Bio-refining with focus on Bio-manufacturing for SAF

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Overview

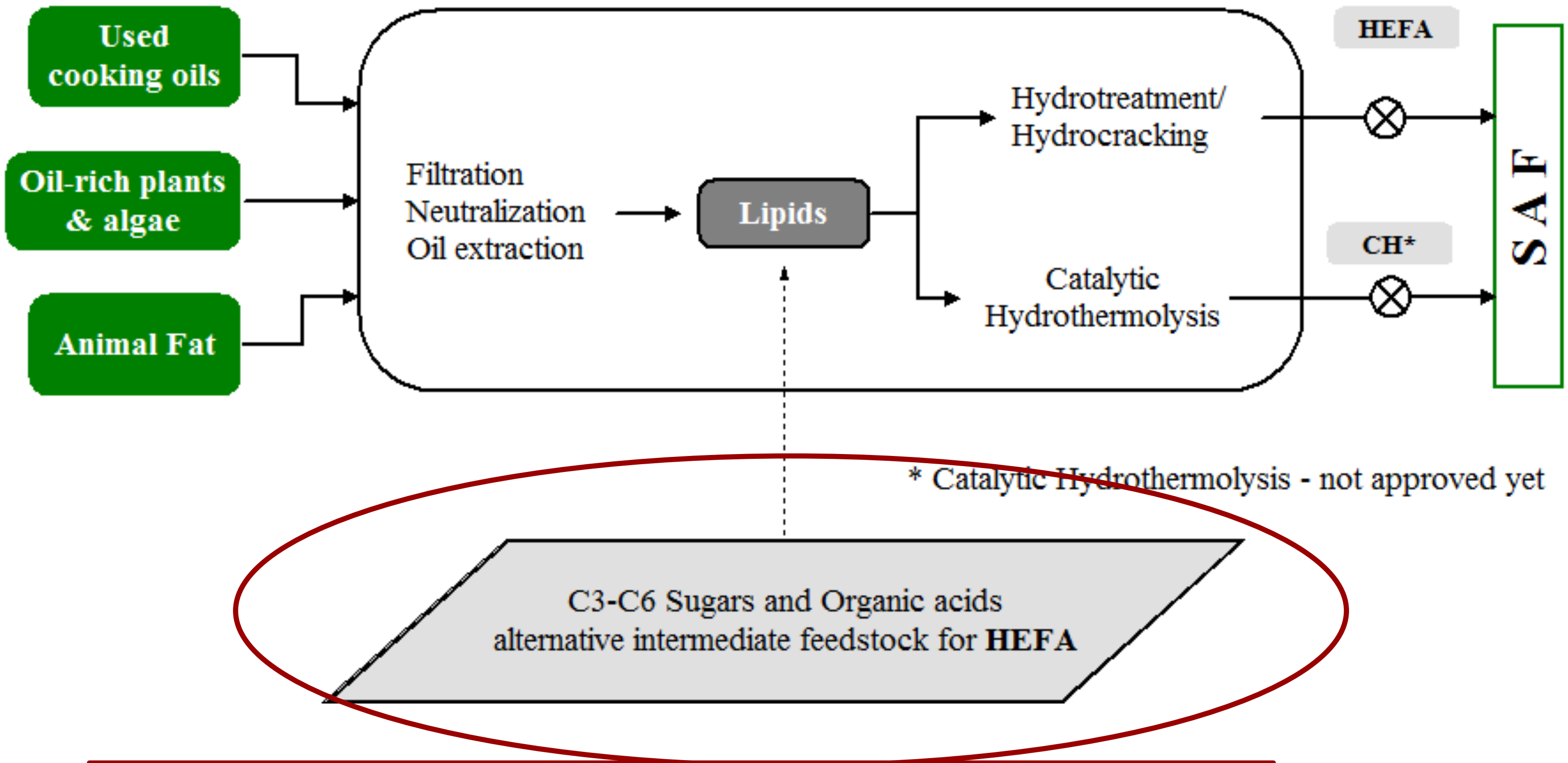
- Microbial lipids as intermediate feedstock for HEFA pathway – coupled with lignin 1st biorefinery

- Coupling gasification and biochemical conversions for AtJ pathway

- CO_2 transformations with renewable H_2 in a highly efficient trickle bed reactor

- TRL of the technologies at DTU Chemical Engineering

De-bottlenecking the HEFA pathway



- Limited availability of waste oils and oil crops in the Nordics
- Imported feedstock for the Nordics
- Forecasted heavy competition with the biodiesel industry – EU countries

Microbial lipids

- Microbial lipids are accumulated intracellularly under conditions of unbalanced growth and serve as carbon and energy reserves for the cells
- Their technical profile is similar to plant oils and animal fat

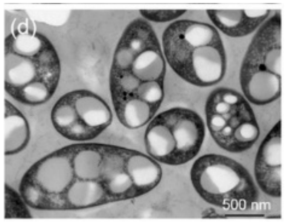


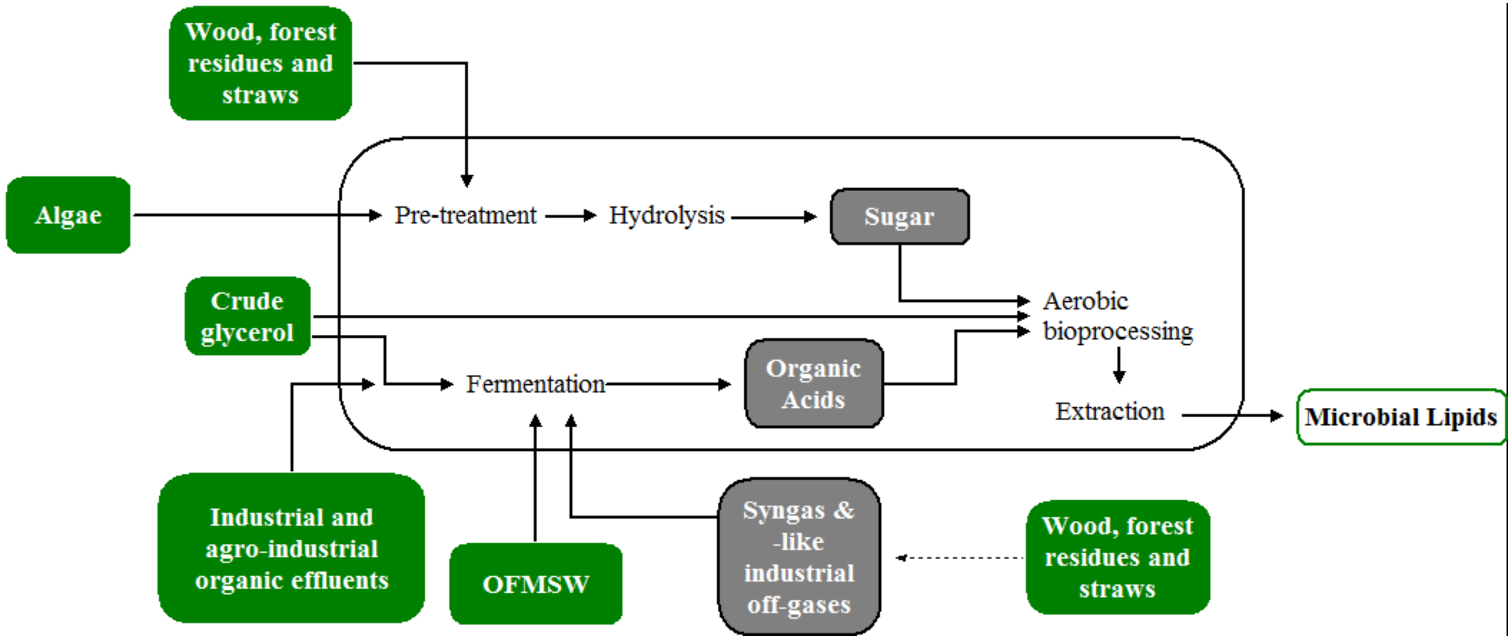
Table 7 Representative fatty acid composition of SCO produced by various oleaginous yeast strains and comparison to a number of technical oils

