Design and Construction of Biogas Plants Worldwide

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National Dong Hwa University, Taiwan
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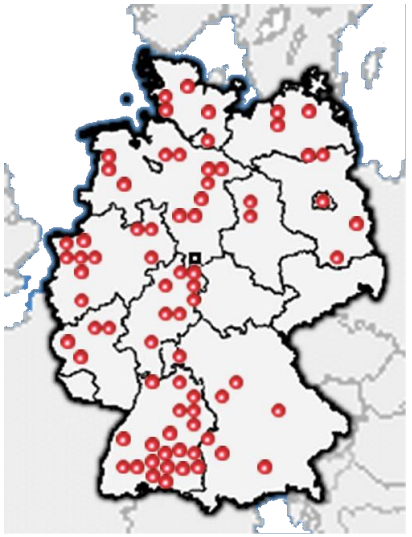
Content

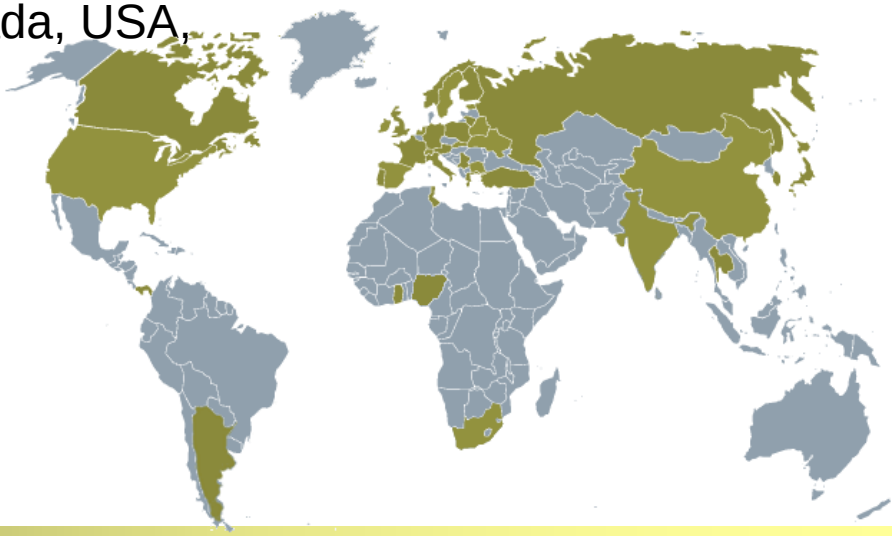
- **Introduction**
- Reference projects
- Usable substrates
- Pretreatment of substrate
- Different types of digester
- Use of biogas (CHP, biogas upgrading)
- Safety and health risks
- Use of digestate

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





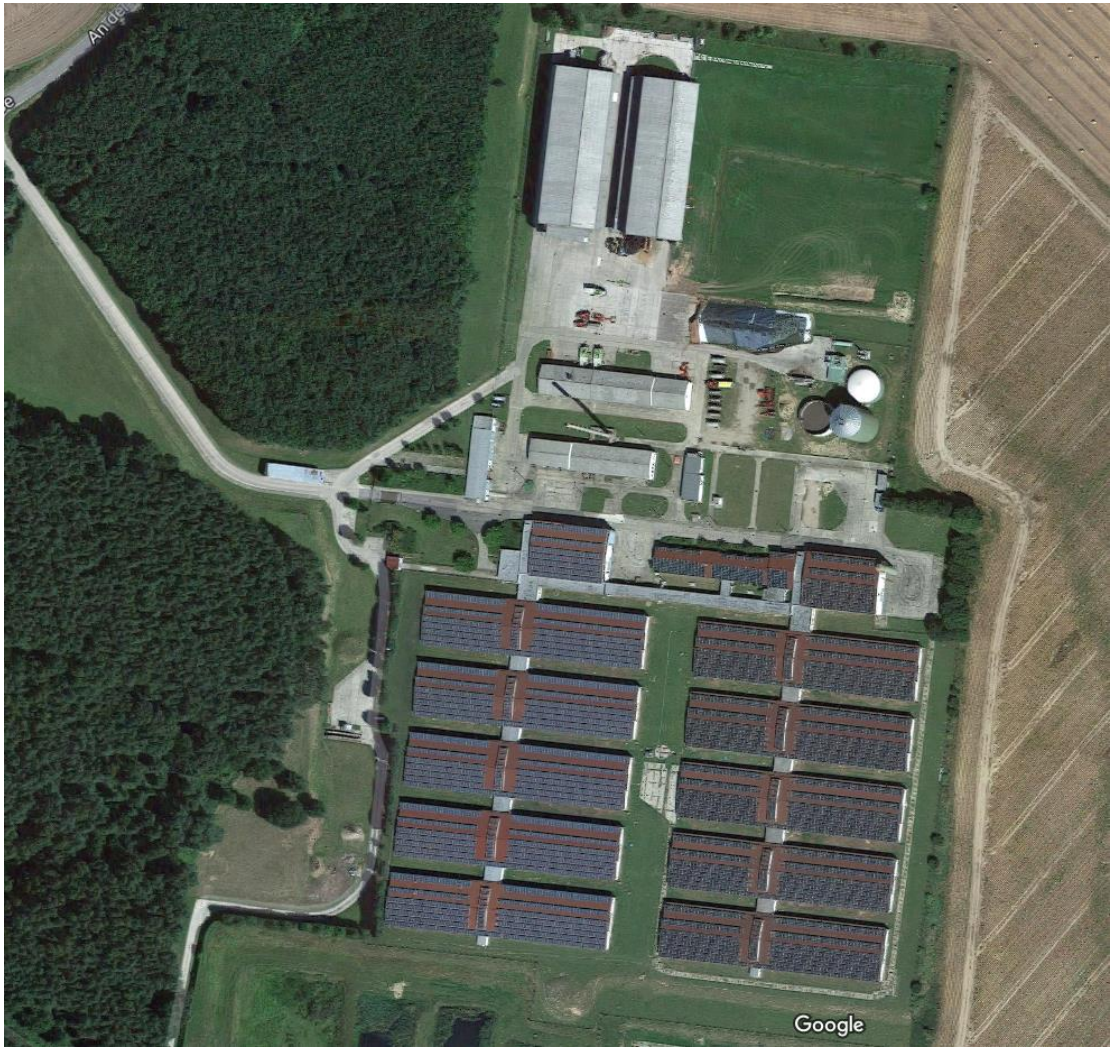
Service offerings of Krieg & Fischer in the field of Biogas

- 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

Biogas Plant Todendorf, 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

Biogas Plant Todendorf, Germany

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Biogas

CHP

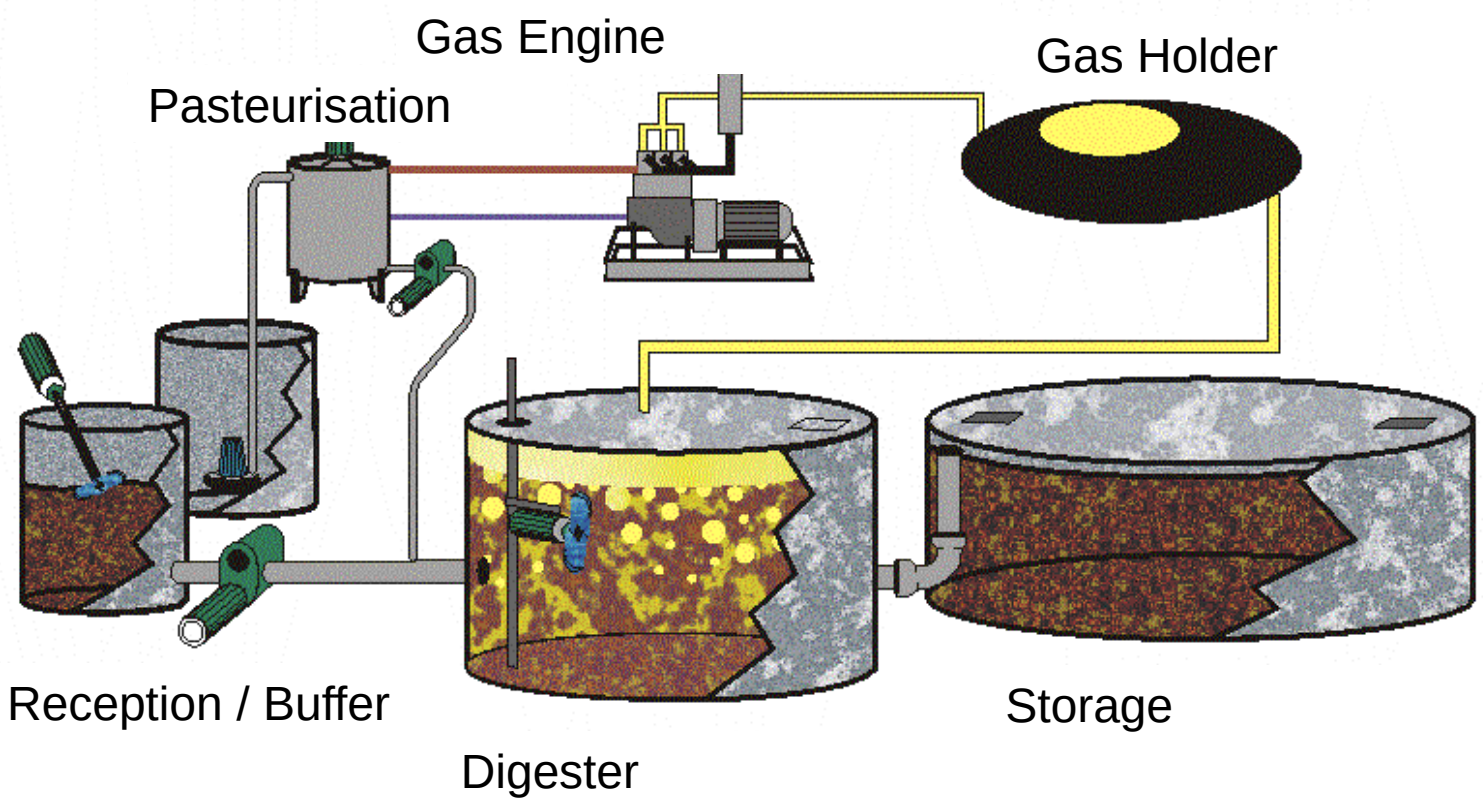
Electricity
Heat

The produced electricity is fed to the public grid.

The heat produced in cogeneration is used in the farm.

In Todendorf the produced biogas is used in two dual fuel engines with 180 kW_{el} each.

Biogas concept



Biogas concept

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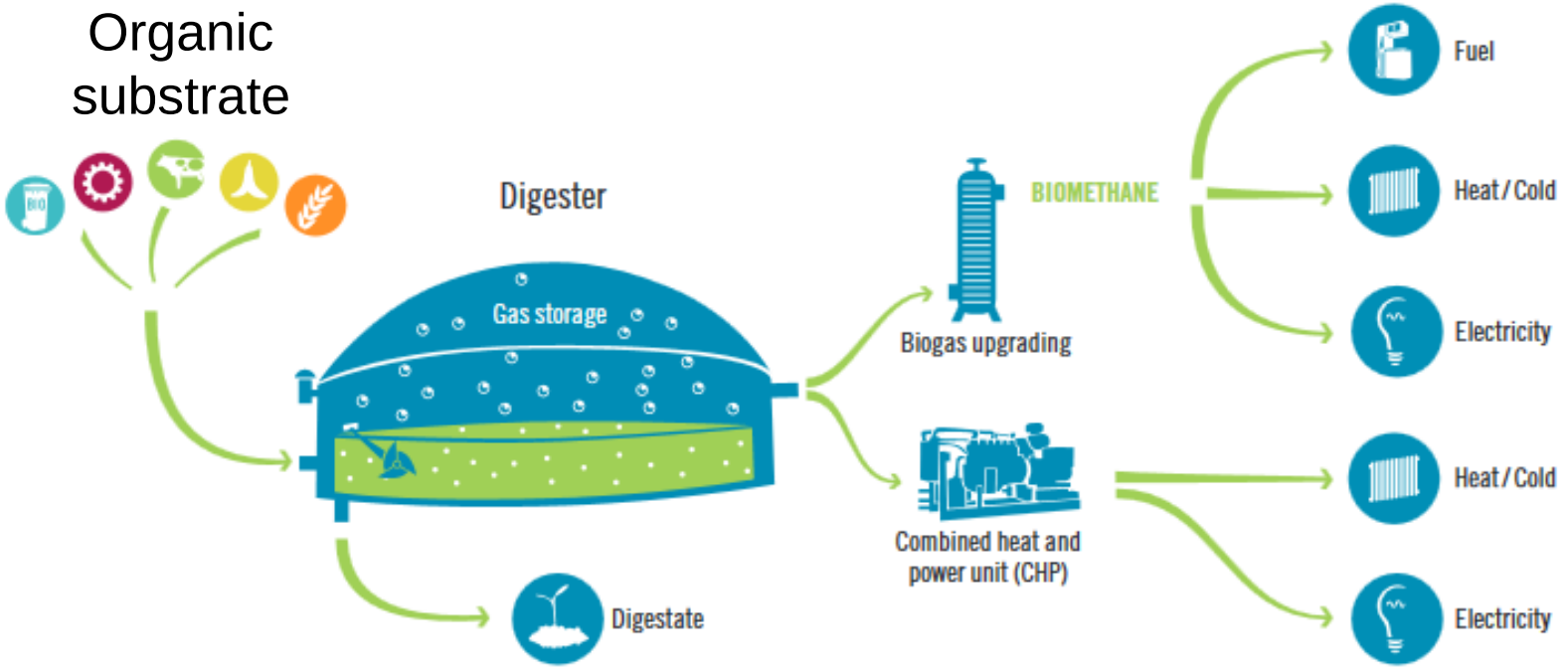
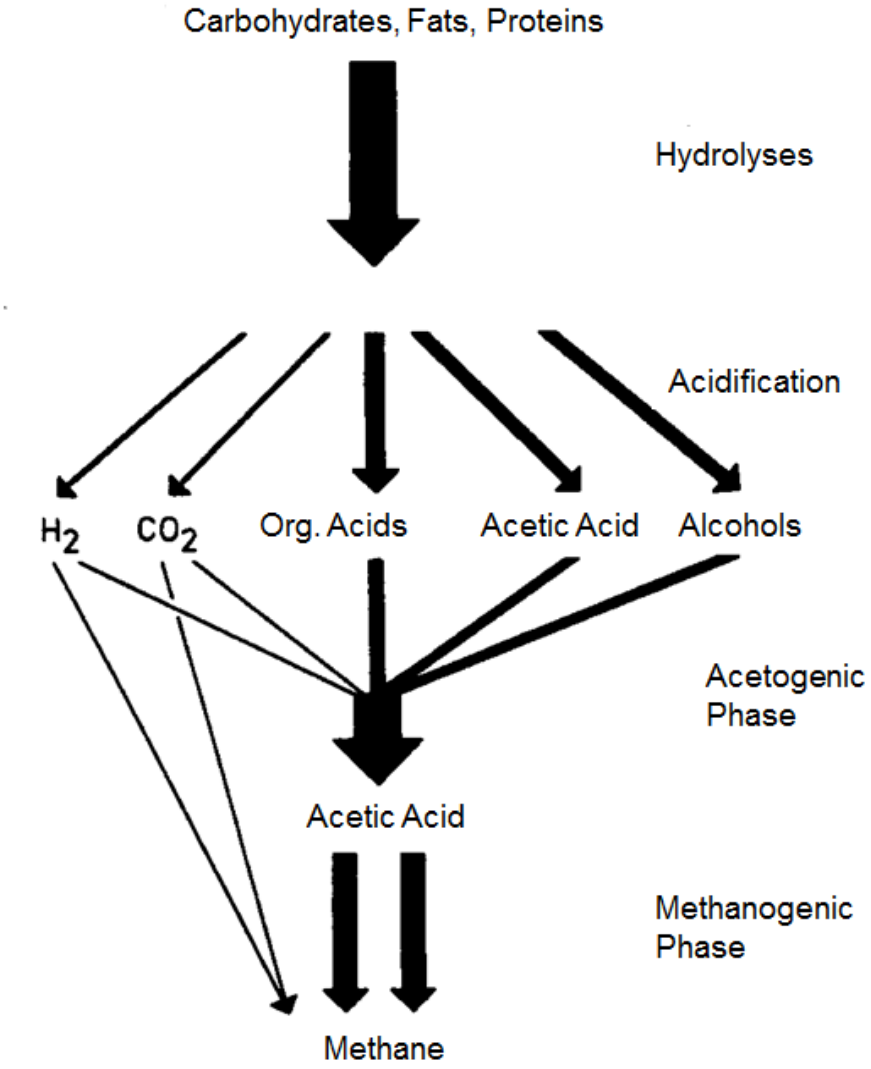
Energy

