Design and Construction of Biogas Plants Worldwide

Torsten Fischer and Dr Katharina Backes

Krieg & Fischer Ingenieure GmbH
Bertha-von-Suttner-Straße 9, D-37085 Göttingen, Germany
Tel.: ++49 551 900 363-0, Fax: ++49 551 900 363-29
Fischer@KriegFischer.de
www.KriegFischer.de

National Dong Hwa University, Taiwan
December 4, 2017
Content

- Introduction
- Reference projects
- Usable substrates
- Pretreatment of substrate
- Different types of digester
- Use of biogas (CHP, biogas upgrading)
- Safety and health risks
- Use of digestate
Krieg & Fischer Ingenieure GmbH

Engineering Office, specialized in Design and Engineering of Biogas Plants

Foundation: 1999

Team: 20

Experience: > 30 Years

References: ca. 150 Biogas Plants

in: Germany, Japan, Netherlands, Austria, Switzerland, Lithuania, Italy, Slovakia, Canada, USA, Spain, France, Ireland, Russia, India, China and Argentina

Partner in: Japan, Canada, Bulgaria, France, Poland, Italy, Spain, Serbia, Greece and China
Service offerings of Krieg & Fischer in the field of Biogas

- Studies
- Concept Development
- Calculations
- Permits & Approvals
- Engineering
- Tendering and Commissioning
- Supervision of Construction
- Start-up
- Optimization/Retrofits
- Supervision and Consulting
Biogas Plant Todendorf, Germany

The heat produced in cogeneration is used in the farm
Biogas Plant Todendorf, Germany

Todendorf with 20,000 pigs, belongs to the biggest pig farms in Germany
In the biogas plant pig manure is digested together with grass silage
Biogas Plant Todendorf, Germany

- Built: 2002/2003
- Substrate: Pig manure, grass silage
- Digester: 2,400 m³ Steel tanks
- CHP: 2 x 180 kW$_e$ dual fuel engine
- Digester, secondary digester with gas holder roof
- Heat utilization in the pig farm
In Todendorf the produced biogas is used in two dual fuel engines with 180 kW_{el} each. The produced electricity is fed to the public grid. The heat produced in cogeneration is used in the farm.
Biogas concept

- Pasteurisation
- Gas Engine
- Gas Holder
- Reception / Buffer
- Digester
- Storage
Biogas concept

Carbohydrates, Fats, Proteins

Hydrolyses

Acidification

H₂, CO₂, Org. Acids, Acetic Acid, Alcohols

Acetogenic Phase

Acetic Acid

Methanogenic Phase

Methane
Development of Biogas in Germany

[Graph showing the development of biogas plants and installed electric capacity in Germany from 1992 to 2017, with a forecast for 2018.]

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Renewable energy share in gross final energy consumption and gross electricity consumption*

Source: http://www.umweltbundesamt.de/en/indicator-renewable-energy#textpart-1

* Gross final energy consumption calculated according to Energy Concept; values for 2016 preliminary
** Source targets: Energy Concept 2010 and EEG 2016; additional targets: share of gross electricity consumption 2025:
55: 60 %, 2040: 65 %, 2050: 80 %; share of gross final energy consumption 2040: 45 %, 2050: 60 %

Source: German Environment Agency on the basis of Working Group on Renewable Energy Statistics (AGEE-Stat), as of 08/2017
Development of renewables-based electricity generation in Germany

Source: https://www.bmwi.de/Redaktion/EN/Dossier/renewable-energy.html
Gross electricity generation in Germany in 2016 in TWh

Source: https://www.bmwi.de/Redaktion/EN/Dossier/renewable-energy.html
### Biogas Sector Statistics in Germany at a Glance
(as of 10/2017)

