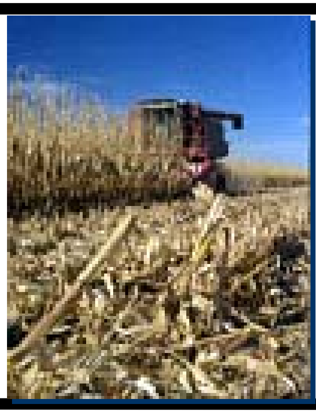
Biomass: Basics, Bio-conversion, crop and sewage treatment

- Introduction
- Basics
- Multifunction of biogas
- Scheme of a biogas plant
- Types of digestion
- Operation, control & costs of plant
- Application of biogas
- Principle of the fermentation
- Impact parameters
- Literature

Dr. Spiros Alexopoulos

Summer School in RES, Patra 4.07.2012

Biomass feed stocks



Wood Residues

- Sawdust
- Wood chips
- Wood waste
  - pallets
  - crate discards
  - wood yard trimmings

Agricultural Residues

- Corn stover
- Rice hulls
- Sugarcane bagasse
- Animal waste

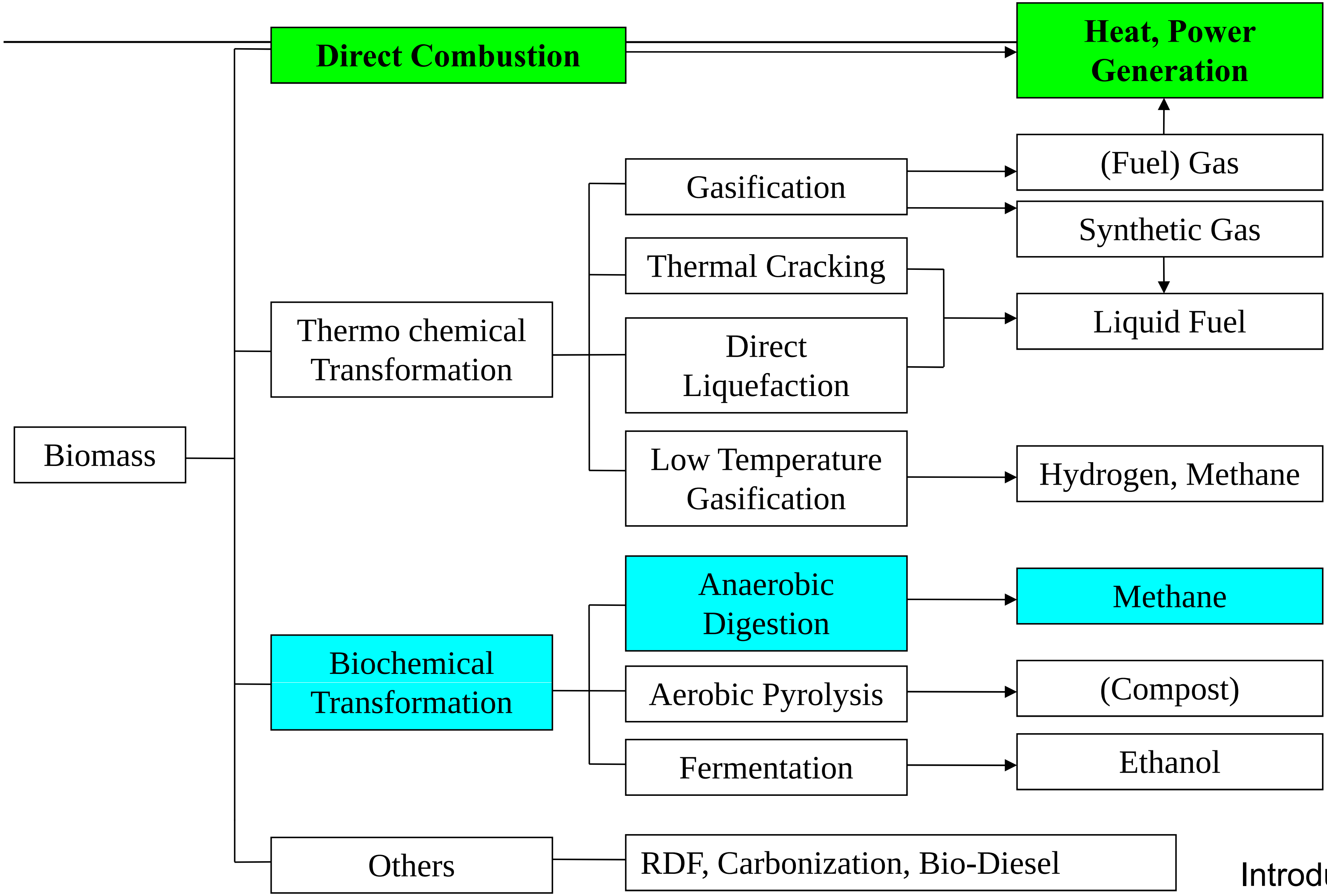
Energy Crops

- Hybrid poplar