Microorganism	Total lipid content (%, w/w)	Fatty acids (%, w/w of total lipids)					Analogous (similar) technical profile
		C16:0	C16:1	C18:0	C18:1	C18:2	
Candida curvata D	58	32	—	15	44	8	Palm/Palm olein
Candida 107	42	44	5	8	31	9	Palm
Cryptococcus albidus	65	12	1	8	73	12	Olive oil
Lipomyces starkeyi	63	34	6	5	51	3	Palm/Palm olein
Lipomyces starkeyi	68	55.9	1.8	13.8	25.8	0.1	Cocoa butter
Trichosporon pullulans	65	15	—	2	57	24	Canola/olive
Yarrowia lipolytica	43	15	3	11	47	21	Chicken fat
Rhodosporidium toruloides	67.5	20	0.6	14.6	46.9	13.1	Lard

Koutinas et al., 2014, Chem.Sco.Rev. 43:2587

Microbial lipids

- Carbon source: C_3-C_6 sugars and lower molar mass organic acids as carbon sources
- Versatile feedstocks: lignocellulosic biomasses, municipal wastes, industrial and agroindustrial effluents rich in organic matter, crude glycerol and syngas



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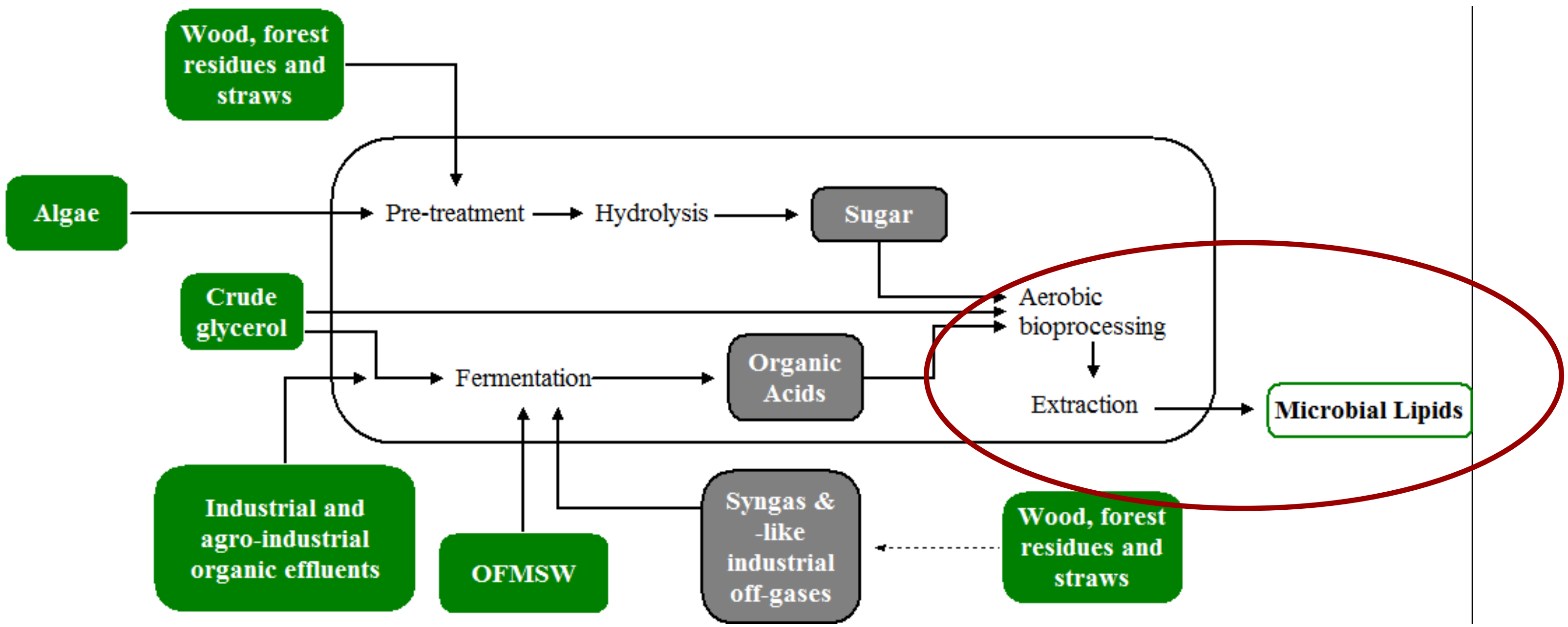
- Sugars and Organic acids-to-Lipids: TRL 3 internationally
- Lignocellulose-to-sugars: TRL 7 in DK BUT lignocellulosic sugars-to-lipids is currently investigated

Microbial lipids from sugars and organic acids

- Technology validated in the lab – what is the challenge for going further?



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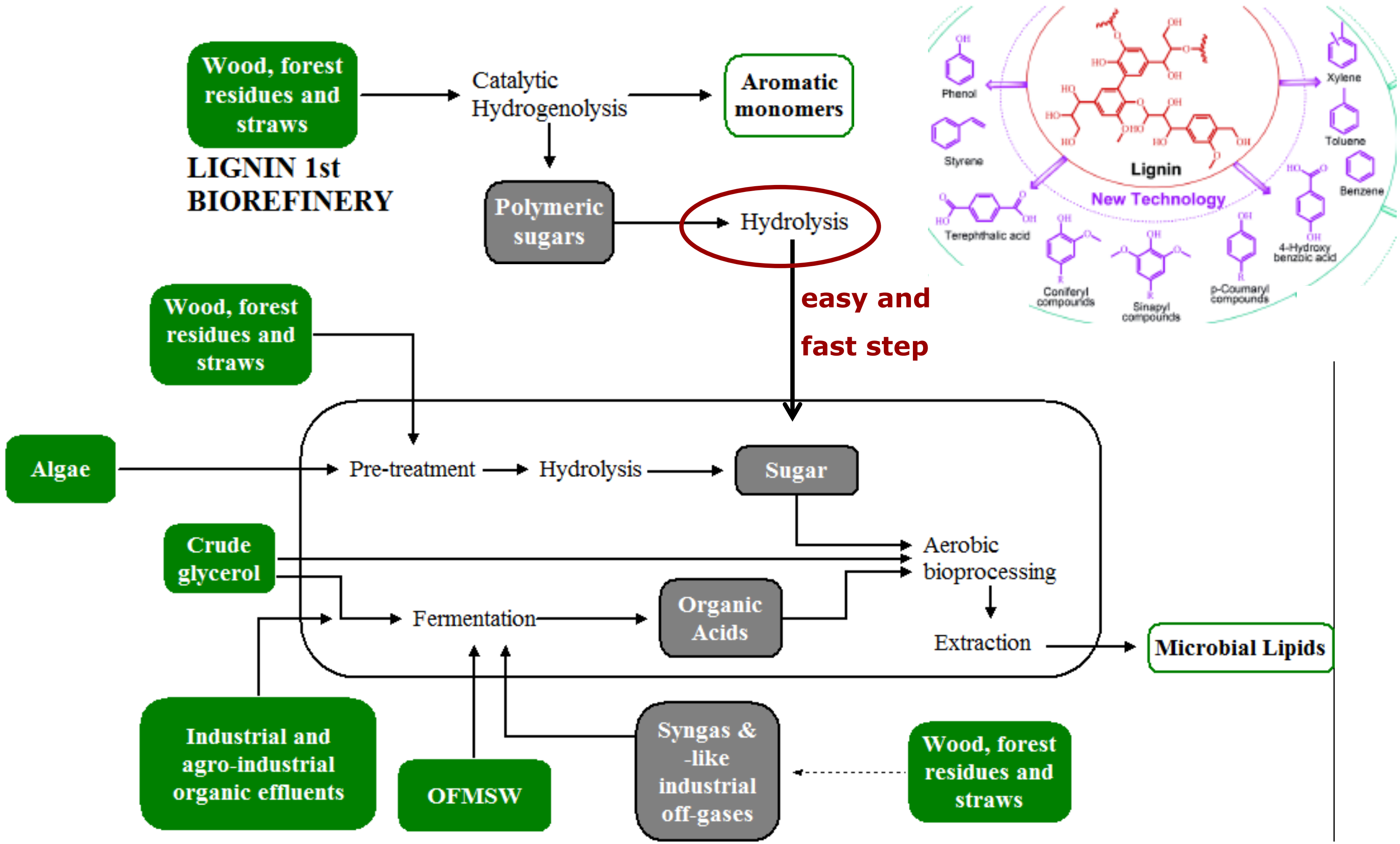
- Higher volumetric productivities and concentrations; threshold of 90 g/L and 1.3 g/L/h given a yield of 0.28 g lipids / g sugar (Davis et al. 2013, NREL/TP-5100-60223)
- More efficient extraction methods
- Produce high value products along with lipids