<table>
<thead>
<tr>
<th></th>
<th>2016*</th>
<th>Forecast 2017**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of biogas plants (biogas plants with biomethane injection)</td>
<td>9,209 (193)</td>
<td>9,346 (197)</td>
</tr>
<tr>
<td>Installed electric capacity in MW</td>
<td>4,237</td>
<td>4,497</td>
</tr>
<tr>
<td>Gross electricity production in TWh per year</td>
<td>32.8</td>
<td>33.0</td>
</tr>
<tr>
<td>Households supplied with biogas-based electricity in millions</td>
<td>9.4</td>
<td>9.4</td>
</tr>
<tr>
<td>CO$_2$ reduction by biogas in million tonnes</td>
<td>19.8</td>
<td>19.9</td>
</tr>
<tr>
<td>Turnover in Germany in Euro</td>
<td>9.4 Billion</td>
<td>9.4 Billion</td>
</tr>
<tr>
<td>Jobs in the biogas sector</td>
<td>46,000</td>
<td>46,000</td>
</tr>
</tbody>
</table>

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* Own extrapolation based on country data / plant register BNetzA
** Based on a expert survey / plant register BNetzA
Daily production and consumption

Biomass as a base load

Daily power production and consumption
Biomass as a peak load

Solar power covers peak demand at lunchtime

Export or storage of oversupply

Power generation from wind energy fluctuates strongly

- Export
- Power consumption
- Hydropower
- Wind energy
- Solar energy
- Bio energy

http://www.biopower2gas.de/
Flexibilization of electricity production

https://www.unendlich-viel-energie.de/media/image/1299.AEE_Flexibilisierung_einer_Biogasanlage_72dpi.jpg
Flexibilization of electricity production

Gasholder with additional storage capacity

Biogas

Additional CHP

CHP

Heat storage

Heat usage

Electricity fed to the power grid in times of high energy demand

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- Introduction
- **Reference projects**
- Usable substrates
- Pretreatment of substrate
- Different types of digester
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- Safety and health risks
- Use of digestate
References worldwide

Prince Edward Island

Cudworth Pork

Inland Empire

Bekkai

Montargull

Noyon

Fairyland

Prato
Biogas Plant Britany, France

- Built: 2012
- Substrate: Pig manure, sewage sludge, fats, food residuals
- Digester: 2 x 1,100 m³ concrete tanks
- CHP: 400 kW$_e$ gas engine
- Two digester and secondary digester with gas holder roof
- Digestate treatment with separation, heat utilization
Im Brahm, Germany

Heat utilization

- Built: 2005
- Substrate: kitchen waste, pig manure, horse dung
- Digester: 2 x 1,205 m³ concrete tank
- CHP: 4 x 190 kWₐ gas engine
- Mesophilic process, engineering with hydrolysis
Rio Cuarto, Argentina

- Build: 2013/14
- Substrate: cattle manure, corn silage
- Digester: 4,600 m$^3$ steel tank
- CHP: 1.2 MW$_e$
- Digester, secondary digester, thermophilic
- First biogas plant using energy crops in Argentina
Werlte, Germany

- Built: 2002
- Substrate:
  - manure 90,000 m³/a, fats 20,000 m³/a
- digester 2 x 3,200 m³ steel tank
- CHP: 2 x 1,3 MWₑ gas engine
- Gasholder above secondary digester, heat usage; gas conditioning of 500 m³/h
Wiesenau, Germany

- Built: 2007
- Input: cattle manure, cattle dung, corn-, grasssilage
- Digester: 4.300 m³ concrete
- CHP: 2 x 526 kW<sub>e</sub> gas engine
- Gasholder above secondary digester
Prince Edward Island, Canada

- Built: 2008
- Substrate: potato residues, oil, potato starch
- Digester: 4 x 5,500 m³, steel tank
- Size: 12 MW_{th}
- 2 stage digestion with hydrolysis, 2 secondary digesters with gas holder roof
- Biogas is used for heating purposes – hot water production
Dinteloord, The Netherlands

- Build: 2011
- Substrate: sugar beet ends, sugar beet leafs, sugar beet, vegetable waste 114,000 t/a
- Digester: 4 x 4,480 m³ steel tank
- Upgrading of 1,750 m³/h biogas to 990 m³/h methane
- Gas holder above secondary digester
- Treatment of digestate with decanter
Saskatoon, Saskatchewan, Canada

- 40° C Ambient Temperature

- Built: 2003
- Substrate: pig manure, potatoes
- Digester: 2,000 m³, steel tank
- CHP: 4 x 30 kW_e microgasturbines
- Designed for low outside temperature; special design: gas holder in a tank (left tank); special building material for gas holder roof and insulation
Chino, California, USA