Organic substrate



Source: Fachverband Biogas: http://www.biogas-to-biomethane.com/Download/BTB.pdf


Carbohydrates, Fats, Proteins
Hydrolyses
Acidification
H_2
CO_2
Org. Acids
Acetic Acid
Alcohols
Acetogenic Phase
Acetic Acid
Methanogenic Phase
Methane

Development of Biogas in Germany

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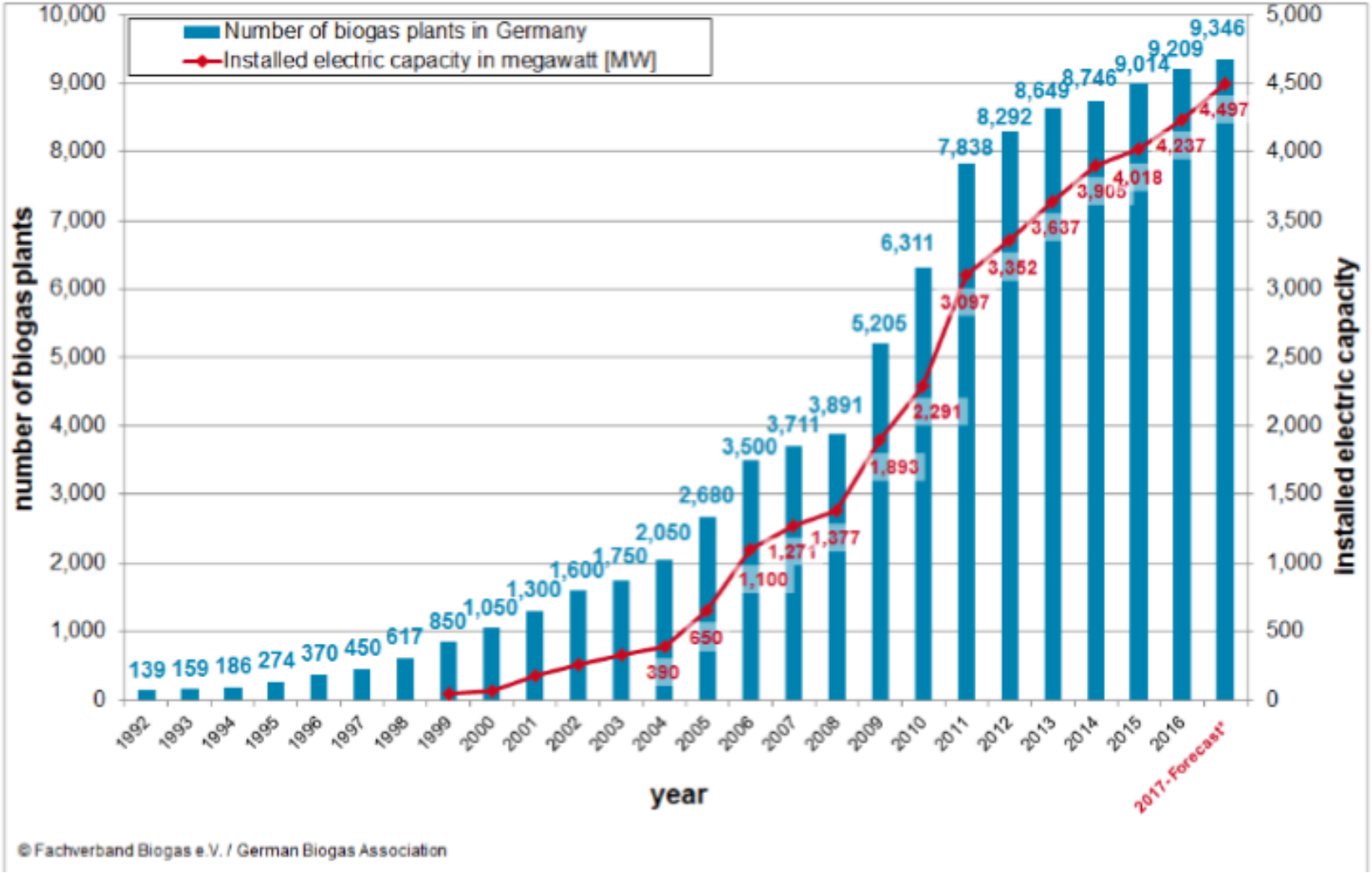
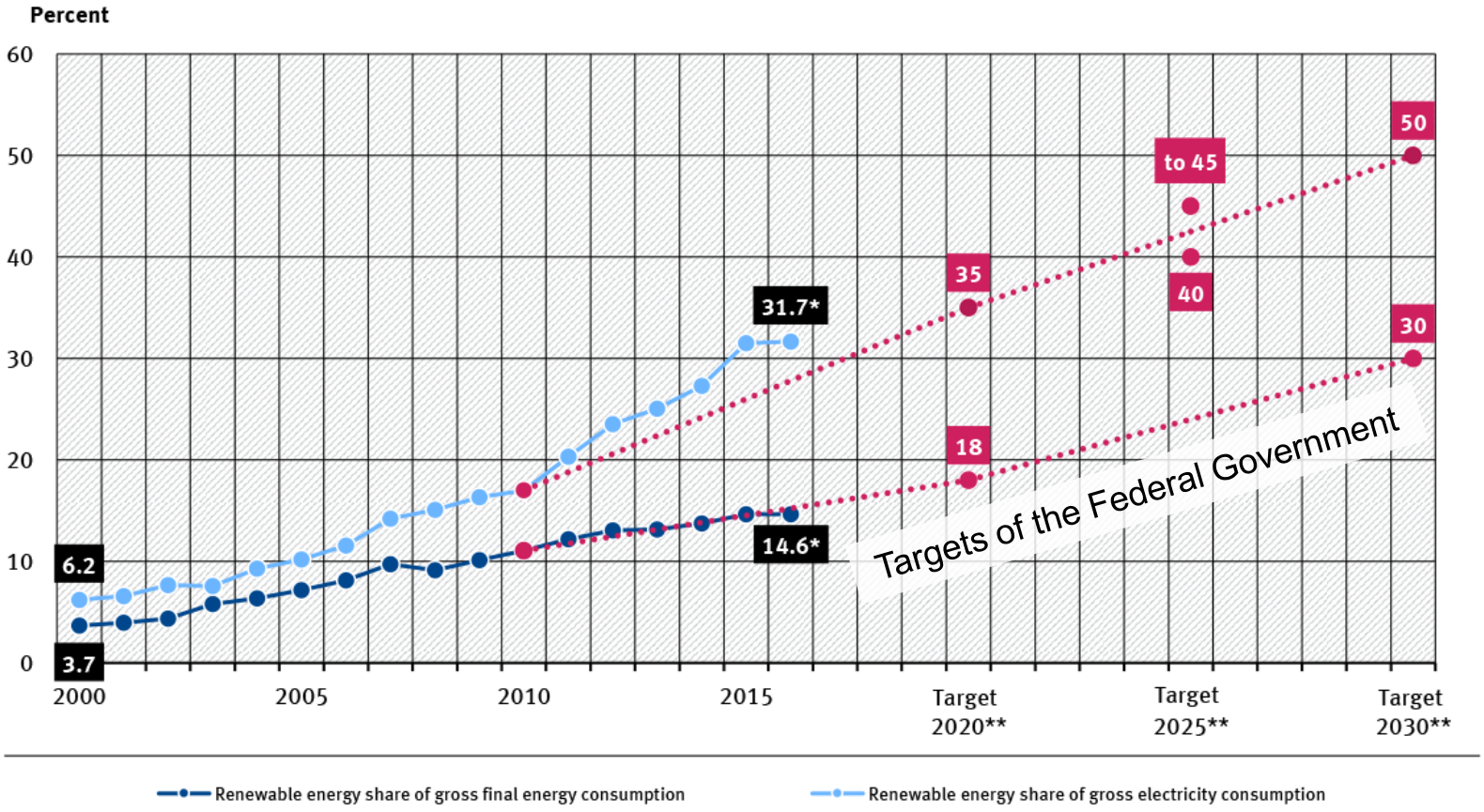


Renewable energy share in gross final energy consumption and gross electricity consumption*



* Gross final energy consumption calculated according to Energy Concept; values for 2016 preliminary
** Source targets: Energy Concept 2010 and EEG 2014; additional targets: share of gross electricity consumption 2035: 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

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

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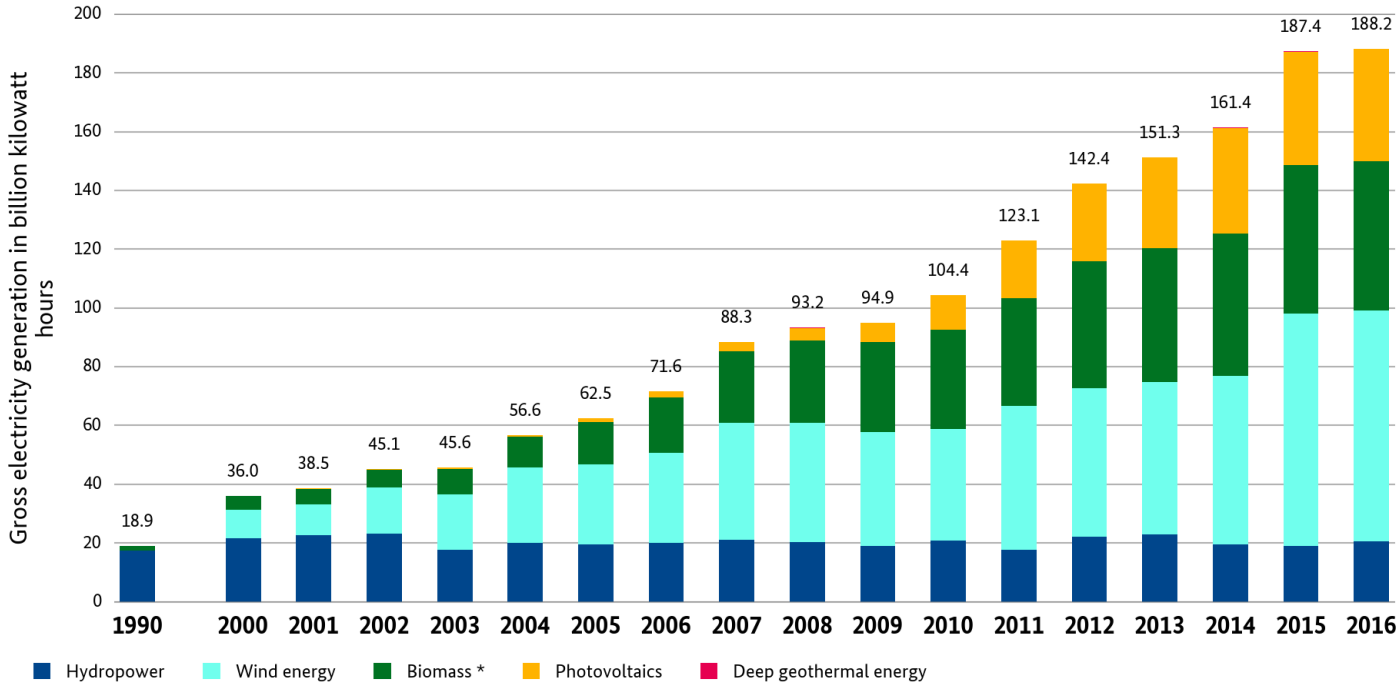
Federal Ministry
for Economic Affairs
and Energy

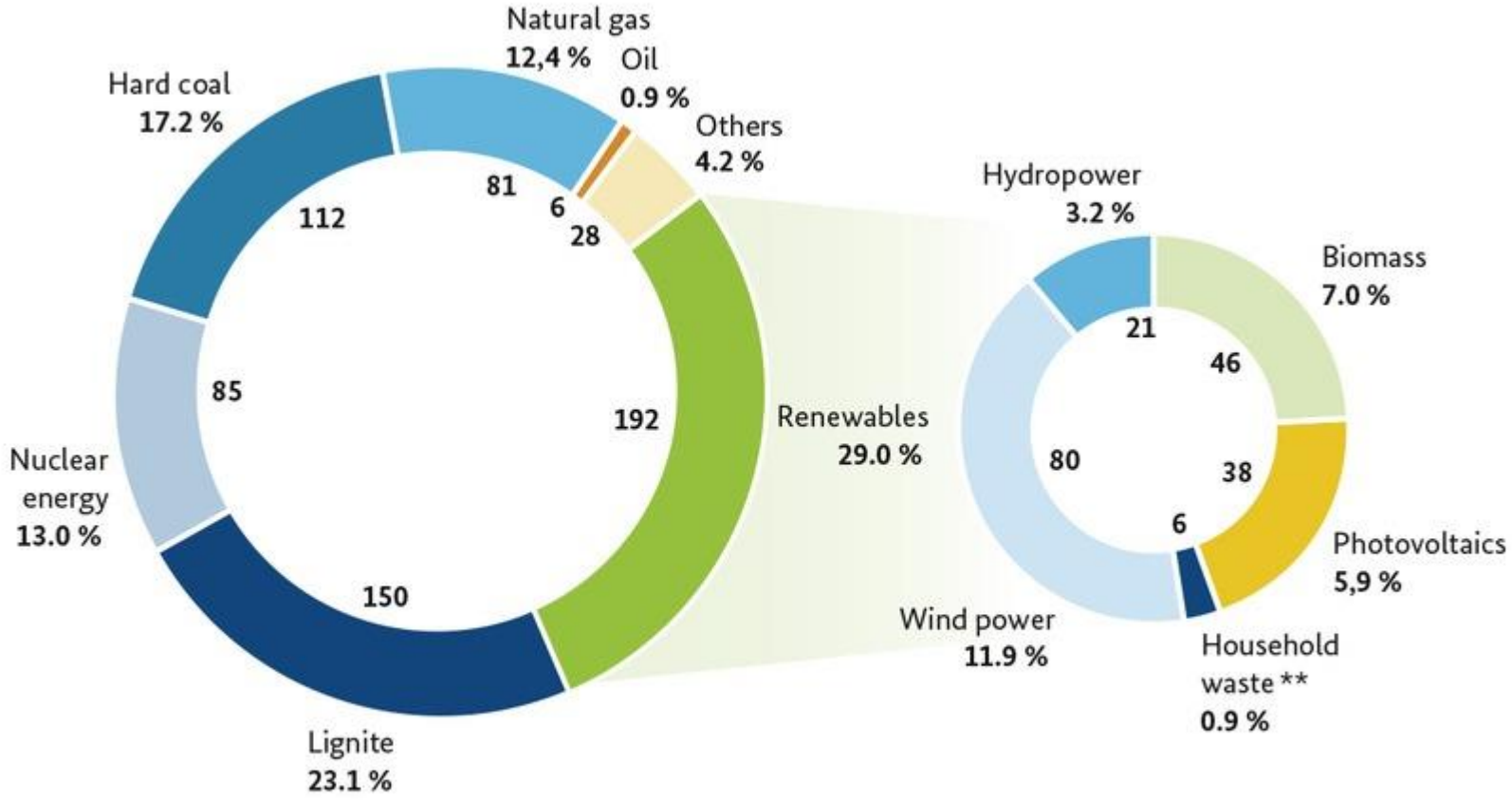
AGEE Stat
Arbeitsgruppe Erneuerbare Energien - Statistik

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

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Biogas Sector Statistics in Germany at a Glance

(as of 10/2017)

	2016*	Forecast 2017**
Number of biogas plants (biogas plants with biomethane injection)	9,209 (193)	9,346 (197)
Installed electric capcity in MW	4,237	4,497
Gross electricity production in TWh per year	32.8	33.0
Households supplied with biogas-based electricity in millions	9.4	9.4
CO_2 reduction by biogas in million tonnes	19.8	19.9
Turnover in Germany in Euro	9.4 Billion	9.4 Billion
Jobs in the biogas sector	46,000	46,000