Microbial lipids as part of Lignin-1st biorefinery



Microbial lipids from sugars and organic acids

- Reactor development for higher productivities and concentrations
  - Under development for other intracellularly accumulated compounds at DTU- Chem. Eng.
  - Time horizon for lipids at TRL 4 after resources are raised: 3-4 years

- Novel solvents and solvent combinations for more efficient extraction based on computer-aided solvent design methods (ICAS software in DTU Chem Eng)
  - Time horizon for TRL 4 after resources are raised: 3-4 years

- Lignin 1st biorefinery for obtaining high value products along with lipids
  - Catalytic part is at TRL 3 - 4*****
  - Time horizon for TRL 5 after resources are raised: 3 years

***S. Ghafarnejad**, 2018 Catalytic Hydroliquefaction of lignin to Value-Added Chemicals

PhD thesis, DTU-Chemical Engineering, Principal Supervisor: **Anker Degn Jensen**

Coupling gasification and biochemical conversions in the frame of SYNFERON project

Innovation Fund Denmark
RESEARCH, TECHNOLOGY & GROWTH

Gasification

DGC, DK
ISU, US
agnion Technologies GMBH, DE

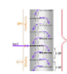
Fermentation to alcohols

Biomethanation

CERE-DTU, DK
PROSYS-DTU, DK
ISU-US
DGC, DK

Downstream processing

Up-concentration with Aquaporins



Diabatic Distillation

PROSYS-DTU, DK
CERE-DTU, DK
BIOSYSTEMER APS, DK
Aquaporin A/S, DK

Engineering Analysis of the proposed platform

CERE-DTU, DK
DGC, DK

Collaborators for the BIO-part:

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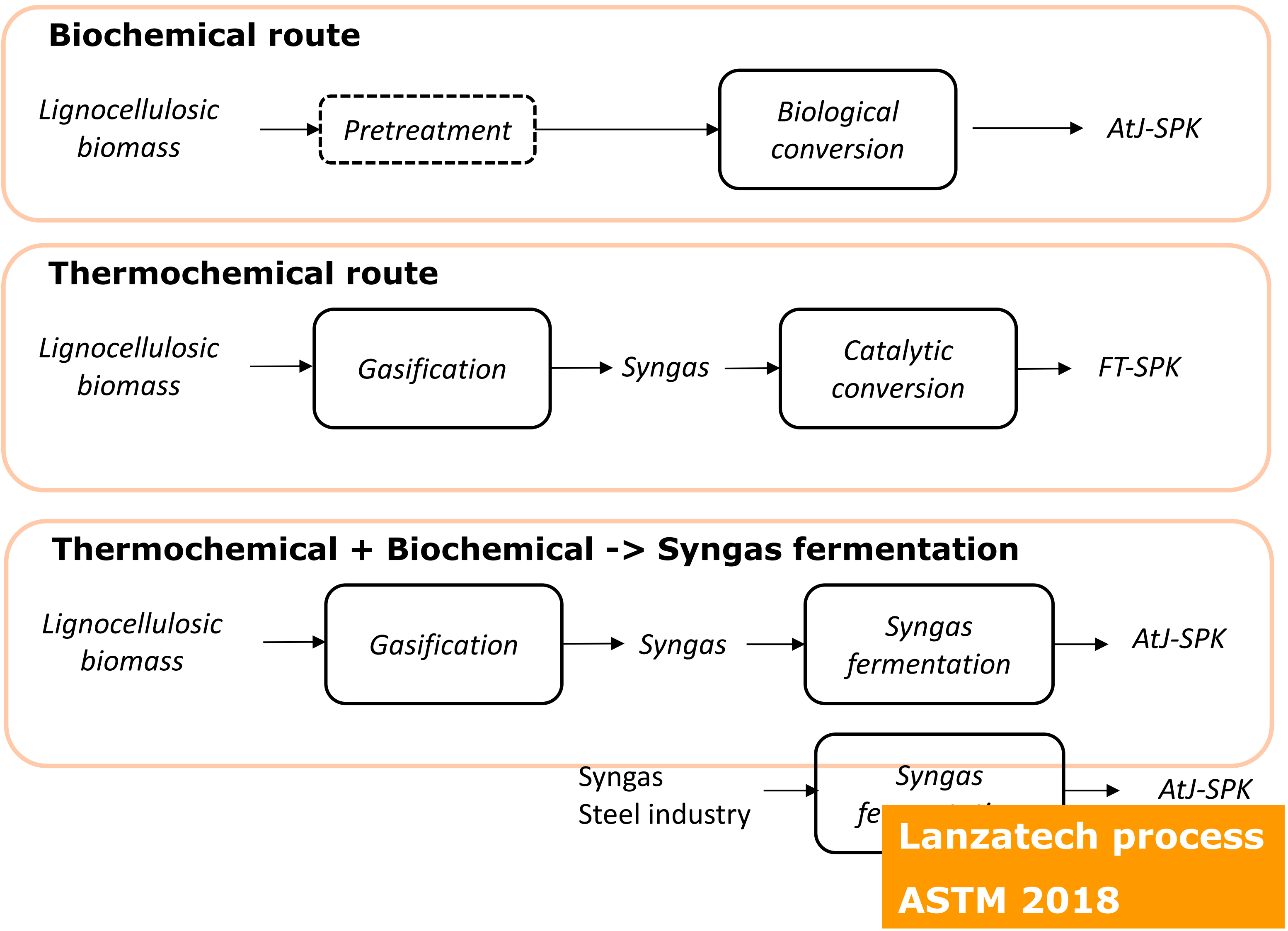
K Asimakopoulos
C Etler
IV Skiadas

http://www.cere.dtu.dk/research-and-projects/framework-research-projects/biorefinery-conversions/optimised-syngas-fermentation-for-biofuels-production-synferon

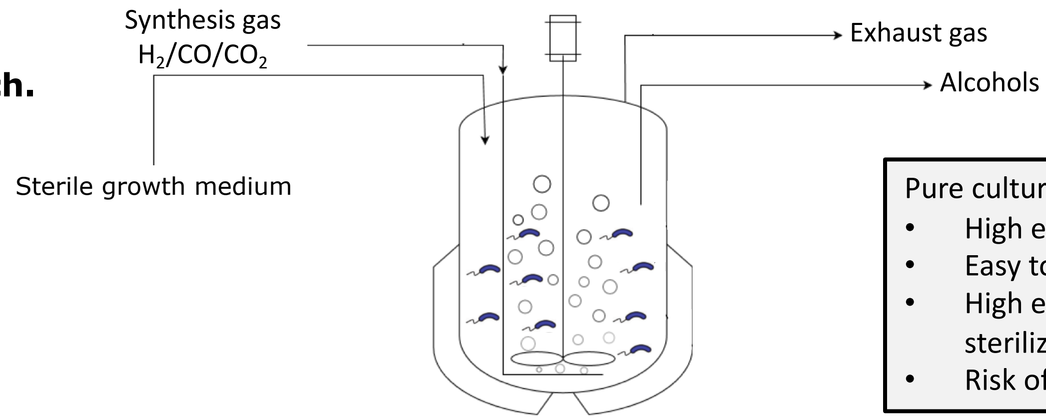
Coupling gasification and biochemical conversions for AtJ pathway



