Efficiency of Biogas Processes

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Who we are

Anaerobic digestion
Technology development
- Pre-treatment
- Fermenter Technology
- Products Upgrading
- Control

Renewable Energy Systems
Integration
- Methanation
- Methanol Synthesis
- Power to Chemicals

Closing nutrient loops
- Algae as nutrients collectors are digested
- Biogas in artificial food cycles (Hydroponics, Aquaculture, etc.)

Process integration in Biorefineries
- Waste valorization in Food Industries
- Efficiency studies

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Innovative Fermentation Technologies

Adapt the reactors to the microbial processes

Make anaerobic digestion robust against sudden substrate changes (shock loads)

Increase concentrations of value added products in the reactor like the ruminants do

Keep the actors (catalysts or micro organisms) always in the fermenter

Transfer the whole feedstock into value added products

Make it simple, robust and standardized: fermentation in containers

→ Start-Up Company Conviotec GmbH
In contrary to all other bioenergy options (except combustion)

WHY BIOGAS TECHNOLOGY WILL HAVE A BRIGHT FUTURE
# Reasons for Biogas Production

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Main Goal</th>
<th>Attractive Goal</th>
<th>Additional Goal</th>
<th>Renewable Energy Regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastewater</td>
<td>Disposal</td>
<td>Nutrients Recycling</td>
<td>Energy Production</td>
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<td>Manure</td>
<td>Disposal</td>
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<td>Energy Production</td>
<td></td>
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<tr>
<td>Energy Crops</td>
<td>Energy Production</td>
<td></td>
<td></td>
<td>Power to Chemicals</td>
</tr>
<tr>
<td>Integrated Farming Biorefinery</td>
<td>Technical Destruent</td>
<td>Nutrient Recycling</td>
<td>Energy Production</td>
<td>Power to Chemicals</td>
</tr>
</tbody>
</table>
Highly Flexible Portfolio

Allows allocation of costs depending on particular incomes and market opportunities:

• Technical destruents as environmental service
• Back to the roots – organic degassed fertilizer as a value added product
• Two new opportunities in renewable energy regimes

=> Need for efficient processes
EFFICIENCY OF BIOGAS PLANTS
Efficiency Activities

• RoI dependend on process efficiency
• In Germany: Remaining term of feed in tariff security – what happens thereafter?
• Singular control of biogas potential is not relyable for economic risk calculations

Consequences
• Continuous control strategies with adapted analytical tools needed:
  – Biomethane potential test needs 60 days
  – FoTS based on general statistical considerations
  – Method of 100% based on time series control and HHV determination
Motivation and Goal:

• Methode of theoretical 100%: analysis of more than 200 biogas plants -> high variance width in efficiency

• Long term control in reasonable frequencies allows more detailed information:
  – Sampling
  – Saisonal variations
  – Substrate quality and –quantity
  – accidents
Time Series Analysis

• Statistical method to control quality of products and processes variances (storage of silage)

• Allows to identify time shifts between input and output streams caused by kinetic processes (hydraulic retention times in biogas processes) and influences of changes in the input streams to the process output
Sampling during Time Series Analysis
Overall Mass Balance

![Mass Balance Graph]

- **Substrate**
  - VS
  - Water

- **Digestate**
  - VS
  - Water

- **Biogas**
  - Biogas
  - Water
Determination of Energy Content: Methode of Theoretical 100%

- Energy content of substrates and of digestate determined by:
  - Higher heating value (HHV) determination (preliminary drying required)
  - Determination of total solids (TR) and ash content:

\[ E_i = m_i \cdot TR_i \cdot HHV_i \]

Absolute Efficiency:

\[ \eta_{abs} = \frac{\text{Energy Input} - \text{Energy Output}}{\text{Energy Input}} = \frac{\sum_S m_S \cdot TR_S \cdot HHV_S - \sum_G m_{GP} \cdot TR_{GP} \cdot HHV_{GP}}{\sum_S m_S \cdot TR_S \cdot HHV_S} \]
Methode of Theoretical 100% further assumptions

Energy in the digestat is based on non digested carbohydrates and lignin:

1. Anaerobically digestable: carbohydrates like cellulose and hemicellulose
2. Inert material: lignin
HHV of Binary Mixtures

\[ \eta_{\text{digestable}} = \frac{\text{Digestable Energy Input} - \text{digestable energy Output}}{\text{Digestable energy Input}} \]

\[ \eta_{\text{digestable}} = \frac{\Sigma_S \dot{m}_S \cdot TR_S \cdot HHV_S - \Sigma_{GP} \dot{m}_{GP} \cdot TR_{GP} \cdot HHV_{GP}}{\Sigma_S \dot{m}_S \cdot TR_S \cdot HHV_S - \Sigma_{GP} \dot{m}_{GP} \cdot TR_{GP} \cdot oTR_{GP} \cdot w_L \cdot HHV_L} \]
Efficiency Related to Digestable Content

- Substrate costs: 39 €/t
- 3 ct/kWh
- 200 kWh ↔ 6 €
Sampling and Analytical Procedures

• Weekly sampling
  – VDI 4630, feste Stoffe an 6 verschiedenen Stellen
  – Flüssige Stoffe nach kräftiger Durchmischung der Behälter