- Switchgrass
- Willow

Fuel	Heating value
biogas	6.0 kWh/m³
wood	4.4 kWh/kg
crop	4.2 kWh/kg

Fuel	Heating value
gas	8.3 kWh/m3
oil	11.7 kWh/kg
lignite	5.6 kWh/kg

Biomass transformation as energy



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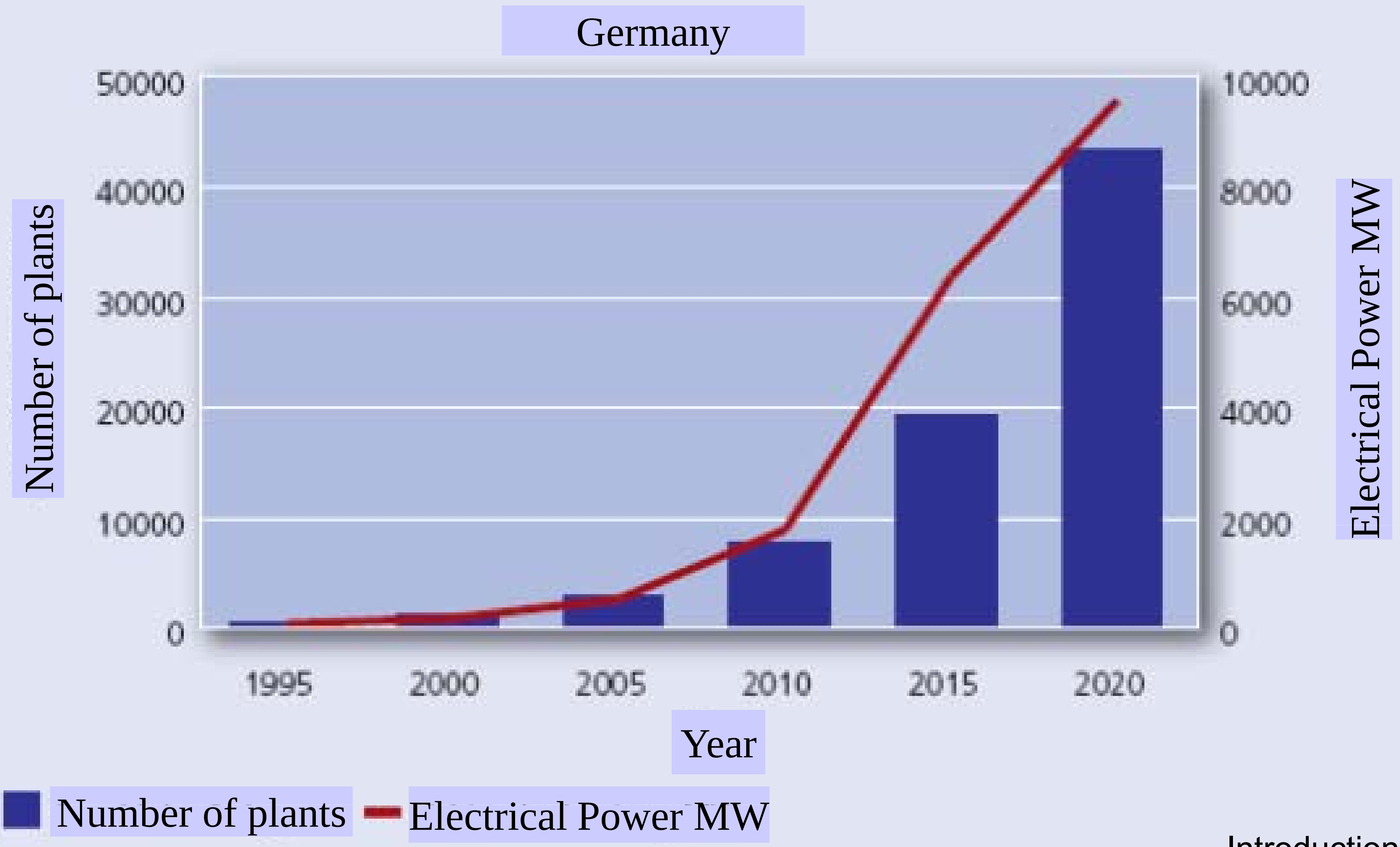
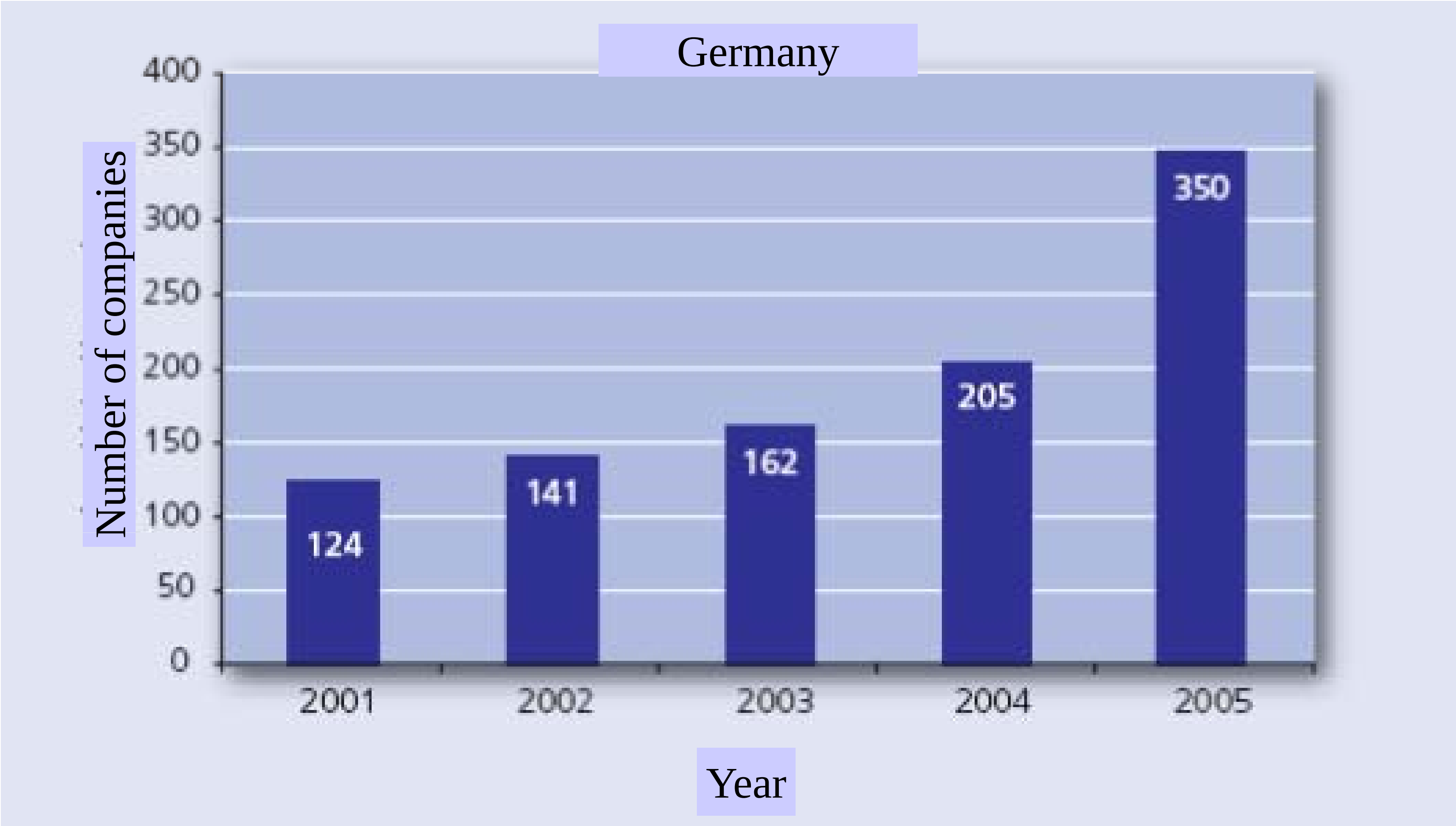
Introduction