One step forward for cost reduction at DTU-Chemical Engineering

Pure cultures

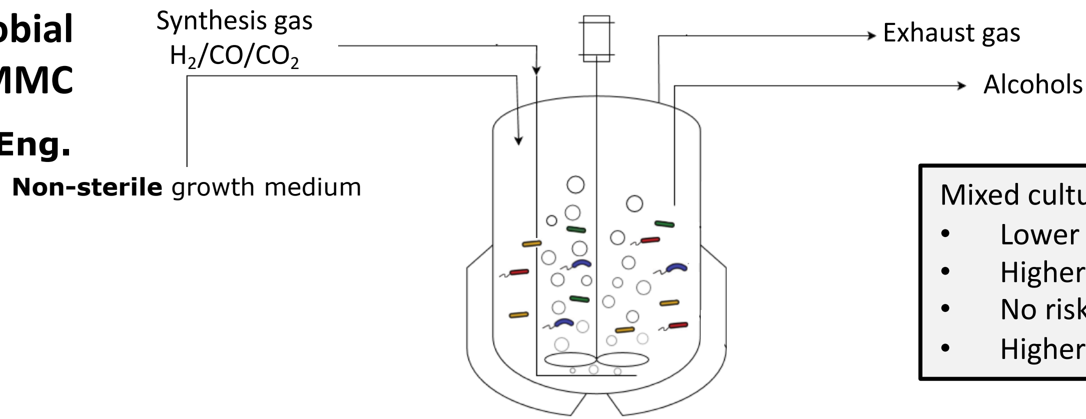
Lanzatech tech.



Pure cultures
- High efficiency
- Easy to control
- High energy demand due to sterilization
- Risk of contamination

Mixed Microbial Consortia, MMC

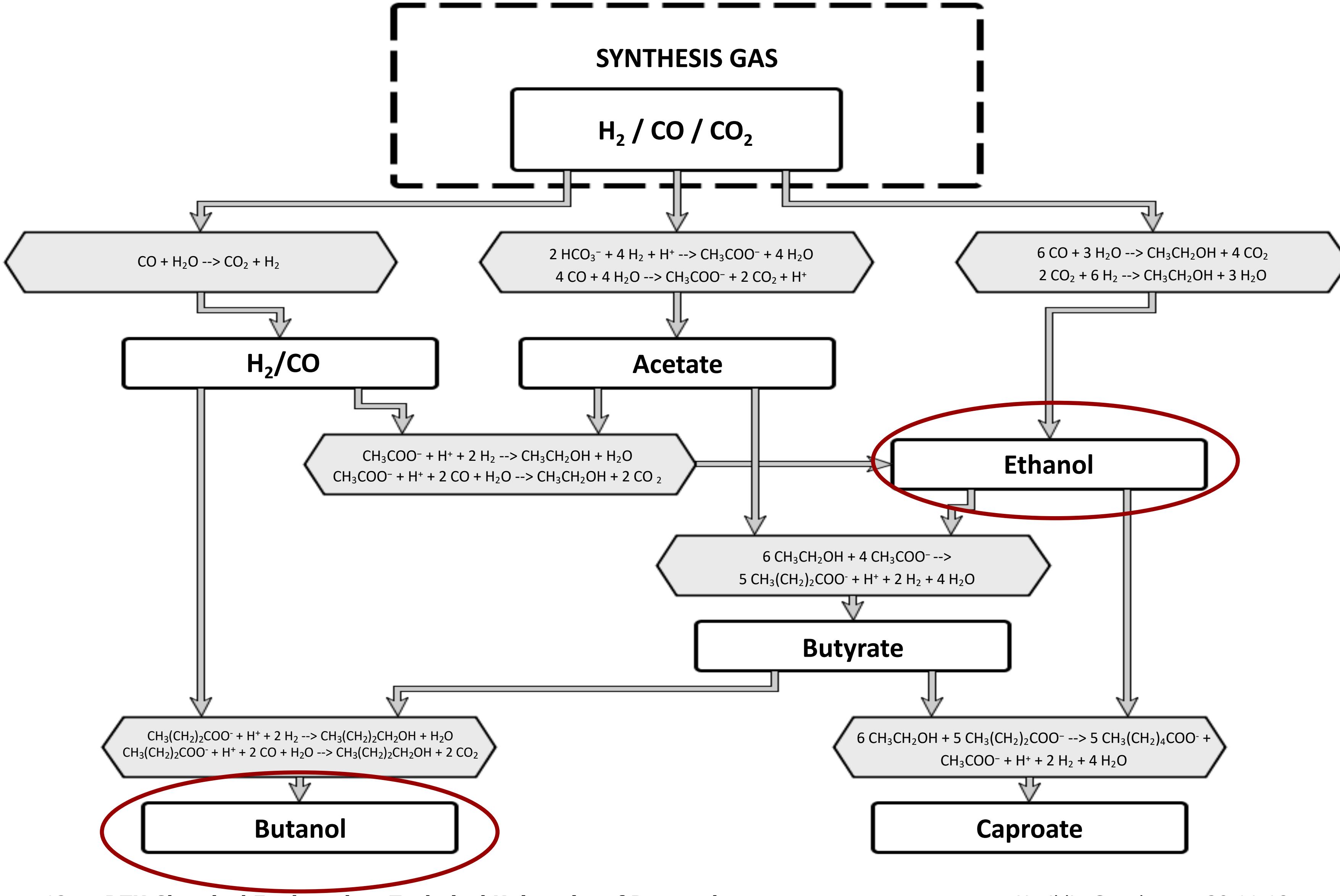
DTU Chem. Eng.



Mixed cultures
- Lower operational cost
- Higher tolerance and adaptability
- No risk of contamination
- Higher complexity

http://www.cere.dtu.dk/Research-and-Projects/PhD-Projects/Fermentation-of-Synthesis-Gas-to-gaseous-and-liquid-fuels

Syngas fermentation to alcohols
Metabolic network of acetogenic Mixed Microbial Consortia



Thermodynamics of net metabolic reactions for metabolic network selectivity towards alcohols

Feasibility study based on $\Delta_r G'_T$ of all reactions occurring in MMC

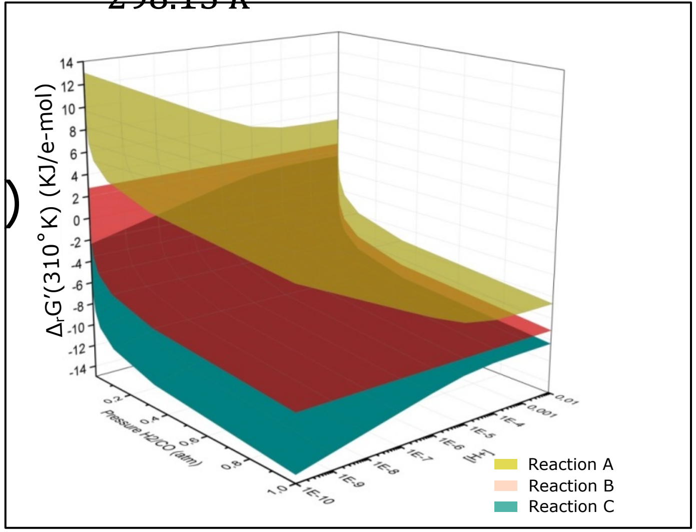
Gibbs free energy change

- $\Delta_r G' = \Delta_r G°(I = 0.08\ M) + RT \ln \frac{[C]^c [D]^d}{[A]^a [B]^b}$
- $\Delta_r G'_T = \Delta_r G'_{298.15\ K} \cdot \frac{T}{298.15\ K} + \Delta_r H'_{298.15\ K} \cdot \frac{298.15\ K - T}{298.15\ K}$

Thermodynamic potential factor (F_T)

- $r = \frac{k_{max} \cdot S}{k_s + S} \cdot X \cdot F_T$ (Jin & Bethke 2007)
- $F_T = 1 - \exp\left(-\frac{\Delta G_A - \Delta G_C}{\chi RT}\right)$

$\Delta G_A = -\Delta_r G_T$
$\Delta G_C = Y_{ATP} \cdot \Delta G_p$



$F_T \approx 1$ → Kinetic control
$0 > F_T > 1$ → Thermodynamic control
$F_T = < 0$ → Metabolism stops

Grimalt-Alemany et al., 2018 Biotechnology for Biofuels, 11:198, https://doi.org/10.1186/s13068-018-1189-6

