CO2 to Bio-based Building Blocks

The Biocon-CO_2 project

14th October 2021, Dr. Ana M. López Contreras

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CO_2 sources

Emissions of industry
Steel, cement, electricity
Chemical industries
Other (fermentation, etc)

Gasification of organic wastes and lignocelluloses
MSW, forest wastes

Atmospheric CO_2
Carbon capture technologies

CO_2 is already used at commercial scale for chemicals and building blocks:
Urea, **Methanol**, formaldehyde, carbamates, fine chemicals

Estimated consumption of >110 Mt CO_2/year[1]

[1] Guil-López, Ruth, et al. Materials 12.23 (2019): 3902.

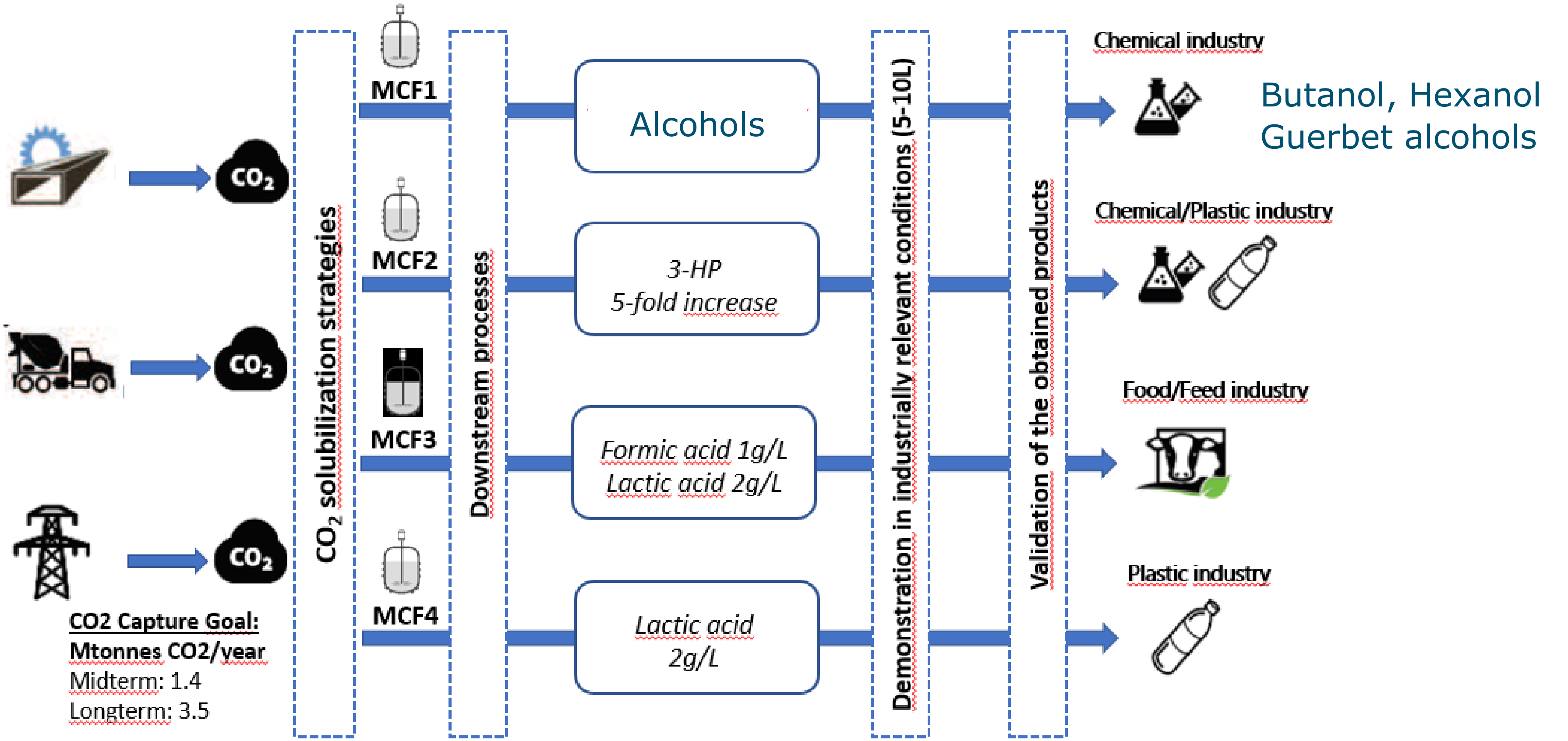
Main components in CO_2-containing streams