Development of biogas plants



Introduction

Biogas industry in Germany



Facts

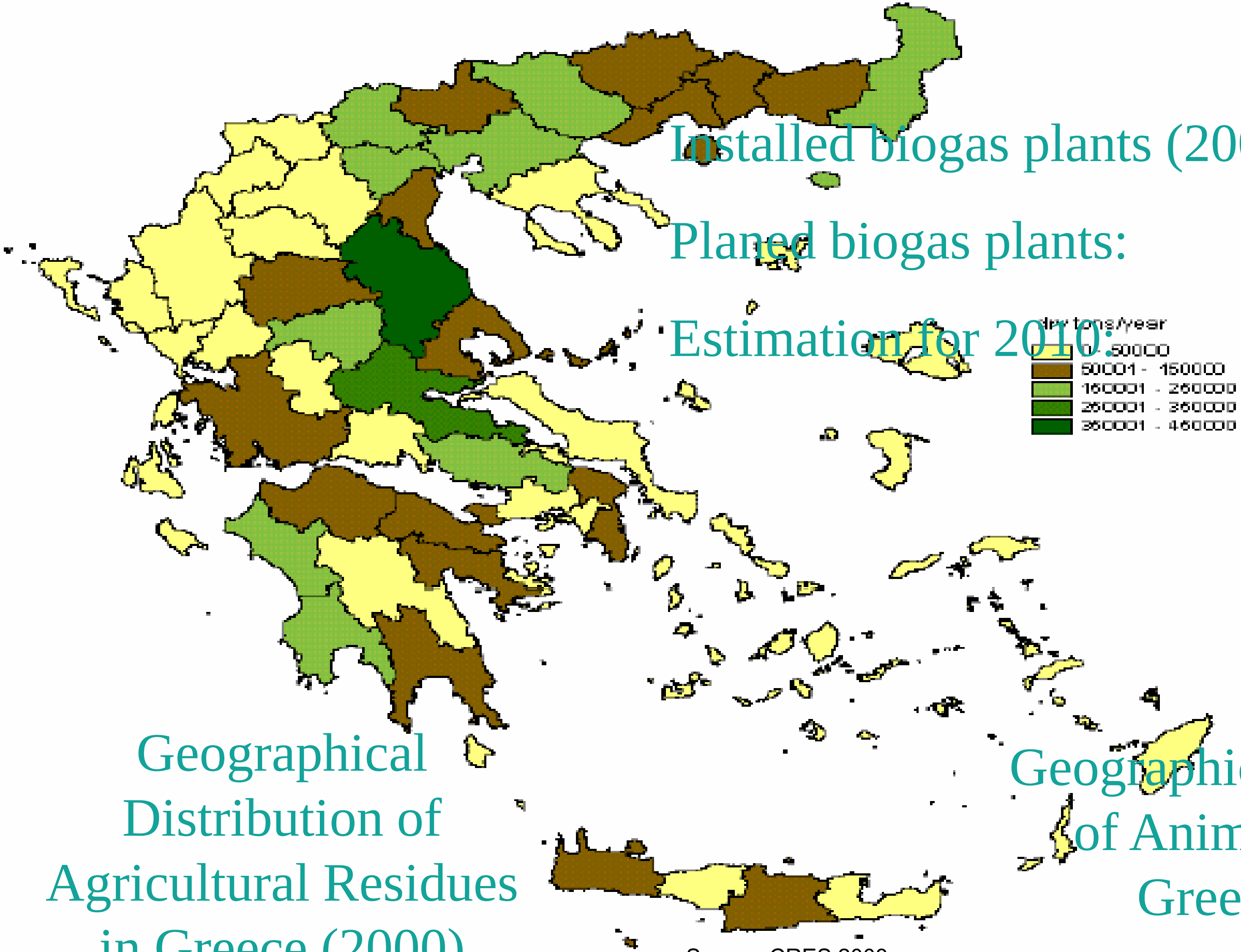
- Total energy potential of Germany: 752 PJ
- Power production in 2005: 3.2 Mio. kWh
  650 MW_{el} plants installed in Germany
- 2.5 Mio. tons CO_2 per year avoided
  resulting in 2020: 60 Mio. tons CO_2
- World estimation for 2020: 15,000 MW
  Germany: 9,500 MW, 20 % electricity production
- extra price for consumer max. 0.1 Cent/kWh
  buyback price for a new plant: 15.5 Cent/kWh

Biomass potential of Greece

Installed biogas plants (2008): 24 MW

Planed biogas plants: 32 MW

Estimation for 2010: 60 MW



Geographical Distribution of Agricultural Residues in Greece (2000)

Geographical Distribution of Animal Wastes in Greece (2000)