* 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

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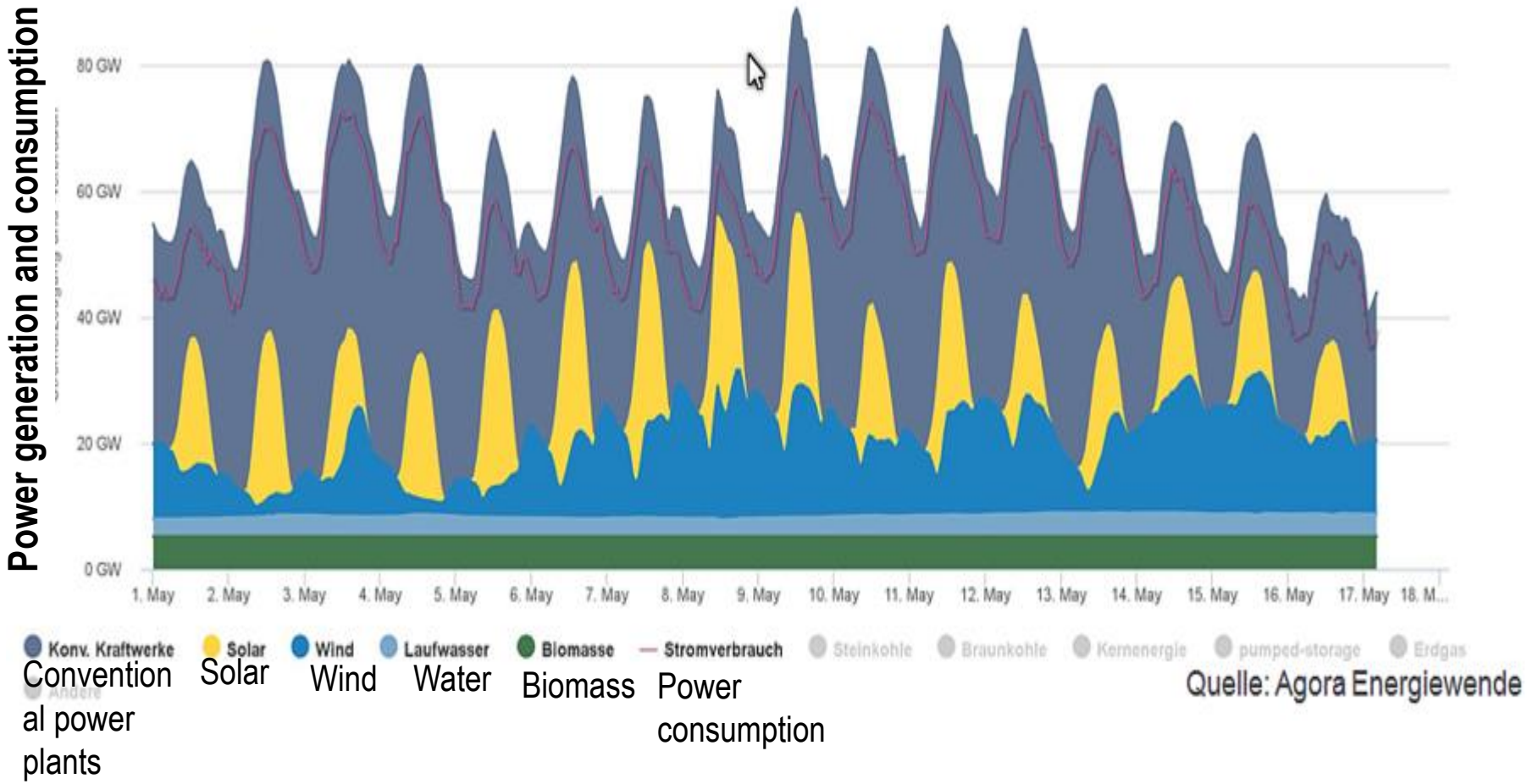


Conventional power plants

Solar

Wind

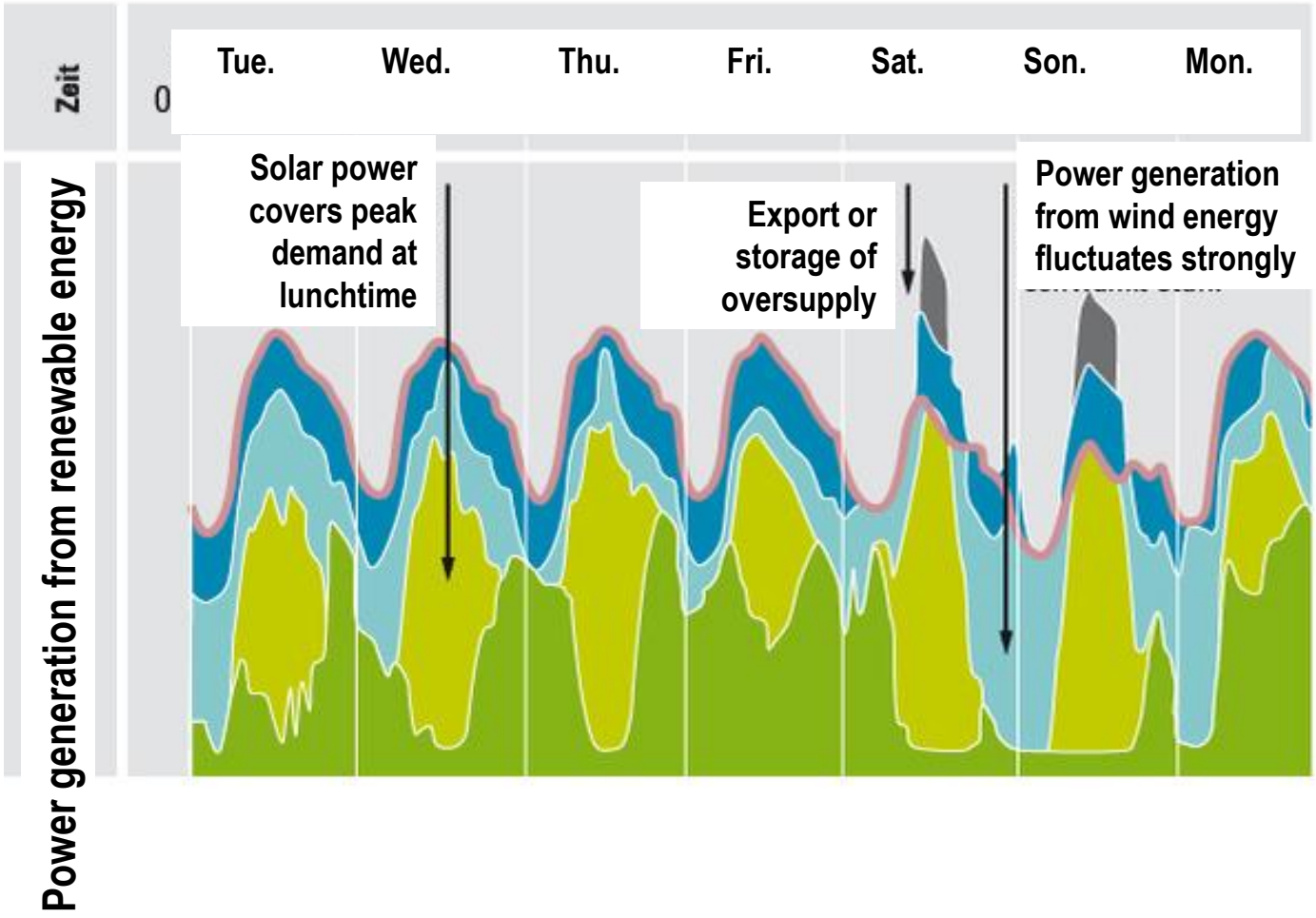
Water

Biomass

Power consumption

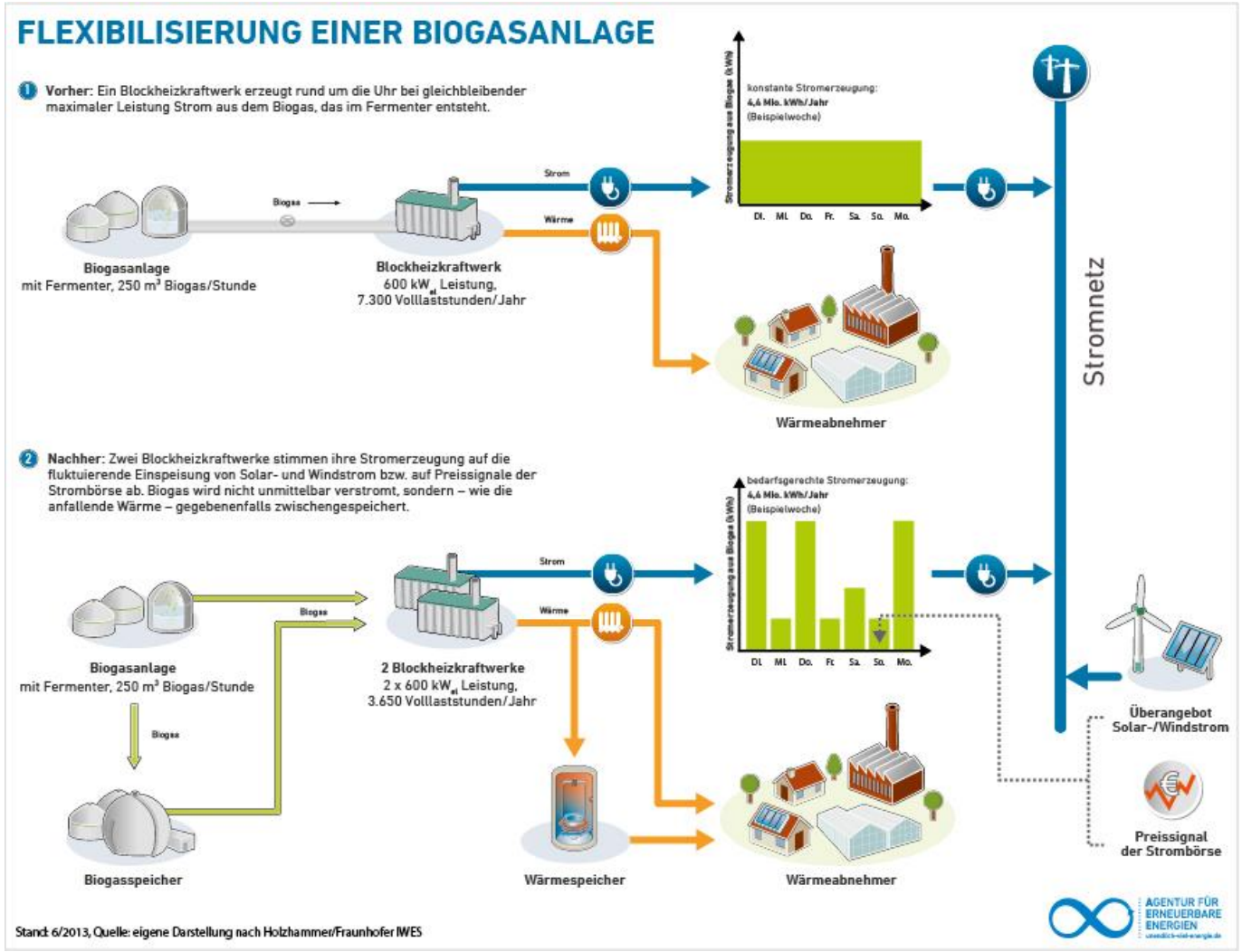
Source: https://kwk-flexperten.net/index.php?energiewende-und-strommarkt

Daily power production and consumption
Biomass as a peak load



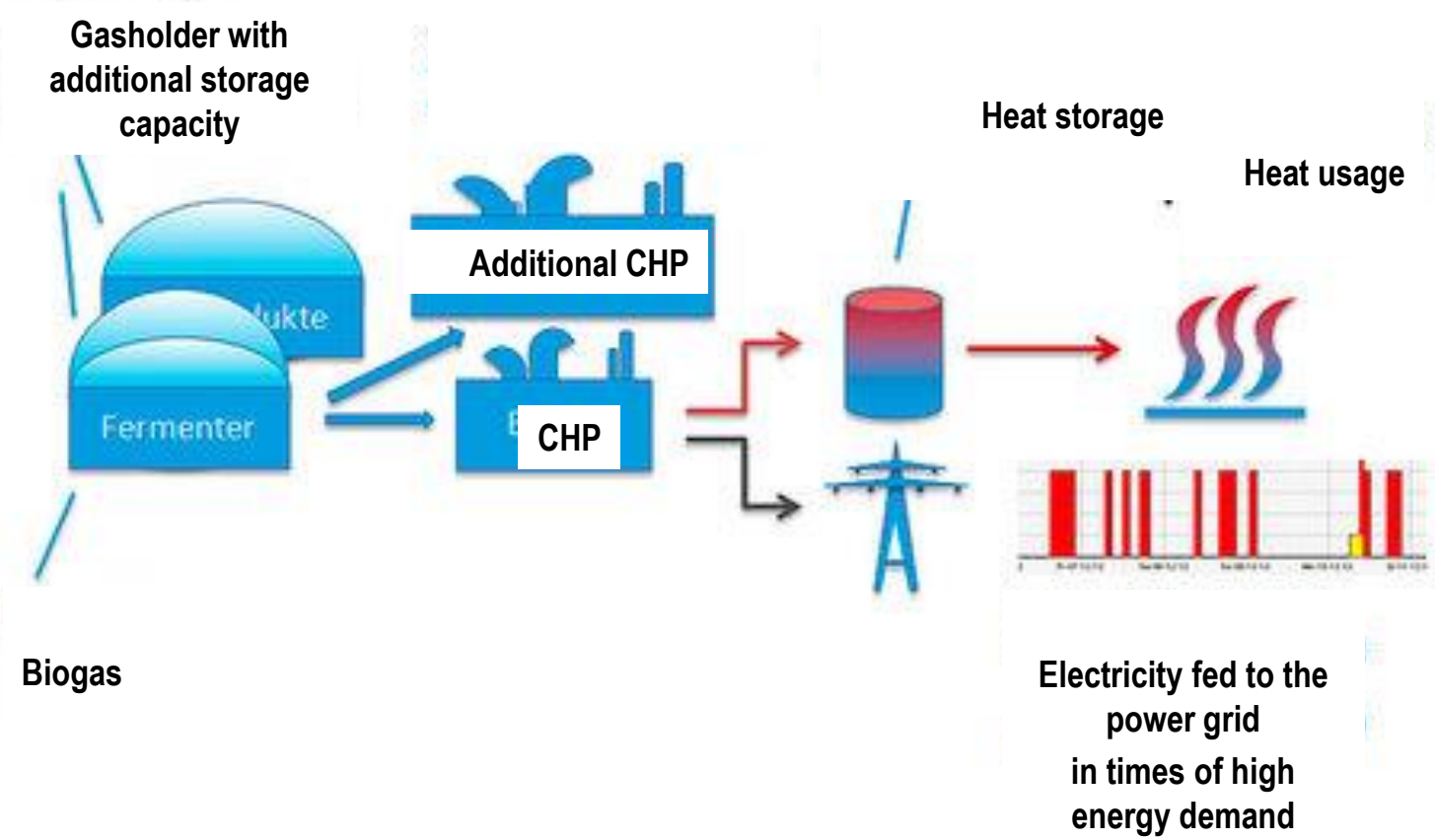
http://www.biopower2gas.de/

Flexibilization of electricity production



https://www.unendlich-viel-energie.de/media/image/1299.AEE_Flexibilisierung_einer_Biogasanlage_72dpi.jpg

Flexibilization of electricity production



https://kwk-flexperten.net/index.php?energiewende-und-strommarkt

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References worldwide

Cudworth Pork

Prince Edward Island

Bekkai

Inland Empire

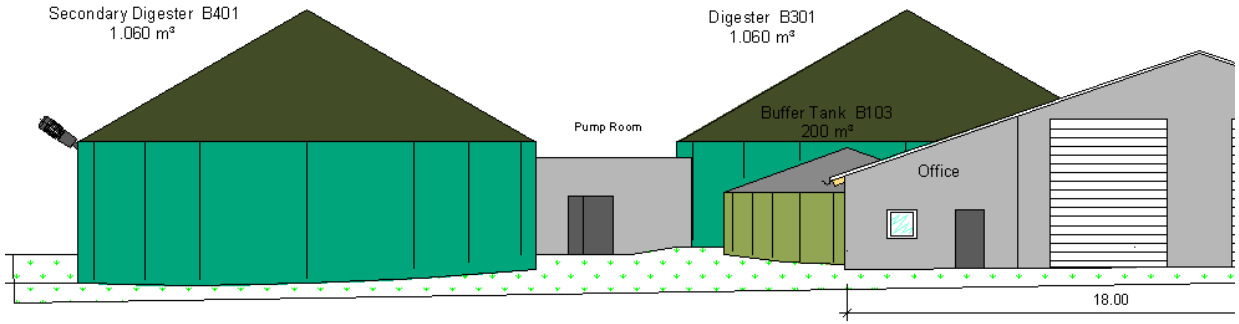
Fairyland

Montargull

Noyon

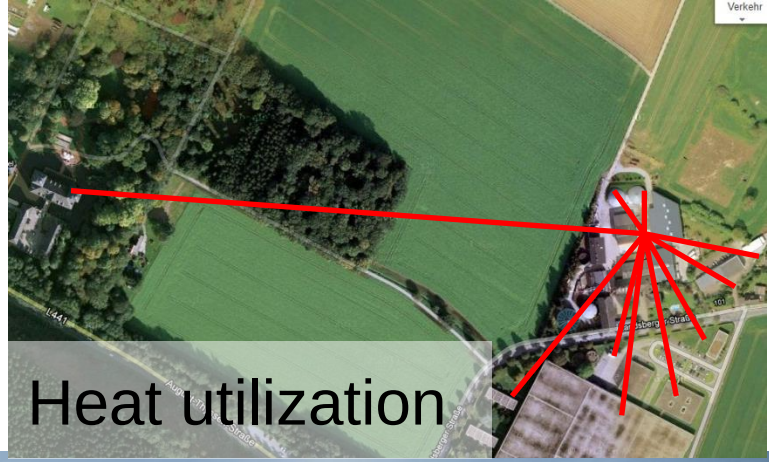
Prato

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



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- Built: 2005
- Substrate: kitchen waste, pig manure, horse dung
- Digester: 2 x 1,205 m^3 concrete tank
- CHP: 4 x 190 kW_e 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

