Biogas technology

a key technology to adjust fluctuating renewable energy sources and
to recycle scarce resources from bio-wastes and residues

Jens Born

jens.born@fh-flensburg.de
http://www.znes-flensburg.de
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

Jens Born
jens.born@fh-flensburg.de
http://www.znes-flensburg.de
http://cats.fh-flensburg.de
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 and robust: fermentation in containers

→ Start-Up Company Conviotec GmbH
Bioenergy is a Source of Renewable Energy
Climate Change Forces Paradigm Shift

Chemical Energy

From

To

Electrical Energy

As

Primary Energy Source
Energy Efficiency of ...

#### a fuel based internal combustion engine

\[ \eta = 25\% \]

Biofuels are here

#### an electrical engine

\[ \eta = 90\% \]
Energy Efficiency Potential > 40%

- Bioenergy is here:
  - Coal Fired Powerplant
  - Gas Combined Cycle Powerplant
  - Hydropower
  - Solarpower
  - Windpower
  - Nuclear Power

- Power Mix Germany

- Electricity
  - Primary Energy
    - 2.4 kWh
  - Electric Energy
    - 1 kWh

- Heat
  - Primary Energy
    - 2.4 kWh
  - Electric Energy
    - 1 kWh
  - Usefull Heat
    - 3 kWh

M. Günther, J. Schmid; BWK 64(9), 2012, 44-50
Space Efficiency
Biomass, Wind or Photovoltaics?

Photovoltaics and wind far superior to biomass

Bossel, 2006
# Supply Chains – Electrical Energy

<table>
<thead>
<tr>
<th>Step</th>
<th>Photo-voltaics</th>
<th>Wind Power</th>
<th>Biomass (Fermentation)</th>
<th>Biomass (Gasification)</th>
<th>Crude Oil</th>
<th>Coal</th>
<th>Nuclear Power</th>
<th>Natural Gas</th>
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<td>CHP</td>
<td>Turbine</td>
<td>Generator</td>
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<td>Turbine</td>
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<td>Gas/Steam</td>
<td>Turbine</td>
<td>Turbine</td>
<td>Turbine</td>
<td>Transport</td>
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<td>Transport and Storage</td>
<td>Gasification</td>
<td>Gas/Steam</td>
<td>Gas/Steam</td>
<td>Gas/Steam</td>
<td>Purification</td>
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<td>Harvesting</td>
<td>Pretreatment</td>
<td>Heat Gasification</td>
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<td>Reaktor</td>
<td>Transport</td>
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<td>Cultivation</td>
<td>Transport</td>
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<td>Transport</td>
<td>Gas Production</td>
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<td>Seeding</td>
<td>Harvesting</td>
<td>Raffination</td>
<td>Purification</td>
<td>Enrichment</td>
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<td>Fertilizer</td>
<td>Cultivation</td>
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</tbody>
</table>

Nach H. Scheer: Solare Weltwirtschaft; 2002; 5. Auflage
# Reasons for Biogas Production: Portfolio of Products and Services

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Main Goal</th>
<th>Attractive Goal</th>
<th>Additional Goal</th>
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<tbody>
<tr>
<td>Wastewater</td>
<td>Disposal</td>
<td>Nutrients Recycling</td>
<td>Energy Production</td>
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<tr>
<td>Manure</td>
<td>Disposal</td>
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<td>Energy Production</td>
</tr>
<tr>
<td>Energy Crops</td>
<td>Energy Production</td>
<td></td>
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</table>
Human Energy demand
- 15 TW for Energy
- 7 TW for Food
Properties of Biomass

• Biomass is a distributed source and available all around the globe (like wind and solar energy)

• Multipurpose function of biomass
  – Natural product for food, construction material, textiles, paper and fuels ...
  – Natural services in balancing water household and temperature, keeping soil quality stable, CO2 sink, bio-organic waste treatment ...