Source: CRES 2003

Introduction

Examples of biogas plants in Greece

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Company	Activity	Electrical Installed Capacity (MW_e)	Thermal Installed Capacity (MW_e)
Water Entity Psytalia	**Sewage treatment plant**	**7.37**	**2.7**
Consortium (munic.+private) Liosia	**Landfill gas**	**13.00**	**16.55**
Munic. Ent. Volos	**Sewage treatment plant**	**0.35**	**0.5**
Munic. Ent. Heraklio	**Sewage treatment plant**	**0.19**	**0.25**
Munic. Ent. Chania	**Sewage treatment plant**	**0.17**	**n.a.**

Region	Electrical Installed Capacity MW_e	Fuel
Tebloni, Corfu	4	Landfill gas
Thermi, Thessaloniki	8	Landfill gas
Liosia, Attiki	9.5	Landfill gas
Metamorfosi, Attiki	0.665	Sewage treatment biogas
Patra, Achaia	0.9	Sewage treatment biogas
Fillipiada, Preveza	4.09	Pig manure

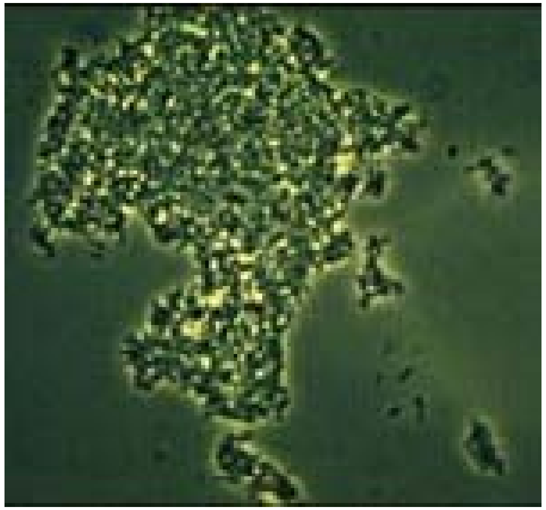
Composition of biogas

Component	Symbol	Concentration
Methane	CH_4	50 - 75 Vol.-%
Carbon dioxide	CO_2	25 - 45 Vol.-%
Water vapor	H_2O	2 – 7 Vol.-%
Oxygen	O_2	< 2 Vol.-%
Nitrogen	N_2	< 2 Vol.-%
Ammonia	NH_3	< 1 Vol.-%
Hydrogen	H_2	< 1 Vol.-%
Sulfide	H_2S	20 – 20.000 ppm

[ppm: Parts per Million]

Source: www.nachwachsende-rohstoffe.de

Importance of burning biogas



Bacteria digest organic compounds in oxygen free environments → biogas

Anaerobic digestion is a naturally occurring process

Methane 21x worse than CO_2 in causing global warming

Removing 1 ton methane from atmosphere = getting rid of 21 tons CO_2

Burning methane converts the methane to CO_2

CO_2 equivalent for methane is 1

Burning methane does not increase carbon in the carbon cycle.

Definition of cattle unit (GVE)

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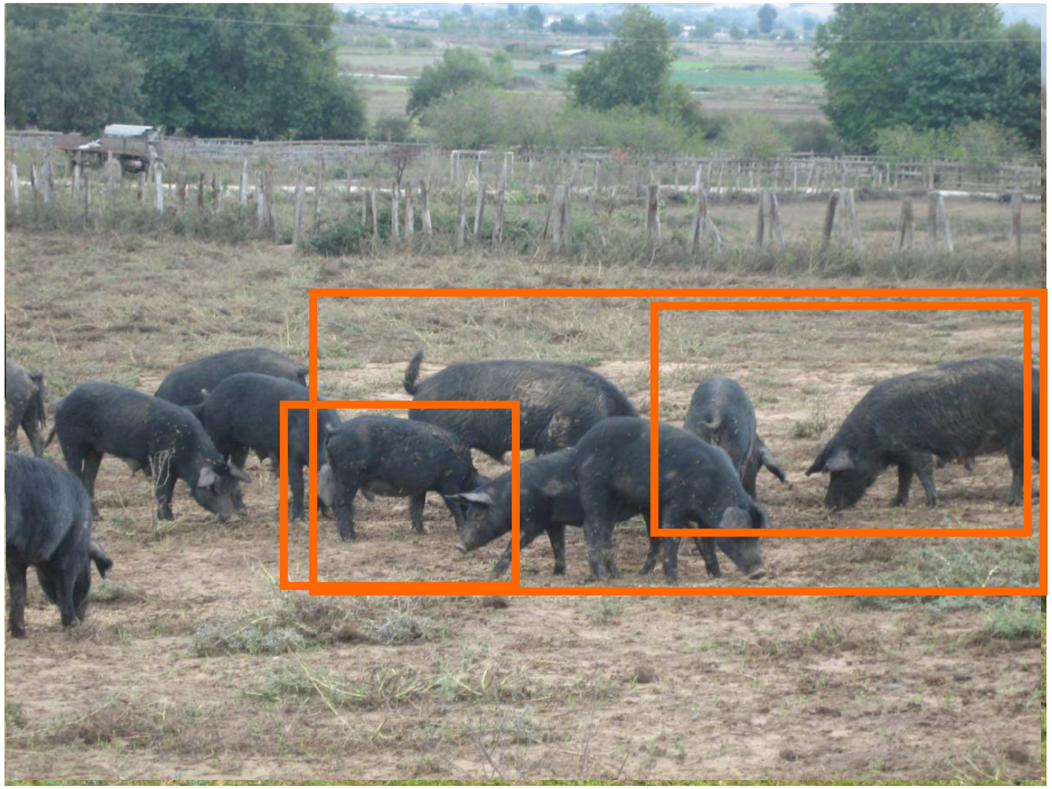
1 GVE produces 1.5 m^3 biogas/day