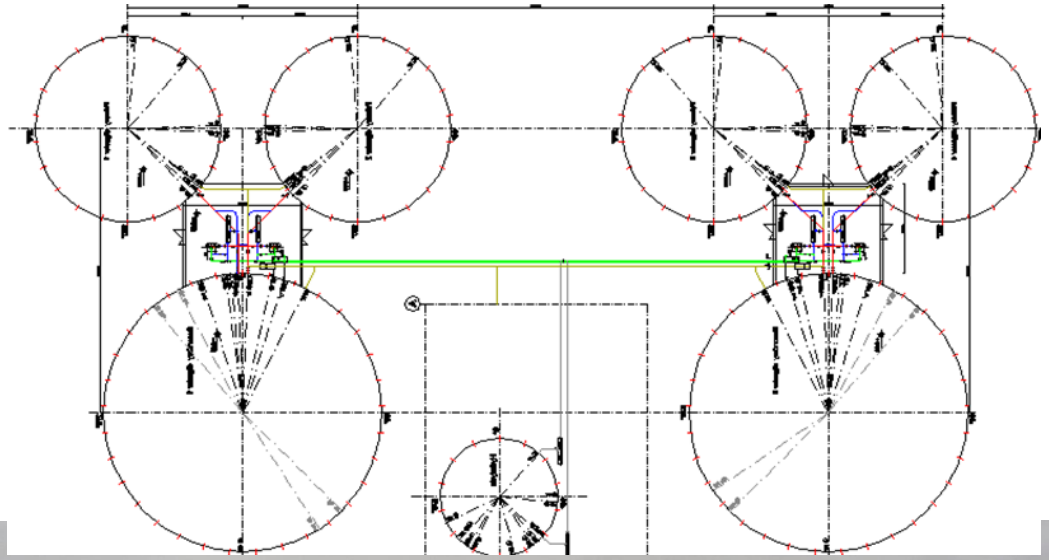
Krieg & Fischer Ingenieure GmbH

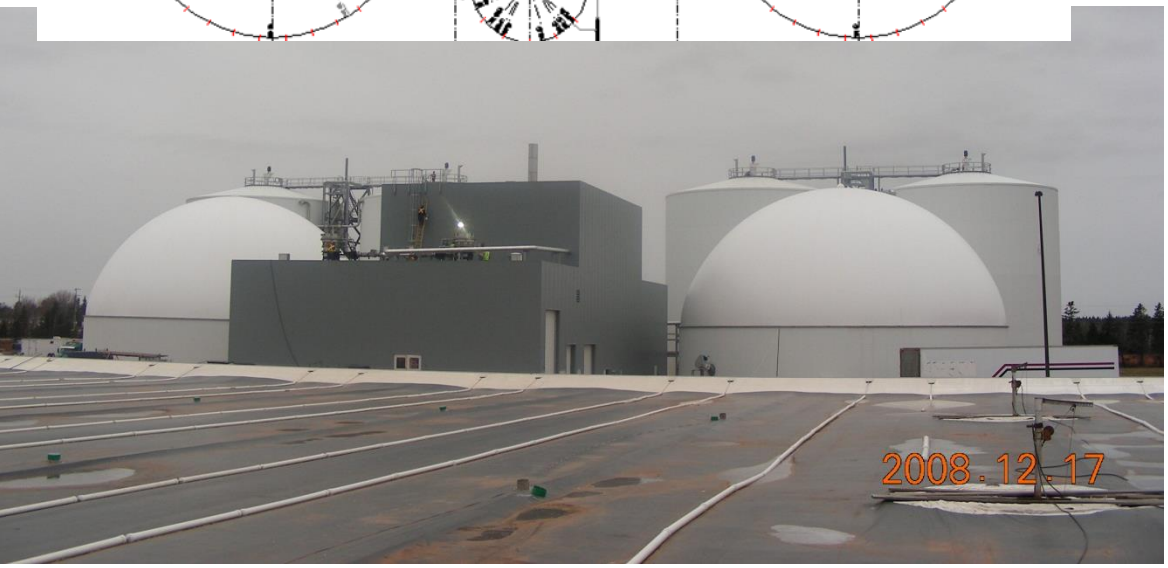
- Built: 2002
- Substrate: manure 90,000 m³/a, fats 20,000 m³/a
- digester 2 x 3,200 m³ steel tank
- CHP: 2 x 1,3 MW_e gas engine
- Gasholder above secondary digester, heat usage; gas conditioning of 500 m³/h

Wiesenau, Germany

- Built: 2007
- Input: cattle manure, cattle dung, corn-, grasssilage
- Digester: 4.300 m^3 concrete
- CHP: 2 x 526 kW_e gas engine
- Gasholder above secondary digester

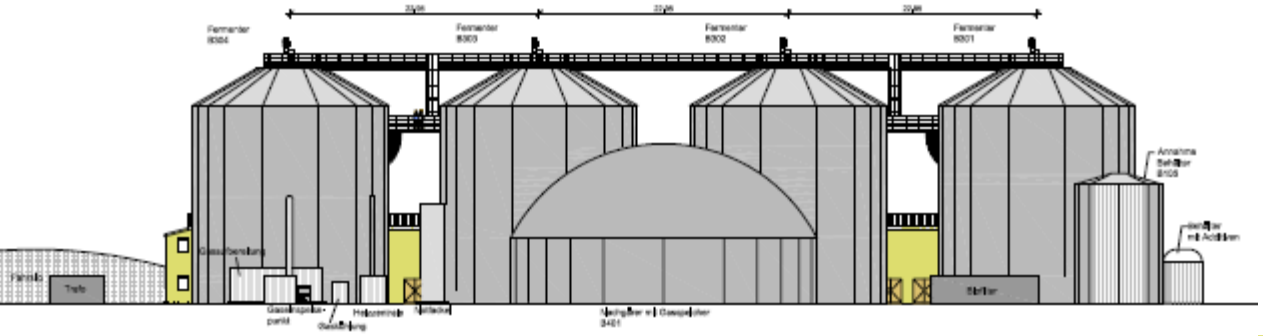
Prince Edward Island, Canada





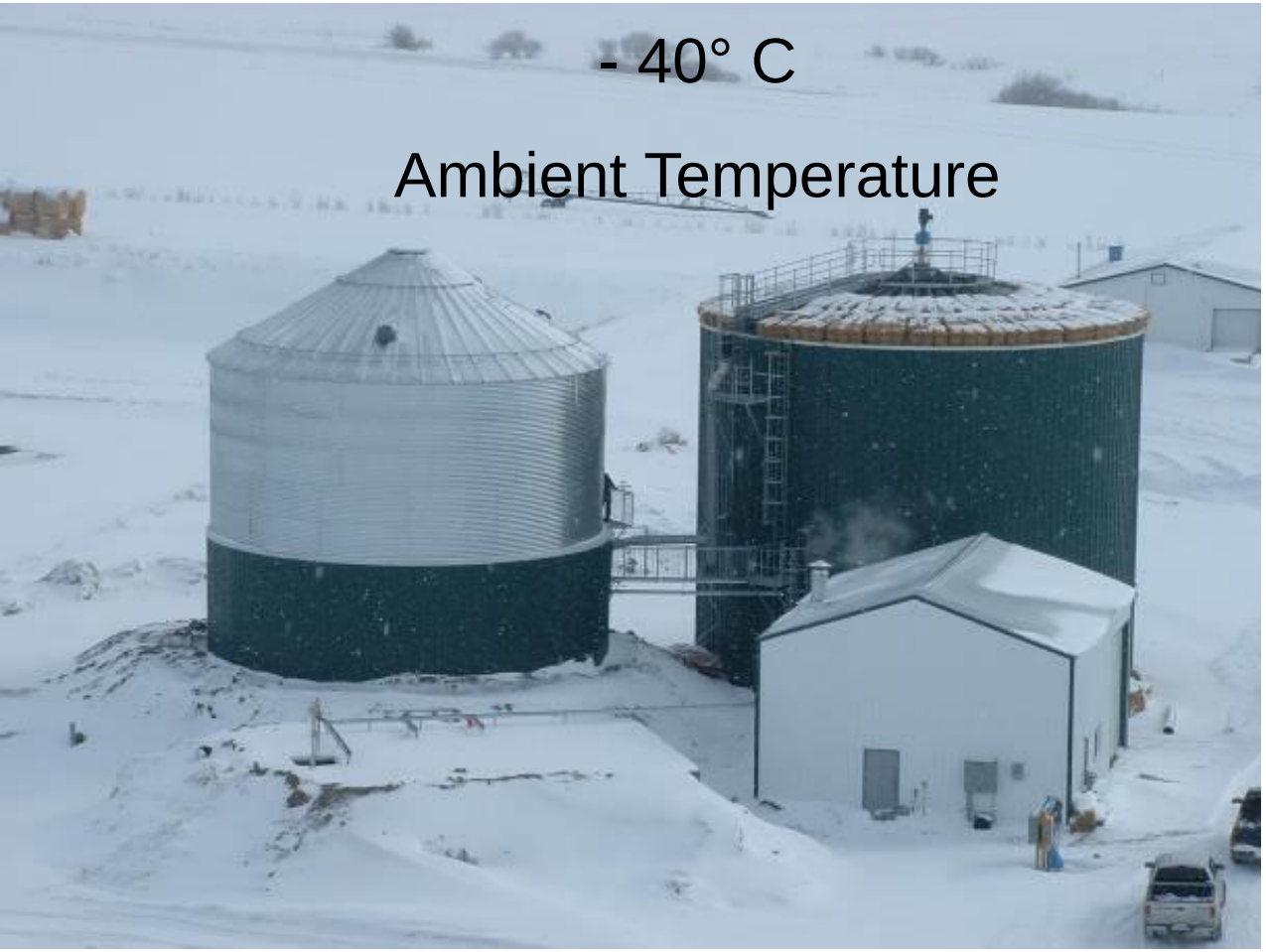
- Built: 2008
- Substrate: potato residues, oil, potato starch
- Digester: 4 x 5,500 m³, steel tank
- Size: 12 MW_{th}
- 2 stage digestion with hydrolysis,
  2 secondary digesters with gas holder roof
- Biogas is used for heating purposes – hot water production

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



- 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

- 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 m^3/d)
- Power generation capacity: 1,500 kW_e
- Construction costs: $ 5 million

Projects in China (2009 – 2017)

中国的项目

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- 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

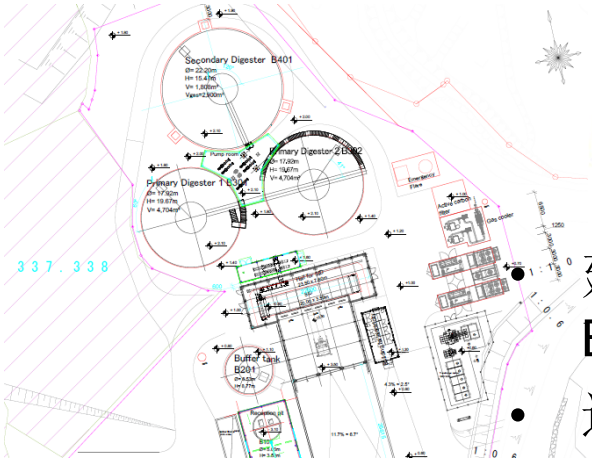
Krieg & Fischer Ingenieure GmbH

- 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



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- 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 搪瓷拼装罐
  Digester: enameled steel tank 2 x 5,000 m²
- CHP : 2 x 1,056 kW_e
- **中温発酵**,
  Mesophilic process

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Agricultural substrates

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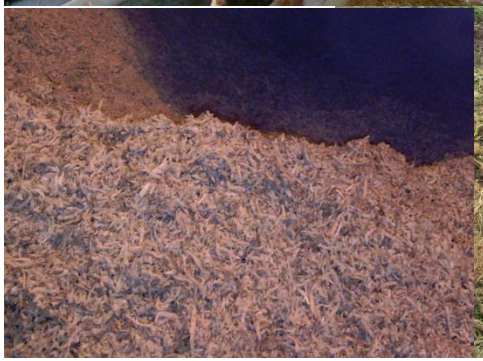
- Manure, dung
  from cattle, pig, poultry etc.


- 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

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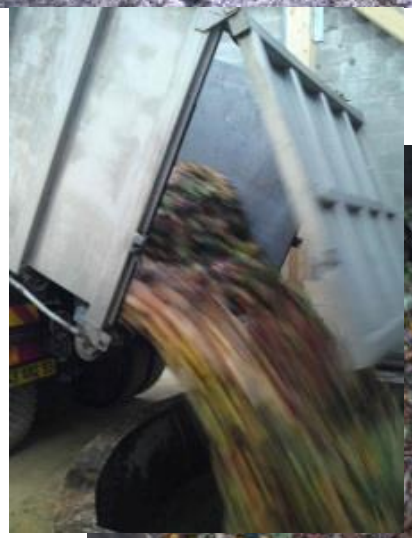
- Source separated bio-waste from households

- Kitchen waste (separate collected waste from canteens kitchens or restaurants)



Biodegradable municipal waste (BMW) in Germany

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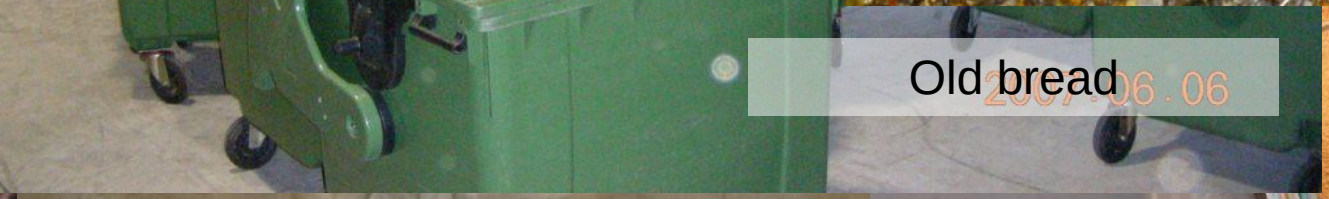
Biogas Production

Corn Silage	1 Mg	30% TS	94% VS	700 l/kgVS	197 m³ Biogas
Wheat Silage	1 Mg	30% TS	90% VS	600 l/kgVS	162 m³ Biogas
Grass Silage	1 Mg	30% TS	89% VS	550 l/kgVS	145 m³ Biogas
Cattle Manure	1 Mg	8% TS	80% VS	200/500 l/kgVS	13/32 m³ Biogas
Pig Manure	1 Mg	6% TS	75% VS	350/500 l/kgVS	16/23 m³ Biogas
Poultry Manure	1 Mg	24% TS	85% VS	300/550 l/kgVS	61/112 m³ Biogas
Kitchen Waste	1 Mg	20% TS	90% VS	700 l/kgVS	126 m³ Biogas
Potato Residues	1 Mg	20% TS	95% VS	620 l/kgVS	118 m³ Biogas
Fats	1 Mg	25% TS	95% VS	1.000 l/kgVS	238 m³ Biogas

