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Waste Management & Energy

Challenges in Data Acquisition and Application for Biogas Process Modelling in Practice

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Focus activities

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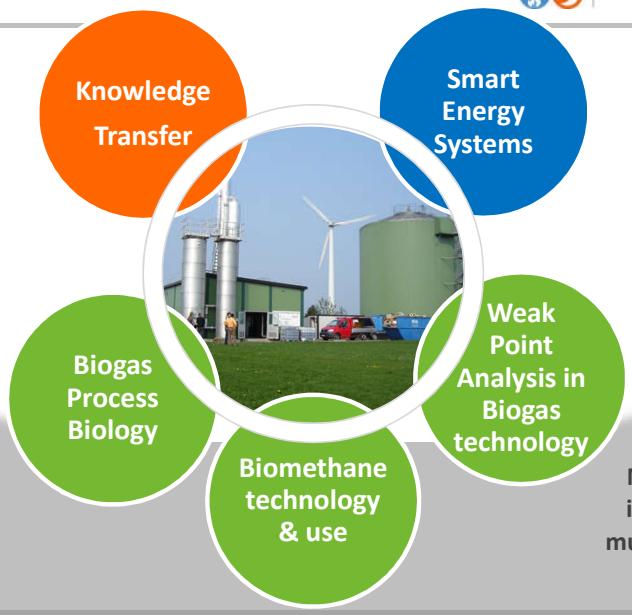

> 10 years experiences in consulting and research

National and international multidisciplinary network

Content

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- Model based process control of large-scale biogas plants
- Experiences with data acquisition in practice
  - Feedstock, sampling and laboratory analysis
  - Documentation of plant feeding
  - Measurement of (stored) biogas quantities
  - Quality of electronic data monitoring and system failures
- Outlook

Modell Based Process Control

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Goal: model based process control of large scale biogas plants by comparing:

i) the simulated gas quantity

with:

ii) the measured gas quantity

on a daily basis.

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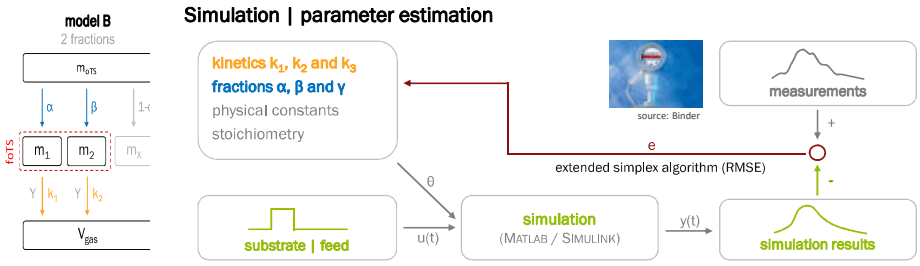

Two different realities…

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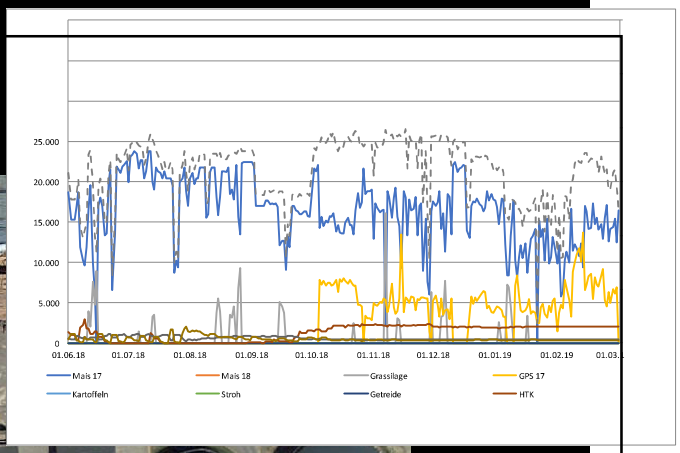
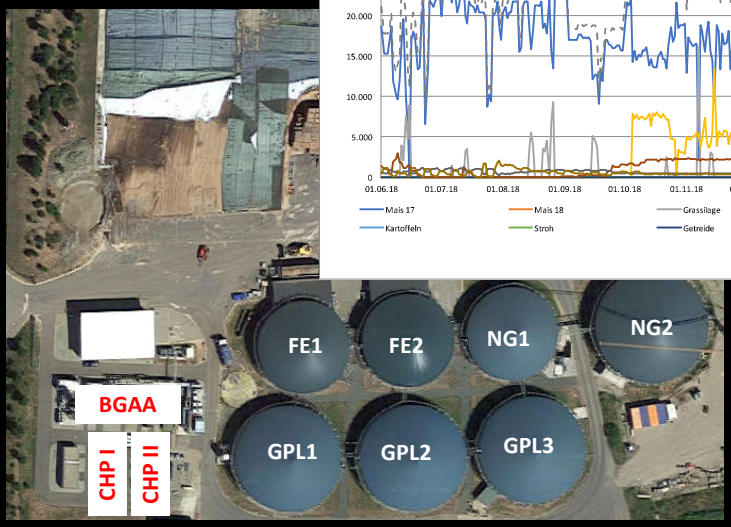
For model based process control in large-scale biogas plants, we need to know:

i. What goes in, how much and when
ii. How much (gas) comes out and when

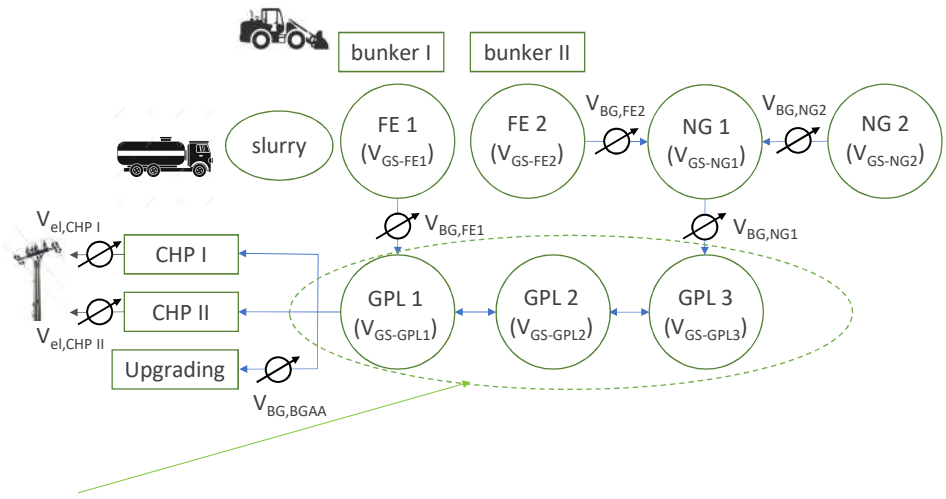
Source: Nils Engler

research in lab vs. practice





Gas Flows and Gas/Energy Measuring



$$V_{BG,GPL\ 1\text{-}3} = V_{BG,CHP\ I} + V_{el,CHP\ II} / \eta_{el,\ CHP\ II} + V_{BG,BGAA} - V_{BG,FE1} - V_{BG,NG1} + \Delta V_{GS\text{-}GPL1} + \Delta V_{GS\text{-}GPL2} + \Delta V_{GS\text{-}GPL3}$$

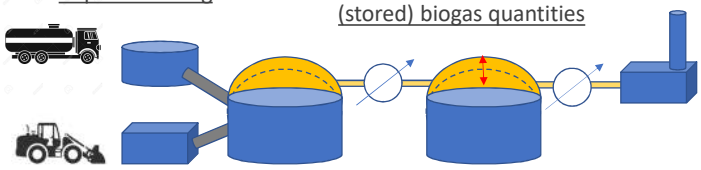
Uncertainties of Available Data

A) feedstock, sampling and laboratory analysis

Source: N. Engler

B) documentation of plant feeding

C) measurement of (stored) biogas quantities



D) Quality of electronic data monitoring and system failures

Inhomogenes Quality of Feedstock

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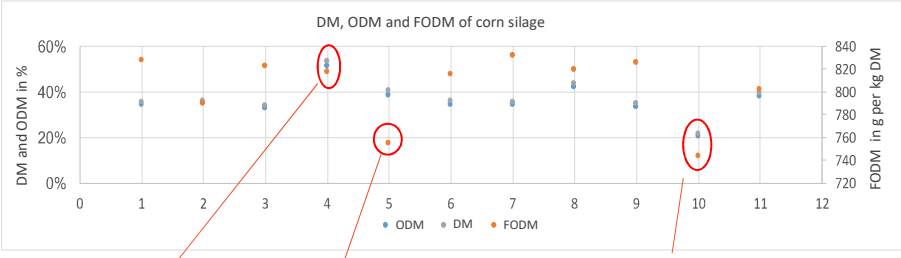

from cutting edge (dry)

from edge (moldy)

unknown reasons, sample taken by personal

calculated Biogas Yield based on FODM:

- average: 667 Nm^3/kg_{ODM} and 248 Nm^3/kg_{DM}
- max: 684 Nm^3/kg_{ODM} and 360 Nm^3/kg_{DM}
- min: 618 Nm^3/kg_{ODM} and 132 Nm^3/kg_{DM}
- σ: 22 Nm^3/kg_{ODM} and 51 Nm^3/kg_{DM}