• Biomass is stored solar energy in form of chemical energy with
  – long-term storage options (available every time)
  – low energy density
Logistic Aspects of Bioenergy
Pro’s and Con’s of Bioenergy

**Pro**
- Bioenergy matches into traditional and industrial energy systems
- Option for climate change mitigation
- Energy storage properties

**Con**
- Land-use competition food versus fuels versus natural ecosystems
- Human alteration of net primary productivity of ecosystems
- Long and complex supply chain
- Low energy density
- Matches not really into a renewable energy based energy system

Figure 1. Renewable Energy Share of Global Final Energy Consumption, 2009
Intermediate Conclusions

- Bioenergy fits well into traditional and industrial energy systems
- Biomass stores solar energy, but with low energy density
- Bioenergy production should be combined with the transfer of residues/wastes into nutrients for biomass production (based on solving environmental problems)

=> Biogas Technology is a solution of choice!!!

- The production of energy via energy crops is the most expensive way to produce renewable energy
- Land-use competition due to multipurpose role of biomass and scarce availability of arable land
WHAT IS THE FUTURE ROLE OF BIOENERGY – BIOGAS TECHNOLOGY?
The Future Role of Bioenergy

Energy Security
- Energy Storage
- Fluctuating Renewable Energy Sources
- Complementary Energy

Bioenergy
- Waste treatment and sanitation
- Nutrients Recycling

Food Security
- Biorefinery (Food and Materials Production)

Energy Security and Food Security overlap through Bioenergy.
Biorefineries will be created as utilisation cascades – the value first the residues for energy.

Based on: Gruber: Macromolecular Chemistry of Renewable Resources, 2001
Biorefineries always have value-added products and wastes for energy.
Food Processing is a Biorefinery

Power
Water
Feed

Porkers
Waste
Food Processing is a Biorefinery

Power

Water

Feed

Porkers

Fertilizer Gas

Waste Heat
Food Processing is a Biorefinery
Food Processing is a Biorefinery

- Rainwater
- Solar Energy
- Feed
- Waste
- Heat
- Fertilizer Gas
- Meat
- Waste
- Heat
- Rainwater
- Feed
- Waste
- Heat
Food Processing is a Biorefinery

Rainwater → Solar Energy → Waste → Fertilizer

Feed → Solar Energy → Waste → Heat

Waste → Heat

Vegetables

Gas

Meat
Waste Treatment and Sanitation
# Reasons for Biogas Production

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<td>Energy Production</td>
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Biogas Waste to Energy Systems

Small Scale

Waste-water-treament

Large Scale
Adding Value to Waste: Fuels and Recycling of Nutrients

Anaerobic fuel production from biomass residues and wastes generates:

• gaseous fuel for different purposes

• high value fertilizer as additional product
Biogas Repowering Goals

- Biogas plants have to be substrate invariant (Co-Fermentation)

- Biogas technology on the countryside has to be
  - decentralized and
  - directed to the respective situation
  - Simple* and robust

  And has to guaranty maximum methane yield per mass unit within shortest retention time

* Progress is the way from the primitive to the complex to the simple (W.v.Braun)
A conventional biogas plant is – from the chemical engineering point of view – a complex process plant, i.e. has to be designed and operated professional.

Affordable professional services in
- Engineering
- Maintenance
- Operation
Substrate Pre-Treatment

Grinding – Principle squeezing and cutting

Mixed with recycled sludge from fermenter and pumped back into the fermenter
Substrate Pre-Treatment

Rape- and wheat straw with or without mechanical and/or thermal pretreatment

The mechanical pretreatment with hammer mills accelerates the conversion process substantially and increase gas yield.

Further research with any kind of straw, MSW, wood, jetsam and other is under Development in the LSBEL framework.
Control

Quality control of feedstock:
Goals:
• Maximum energy content per mass unit in the product gases
• Homogeneity of the substrats over long time periods

Process control:
Goals:
• Maximum energy content per mass unit in the product gases
• Maximum space-time yield
• Stable Processes
Control Procedures

Process control:

Problem:
• Lack of efficient monitoring (LSBEL)
• No process model available
• Limited number of actuators

Future Solutions:

Models
• Fuzzy control
• Chemometric models
• ADM 1

Actuators
• Substrats
• Minerals
• Enzymes
• Starter cultures
Fermenter technology