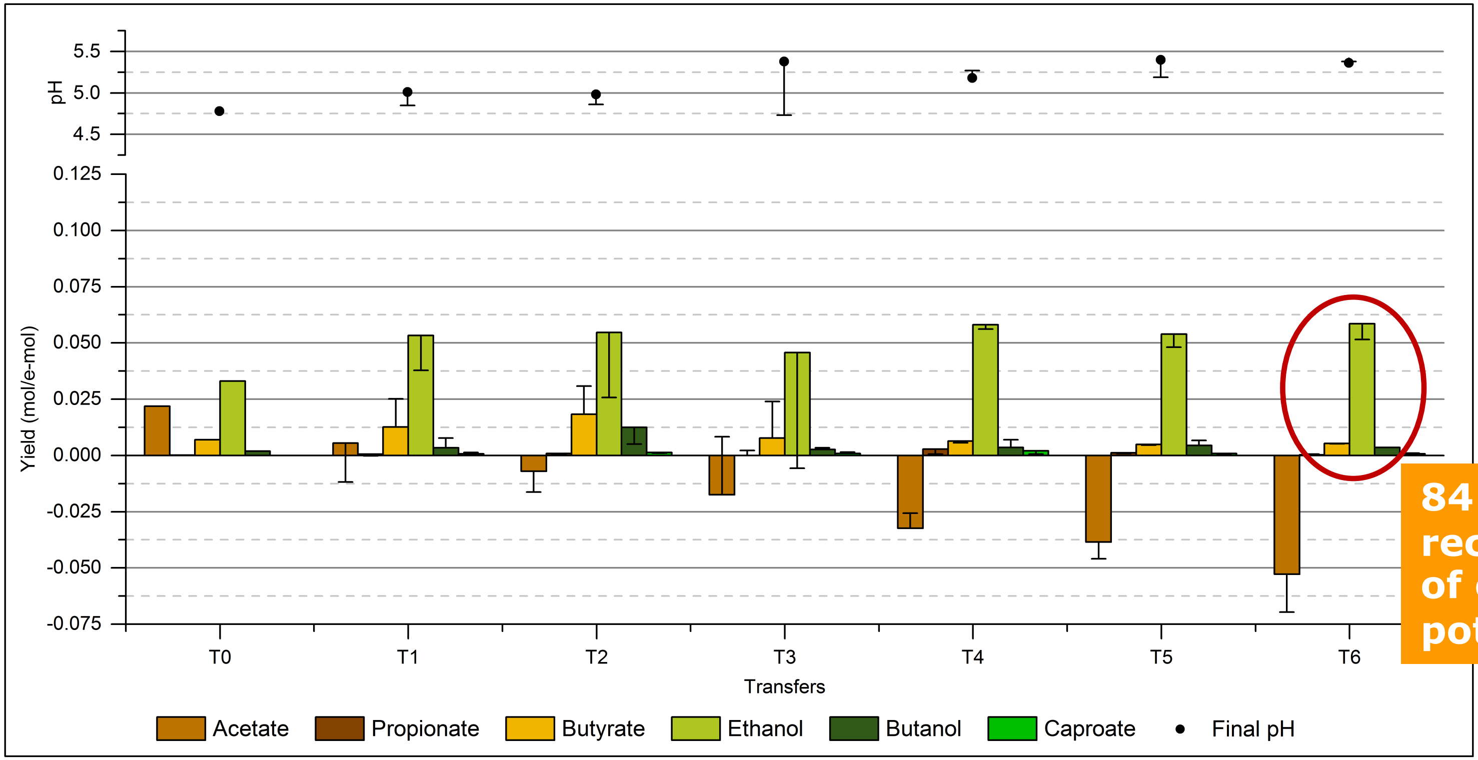
Syngas fermentation to ethanol

Effect of acetic acid concentration on $\Delta_r G'_{310K}$ and F_T

Initial conditions:

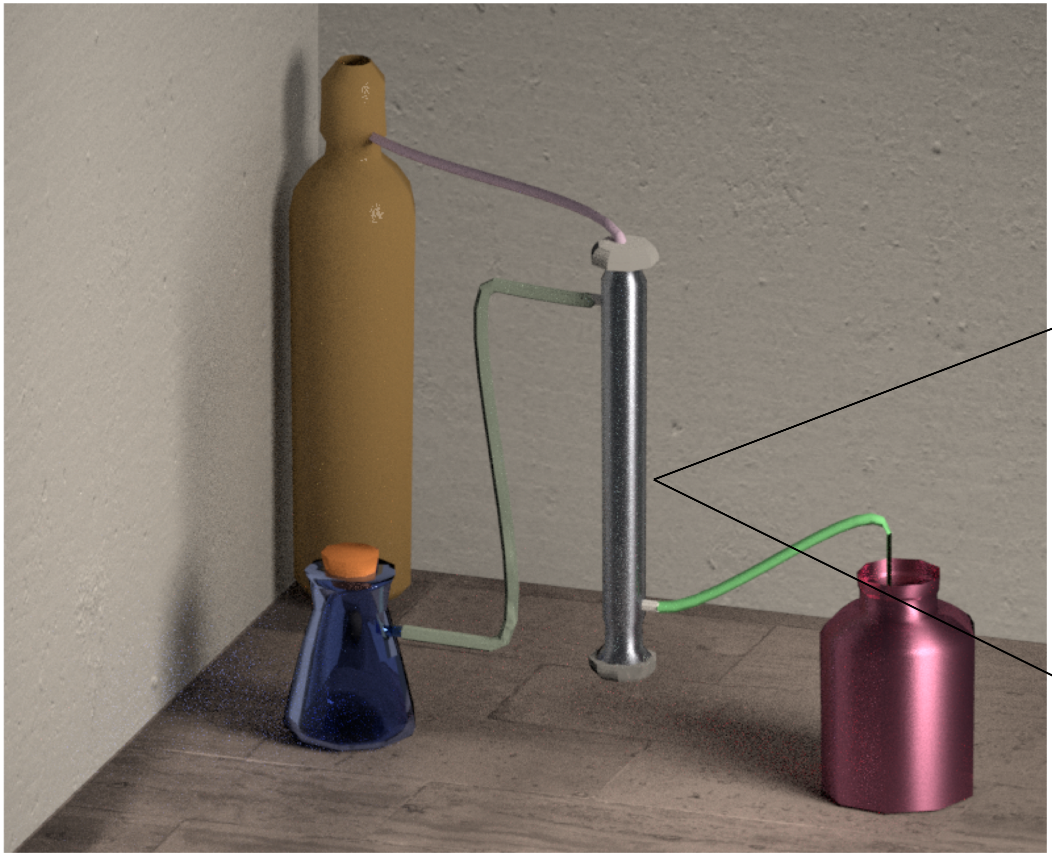
Substrate	-> H_2 (1.05 atm), CO_2 (0.60 atm), CO (0.45 atm)
Product concentration	-> 1 mM except acetate
Temperature	-> 310 K
Ionic strength	-> 0.08 M
pH	-> 5

Product yields (mol/e-mol) - Enriched culture with addition of 20 mM of acetic acid