Slaughterhouse waste

Municipal organic waste



Old bread

Potato pieces

Waste french fries

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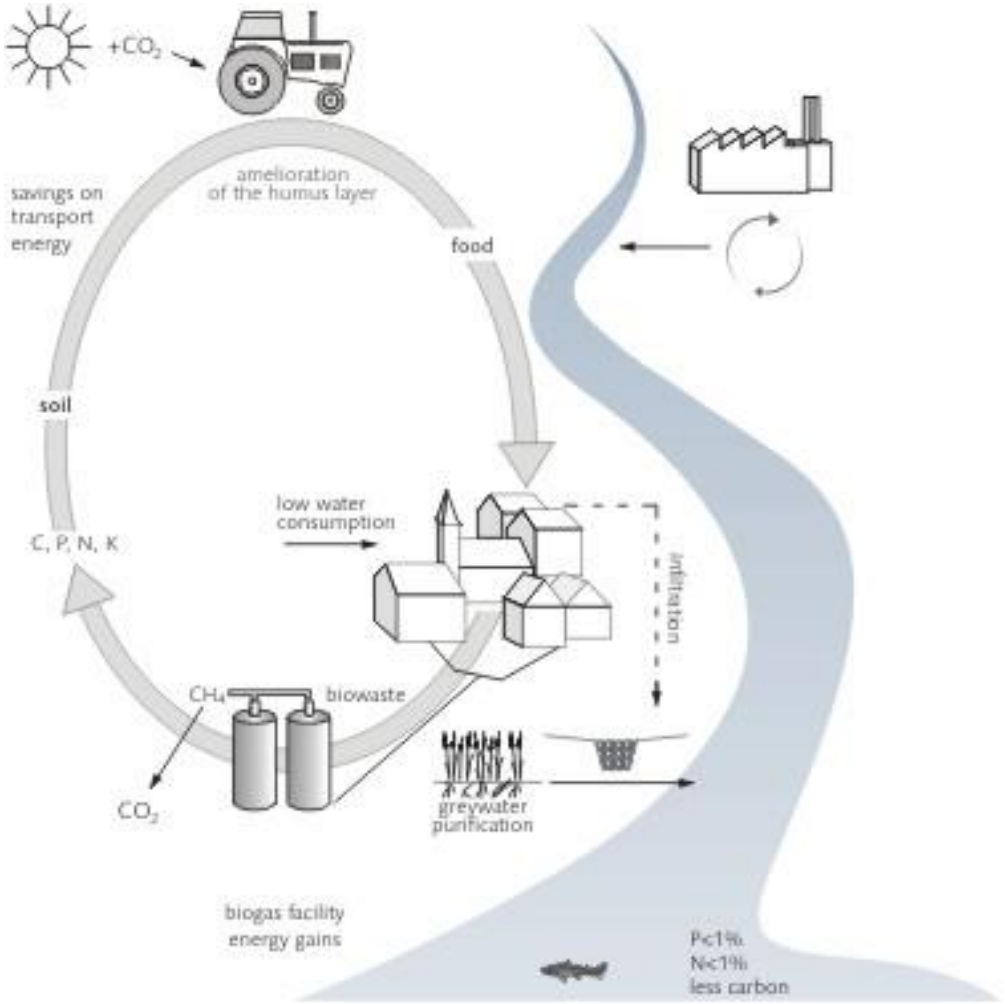
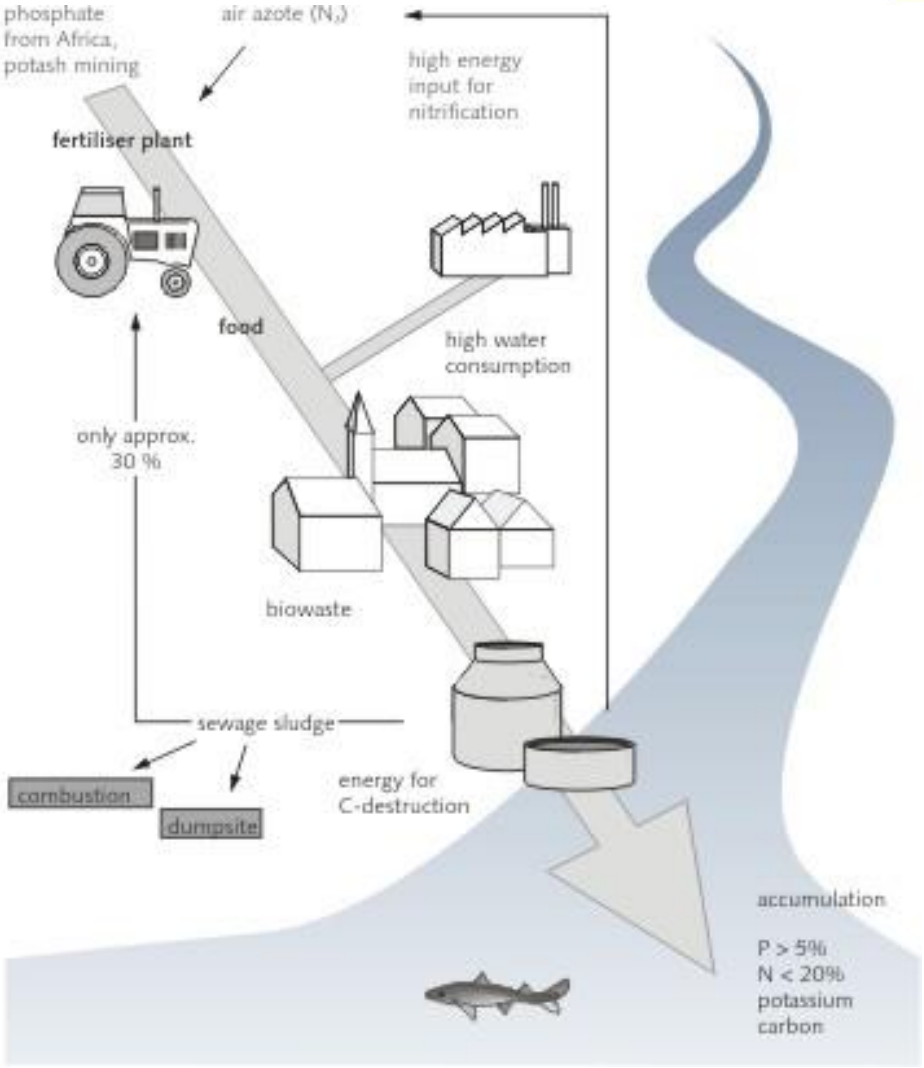
Sustainable substance flow (Europe)



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

Linear substance flow



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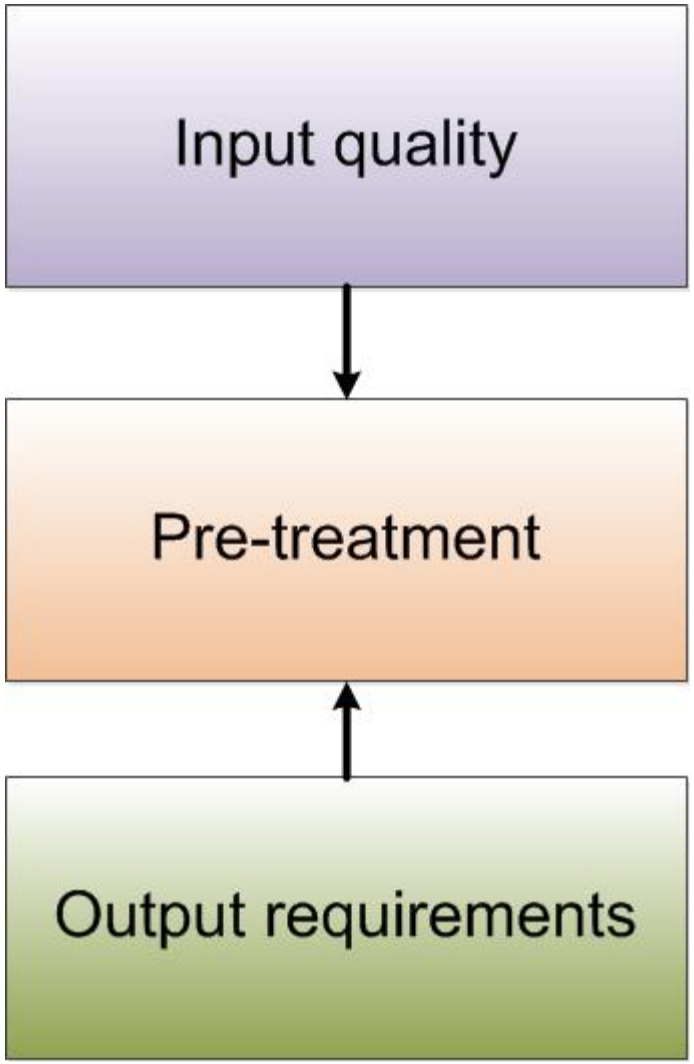
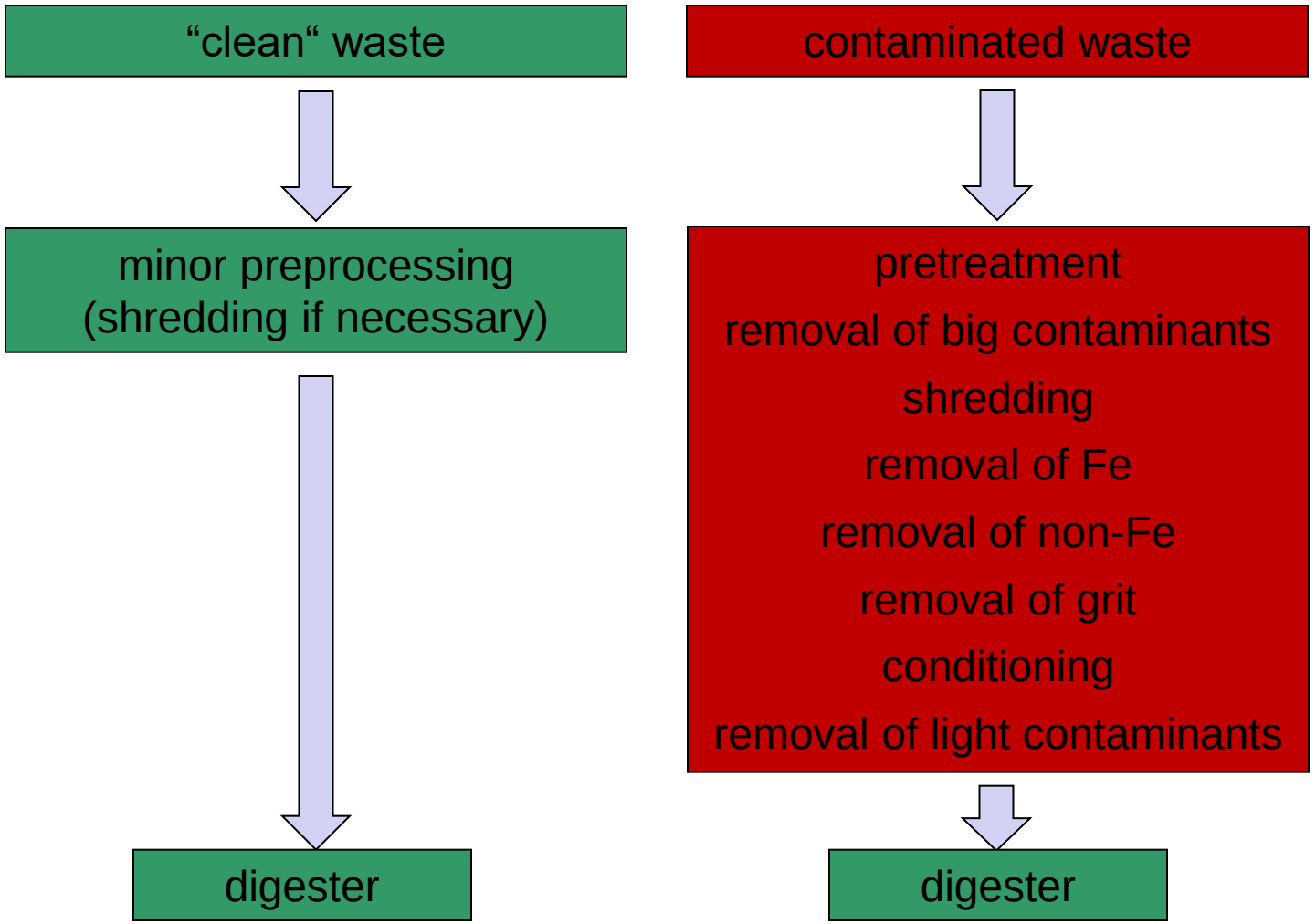
Pre-treatment



What is the aim ???

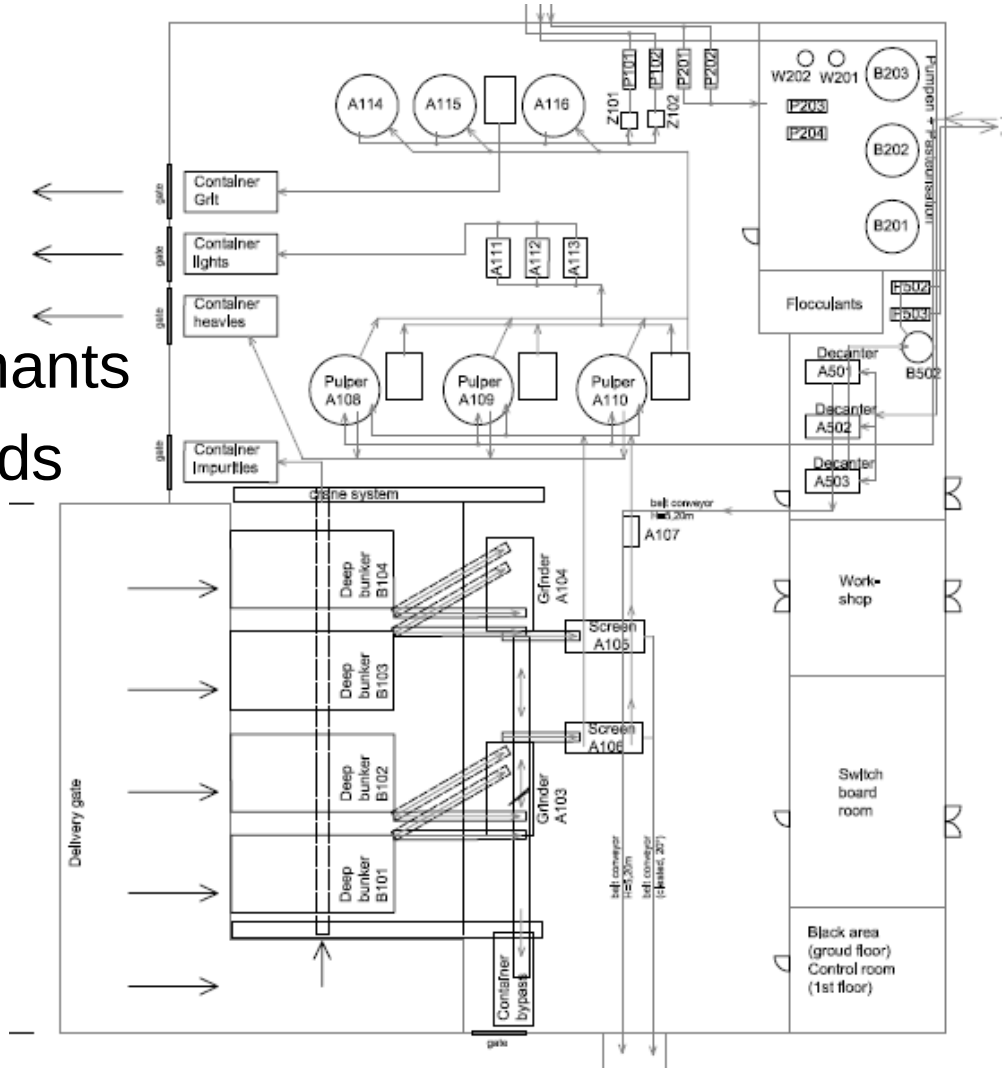
Pre-treatment



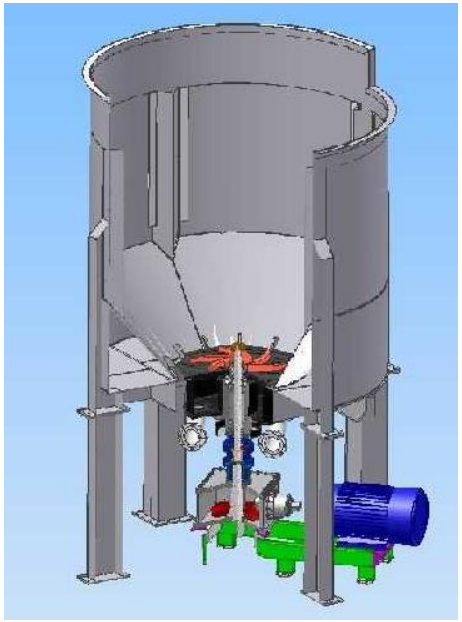
Selection Pretreatment Technology

Depends on:

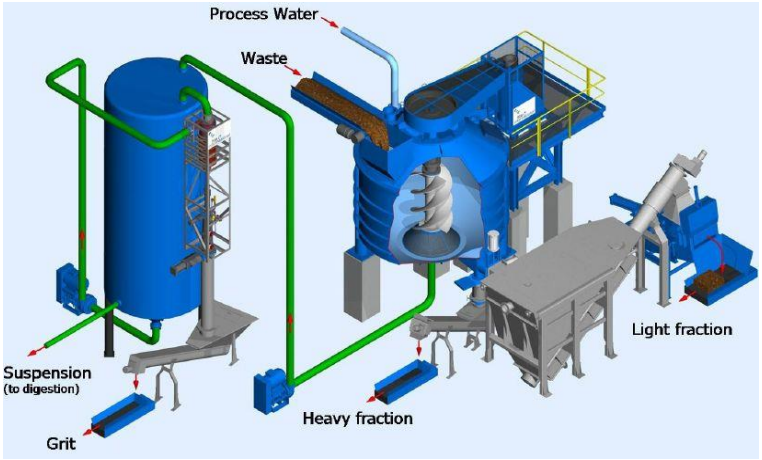
- Kind of Substrate
  - Dry matter content
  - Amount of contaminants
  - Content volatile solids
  - Particle size
  - Seasonal variation
- Location
- Logistic
- Use of digestate



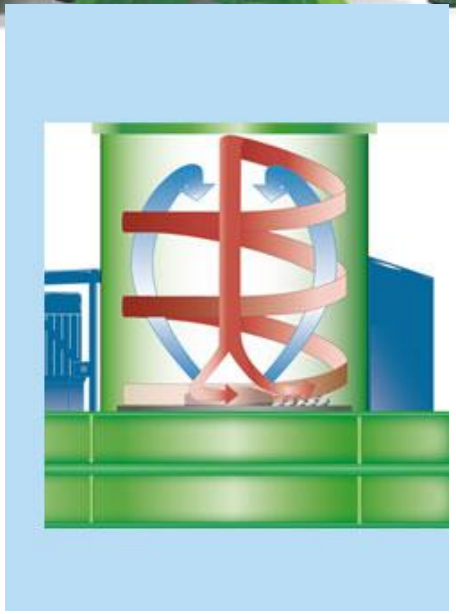
Pre-treatment



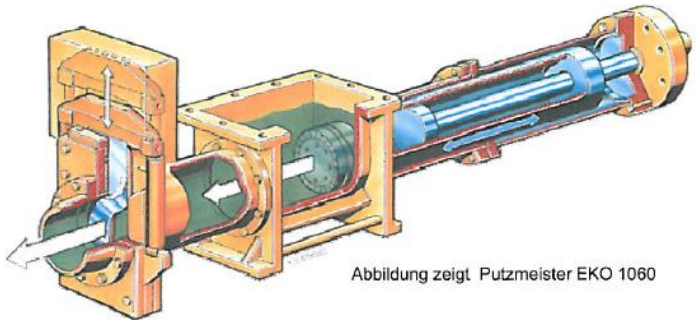
pulper



Pre-treatment



Cross flow shredder



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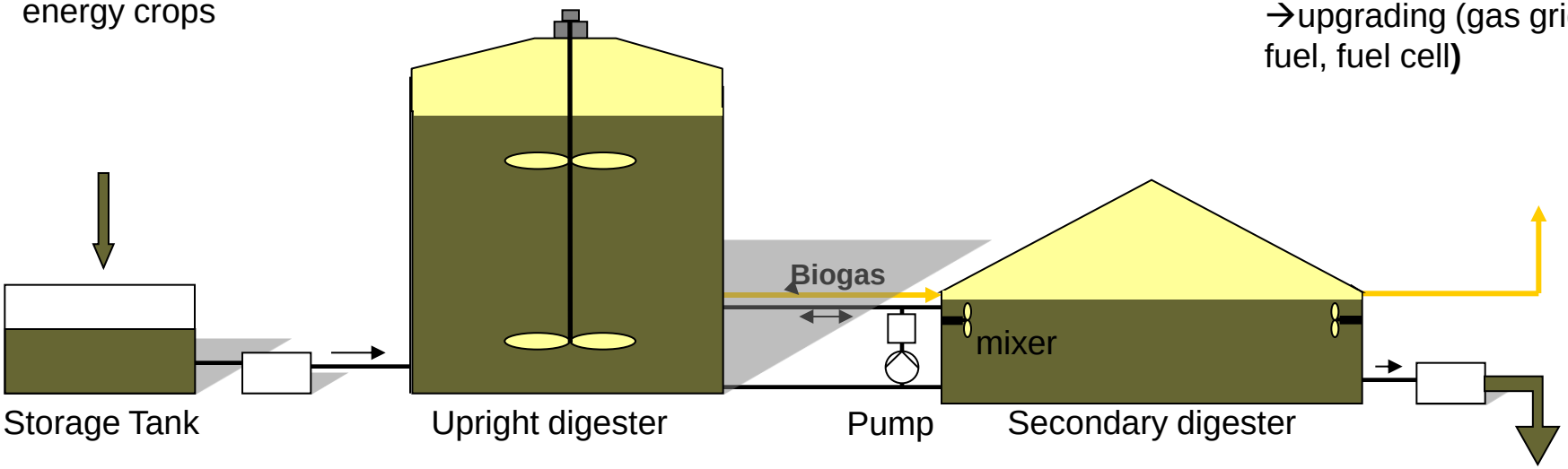
- Pretreatment of substrate
- Different types of digester
- Use of biogas (CHP, biogas upgrading)
- Safety and health risks
- Use of digestate

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)



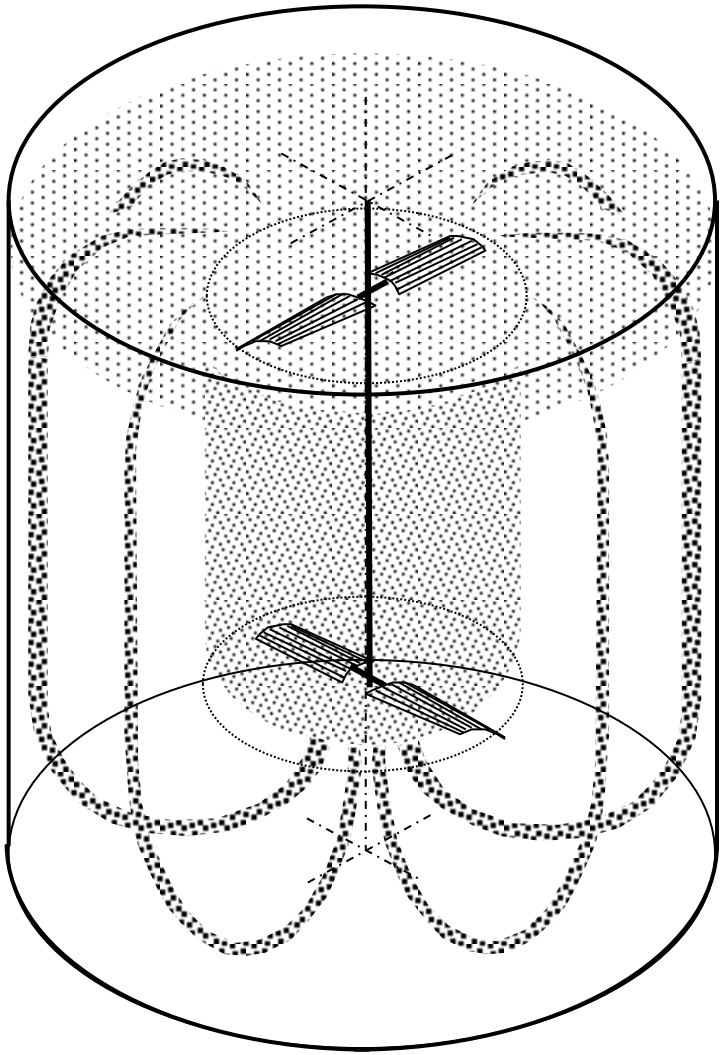
Input device
→piston pump, screw etc. (solids)
→pump (fluids)

Digested substrate
→storage and use as fertilizer
→treatment

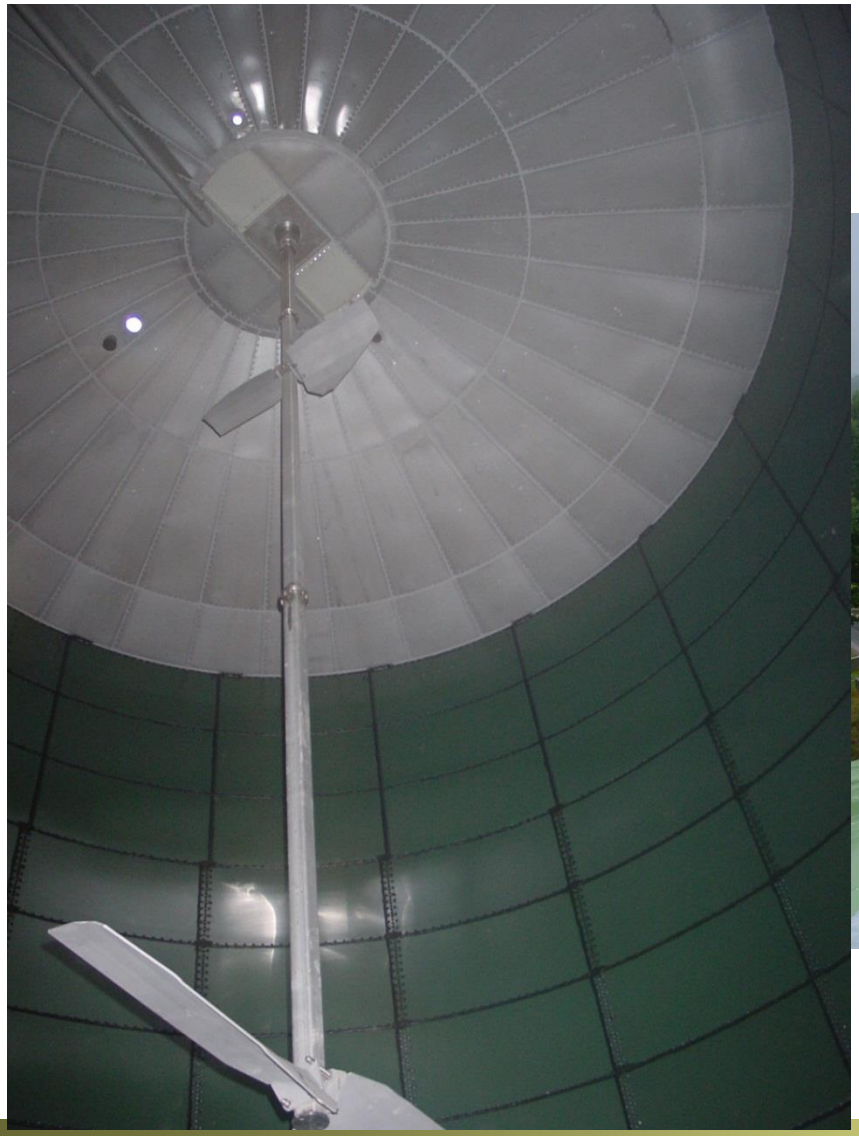
Tall Digester, Top Mounted Mixer

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 KW_e each
- Gas holder above secondary digester, thermophilic, heat usage

Wietzendorf, Germany

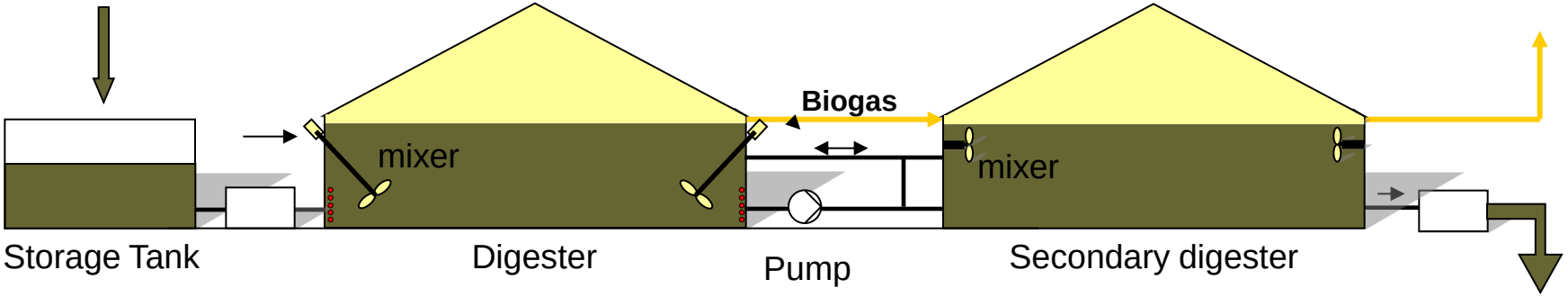
- Built: 2000-2002
- Substrate: waste water of starch production (potato-starch) potato residues
- 4 digester, 2.500 m^3 each, secondary digester with gas holder roof
- CHP: 4 x 2,1 MW_e gas engine
- Protein recovery, reverse osmosis, retention of biomass through decanter

Biogas concept with flat digester

Substrate

manure
organic waste
energy crops

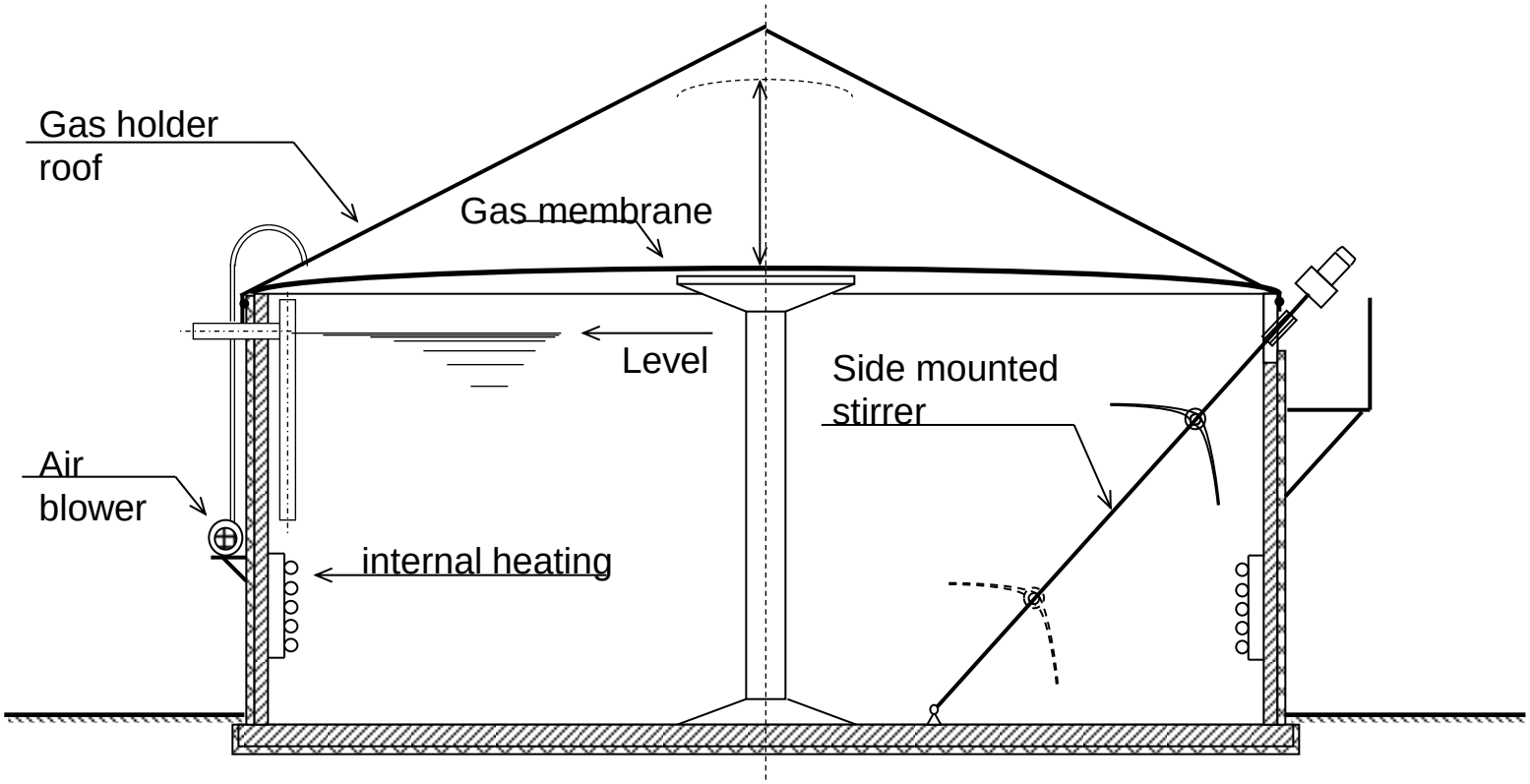
Gas utilization
→CHP (power, heat)
→direct use (heating, cooking, light)
→upgrading (gas grid fuel, fuel cell)



