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Methanogenesis beyond Power to Gas, New Applications

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IEA Taskmeeting Biomethane, online, 15.04.2021

Krajete GmbH

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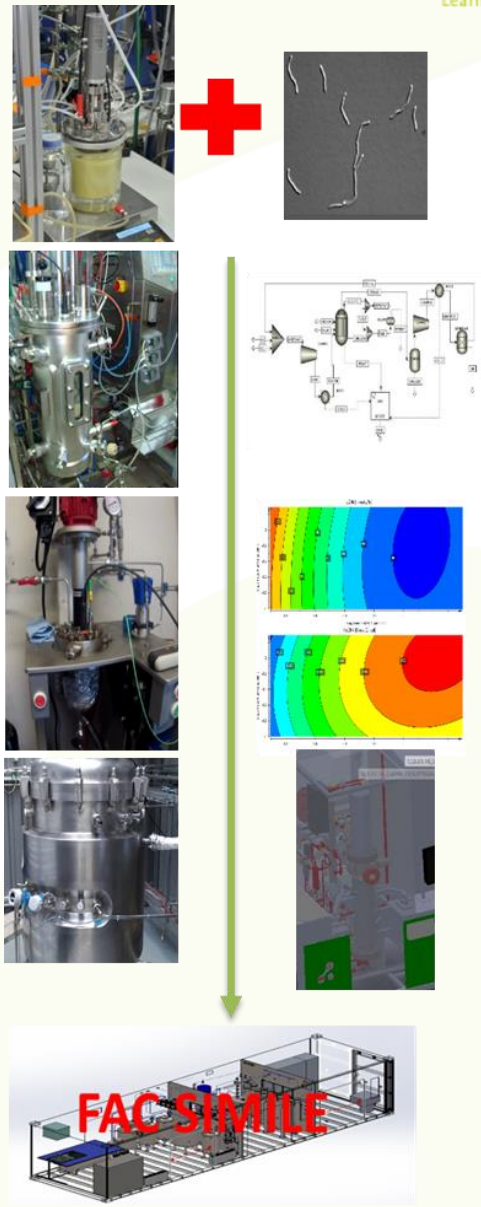
Company overview

- **Krajete GmbH** is an Austrian SME established since 2012 and working in three different business segments:
  - **Biomethanation**
  - Gas purification
  - Industrial gas sampling
- 1 granted patent & 7 patent applications
- **> 15 peer reviewed publications** (2011-2021) support the licensing and technology transfer of the proprietary biomethanation process



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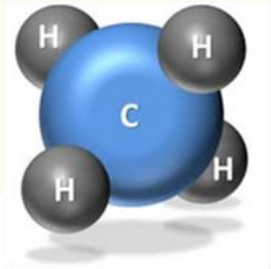
CO_2 based **B**iological **M**ethane **P**roduction (CO2-BMP) process

The CO2-BMP process

Axenic, Unsterile, Methanogenic Archaea culture grown in a fully defined mineral media



Process declinations:

- Waste to value
- Power to Gas (**P2G**)
- Green mobility
- Intermittent methanation

Fast kinetic

"Photosynthetic Bypass"

4th biofuel generation

(Productivity **>** 25 kg_{CH4} m^{-3} h^{-1})

out of "food for fuel"

Benefits of CO2-BMP process

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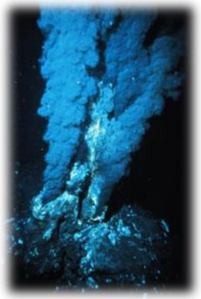
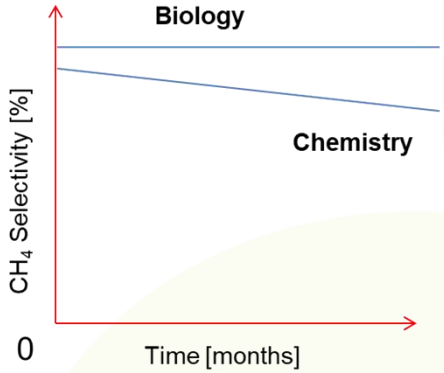
- The process uses archaea microorganisms as biological catalyst to perform a carbon activation and methanation reaction by converting H_2 and CO_2 directly into methane, water and biomass





- **<u>Key process advantages:</u>**
  - Mild operating conditions
  - High selectivity (>95%)
  - Stable, Adaptative & Easy Control
  - Tolerance against wide range of impurities
  - One step reaction/conversion
  - High volumetric conversion rates
  - Autobiocatalytic process (catalyst renews itself)
  - Low media demands, CO_2 = sole carbon source
  - Sustainable “green” process (REACH compliant)

Biology makes from mixtures 1 product while Chemistry makes from pure components mixtures !

CO2-BMP = CO_2 utilization !