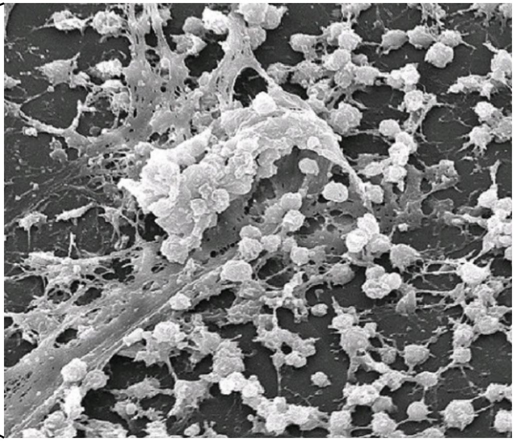


84 % recovery of energy potential

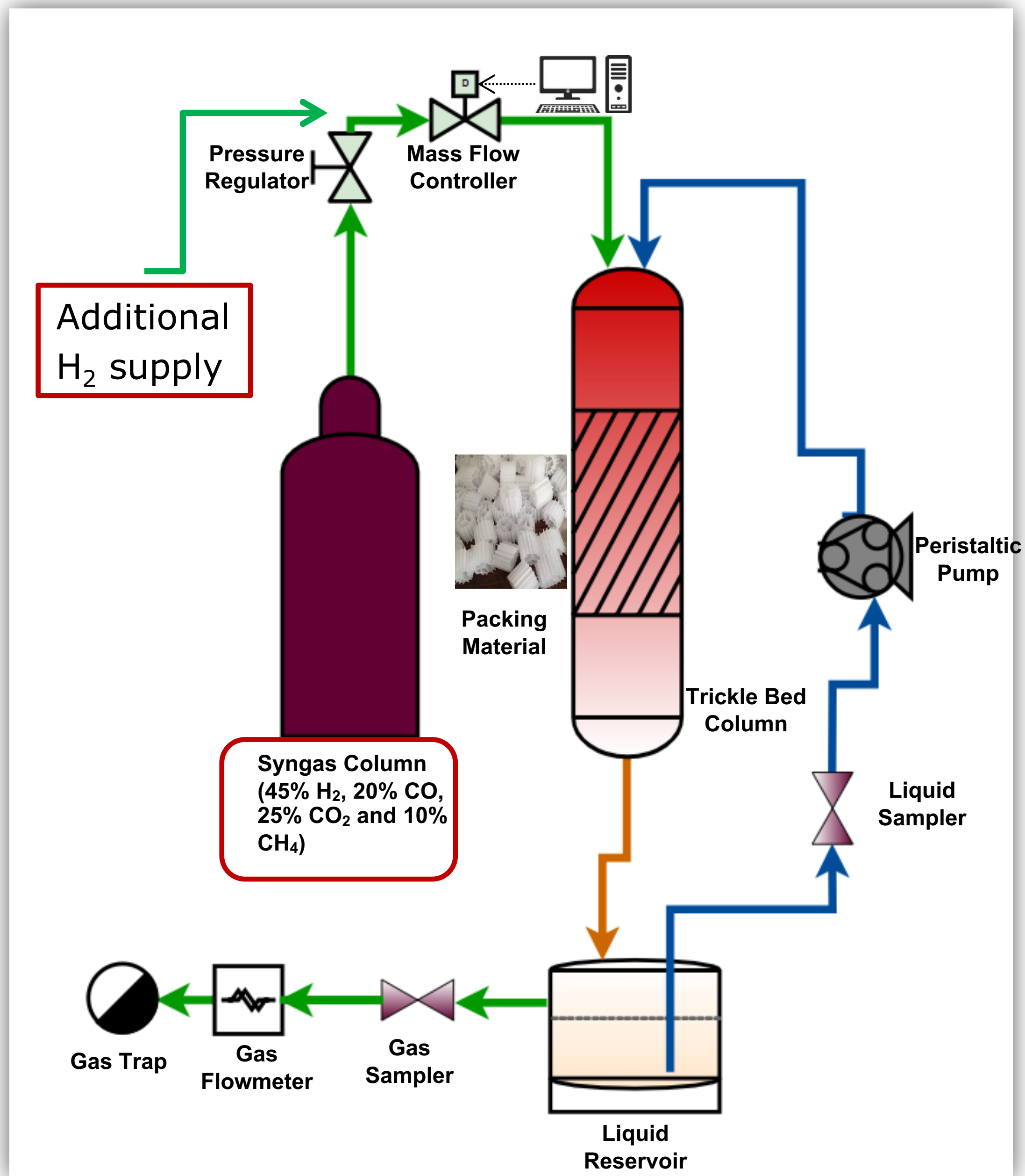
Tackling mass transfer limitations at DTU-Chem Eng
Mixed cultures allow for biofilm-based processes



- **Trickle bed reactor**
  - High Mass Transfer Rates
  - Biofilm formation



http://www.cere.dtu.dk/Research-and-Projects/PhD-Projects/Fermentation-of-Synthesis-Gas-and-design-of-bioreactors

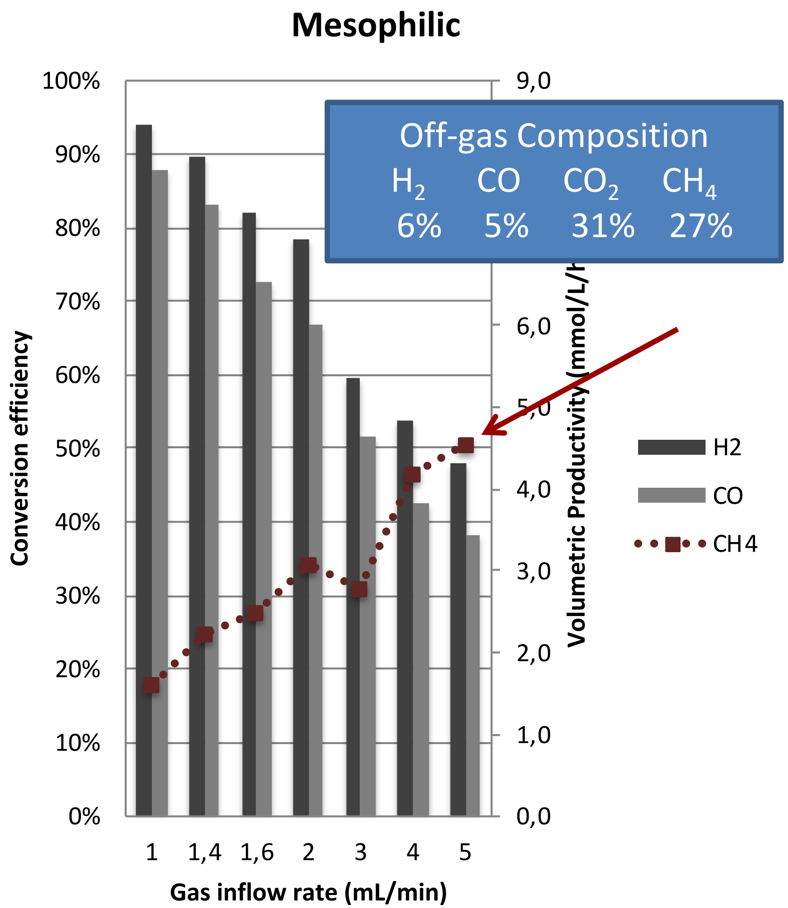


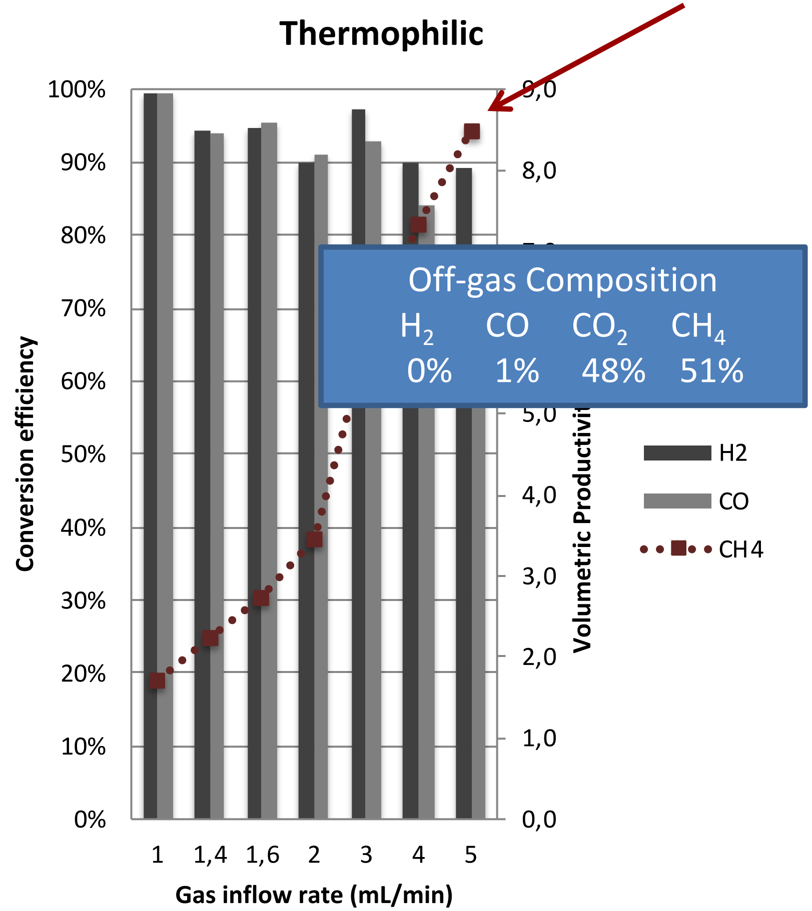
Trickle Bed Reactor – operating conditions