	CO_2	CO	CH_4	O_2	H_2	N_2	H_2O	Ref
Industry emissions								
Fossil power plant	13.3			3.8		71.6	11.2	5
Cement (Kiln)	14-33			2-4		84-66		4
Steel (Blast Furnace gas)	17-25	20-28			1-5	50-55		3
Gasification of Biomass								
Municipal solid waste	20.2	0.1	7.1		4.5	66		2
Torrefied woods/pellets	6.7	29	2.4		10.3	48.3		1

Gases show variable composition, depending of source and operation conditions
Gas upgrading is usually required for removal of toxic compounds (mercury, sulfur) and contaminants (aromatics, Nox, SO_2,...)

1 Dudyński M et al (2015). Fuel Processing Technology 131: 203-212.; 2 del Alamo G et al (2012). Waste Management 32: 1835-1842.; 3 Frey et al (2018). Chemie Ingenieur Technik 90.10: 1384-1391.; 4 Zheng, Yuanjing, et al (2012). Progress Energy Combustion Sci 38.5: 599-629.5 Gilassi, S et al. (2020) Separation Purfication Technol 248 (2020): 116941.

CO_2 conversion by Microbial Cell Factories



MCF1: *Clostridium* – a versatile genus for basic and applied research

Gram positive, anaerobic bacteria

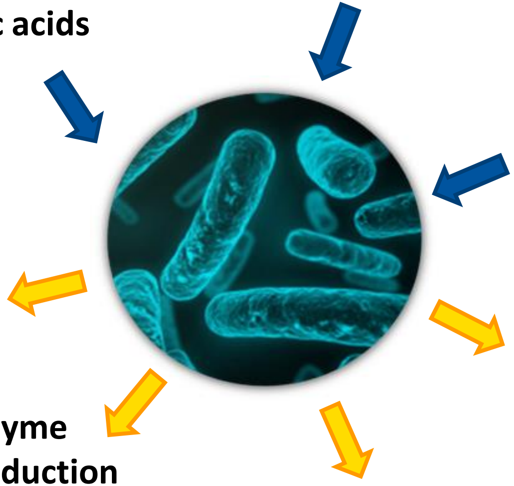
High relevance in medical, ecological and biotechnological sciences

> 100 strains sequenced

Tools available for genetic manipulation

Acetogens: *C. ljungdahlii, C. autoethanogenum*

Solventgens: *C. beijerinckii, C. acetobytilicum*



Other anaerobic organisms for C1 gas conversion:

Acetobacterium, Moorella, Alkalibaculum, Thermoanaerobacter

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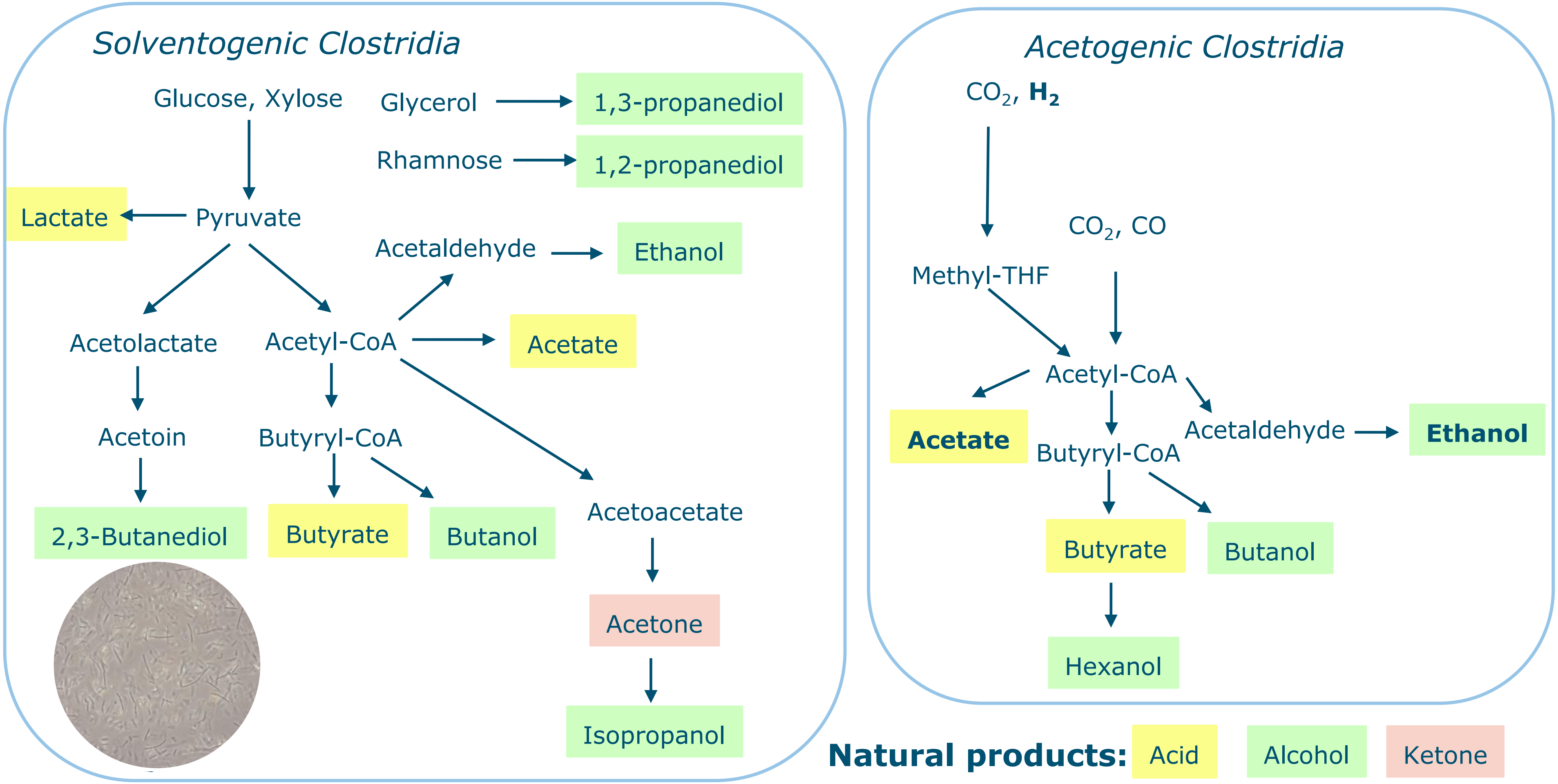
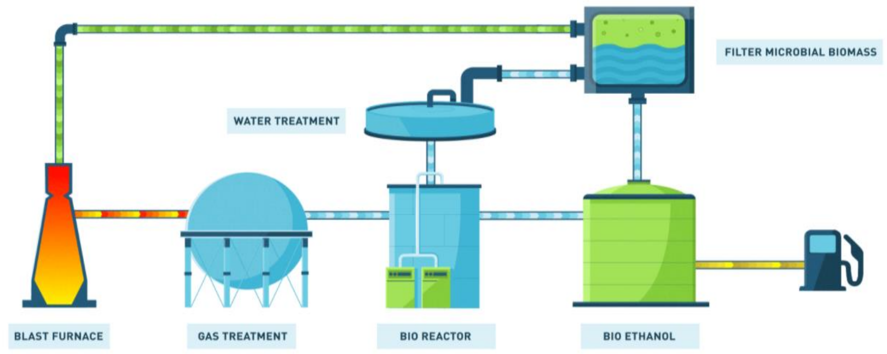
Fraunhofer IME