• Determination of total solids (TR)
  – DIN 38414 S2

• Determination of ash content
  – DIN 38414 S3

• Determination specific HHV
  – DIN 51900 S3, 3-fach Bestimmung
Results: Substrates (Corn Silage)

Maissilage, frisch

Kalenderwoche

spez. Energie [kWh/t]

0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200

BGA 1+2
BGA 3
BGA 4
BGA 5

New harvest

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Ergebnisse: Substratvergleich (1)

Maissilage, normiert auf 35%-TR

Kalenderwoche

spez. Energie [KWh/t]

BGA 1+2
BGA 3
BGA 4
BGA 5

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Results: Substrates (Manures)

vorverdaute Reststoffe, frisch

spez. Energie [kWh/(tFM)]

Kalenderwoche

- Schweinegülle
- Hühnertrockenkot
- Rinderfestmist
Results: Substrates (Manures)
Results: Efficiency Development

![Graph showing the efficiency development over time with various substrates and weeks.]
Results: Efficiency Development
Results: Efficiency Development
Results: Efficiency Development

Enzyme-Addition, new harvest, Cold period
92,6 % → 93,2 % (digestable)
Conclusion

- Efficiency is dependend on substrates quality and quantity
- Substrate chances have a negative effect on efficiency
- Efficiency varies higly

Time series analysis is important for efficiency control
Derived Simulation Approaches

• Mass and energy balances of commercially running biogas plants are usually incomplete

• Results of the time series analysis and the methodology of the 100% allows a reasonable and representative modelling of mass and energy balances of biogas plant processes

• Relyable mass and energy balances are prerequisite of efficiently running biogas plants
Derived Simulation Approaches

- Substrates (mass and energy)
  - Biogas (Energy, Gas composition)
  - Digestate (rel. Energy, ash and lignin as in input)
### Derived Simulation Approaches

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<thead>
<tr>
<th>Nutzenergie</th>
<th>Angaben aus Betriebstagebuch</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGA</td>
<td>550 kWel</td>
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<tr>
<td>Wirkungsgrad BHKW</td>
<td>40,45%</td>
</tr>
<tr>
<td>Volllaststunden</td>
<td>8.322 h/a</td>
</tr>
<tr>
<td>Feuerungswärmeeistung Gas</td>
<td>11.315.451 kWh/a</td>
</tr>
</tbody>
</table>

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<tr>
<th>Feed</th>
<th>Ergebnisse</th>
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<tbody>
<tr>
<td>Masse Substrat</td>
<td>8.045.702 kg(FM)/a</td>
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<tr>
<td>TR Feed</td>
<td>33%</td>
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<tr>
<td>oTR Feed</td>
<td>97%</td>
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<tr>
<td>Masse Substrat</td>
<td>2.616.462 kg(TR)/a</td>
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<tr>
<td>HHV Substrat</td>
<td>18,76 MJ/kg(TR)</td>
</tr>
<tr>
<td>Feuerungswärmeeistung Feed</td>
<td>13.631.042 kWh/a</td>
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<tr>
<td>Masse Lignin im Feed</td>
<td>171.005 kg(Lignin)/a</td>
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</tbody>
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<tr>
<th>GPL</th>
<th>Ergebnisse</th>
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<tbody>
<tr>
<td>Masse GPL</td>
<td>444.475 kg(TR)/a</td>
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<tr>
<td>HHV GPL</td>
<td>19 MJ/kg(TR)</td>
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<tr>
<td>oTR GPL</td>
<td>83%</td>
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<tr>
<td>FWL GPL</td>
<td>2.335.222 kWh/a</td>
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<tr>
<td>Cellulose</td>
<td>0,53%</td>
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<tr>
<td>Lignin</td>
<td>0,47%</td>
</tr>
<tr>
<td>Masse Lignin im GPL</td>
<td>171.005 kg(Lignin)/a</td>
</tr>
<tr>
<td>Feuerungswärmeeistung Lignin</td>
<td>1.387.037 kWh/a</td>
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<tr>
<th>Ergebnisse</th>
<th>Restgaspotenzial</th>
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<td>948.185 kWh/a</td>
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Constraints of the Method

- Collection of volatile substances (organic acids etc.) which can be solved by chromatography and stoichiometric calculations
- Lignin as a prerequisite (reference)
- Sufficient longterm retention time needed – digestate as binary mixture of carbohydrates and lignin
- Difficulty of representative sampling
- Modelling of mass and energy balances with incomplete data sets
Derived Simulation Approaches - Conclusions

- Time series analysis and methodology of 100% allows reliable estimations of mass and energy balances of commercial biogas plants with a minimum of effort.
- Mass and energy balances shows how much digestable potential energy ends in gas and how much ends in the digestate, i.e. is a potential greenhouse gas
- Nonetheless the efficiency of the biogas plant is not only a need for optimization of the profitability of a biogas plant but also for the greenhouse gas impact
Future Options

• Time dependent shift of energy output under consideration of the retention time distribution
• Research on competition on utilization via BMP
• Analysis of resulting shift profiles of hydraulic retention times