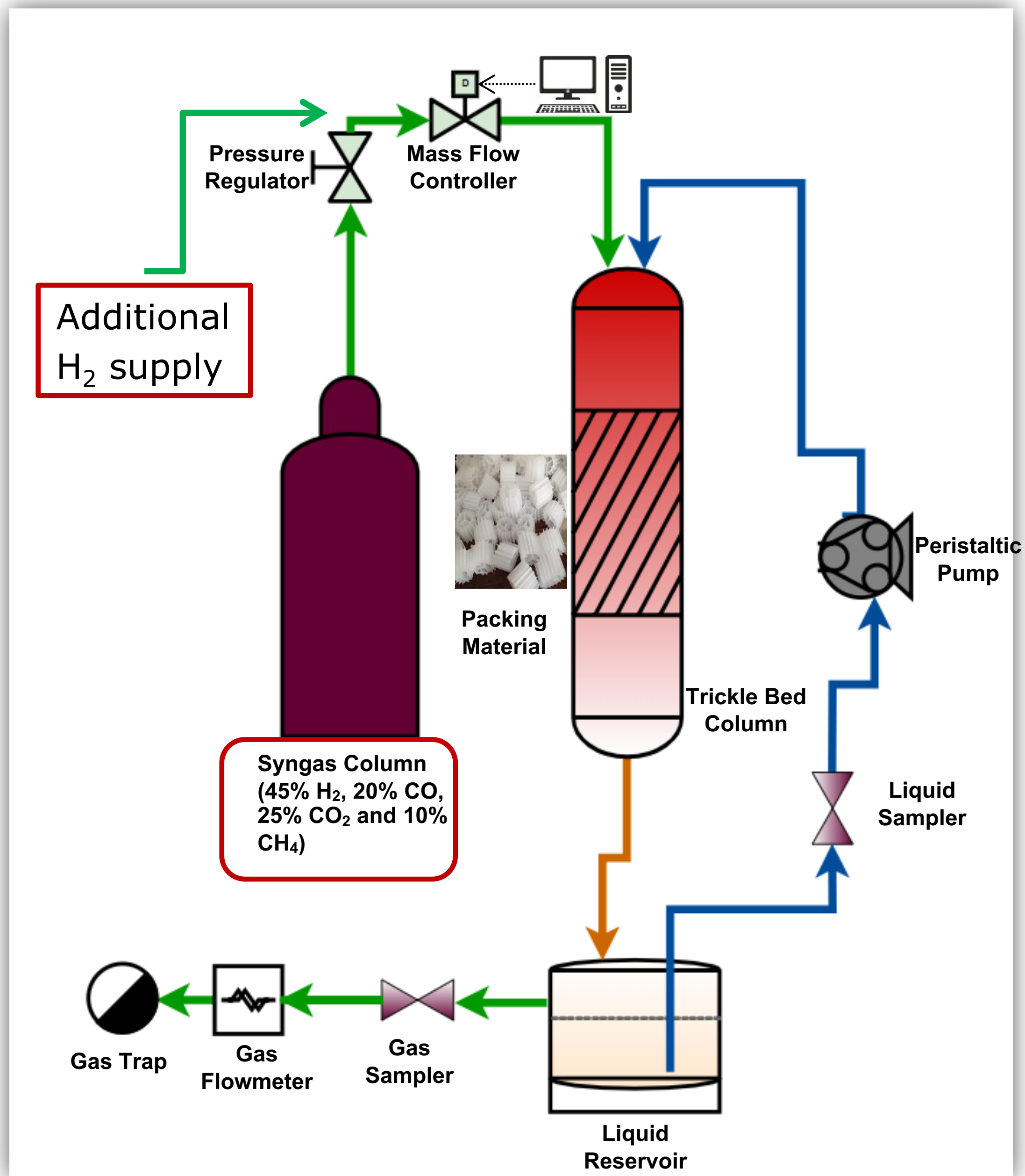
- So far tested for syngas-to-CH_4 with and without additional H_2 supply
- Temperature: 37 and 60 °C
- # pH control
- Pressure: 1 atm

Conversions and production rates

! >100% enhancement compared to best reported production rates







Trickle Bed Reactor – with additional H_2

- Conversion efficiency

H_2	CO	CO_2
99.5%	99.5%	97.8%

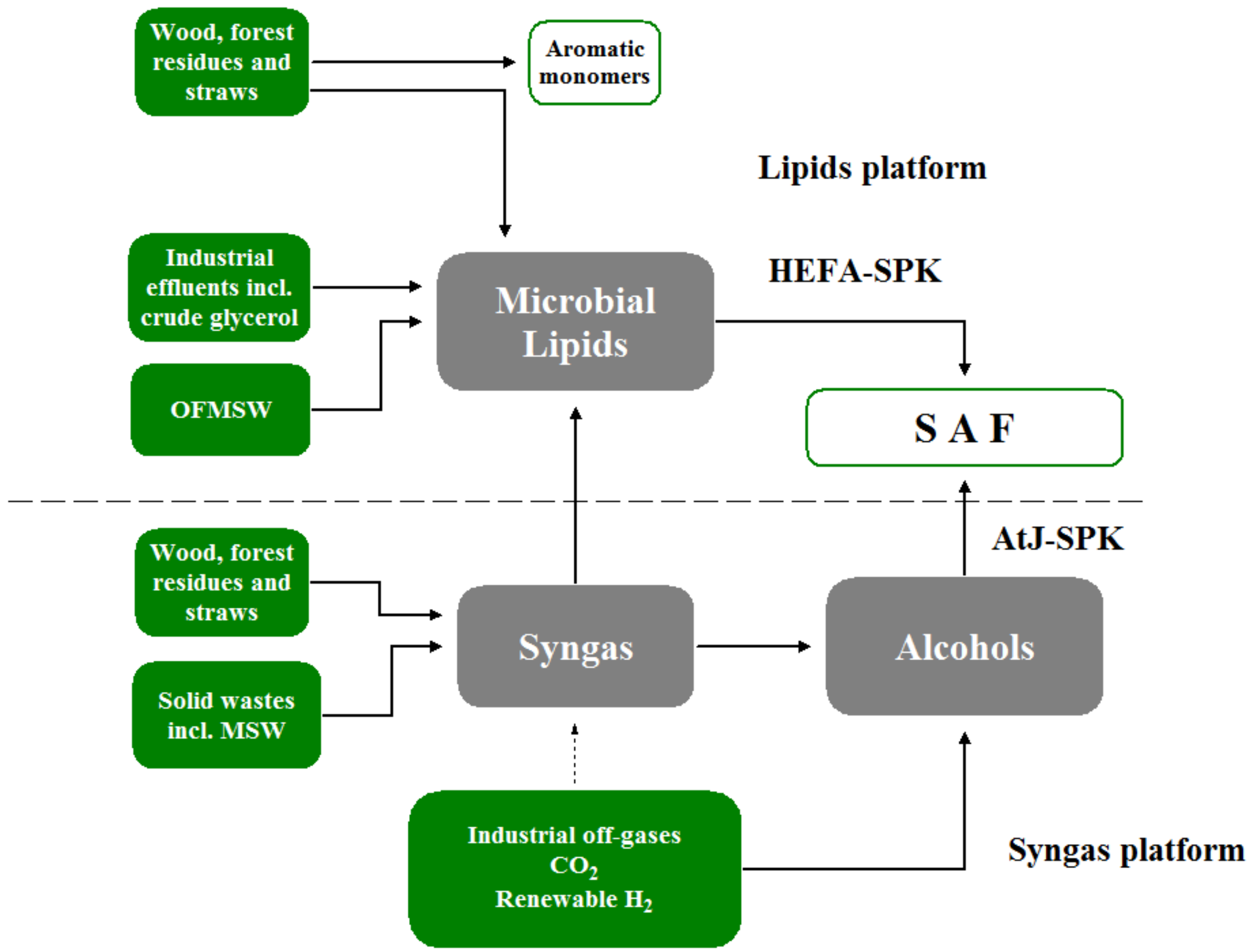
- Off-gas composition

H_2	CO	CO_2	CH_4
2%	0%	2%	96%

Status of syngas bio-transformations in the trickle-bed reactor

- Currently being tested for alcohols production at lab-scale
- Up-scaling and construction finished
- High conversion efficiency of syngas and upgrading with H_2 to be validated at pilot-scale
- Status in 2019:
  - Syngas-to-CH_4 and gas upgrading: TRL 5
  - Syngas-to-alcohols: TRL 3 and time horizon for TRL 5 if resources are raised: 2 years
  - Syngas to lipids: follows microbial lipids planning: 3-4 years for TRL 5