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

Digested substrate
→storage and use as fertilizer
→treatment

Improved standardized agricultural digester



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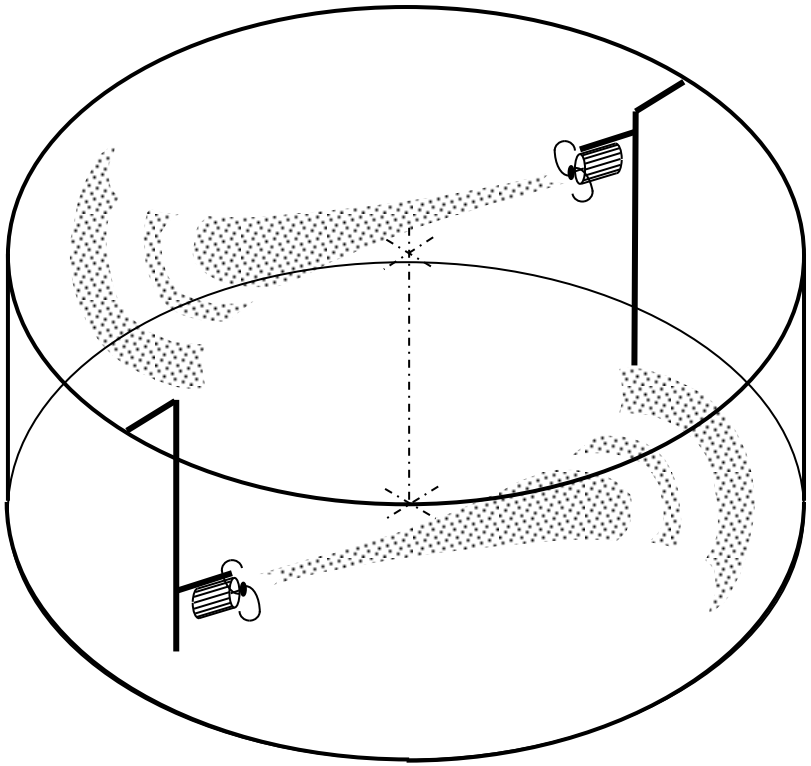
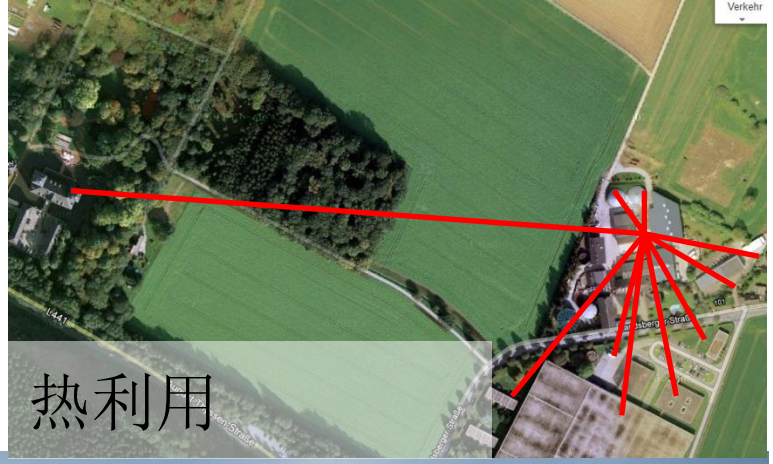
Flat digester, submerged mixer



Im Brahm, Germany
德国



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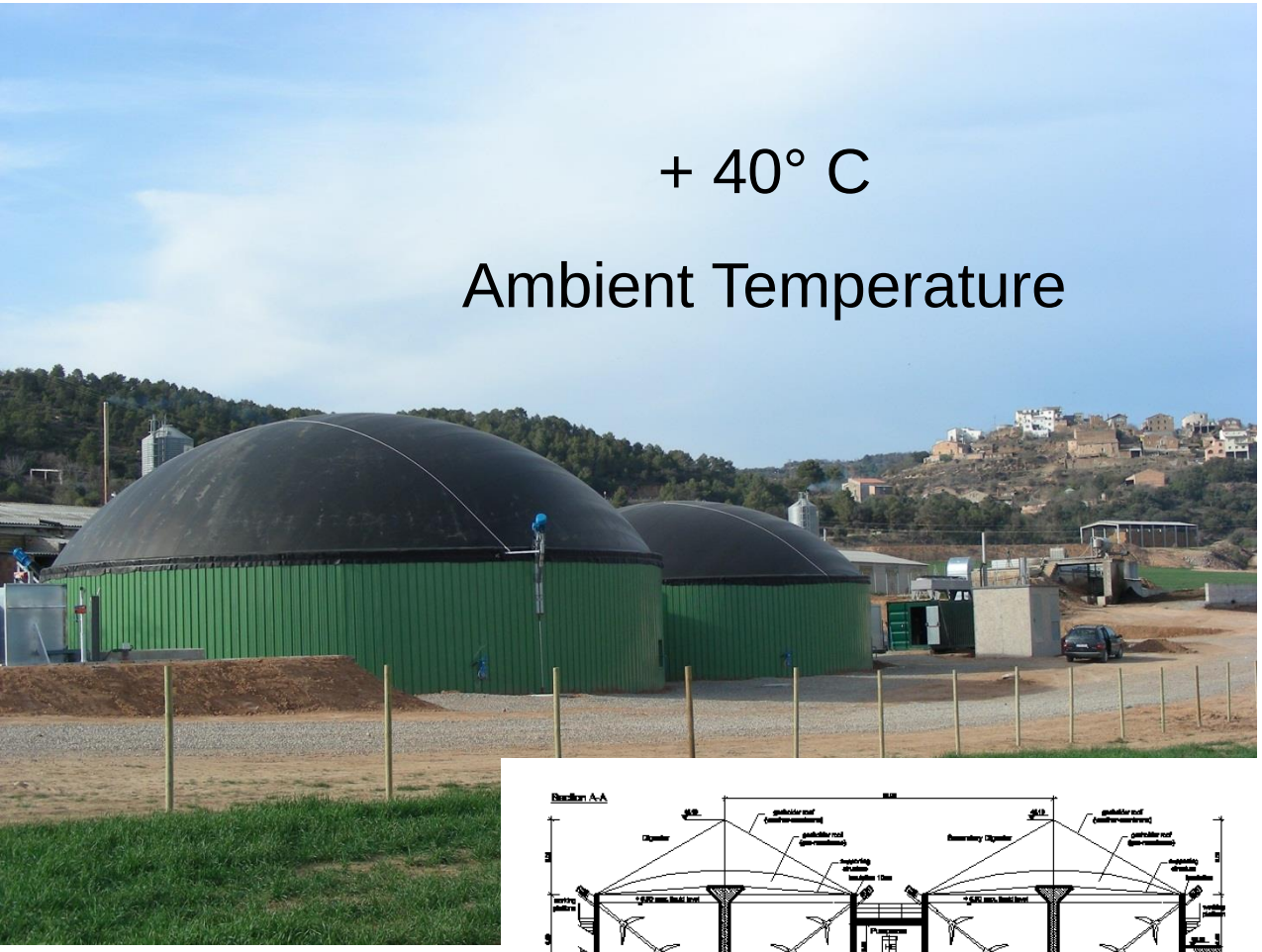
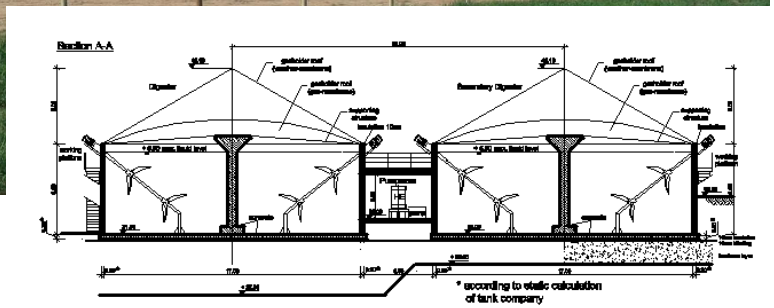
- 建设时间: 2005
- 进料: 餐厨垃圾, 猪粪, 牛粪
- 厌氧发酵罐: 2 x 1,205 m^3 ， 混凝土罐体
- 热电联产: 4 x 190 kW_e 燃气发电机
- 中温发酵,
  工艺中包含酸化罐

Montargull, Spain





- 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

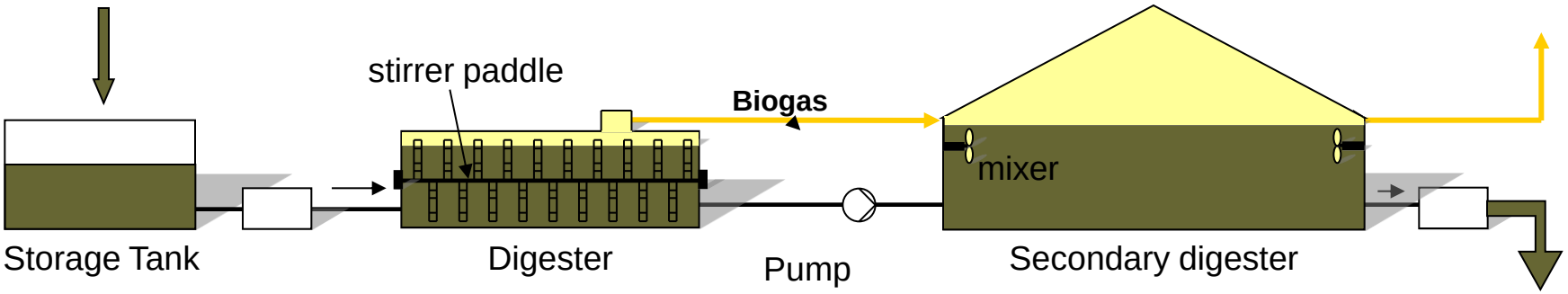
Krieg & Fischer Ingenieure GmbH

Substrate

manure
organic waste
energy crops

Gas utilization

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



Input device

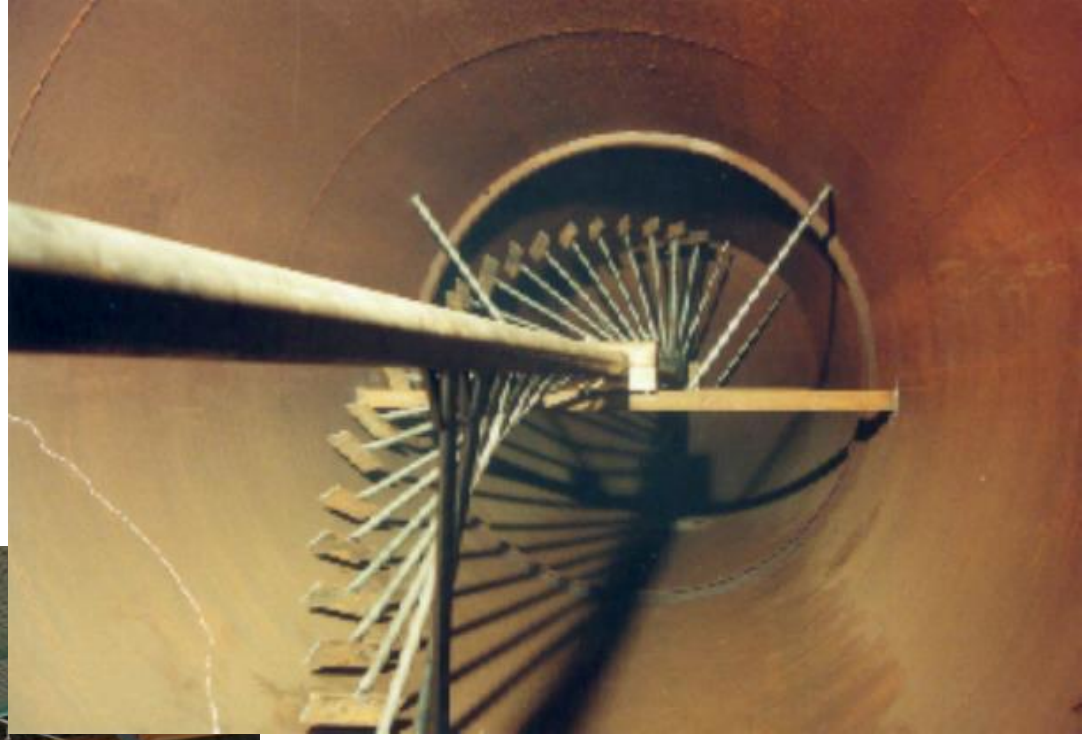
→piston pump, screw etc. (solids)

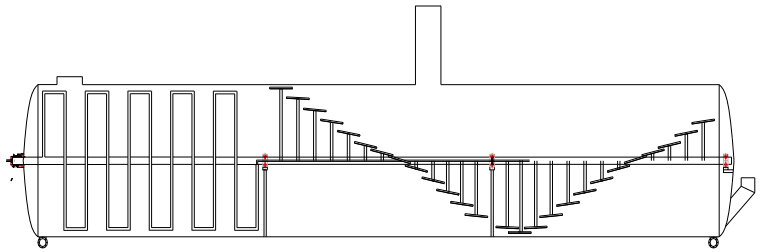
Digested substrate

→storage and use as fertilizer
→treatment

Stirring and mixing technology

Horizontal digester



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Biogas concepts

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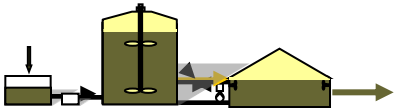
Local usage



CHP

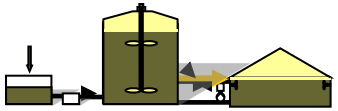
Electricity

Heat

Local heat usage

Public grid

Transport of biogas



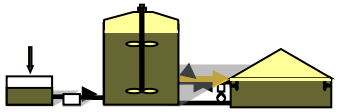
Biogaspipe

CHP

Electricity

Heat

Transmission of biomethane



Biogas plant

Biogas upgrading

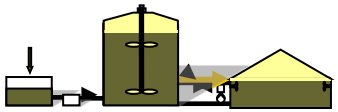
Gas grid

CHP

Electricity

Heat

Biomethane feeding-in



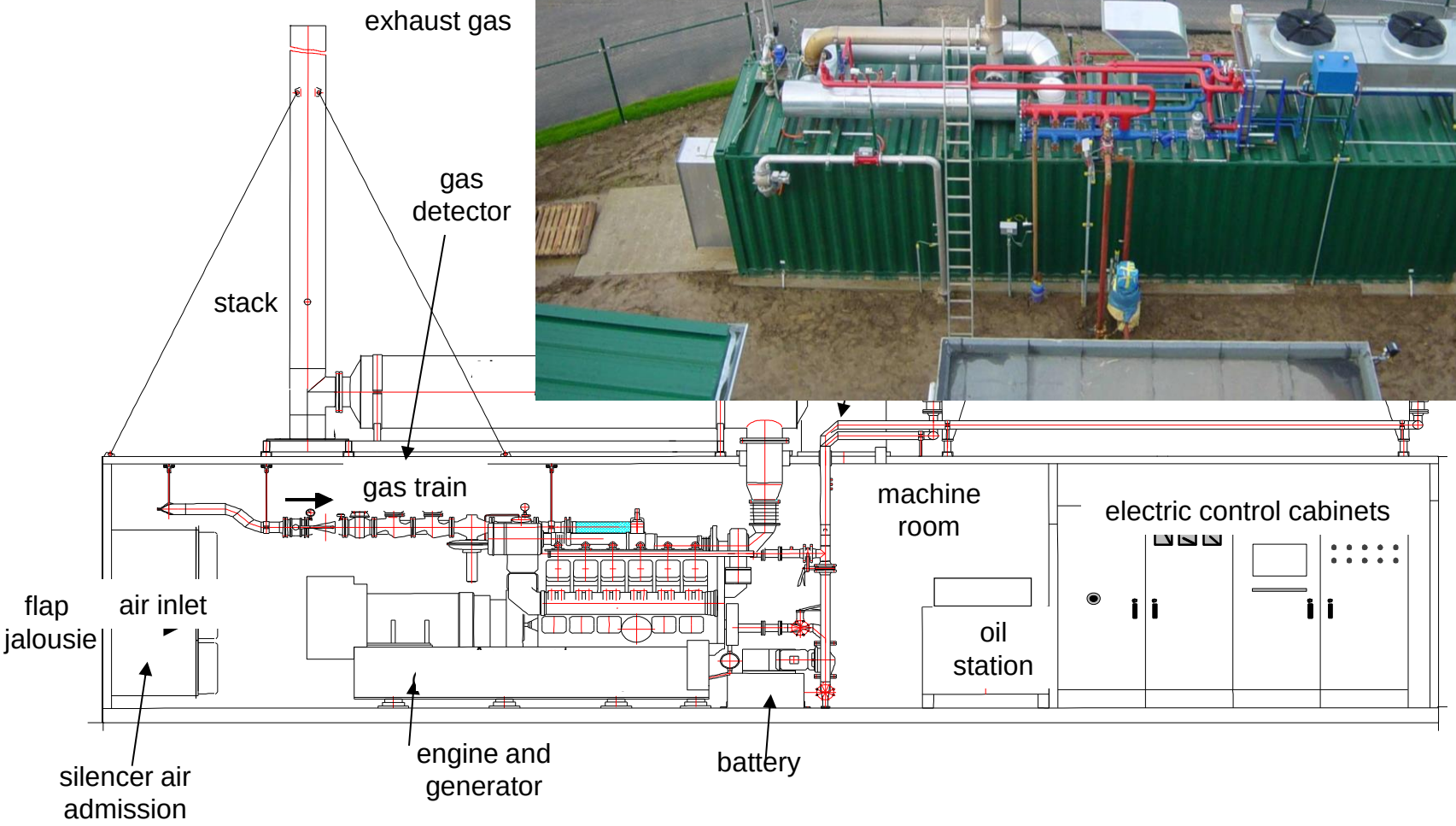
Biogas plant

Biogas upgrading

Biomethane

Biomethane sold to the grid owner

Introduction CHP
Combined heat and power plant



Sugar industry
Anklam, Germany

Krieg & Fischer Ingenieure GmbH

Biogas upgrading system

SUIKER UNIE

Content

- Introduction
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- **Safety and health risks**
- Use of digestate