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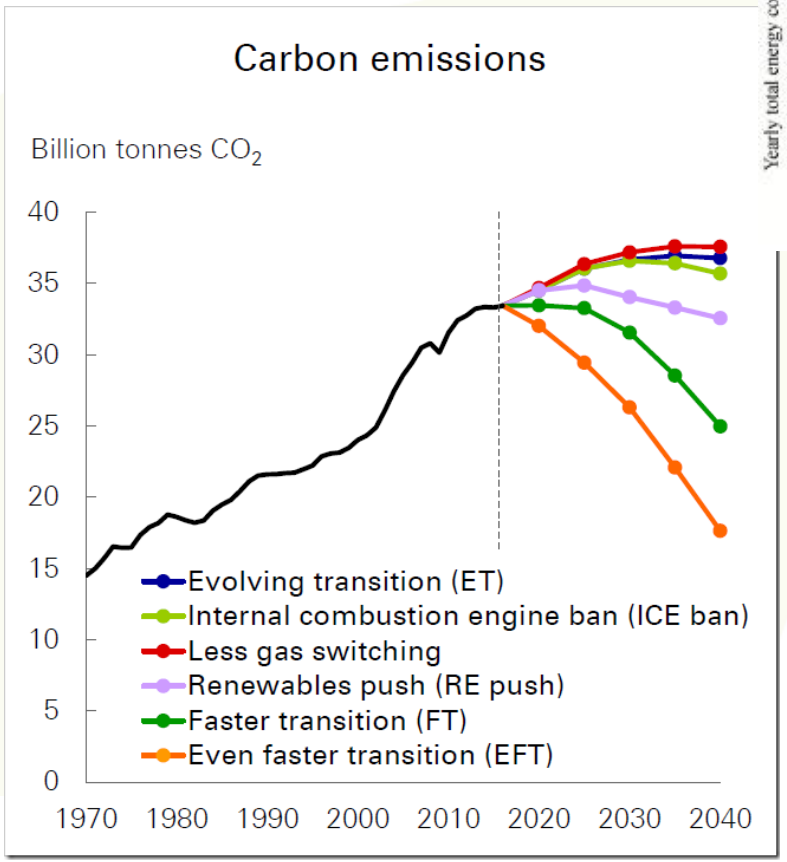
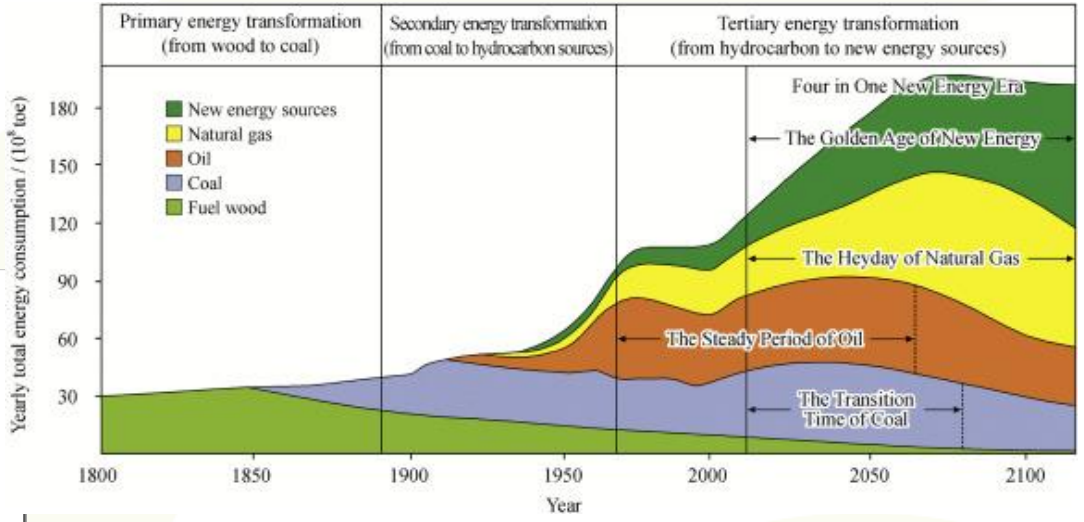
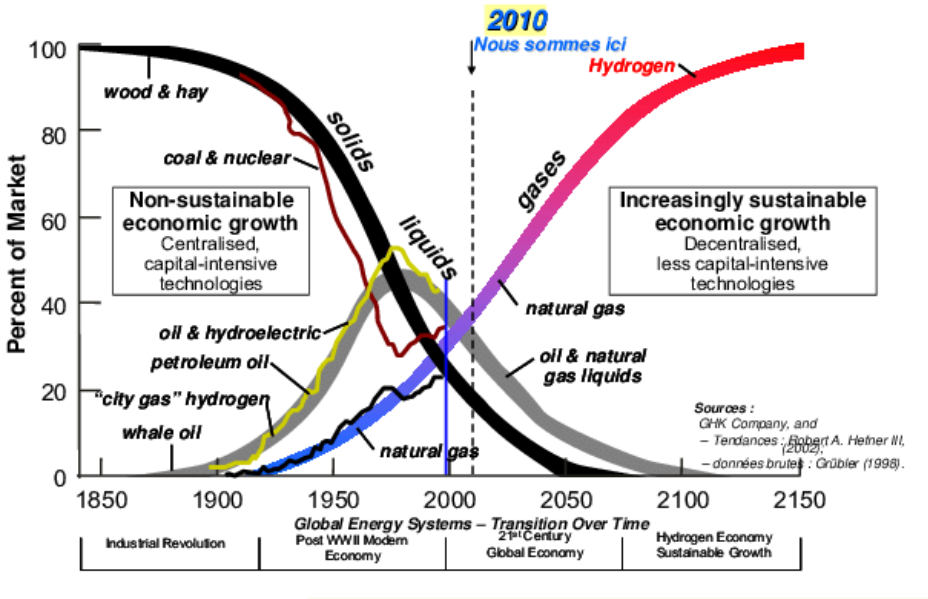
- How will the energy transition look like?







@Sovakool et al. & Amrouche et al. & @Fossil Fuels and Emissions Forecast To Continue To Rise – BP Energy Outlook

