case assumptions:

Biomass cost	3.29€/t
Interest rate	3%
Water cost	1.77€/Nm^3
Electricity cost	0.31€/kWh

Interest rate, Biomass, Water and electricity cost only have a minor influence on TPC

Conclusion

Conversion process for clean liquid biofuel production

Process modeling shows huge potential of novel gasification + syngas fermentation process

Carbon efficiency

Product yield: 0.16t/ $t_{Biomass,dry}$

High selectivity towards acetic acid & EtOH

- Total Capital Investment for 15MW_{th} BtL plant: ~40Mio€
  - Gasifier makes up half of the capital invest
- About half of the final product cost from variable costs
  - Biggest contributors to variable costs: Labor, Nutrient solution make-up and adsorbent packings
  - Changes in Interest rate, Biomass, water and electricity cost only have a minor influence on TPC

➡ Production costs of acetic acid (8.5 €/kg), Ethanol (11.8 €/kg), Butyric Acid (10.5 €/kg) and 1-Butanol (10.3 €/kg) show feasibility compared to market prices under base case assumptions

Outlook – Future Work

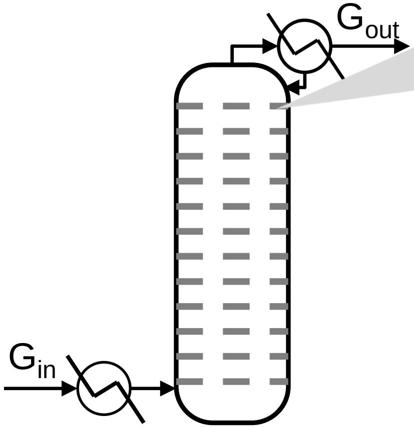
Currently: Advanced syngas fermentation modelling for up-scaling

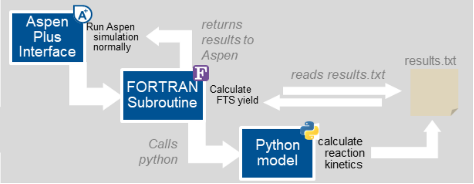
- Include pollutant from GOLD project
- Gasfermentation kinetics: Formal kinetic approach for C. Carboxidivorans in CSTR
- Scale-up using bubble column reactor
- Cascade reactor network to further increase carbon efficiency

➔ **Maximizing feasibility**

Phase equilibrium:

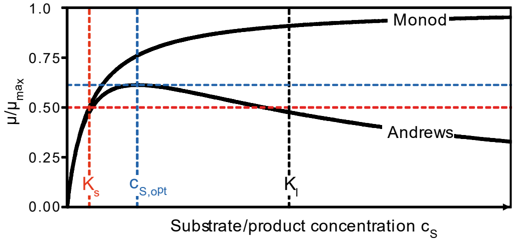
Henry's Law for equilibrium at the phase interface





Gasfermentation kinetics:

Formal kinetic approach C. carboxidicorans



Thank you for your attention
Any questions?

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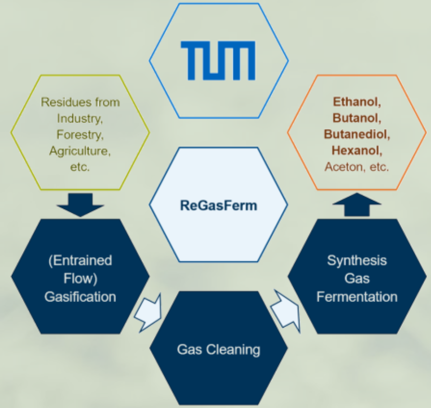

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GOLD develops solutions to grow lignocellulosic crops on conatminated sites

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