Characteristics of biogas

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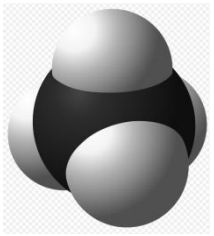
- Methane CH_4: 45-70 %
- Carbondioxide CO_2: 25-55 %
- Hydrosulphide H_2S: 10-30,000 ppmv
- Water vapour : 100 %
- Heating value 4.5-7 kWh/m³

- 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



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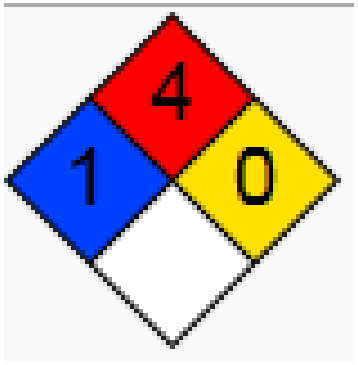
- Not toxic
- Extremely flammable
- Danger of ignition and fire or explosion (explosive mixtures with air between (5–15%)
- Greenhouse gas



Explosion

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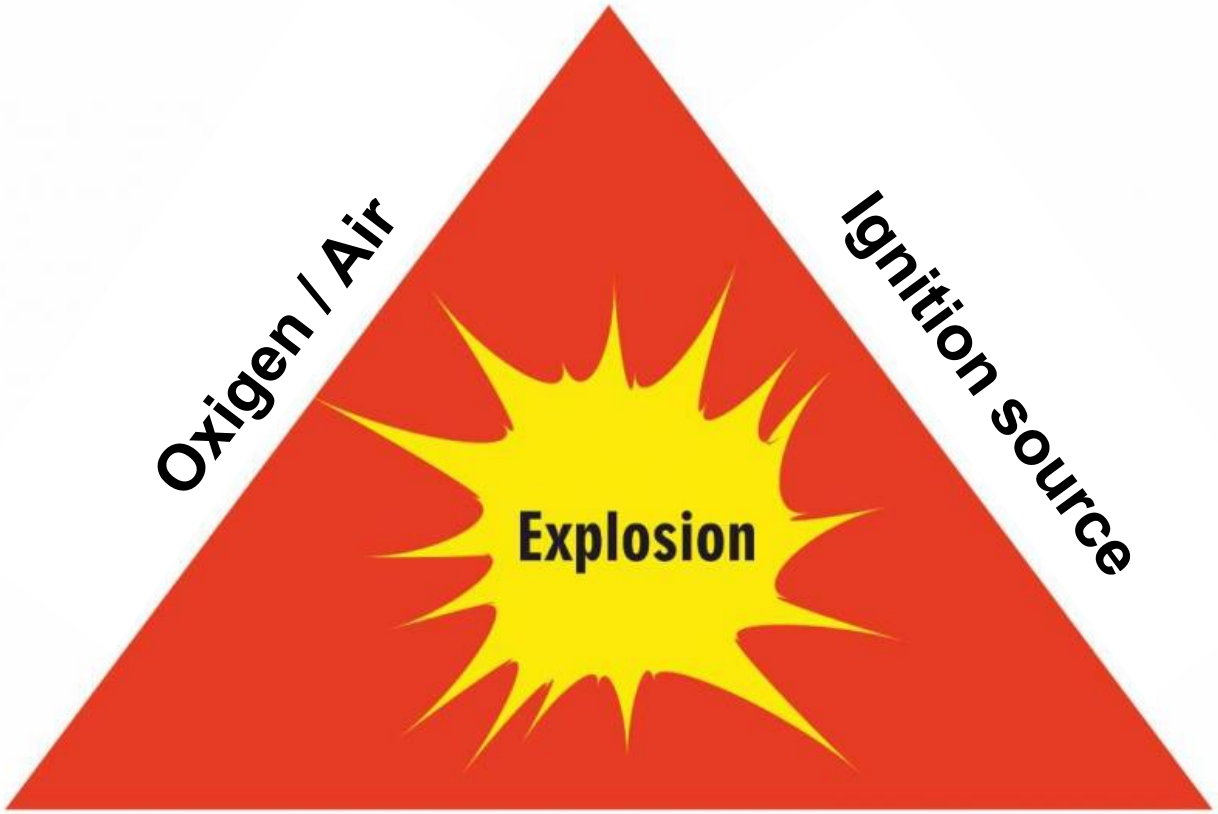
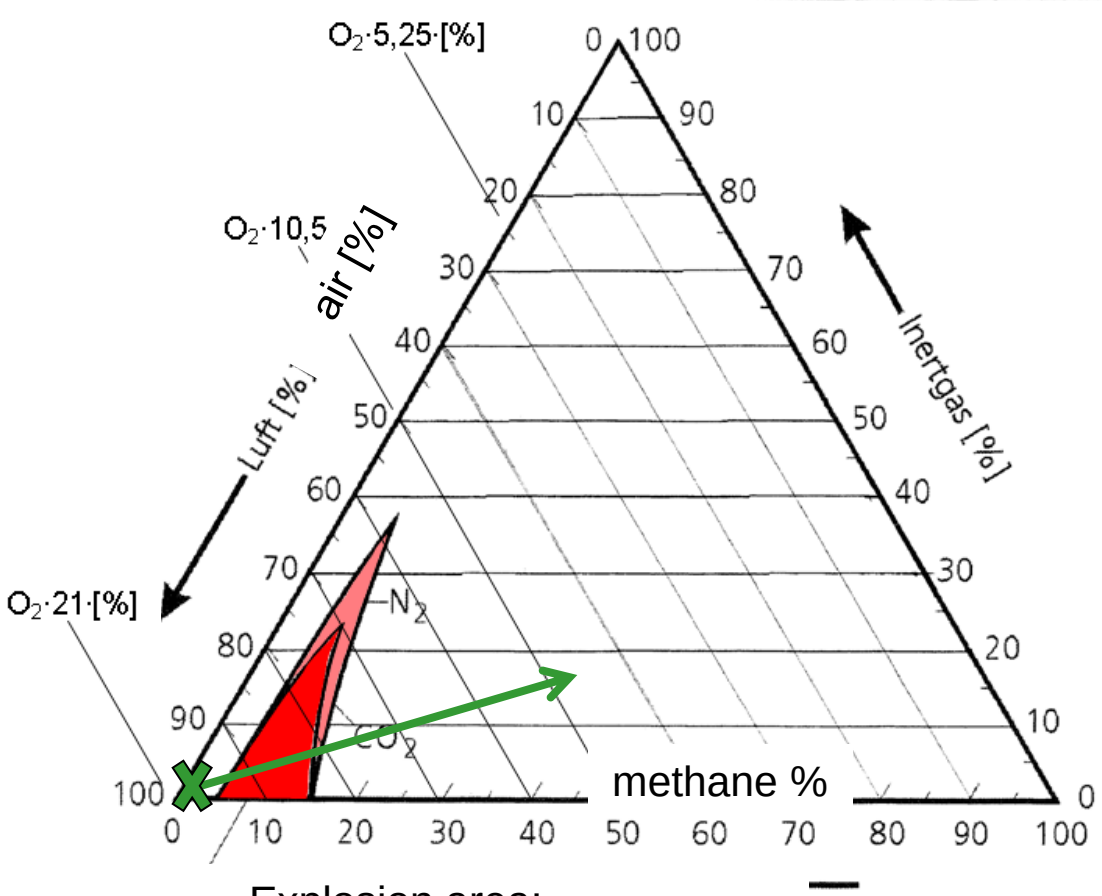


Safety
Lower and Upper Explosive Limit

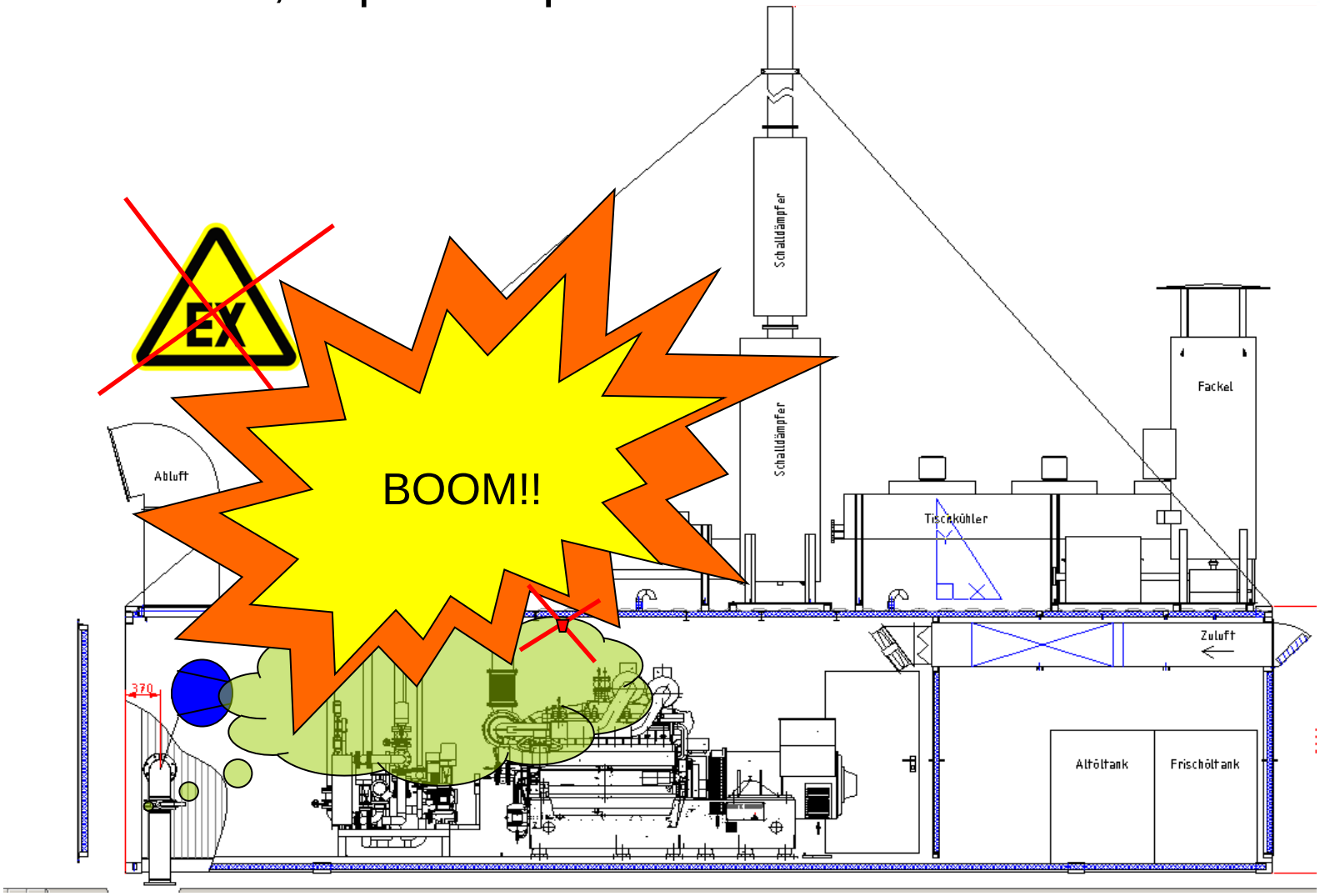


Start-up new digester

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

Safety
Blower, explosion protection



Danger caused by fire

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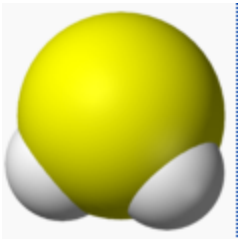
Fire test of a single membrane gas holder roof

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 H_2S



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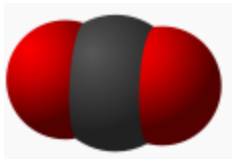
- **10–20 ppm** is the borderline concentration for eye irritation.
- At **100–150 ppm** the olfactory nerve is paralyzed after a few inhalations, and the sense of smell disappears, often together with awareness of danger.
- **320–530 ppm** leads to pulmonary edema with the possibility of death.
- **800 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



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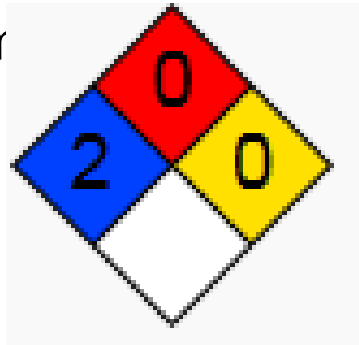
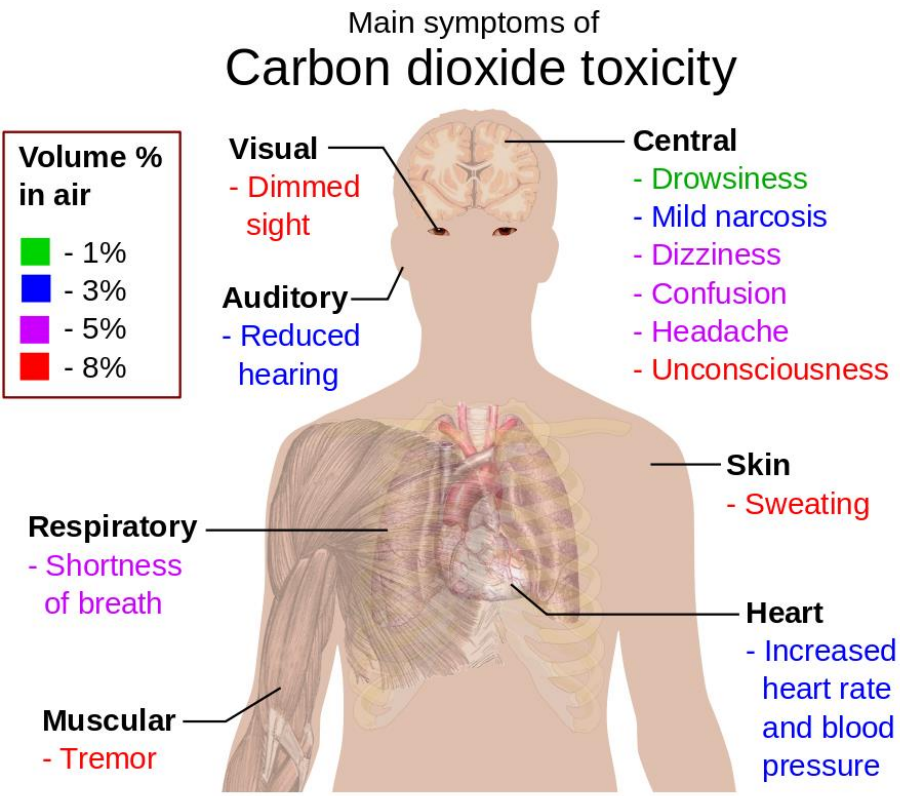
- Carbon dioxide extinguishes flames
- Danger of suffocation: displacement of air in cellar room inspection pits





Source: Freiwillige Feuerwehr Hatzendorf

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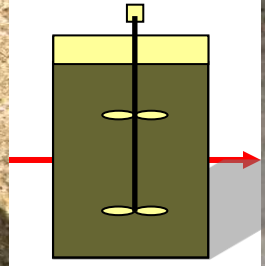
Digestate

before



Digester

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)
  and → drying (fuel…)

  → fluid digestate

  →use as process water

  →further treatment (reverse osmosis, ultra filtration)

Treatment of digestate
Separator

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Solid fertilizer from BMW in Germany

- Solid fertilizer from BMW (Göttingen)

Treatment of digestate
Drum dryer

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Design and Construction of Biogas Plants Worldwide

Torsten Fischer and Dr Katharina Backes

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