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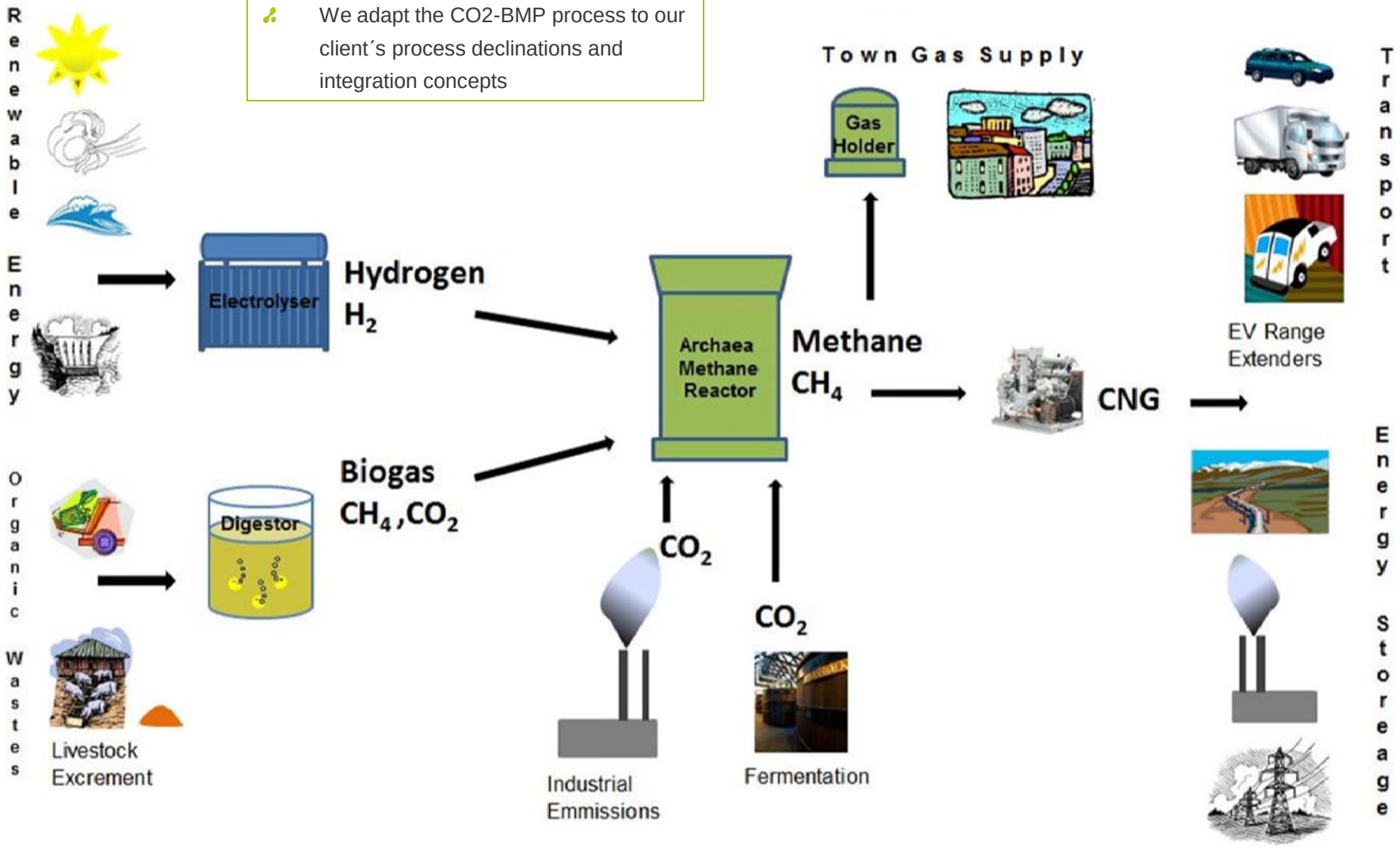
Applications and integrations examples of the CO2-BMP process

CO2-BMP in PtG frames

- We adapt the CO2-BMP process to our client´s process declinations and integration concepts



CO2-BMP from pyrolysis gas

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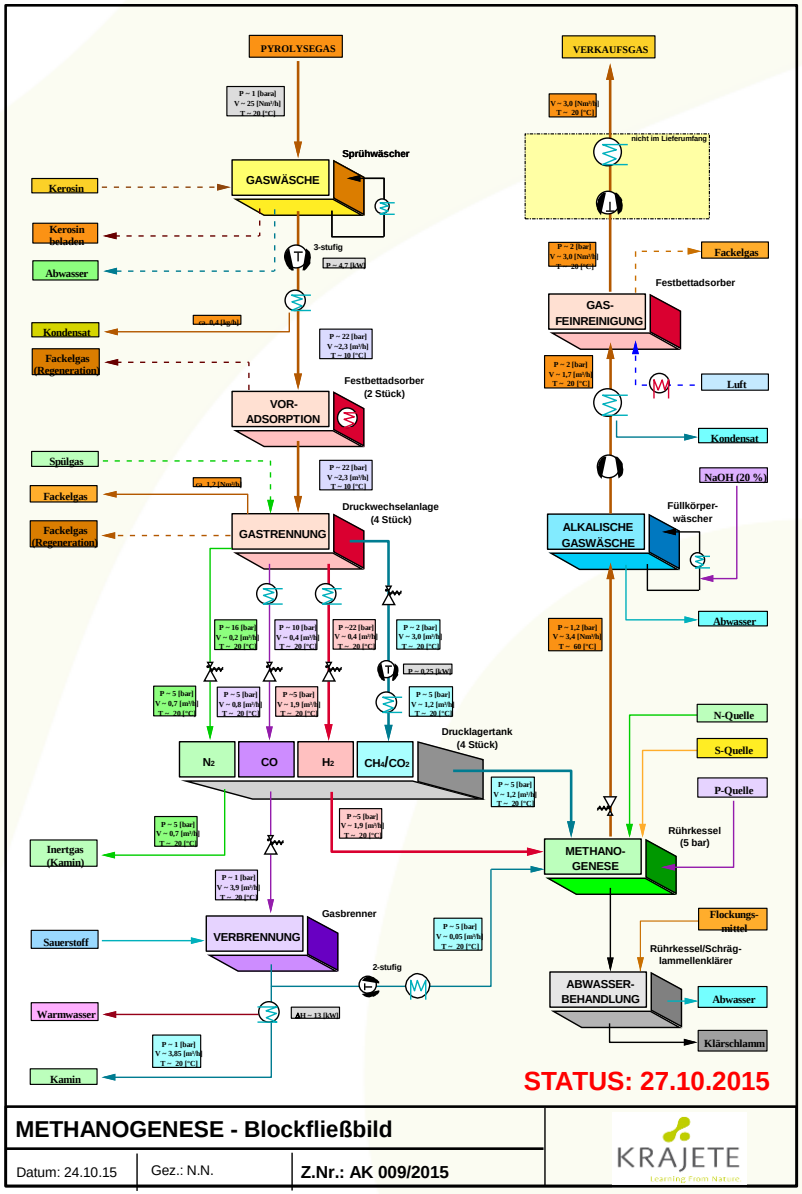
5 step Process

1. Condensation
2. Adsorptive separation
3. CO oxidation
4. **Methanogenesis**
5. Product Gas Purification

- We adapt the CO2-BMP process to our client´s process declinations and integration concepts