Our vision on Advancing Bio-manufacturing for SAF in combination with thermochemical/catalytic/renewable electricity routes



From proof-of-concept to demonstration: Pilot-facilities at DTU - Chemical Engineering

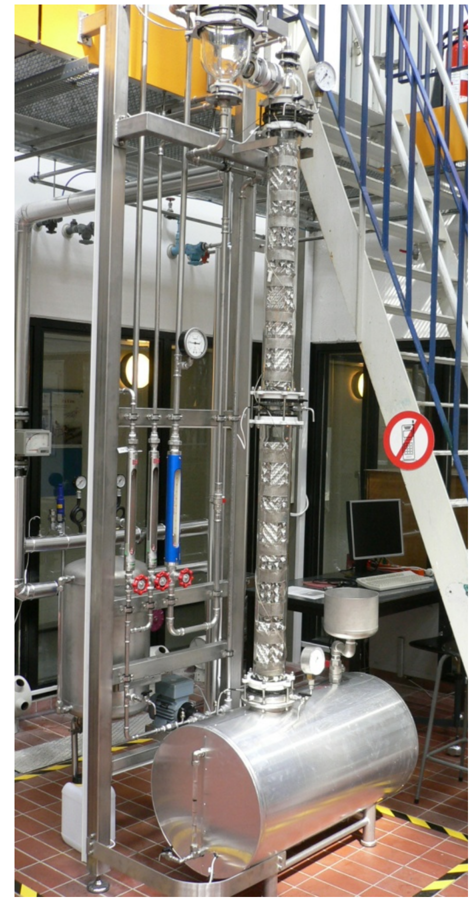
- 700 m^2 pilot plants, laboratories and workshop + 500 m^2 under construction

Column operations

Continuous distillation
in bubble-cap tray column

Absorption of ammonia in
packed column

Hydrodynamics of gas/liquid flow in packed columns

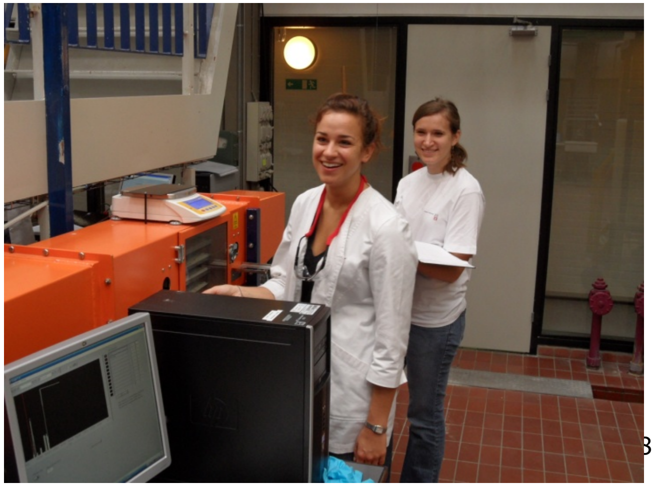


Batch distillation
of alcohols
using structured
packing

Drying processes

Spray drying

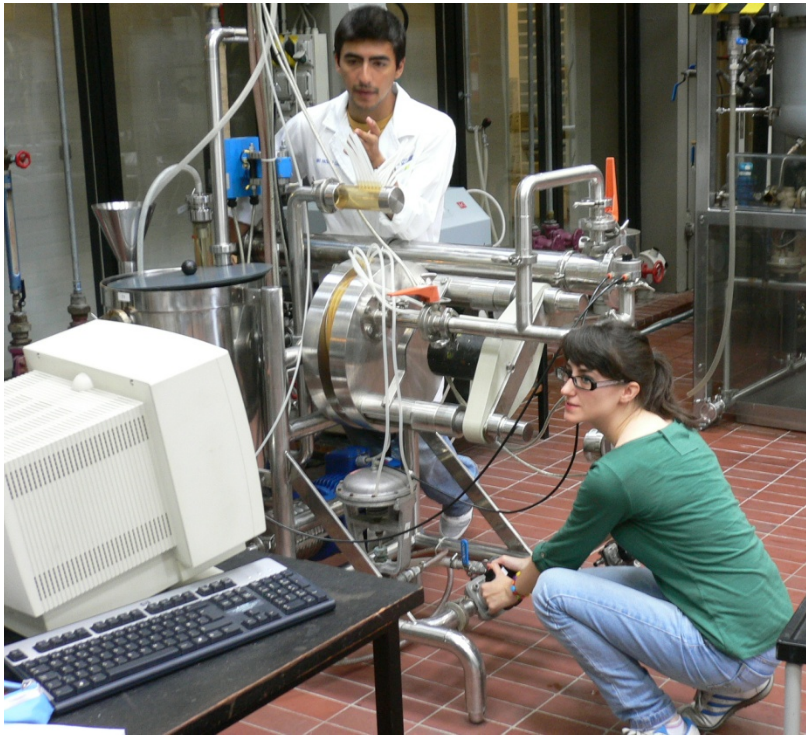
Fluidization and fluid bed drying



Drying on trays
in a tunnel

Separation processes, 1

Disk-stack centrifugation



Ultrafiltration

Separation processes 2

Ammonia
tray stripper

Vacuum crystallisation

Evaporation in falling film evaporator

Chemical and biochemical reactions

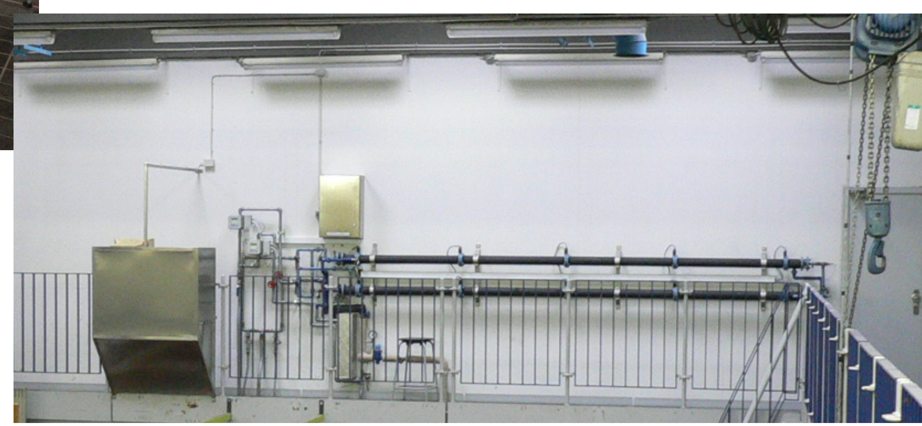
Fixed bed for immobilized enzyme processes, ion exchange or chromatographic separations

Multipurpose plant for organic synthesis

Other operations

Liquid/liquid extraction

Solid/liquid extraction



Heat transfer in pipes and plate heat exchangers

Fermentation

An advanced fermentation platform with lab- and pilot- fermentors will be established in DTU Chemical and Biochemical Engineering Dept. within 2019

THANK YOU !