Kinetics of Substrates Fermentation

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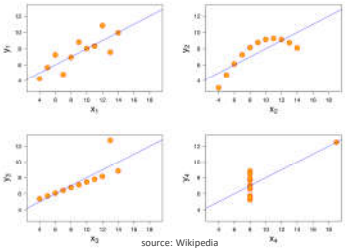
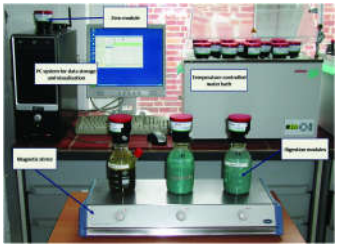
Anscombe-quartett



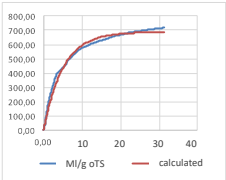
source: Wikipedia

- mean of y = 2 decimals
- variance of y +/- 0.003
- R^2 = 2 decimals (0.67)



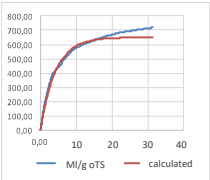
Source: Nils Engler, University of Rostock

results of ANKOM-tests for corn silage: $V(t) = V_{max} \cdot (1 - e^{-kt})$



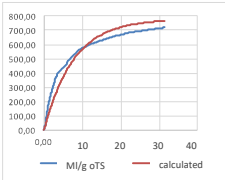
V_{max} and k variable:

V_{max} = 688 ml/g_{oTS}; k = 0,191; R^2= 0,982; VDI 4630: 1,4 %



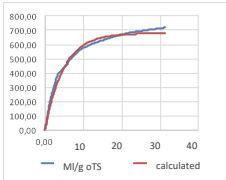
V_{max} = 650 ml/g_{ODM} (**KTBL**) and k variable:

k = 0,229; R^2= 0,968



V_{max} = 780 ml/g_{ODM} (**ADL**) and k variable:

k = 0,125; R^2= 0,977



V_{max} = 684 ml/g_{ODM} (**FODM**) and k variable:

k = 0,195; R^2= 0,980

Kinetics of Slowly Degradable Substrates (Straw)

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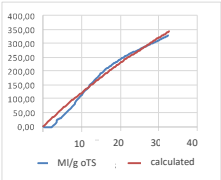
i) Kinetic parameters k and V_{max} based only on test results



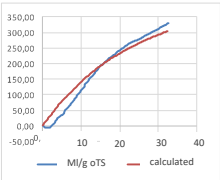
V_{max} = 903 ml/g_{ODM}

k = 0,0146

R^2= 0,986

VDI 4630 = 6,3 %

ii) Kinetic parameter k based only on test results and V_{max} from literature



V_{max} = 400 ml/g_{ODM} (**KTBL**)

k = 0,0436

R^2= 0,992

For slowly degradable substrates:

- ANKOM-tests over a long period of time (VDI 4630 </= 1 %)

or:

- determination of V_{max} in parallel batch-test (also for a long period of time)

or:

- V_{max} based on substrate specific analytical values (e.g. FODM) and/or from literature values

Plant Feeding

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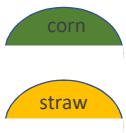

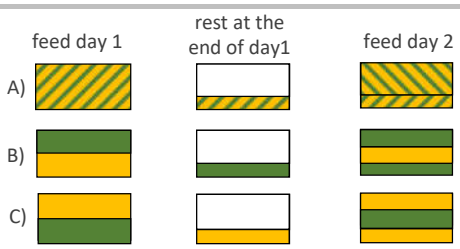

Biogas yield of corn: 220 m^3 Biogas per ton_{FM}

Biogas yield of straw: 124 m^3 Biogas per ton_{FM}

Uncertainties based on static calculation of the daily biogas yield:

Case B compared to A:

- maximum relative daily error* = 87 %
- average relative error = 12 %

$$\frac{\left|Y_B - \left(\frac{Y_B + Y_A}{2}\right)\right|}{Y_B}$$

Case C compared to A:

- maximum relative daily error* = 42 %
- average relative error =20%

$$\frac{\left|Y_C - \left(\frac{Y_C + Y_A}{2}\right)\right|}{Y_C}$$

Measurement of Biogas Quantities

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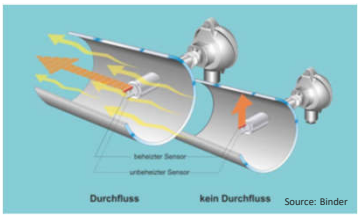
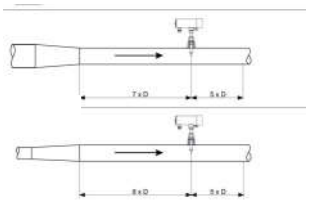
Thermal measurement principle