CO2-BMP & grid independency

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- We adapt the CO2-BMP process to our client´s process declinations and integration concepts

H_2

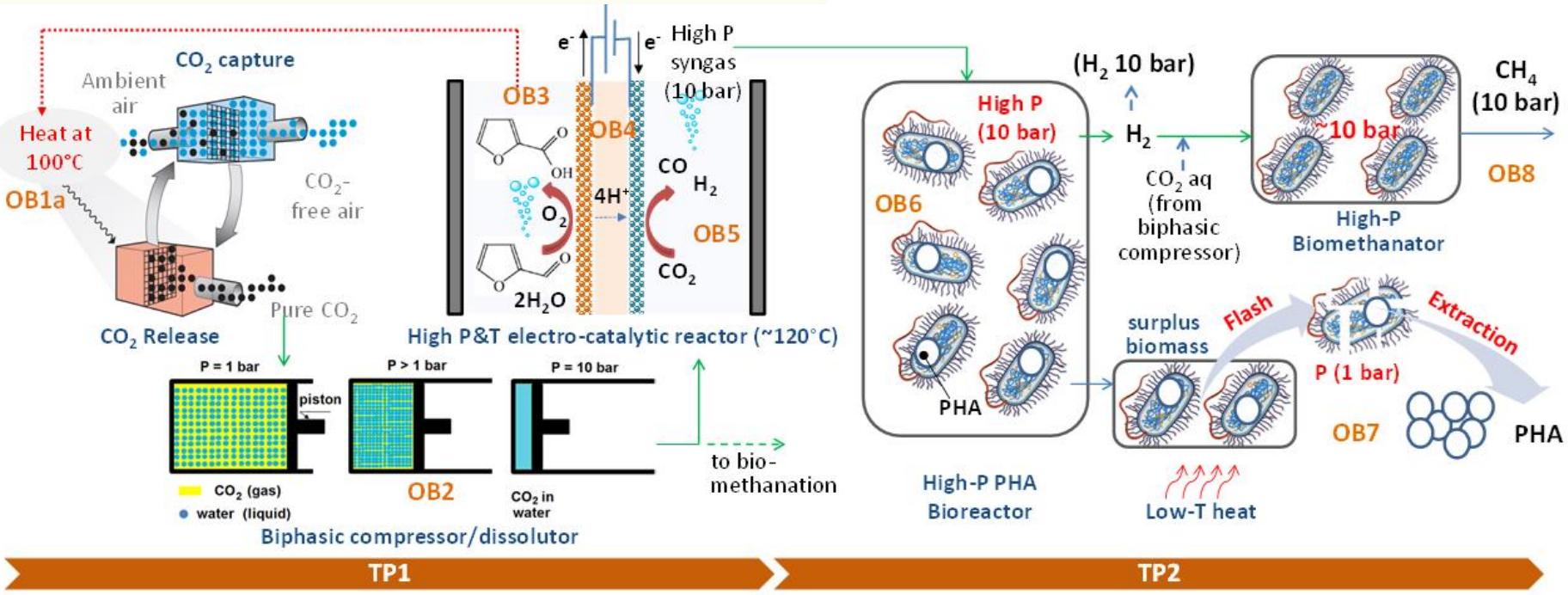
CO_2

CH_4

Bio fertilizer

CO2-BMP in H2020 Celbicon

- CO_2 extracted from air is converted and pressurized to feed an electrocatalytic step which produces a CO/H_2 syngas used to grow CO metabolizing microorganisms producing PHA bioplastics by releasing H_2 and CO_2 upgraded to $BioCH_4$



CO2-BMP & diamond synthesis

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- CO_2 is extracted from air and combined with H_2 produced from renewable electricity and rainwater that is used for the CO2-BMP medium. This allows to produce a high quality (>>99.99 Vol.%) CH_4/H_2 - gas mixture used for producing synthetic diamonds

CH_4/H_2

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R&D in gas converting bioprocess technologies

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CO2-BMP proc. development

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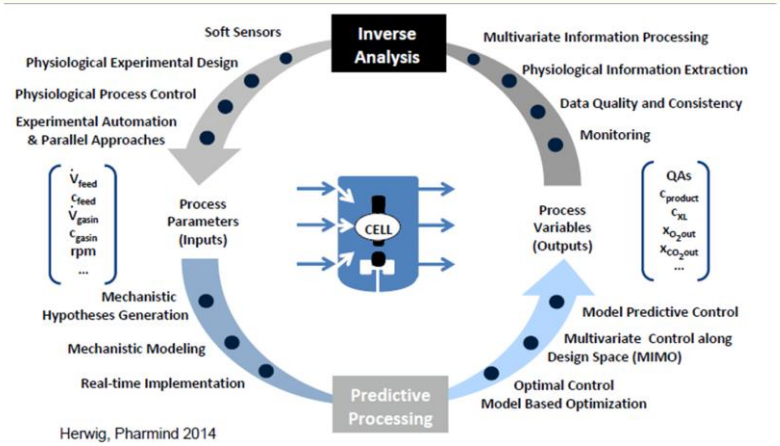
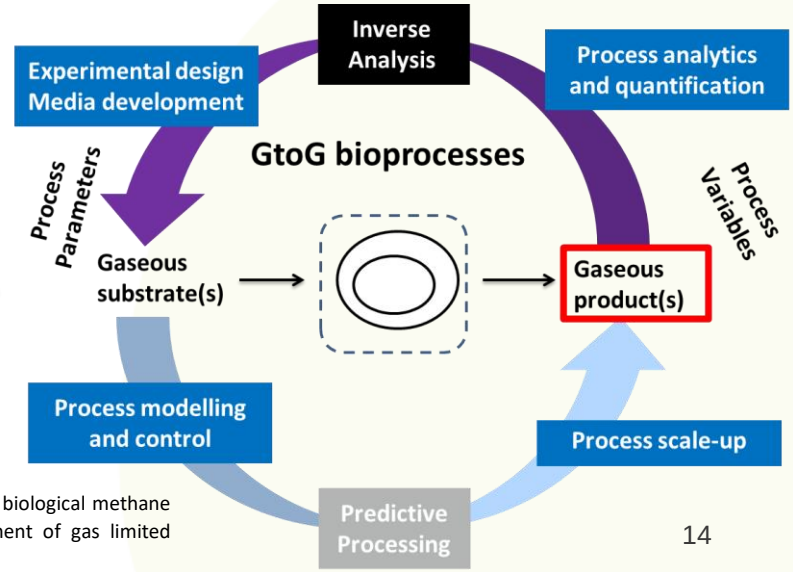
- How should the development steps of a **gas converting bioprocess** be structured?
- How and which key physiologic parameters need to be determined in a gas transfer limited bioprocess operation?
- Which are the most important parameters for scale up?
- On which parameters should the bioprocess control be based?