Metabolism (simplified) & Products



Examples of applied uses:

- **Lanzatech**: acetogens for ethanol production from steel mill gases on site (ex: steelanol project). Plans for production of other chemicals: 2,3-butanediol, isopropanol, other



Source: http://www.steelanol.eu/en

- **Evonik and Siemens**: Pilot production (2000-L scale bioreactor) of butanol/hexanol by acetogenic cultures from CO_2/H_2 (Rethicus project) (https://press.siemens.com/global/en/pressrelease/climate-friendly-industry-using-carbon-dioxide-and-hydrogen-raw-materials-sustainable)

Working under anaerobic conditions

Fraunhofer IME

- Anaerobic jars, e.g:
  - Anaerocult A to remove oxygen

- Anaerobic work chambers, e.g:
  - A) Whitley A35 workstation (Don whitley scientific)
  - B) Bactron-600 (Shellab)
  - C) Type A anaerobic chamber (Coy laboratory products)

- Cultivation methods
  - Bioreactors: pH control stirring
  - Gas mix station ($CO/CO_2/H_2$)

A

B

C

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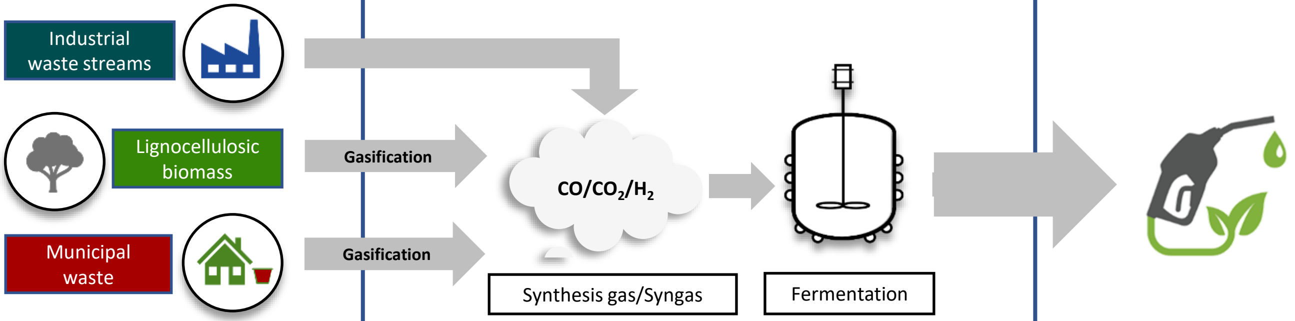
Challenges for this MCF	Possible mitigations
Need for H_2	Use external green H_2, combine process with electrolyzer (Evonik/Siemens approach)
Low solubility of gases in water*	High pressure fermentation, use of enzymatic systems, use nanoparticles in broth, recycle the gases
Toxicity of products	In-situ product removal (extraction, stripping), reactor configuration, adaptation of strains, advanced DSP
Toxicity of substrates (CO, contaminants)	Adaptation, genetic engineering
Low production rates	Genetic engineering for reduction of byproducts, enhance gas consumption rates

***CO_2 (1.45 g/L at 25°C), H_2 (1,6 mg/L at 25°C)**

Advantages compared to mineral-based chemical catalysts	Bacteria are flexible in substrate gas mix Tolerant to contaminats in the gas substrates (BTX, Nox, sulfur, etc) Mild operation conditions (lower T, Lower P) Higher product selectivity

Process improvement in anaerobic gas fermentations



- Non-eatable feedstock
- Feedstock flexibility
- Utilizes all biomass components (Lignin!)