One cattle unit (GVE) equals:

- one cow
- five calves
- six porks
- 250 chicken



CO_2 natural cycle

CO_2

Will take another 20 to 50 years for carbon to be taken out of atmosphere

and

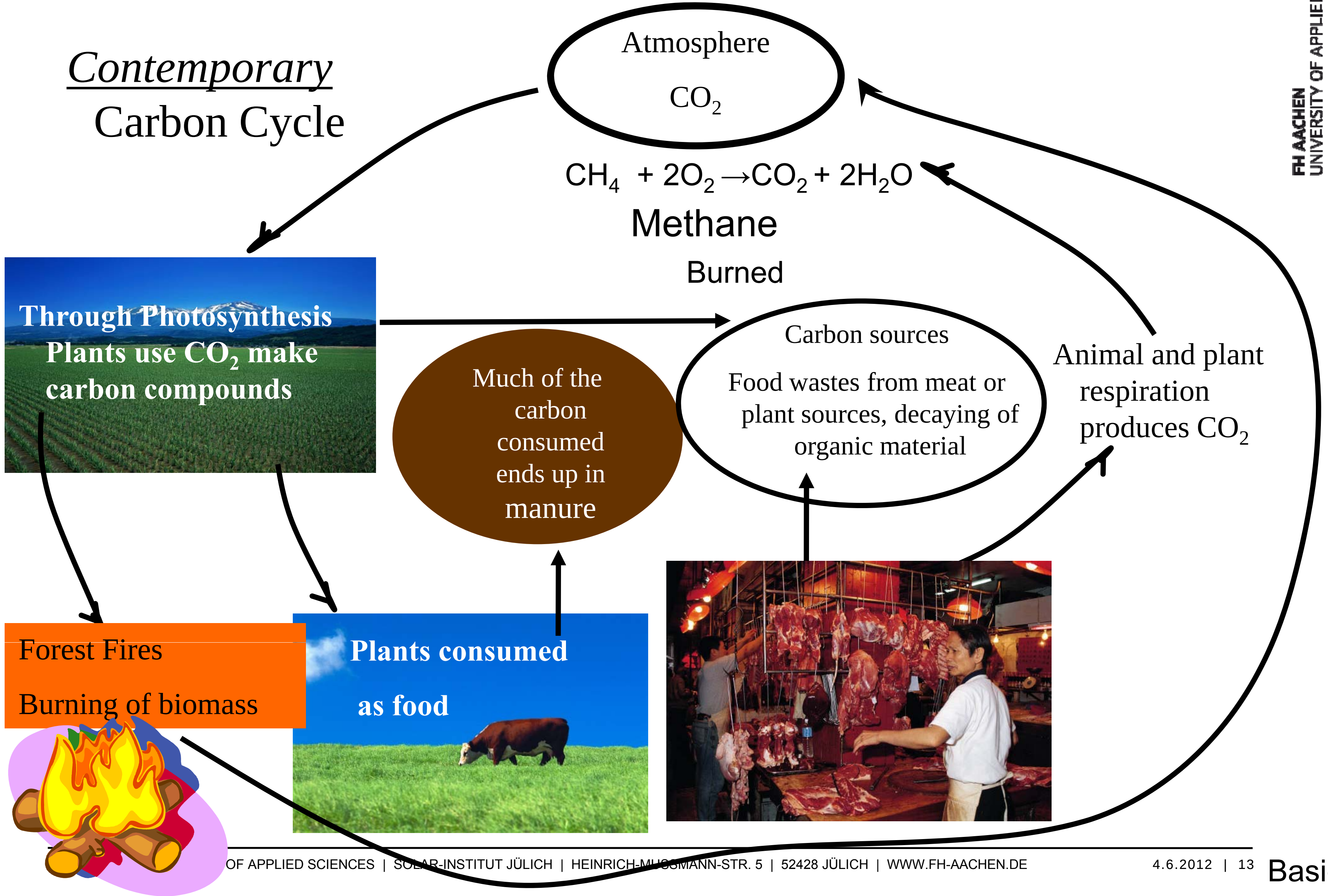
only if enough trees are planted

20 to 50 years growth cycle

Slower carbon cycle can increase atmospheric carbon for 20 to 50 years – Burning forest biomass is a slow cycle

CO_2 contemporary cycle

Contemporary
Carbon Cycle



A need for speed

A fast carbon cycle is important in order to prevent even temporary increase in CO_2