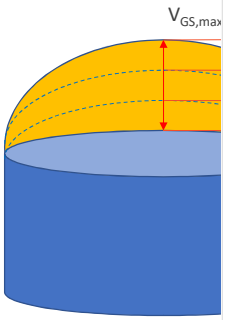


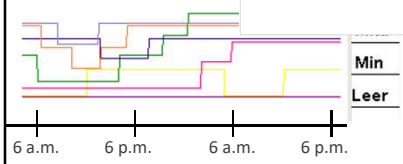
$$w = \left(a + b\frac{U_{Br}^2}{T_S - T_F}\right)^c$$

- measuring gas amounts independent from flow direction (reverse flows must be avoided)
- straight inlet and outlet distances for laminar flow must be given (less relevant for low flow velocities)
- accurate installation and calibration
- contamination of sensors, e.g. with sulphur

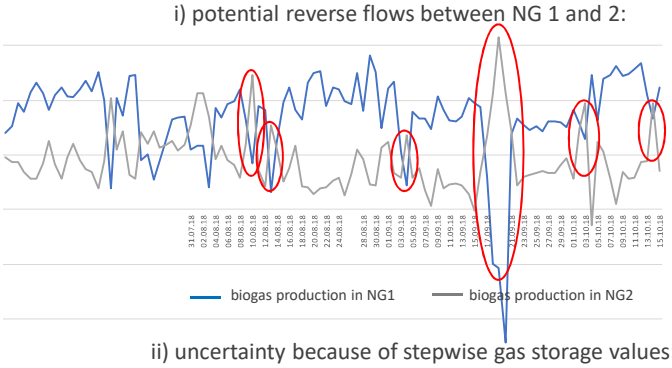


Gas Storage Leve





i) potential reverse flows between NG 1 and 2:



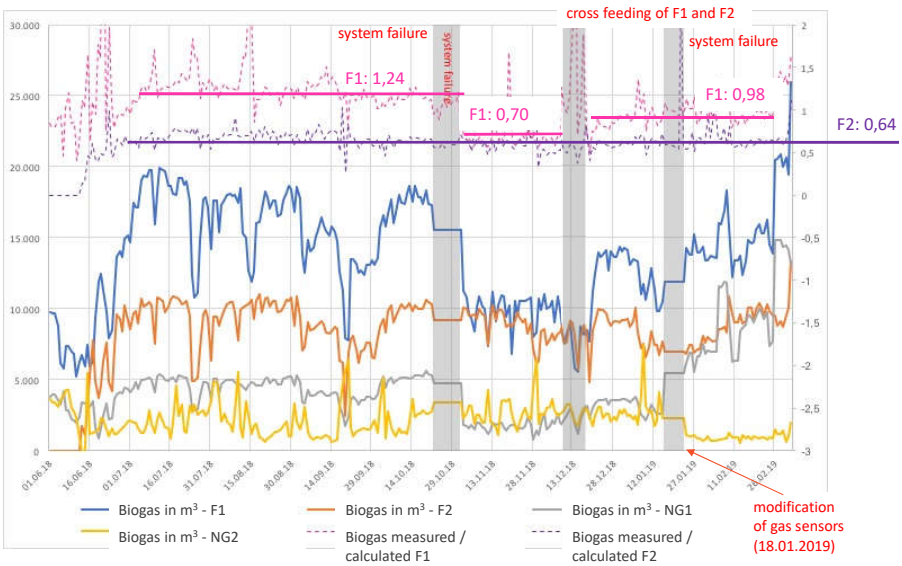
ii) uncertainty because of stepwise gas storage values:

- 1/3 of gas storage volume NG 2 = 848 m^3
- Daily gas production between 750 and 4.100 m^3

→ uncertainty: 21 to 113 % of daily gas production

iii) uncertainty because of real storage volumes per step are not known

Example for System Failures



Outlook

- Measures for reducing the uncertainties of the data, e.g.:
  - **Sensitisation of the personal in charge of biogas plant operation**
  - Precise documentation of plant feeding and changes in substrate qualities
  - Change of gas storage monitoring (infinitely variable, pressure based)
  - Correction of measured gas amounts / calibration
  - Improvement of electronic documentation of plant data
- Simulation based on 1st order model of biogas production (Matlab/Simulink)
- Influence of data uncertainties on the dynamic simulation results
- Suitability of different procedures for estimation of substrate specific biogas potentials and degradation kinetics for model-based process control – finding the right compromise between:

  i. acceptable accuracy / reliability of the results

  and

  ii. limited expenditures for substrate analysis / data monitoring

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Biogas – Key technology for energy systems and material cycles of the future

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