- Mild reaction conditions
  → Energy & cost saving
- Microbial catalysts are more resistant to syngas contaminations than metal catalysts

Wide product range

- Biofuels
- Intermediates
- ...

Liew et al. (2016), Bengelsdorf and Dürre (2017)

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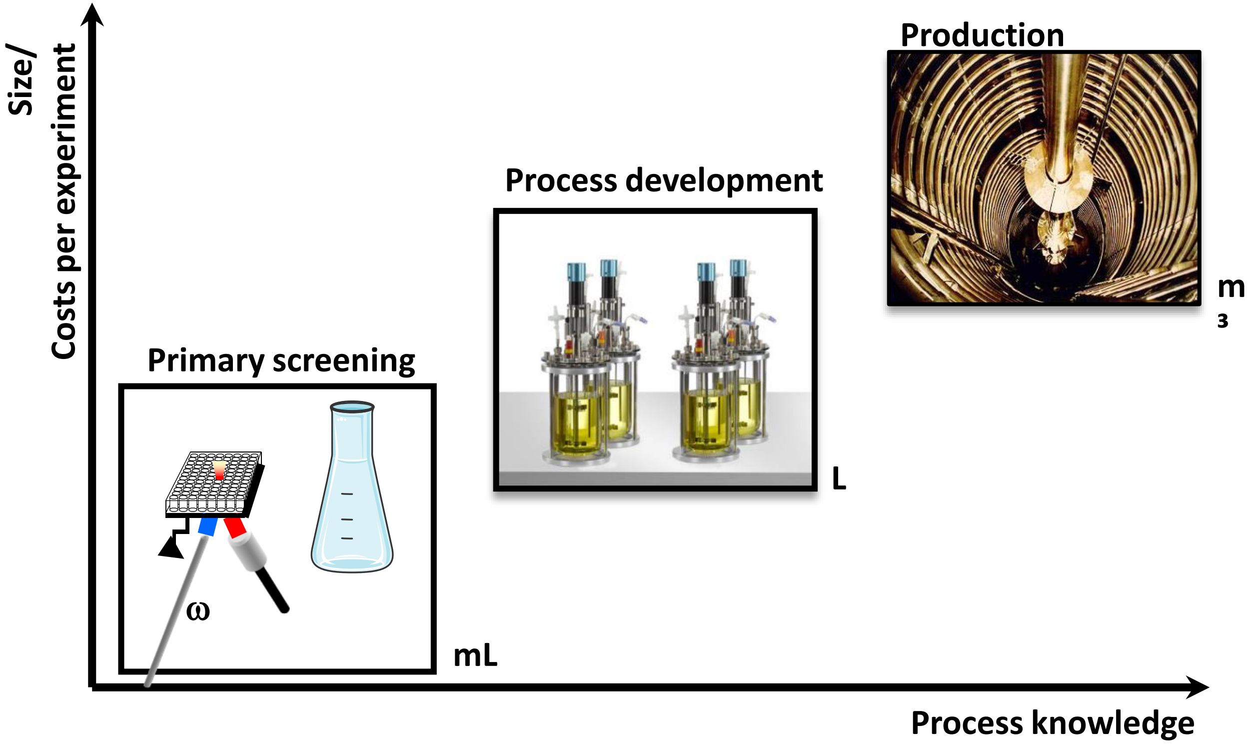
Bioprocessdevelopment