CO_2

In Atmosphere

Methane

Burned as fuel

Crops grown and harvested over several months

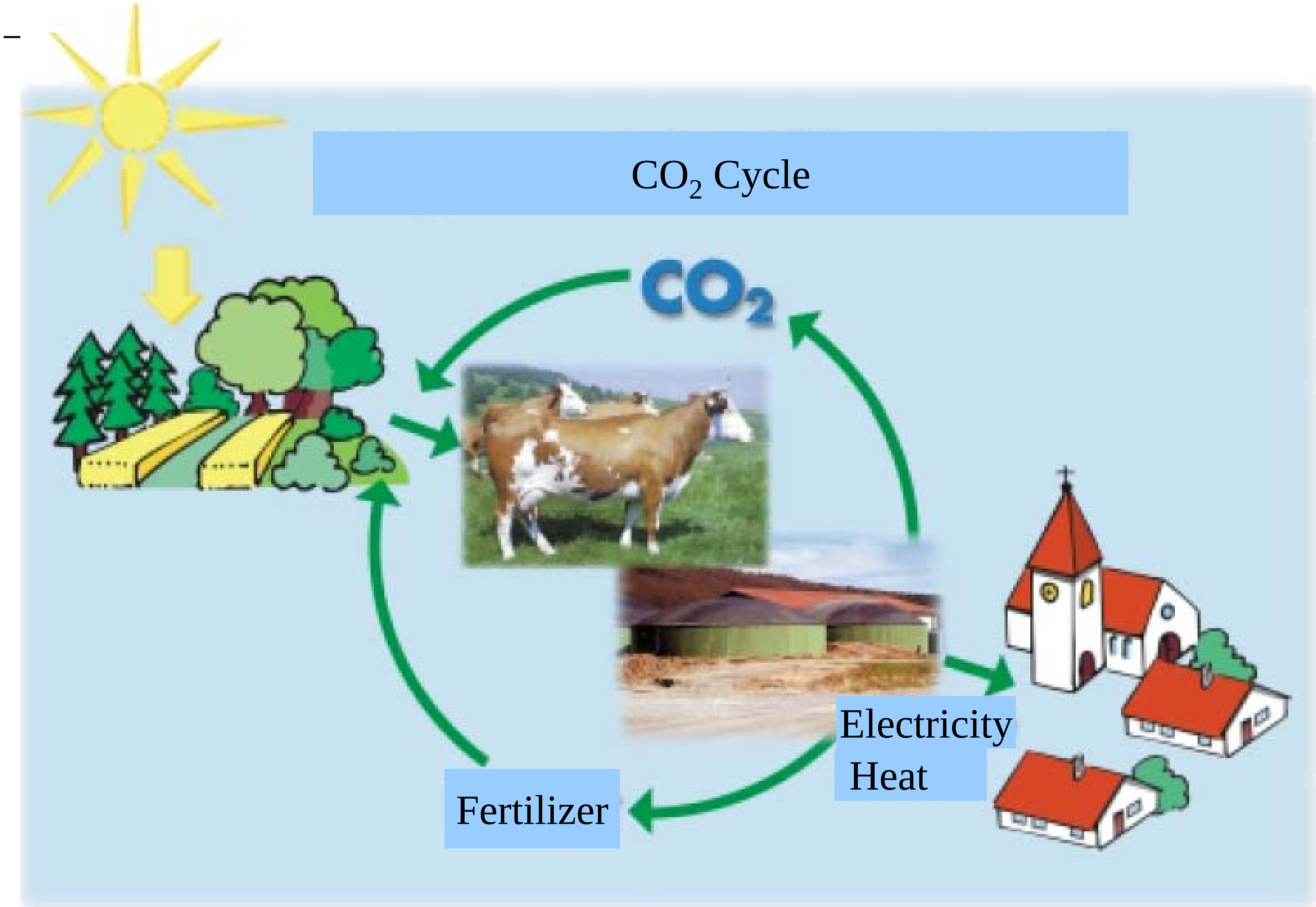