Sébastien Bernacchi, Christoph Herwig: "Application of a modular and interdisciplinary approach to the development of a biological methane production (BMP) process," 2015. Sébastien Bernacchi and Christoph Herwig, "Challenges and solutions for development of gas limited bioprocesses illustrated by the biological methane production (BMP) process development."

CO2-BMP & real gas sources

- Our industrial **gas sampling service** was developed to evaluate *in-house* our bioprocess tolerance to **impurities** that are contained in **real industrial gases** such as raw biogas, combustion gas or syngas

Organic compounds such as: CO, Ethane, Ethene, Toluene, Naphthalene, Benzene, Propane, Butane, Pentane, Hexane, CS_2

Inorganic anions such as: CN(1-), S(2-), SO4(2-)

Inorganic cations such as: Ba(2+), Sn(2+), Zn(2+), Cu(2+), Mn(2+), Hg(2+), Pb(2+), As(3+), Cr(6+)

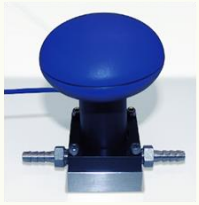
Air compounds: No compounds present in air are toxic unless Oxygen (O2) which is still tolerated to a certain extent

A. H. Seifert, S. Rittmann, S. Bernacchi, and C. Herwig, "**Method for assessing the impact of emission gasses on physiology and productivity in biological methanogenesis**," Bioresour. Technol., vol. 136, pp. 747–751, May 2013.

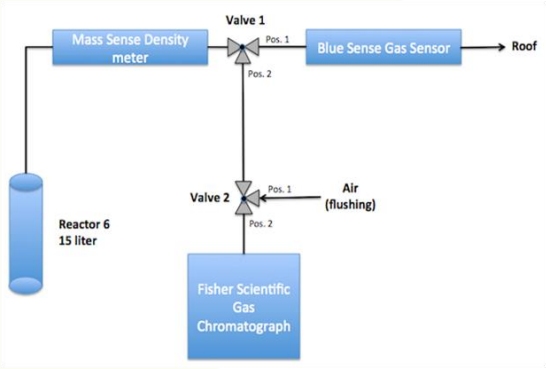
CO2-BMP & PATs

- Balancing on molar basis (C-mol, N-mol, S-mol etc..)
- *E.g.* C-balance: $CO_{2,in} = CO_{2,out} + CH_{4,out} + HCO^{3-}{}_{out} + CO_3^{2-} + C_{biomass,out} + C_{A.ac}$
- Gaseous compounds and main nutrients quantified in **ppm** range and inorganic trace elements up to **ppb** for <u>quantification of scalable uptake rates</u>

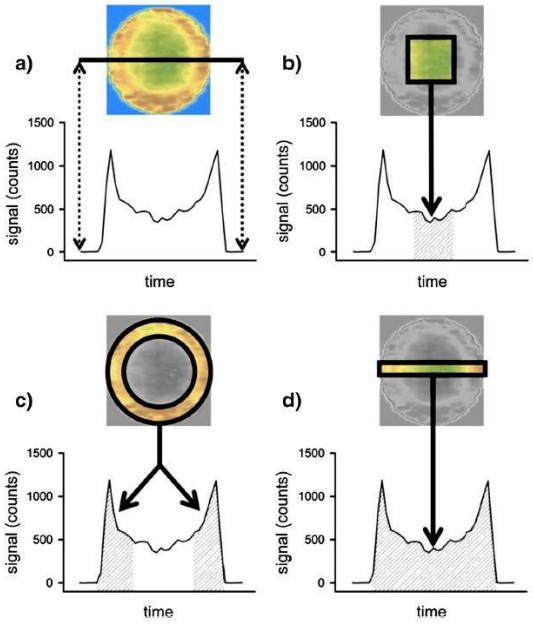
Gas sensors: Online monitoring H2,CO2,CH4



Flow Definer: Off-line



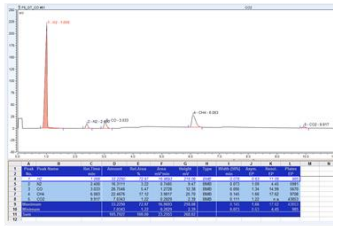
ICP-OES/MS



Density measurement: At-line with modelling

$$\min_x f(x) \text{ such that } \begin{cases} c(x) \le 0 \\ ceq(x) = 0 \\ A \cdot x \le b \\ Aeq \cdot x = beq \\ lb \le x \le ub, \end{cases}$$

Gas chromatography: At-line



W. Nischkauer, F. Vanhaecke, S. Bernacchi, C. Herwig, and A. Limbeck, "Radial line-scans as representative sampling strategy in dried-droplet laser ablation of liquid samples deposited on pre-cut filter paper disks," *Spectrochim. Acta Part B At. Spectrosc.*, vol. 101, pp. 123–129, Nov. 2014.