Seismic Zone IV

- Input: cattle manure (270 t/a, DM 12%), liquid waste from food industry (83 t/a) food waste
- Sediment removal from the digester
- Gas distribution in a biogas grid (~19,000 m³/d)
- Power generation capacity: 1,500 kWₑ
- Construction costs: $ 5 million
Projects in China (2009 – 2017)
中国的项目

- Reference biogas plants
  工程服务 (K&F)
- Studies, planning, consultancy
  GFA, GIZ
  与GIZ的咨询服务项目
- Biogas plant under construction
  在建沼气厂
Qinhuangdao, China

- Built: 2014
- Input: kitchen waste
- Hydrolyses tank 530 m³
- Digester: 2 x 3,400 m³ carbon steel tank
- Upgrading of biogas
- External gasholder
- Pretreatment (hammer mill, hydro-cyclone)
Projects in Japan 2000 – 2017

- Reference biogas plants
- Studies, preplanning
- Under construction
Daisen, Japan

- Build: 2013/14
- Substrate: pig manure, fats, sewage sludge, industrial food waste
- Digester: 5,000 m³ enameled steel tank
- CHP: 3 x 370 kW$_{el}$
- primary digester, secondary digester, mesophilic operation
- Extension and integration of an existing biogas plant
Fukuoka, Japan 福岡

- 建设时间: 2016-17
  Built: 2016-17
- 进料: 餐厨垃圾, 工业食品垃圾
  Substrate: Kitchen waste, industrial food waste
- 发酵罐: 2 x 5,000 m³
  Digester: enameled steel tank 2 x 5,000 m²
- CHP: 2 x 1,056 kWₑ
- 中温发酵
  Mesophilic process
Content

• Introduction
• Reference projects
• **Input Substrates**
  • Pretreatment of substrate
  • Different types of digester
  • Use of biogas (CHP, biogas upgrading)
• Safety and health risks
• Use of digestate
Agricultural substrates

- Manure, dung from cattle, pig, poultry etc.

- Agricultural wastes as sugar beet pulps, straw, green cut, crop residues, food remains

- Energy crops as corn silage, whole plant silage, or grass silage
Industrial waste

- food producing
- juice production as pomace
- slaughterhouse waste
- distilleries, breweries…
- sugar industry
- potato industry
Bio-waste and kitchen waste

- Source separated bio-waste from households

- Kitchen waste (separate collected waste from canteens kitchens or restaurants)
Biodegradable municipal waste (BMW) in Germany
## Biogas Production

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
<th>TS</th>
<th>VS</th>
<th>l/kgVS</th>
<th>m³ Biogas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Silage</td>
<td>1 Mg</td>
<td>30%</td>
<td>94%</td>
<td>700</td>
<td>197</td>
</tr>
<tr>
<td>Wheat Silage</td>
<td>1 Mg</td>
<td>30%</td>
<td>90%</td>
<td>600</td>
<td>162</td>
</tr>
<tr>
<td>Grass Silage</td>
<td>1 Mg</td>
<td>30%</td>
<td>89%</td>
<td>550</td>
<td>145</td>
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<tr>
<td>Cattle Manure</td>
<td>1 Mg</td>
<td>8%</td>
<td>80%</td>
<td>200/500</td>
<td>13/32</td>
</tr>
<tr>
<td>Pig Manure</td>
<td>1 Mg</td>
<td>6%</td>
<td>75%</td>
<td>350/500</td>
<td>16/23</td>
</tr>
<tr>
<td>Poultry Manure</td>
<td>1 Mg</td>
<td>24%</td>
<td>85%</td>
<td>300/550</td>
<td>61/112</td>
</tr>
<tr>
<td>Kitchen Waste</td>
<td>1 Mg</td>
<td>20%</td>
<td>90%</td>
<td>700</td>
<td>126</td>
</tr>
<tr>
<td>Potato Residues</td>
<td>1 Mg</td>
<td>20%</td>
<td>95%</td>
<td>620</td>
<td>118</td>
</tr>
<tr>
<td>Fats</td>
<td>1 Mg</td>
<td>25%</td>
<td>95%</td>
<td>1,000</td>
<td>238</td>
</tr>
</tbody>
</table>
Examples of possible substrates