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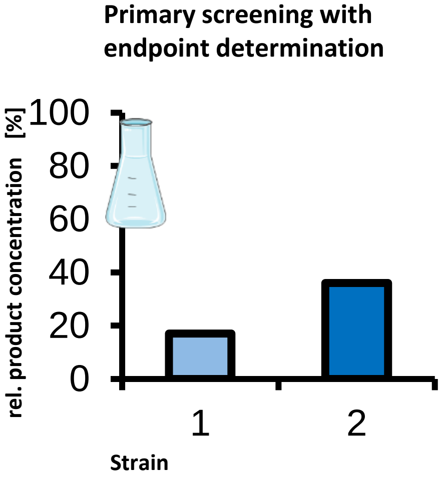
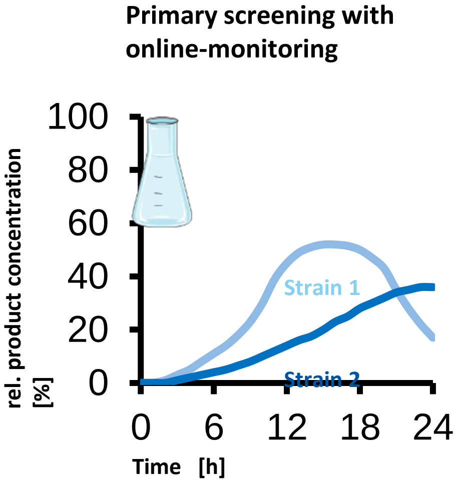
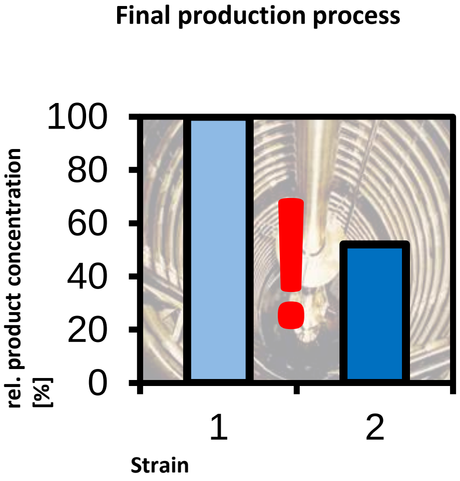
Endpoint determination vs. online monitoring







- Wrong decisions in primary screening cannot be compensated
- Detailed **process understanding** on a **small scale** is required

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AnaRAMOS - Implementation of anaerobic cultivation in shake flask

- RAMOS System „**R**espiration **A**ctivity **Mo**nitoring **S**ystem“
  - Online measurement of OTR and CTR possible

- Sucessful application for anaerobic cultivation on sugars
  - AnaRAMOS System
  - Online measurement of CO_2TR and HTR possible
  - Measuring the CO_2 and H_2 production

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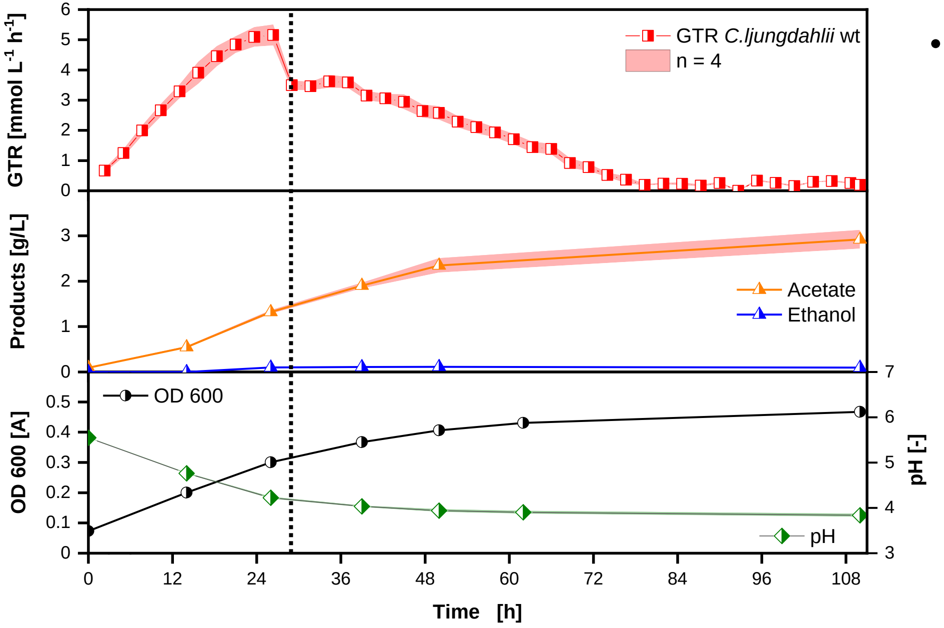
Cultivation of *C. ljungdahlii* on gaseous carbon sources