CO2-BMP & intermittency

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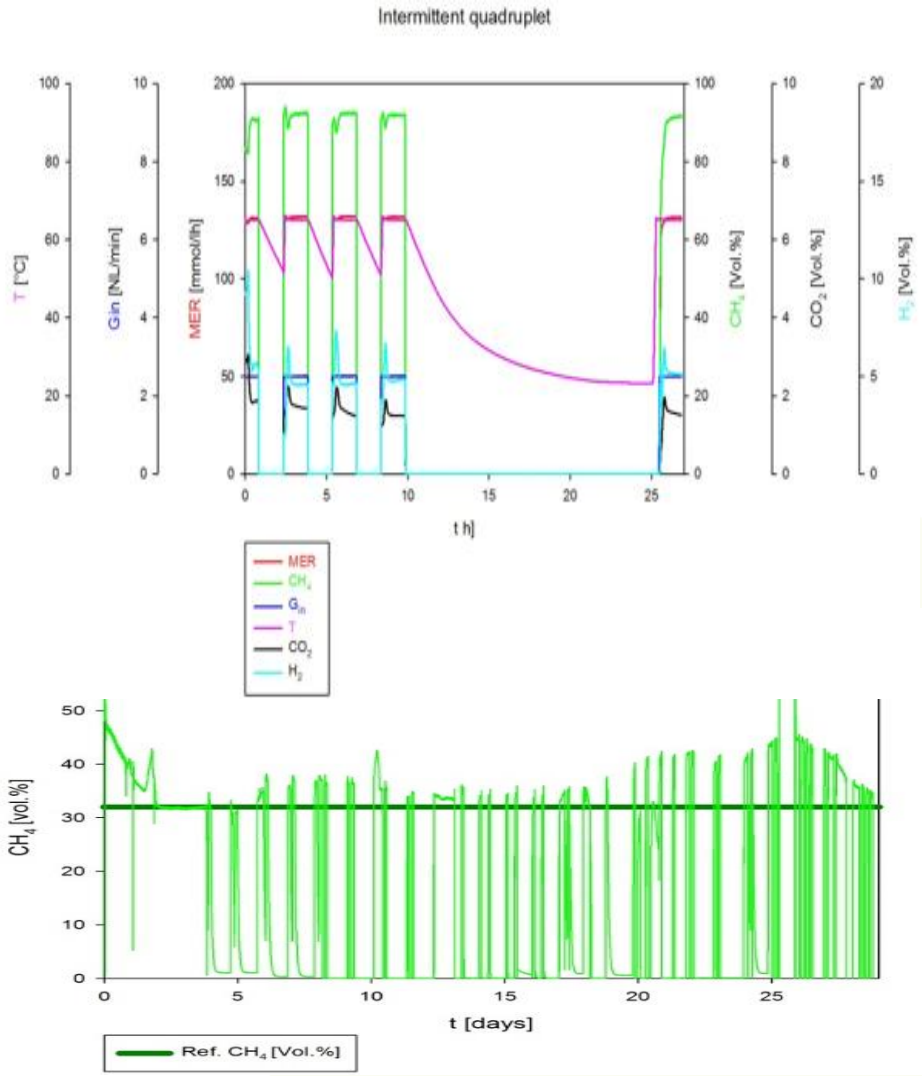
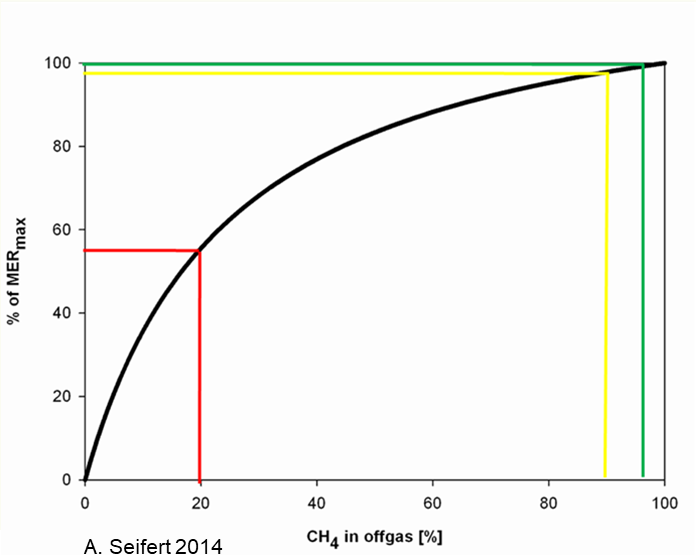
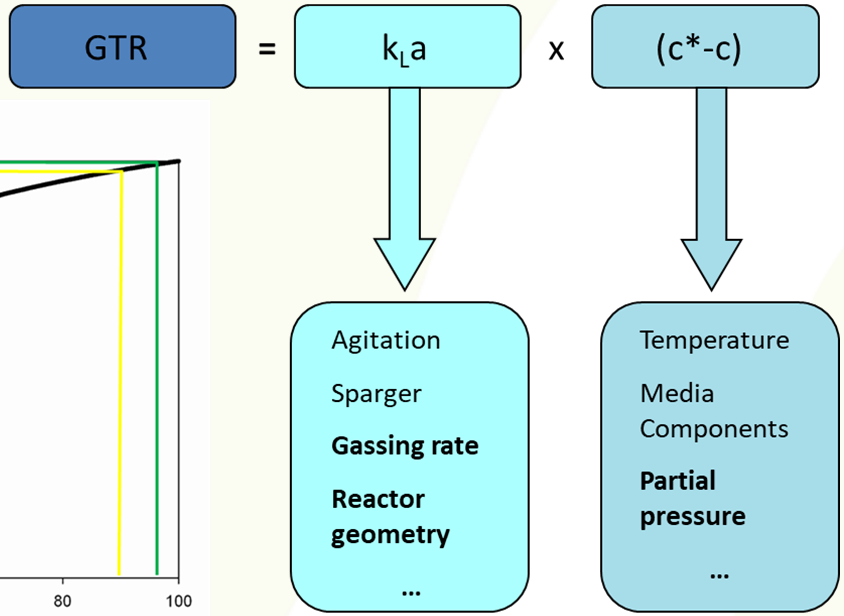
- A challenging offgas quantification:
  - **Stable** for monitoring
  - **Fast** for resolution of dynamic profiles
  - **Reliable** for direct offgas measurement
  - **Accurate** for multiple components: H_2, N_2, O_2, CO, CO_2, CH_4



CO2-BMP & high pressure

- In order to enhance the gas transfer rate [9] of hydrogen to the liquid phase, the use of pressure was investigated
- Tech-transfer of a simplified CO_2-BMP setup for liquid fed-batch and continuously gassed experiments at 10 barg