- Biodegradable municipal waste
- Potato pieces
- Potato waste
- Agricultural waste
- Waste banana
- Distillers wash
- Grape pulp
- Slaughterhouse waste
- Old bread
- Municipal organic waste
- Slaughterhouse waste
- Waste french fries
- Potato pieces
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Sustainable substance flow (Europe)

http://ecobine.de/indexc.php?SESSID=&id=3.5.2.4&kurs=9&l=en
Linear substance flow

http://ecobine.de/indexc.php?SESSID=&id=3.5.2.4&kurs=9&l=en
Pre-treatment

Input quality

Pre-treatment

Output requirements

What is the aim ???
Pre-treatment

“clean“ waste

minor preprocessing (shredding if necessary)

digester

contaminated waste

pretreatment
removal of big contaminants
shredding
removal of Fe
removal of non-Fe
removal of grit
conditioning
removal of light contaminants

digester
Selection Pretreatment Technology

Depends on:

- Kind of Substrate
  - Dry matter content
  - Amount of contaminants
  - Content volatile solids
  - Particle size
  - Seasonal variation
- Location
- Logistic
- Use of digestate
Pre-treatment

pulper
Pre-treatment

Cross flow shredder
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Biogas concept with upright digester

**Substrate**
- manure
- organic waste
- energy crops

**Gas utilization**
- CHP (power, heat)
- direct use (heating, cooking, light)
- upgrading (gas grid fuel, fuel cell)

**Input device**
- piston pump, screw etc. (solids)
- pump (fluids)

**Storage Tank**
- Biogas

**Upright digester**
- mixer

**Secondary digester**
- mixer
- Heat exchanger

**Digested substrate**
- storage and use as fertilizer
- treatment
Tall Digester, Top Mounted Mixer

Operation Top Mounted Mixer
- Permanent=24 h/d
- 13-18 rev/m
- 3.6 – 30 KW
- Frequency inverter for low energy consumption
Top mounted mixer
Falkenstein, Germany

- Built 2008
- Substrate: Energy crops only
- Two digesters: 3,100 m³ each
- Two CHP: 726 kWₑ each
- Gas holder above secondary digester, thermophilic, heat usage
Wietzendorf, Germany

- Built: 2000-2002
- Substrate: waste water of starch production (potato-starch) potato residues
- 4 digester, 2,500 m³ each, secondary digester with gas holder roof
- CHP: 4 x 2,1 MWₑ gas engine
- Protein recovery, reverse osmosis, retention of biomass through decanter
Biogas concept with flat digester

**Substrate**
- manure
- organic waste
- energy crops

**Input device**
- piston pump, screw etc. (solids)
- pump (fluids)

**Storage Tank**

**Digester**

**Pump**

**Secondary digester**

**Biogas**

**Gas utilization**
- CHP (power, heat)
- direct use (heating, cooking, light)
- upgrading (gas grid fuel, fuel cell)

**Digested substrate**
- storage and use as fertilizer
- treatment
Improved standardized agricultural digester
Flat digester, submerged mixer
Im Brahm, Germany

• 建设时间: 2005
• 进料: 餐厨垃圾, 猪粪, 牛粪
• 厌氧发酵罐: 2 x 1,205 m³, 混凝土罐体
• 热电联产: 4 x 190 kW_{e} 燃气发电机
• 中温发酵, 工艺中包含酸化罐
Montargull, Spain

+ 40° C
Ambient Temperature

- Built 2007
- Input: pig manure, FOG, slaughterhouse waste water sludge
- Digester (2.080 m³) and secondary digester with gas holder roof
- Special gas cooling system adopted to high ambient temperature
- CHP: 364 kWe gas engine
- Invest 820,000 €
Biogas concept with a horizontal digester

Substrate
- manure
- organic waste
- energy crops

Input device
- piston pump, screw etc. (solids)