- Drop in gas consumption is likely caused by reaching the critical pH value

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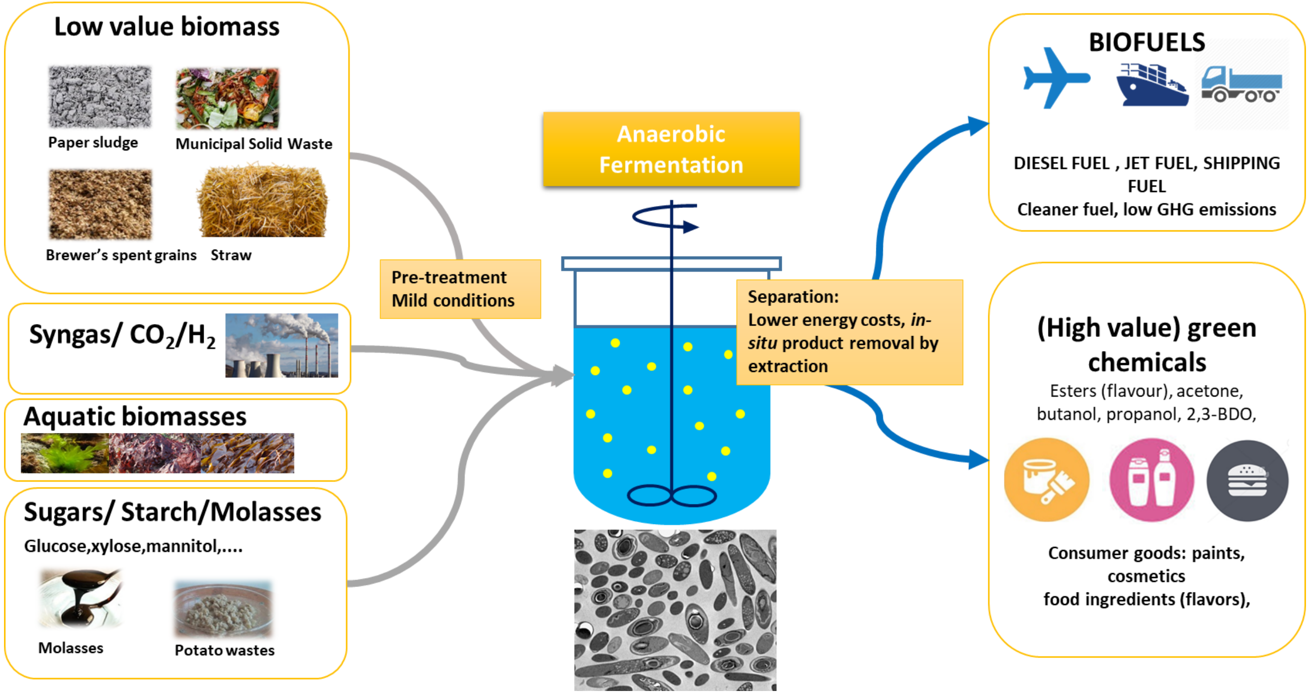
Enable CO_2 use by solventogenic strains by:
- Metabolic engineering for mixotrophy: higher product concentrations
- Co-cultivation with acetogens (use of acetate and ethanol from CO_2)