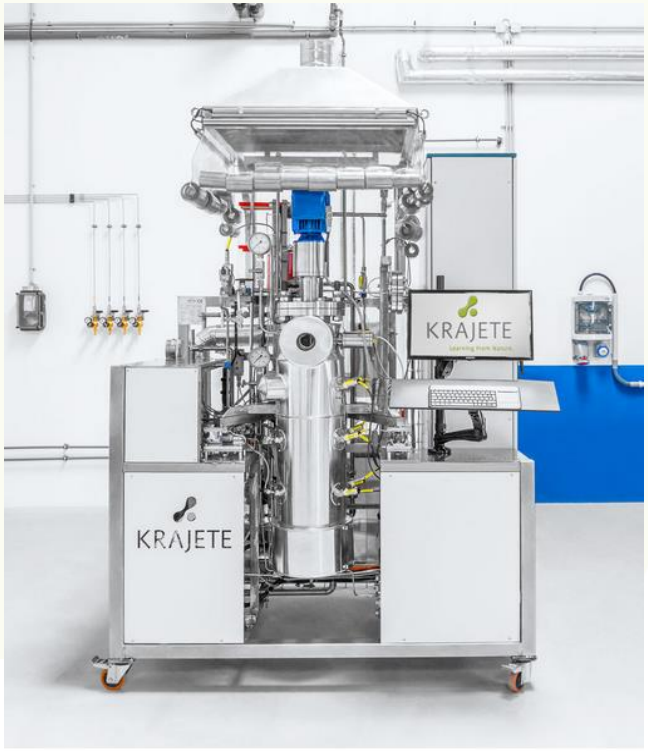


JOHANNES KEPLER UNIVERSITY LINZ

A.H. Seifert, S. Rittmann, C. Herwig, Analysis of process related factors to increase volumetric productivity and quality of biomethane with Methanothermobacter marburgensis, Applied Energy, Volume 132, 2014, Pages 155-162

CO2-BMP R&D reactor

- The "**mother**" R&D reactor used for development of CO_2-BMP process integrations with operating pressure up to 15 barg allows to reach methane evolution rates >1500 $mmol_{CH4}$ L^{-1} h^{-1} with biomass concentration > 20 g_{DCW} L^{-1}
- Corresponds to >33 Nm^3_{CH4} m_r^{-3} h^{-1} with a CH_4 content > 95 Vol.% in the raw wet gas



- Kinetic investigations
- Model based control strategy for client´s specific operations
- Feasibility studies also with industrially sampled gas
- Tecno-economic assessment of active stirring vs passive diffusion
- Development of other gas converting bioprocesses