Gas utilization
- CHP (power, heat)
- direct use (heating, cooking, light)
- upgrading (gas grid fuel, fuel cell)

Digester
- stirrer paddle

Storage Tank

Pump

Secondary digester
- mixer

Biogas

Digested substrate
- storage and use as fertilizer
- treatment
Stirring and mixing technology

Horizontal digester
Referenz liegender Fermenter
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• **Use of biogas (CHP, biogas upgrading)**
• Safety and health risks
• Use of digestate
Biogas concepts

Local usage

Transport of biogas

Transmission of biomethane

Biomethane feeding-in
Introduction CHP
Combined heat and power plant

- Flap
- Air inlet
- Stack
- Gas detector
- Gas train
- Machine room
- Electric control cabinets
- Oil station
- Engine and generator
- Battery
Sugar industry
Anklam, Germany

Biogas upgrading system
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• **Safety and health risks**
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Characteristics of biogas

- Methane CH₄: 45-70 %
- Carbon dioxide CO₂: 25-55 %
- Hydrosulphide H₂S: 10-30,000 ppmv
- Water vapour: 100 %
- Heating value: 4.5-7 kWh/m³

- Ignition temperature: 537° C (methane 595° - 650° C)
- Explosion range: ca. (4.4) 5 – 15 (16.5) Vol%
- Density: 0.96 – 1.46 kg/m³
- Ignition energy (methane): 0.28 mJ
Health risk of methane CH$_4$

- Not toxic
- Extremely flammable
- Danger of ignition and fire or explosion (explosive mixtures with air between 5–15%)
- Greenhouse gas
Explosion

Oxigen / Air

Ignition source

Methane / Biogas
Safety
Lower and Upper Explosive Limit

Explosion area:
Exceeding of 11.6 Vol% oxygen and between 4.4 Vol% methane (100% LEL) and 16.5 Vol% methane (100% UEL)

Source: after Tabarasan / Rettenberger – UBA Forschungsbericht 12/1982, Nr. 1030227 Teil 1

Start-up new digester
Safety
Blower, explosion protection
Danger caused by fire

Fire test of a single membrane gas holder roof

The membrane is burned through and biogas is set free and is burning.

Source: German Biogas Association, M001: Brandschutz bei Biogasanlagen, Aug 2010
Health risk of H₂S

- **10–20 ppm** is the borderline concentration for eye irritation.

- At **100–150 ppm** the olfactory nerve is paralyzed after a few inhalations, and the sense of smell disappears, often together with awareness of danger.

- **320–530 ppm** leads to pulmonary edema with the possibility of death.

- **800 ppm** is the lethal concentration for 50% of humans for 5 minutes exposure (LC50).

- Concentrations over **1000 ppm** cause immediate collapse with loss of breathing, even after inhalation of a single breath.
Health risk of CO$_2$

- Carbon dioxide extinguishes flames
- Danger of suffocation: displacement of air in cellar room inspection pits

Main symptoms of Carbon dioxide toxicity

- **Visual**
  - Dimmed sight

- **Auditory**
  - Reduced hearing

- **Central**
  - Drowsiness
  - Mild narcosis
  - Dizziness
  - Confusion
  - Headache
  - Unconsciousness

- **Respiratory**
  - Shortness of breath

- **Muscular**
  - Tremor

- **Skin**
  - Sweating

- **Heart**
  - Increased heart rate and blood pressure

Source: Freiwillige Feuerwehr Hatzendorf
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Digestate

before

after
Use of digestate

- Use as liquid fertilizer and spread on land. Digestate is a valuable fertilizer and replace mineral fertilizer that has to be produced with high energy demand.

- Treatment
  - Separator
    - solid digestate → composting (solid fertilizer)
    - fluid digestate
      - use as process water
      - further treatment (reverse osmosis, ultra filtration)
Treatment of digestate
Separator
Solid fertilizer from BMW in Germany

• Solid fertilizer from BMW (Göttingen)
Treatment of digestate
Drum dryer
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Krieg & Fischer Ingenieure GmbH
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Tel.: ++49 551 900 363-0, Fax: ++49 551 900 363-29
Fischer@KriegFischer.de
www.KriegFischer.de

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