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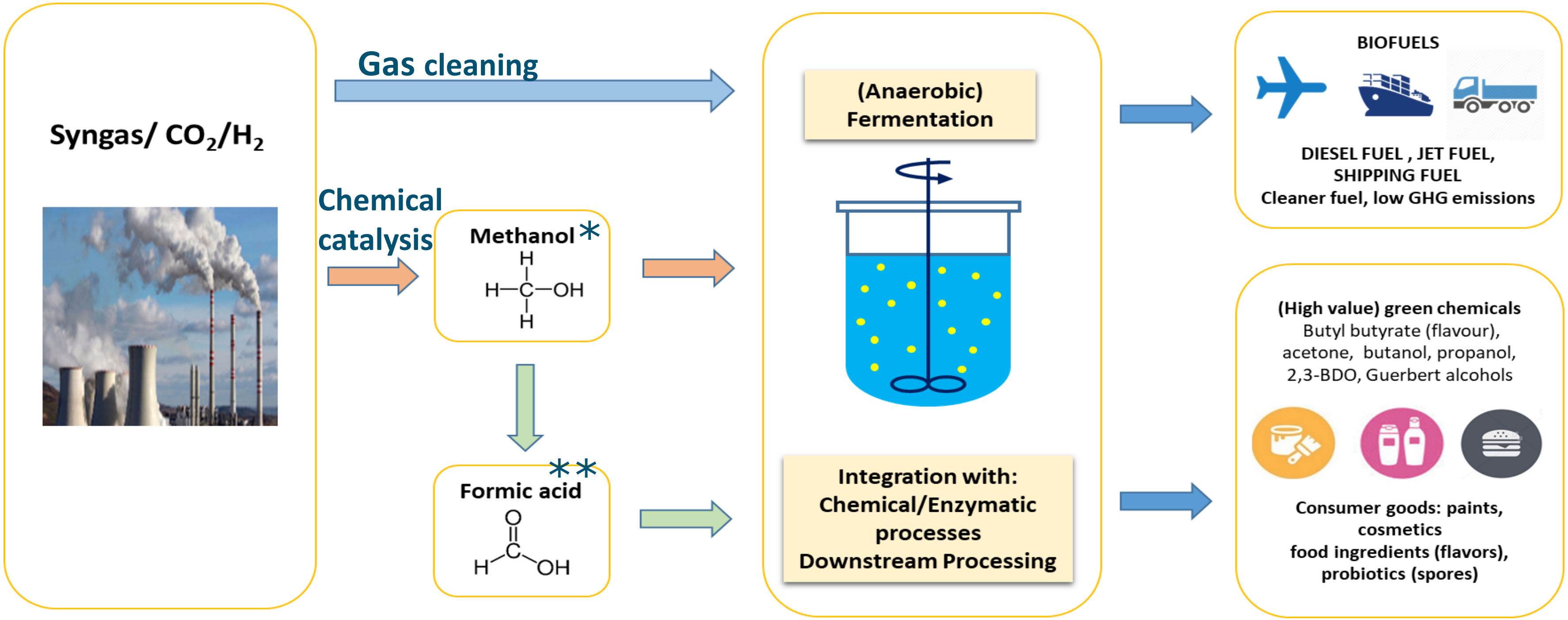
Indirect use of CO_2 as fermentation substrate: Methanol, Formic acid

- Soluble substrates with wide applications



*Methylotrophs used for (commercial) production of: Single Cell Protein, PHAs, organic acids, amino acids, fine chemicals and proteins[1]

** Formate fermentation is being developed currently[2]

[1] Zhanget *al. Biotechnol Biofuels* 11, 260 (2018); [2] Cotton *et al.Current opinion biotechnol* 62 (2020): 168-180

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Summary

- CO_2 sources are diverse, with a wide range of applications
- Anaerobic fermentation using acetogenic *Clostridium* strains can convert CO_2/H_2 mixes into a variety of chemicals
- To overcome the challenges of the gas fermentations, technologies are being developed, that need to be adapted for specific products
- Combinations of Biotechnology with Chemistry and Process Technology are important to solve current challenges

Acknowledgments

The BIOCONCO2 Team

Thank you for your attention

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