CO2-BMP *in silico* optimization

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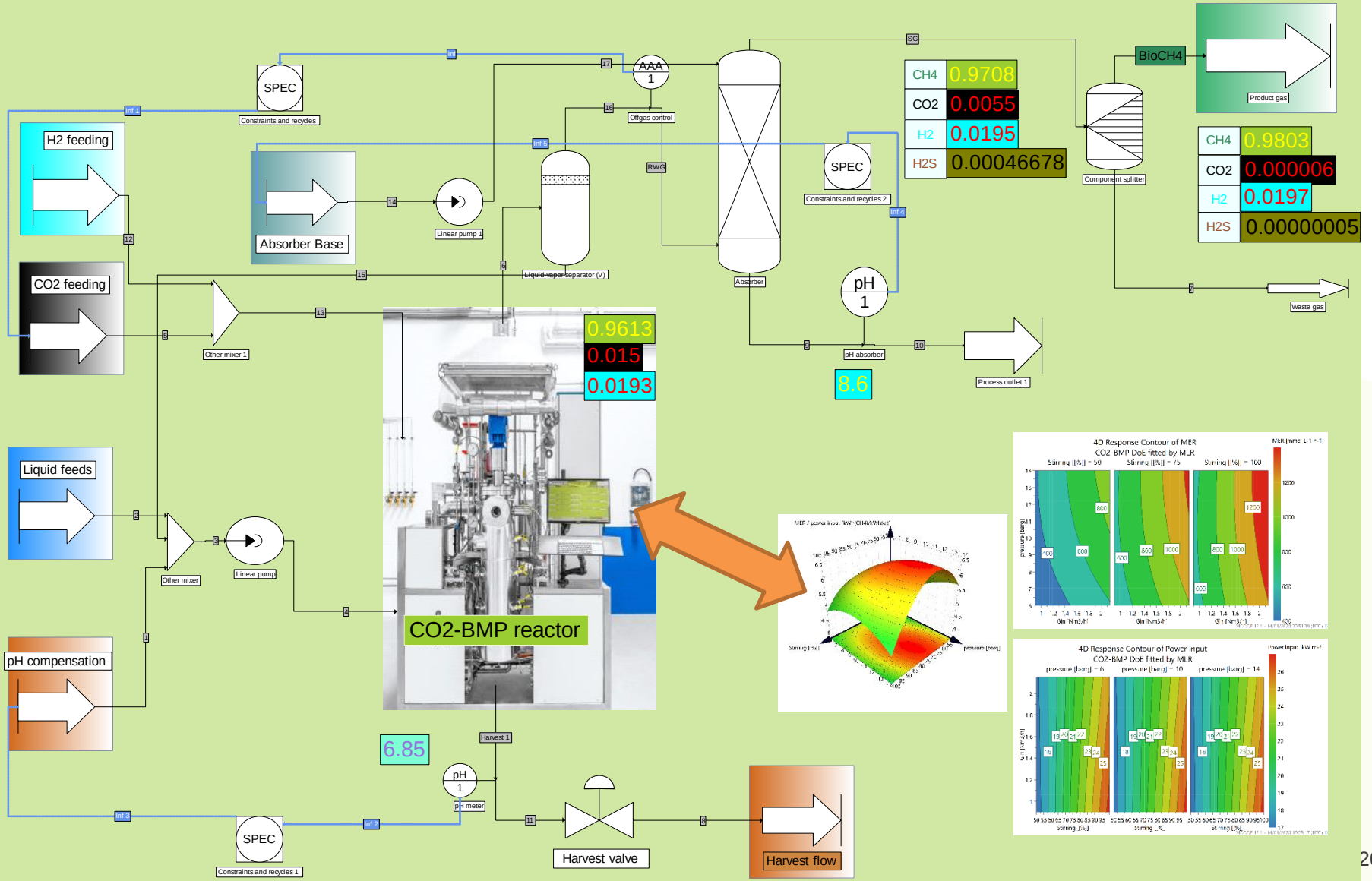
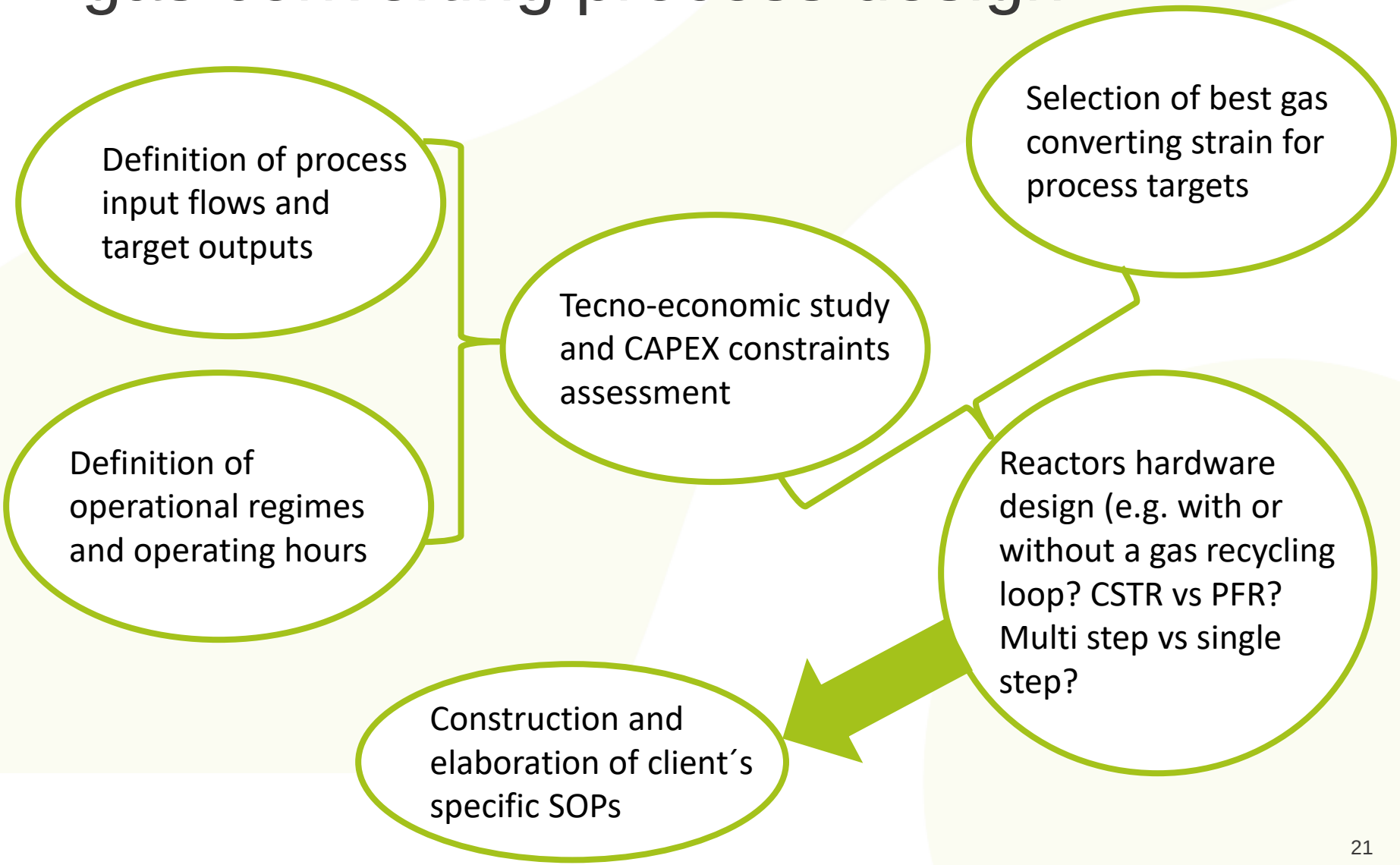


Outlook on gas converting process design



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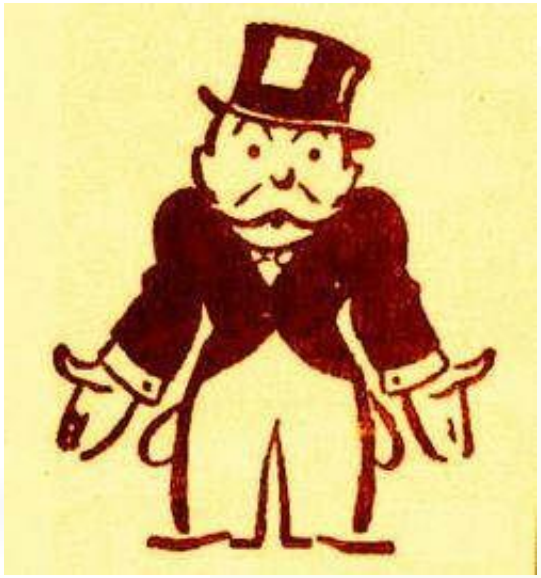
Questions ?



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Thank you for your attention !

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FFG
Forschung wirkt.

ProSim

elbicon

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What we offer

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- CO2-BMP process licensing
- Feasibility studies, basic engineering and custom adaptation of the process to your industrial ecosystem
- Technology transfer and support for hardware design and construction
- Customizable control based on proprietary feed strategy
- Ongoing operational support and process optimization
- Experimental gas transfer determination for turbulent bioreactor regimes
- Consulting for the development of new gas converting bioprocesses
- Industrial and academic network for collaboration in new projects
- CO2 capture and gas purification (upstream or downstream)