Conditions in CSTR

- homogeneous distribution of all individual Components in the fermentation brewth
- and in the outlet L. Flow rate of each individual component* is product out of its concentration and the volumetric flow rate
  ⇒ Volume and volumetric flow have to adapted to biochemical reactiond and bakterial growth rates, i.e. long hydraulic retention times
  ⇒ conditions are equal for all mikroorganisms, i.e. suboptimal

*Components are micro organisms, substrates, intermediates and products
Fermenter technology

Adaption of fermenters to the predilections of the micro-organisms:

• Fermenter cascades
• Creating the possibility to build biofilms
• Combination of both
Fermenter Technology

• Biofilm building


ISET, 2007: FFF – Deployment of a fiber packed bed digester
Fermenter Technology

Fermenter cascades – adaption of process condition to particular optimal microbial conversion rate

<table>
<thead>
<tr>
<th>OLR [kg(oDM)/(m³*d)]</th>
<th>Feed [g/d]</th>
<th>Biogas Yield [m³/t(oDM)]</th>
<th>Spalte1 [L(G)/(L(F)*D)]</th>
<th>pH</th>
<th>Spalte2</th>
<th>Spalte3</th>
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<tr>
<td>2</td>
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<td>721</td>
<td>1,7</td>
<td>7,3</td>
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<td>54</td>
<td>725</td>
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<td>7,3</td>
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<td>81</td>
<td>701</td>
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<td>6,5</td>
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<td>135</td>
<td>100</td>
<td>1</td>
<td>6,1</td>
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</tbody>
</table>

OLR: Organic Loading Rate
oDM: Organic Dry Matter
Fermenter Technology - MABR

Combination of Cascades and Biofilms

- Multifunctional Anaerobic Baffled Reactor: n compartments with settling surface

- Option for inherent biorefinery and internal gas separation (LSBEL)

- Simple and robust container solutions

MABR

ABR installation at Culmore WWTW, Northern Ireland
Conclusions

1. Biogas technology has a lot of innovative potentials:
   ◦ Simplicity and robustness
   ◦ Maximize efficiency
   ◦ Substrat invariance

2. Promising technologies are already introduced in wastewater treatment, but have to be adapted to the prerequisites in agriculture (dry matter content, .
The Future Role of Bioenergy

Energy Security
- Energy Storage
- Fluctuating Renewable Energy Sources
- Complementary Energy

Food Security
- Biorefinery (Food and Materials Production)
- Waste treatment and sanitation
- Nutrients Recycling

Energy Security

Food Security
The County of Nordfriesland

167,279 Inhabitants; 2052 km²

Nordfriesland is the number 3 in Germany in the renewable electricity production to consumption ratio

228 %
## County of Nordfriesland

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>plants</th>
<th>Installed Capacity</th>
<th>Electricity Production 2012</th>
<th>Efficiency</th>
<th>Demand Ratio</th>
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<tbody>
<tr>
<td>Renewables</td>
<td>5,532</td>
<td>247 MWp</td>
<td>2,823,432 MWh/a</td>
<td>10.8 %</td>
<td>18.8 %</td>
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<tr>
<td>Solar Power</td>
<td>587</td>
<td>887 MWp</td>
<td>232,721 MWh/a</td>
<td>10.8 %</td>
<td>18.8 %</td>
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<tr>
<td>Wind Power</td>
<td>178</td>
<td>66 MWp</td>
<td>2,149,922 MWh/a</td>
<td>27.7 %</td>
<td>173.7 %</td>
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<tr>
<td>Biomass</td>
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<td>440,787 MWh/a</td>
<td>76.2 %</td>
<td>35.6 %</td>
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<tr>
<td>Demand</td>
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<td>1,237,864 MWh/a</td>
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</table>

Based on Energymap.info, read 01.02.2013
Complementing the Fluctuating Renewable Energy sources

The five fold amount of electricity from wind or solar energy compared to the electricity produced by the biogas plant may redirected into the gas grid.

The gas grid capacities are much more elastic (4000 fold) than the power grid

(Project within the LSBEL framework)
Conclusions

• Biogas has to be integrated into application contexts
• Biogas offers additional nutrient recycling options
• Biogas offers storage and balance of energy supply to demand relations
• Biogas is a source primarily for decentralized utilisation