Carbon continually recycled

Digester

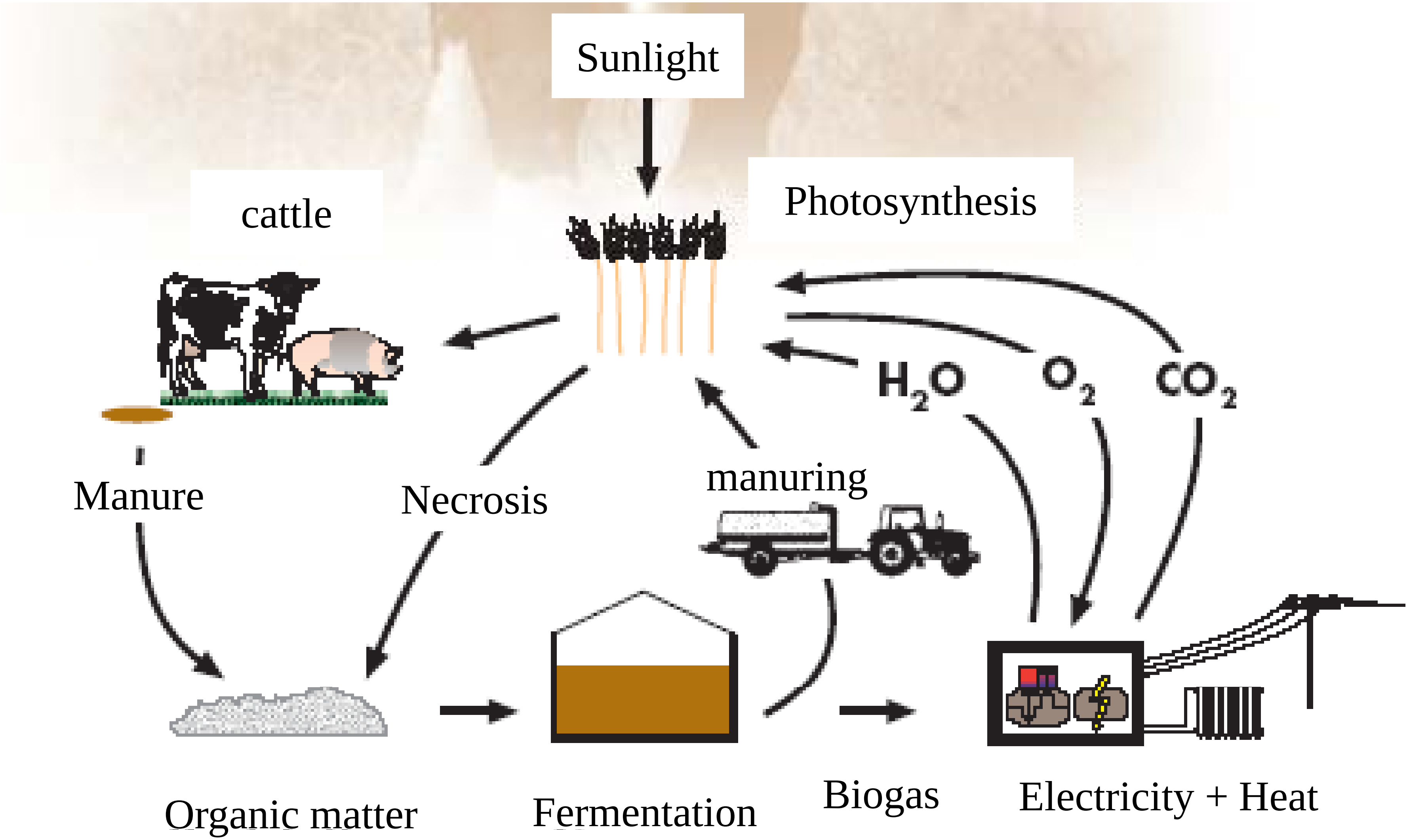
Manure

FOOD WASTE

CO_2 and cycle of matter



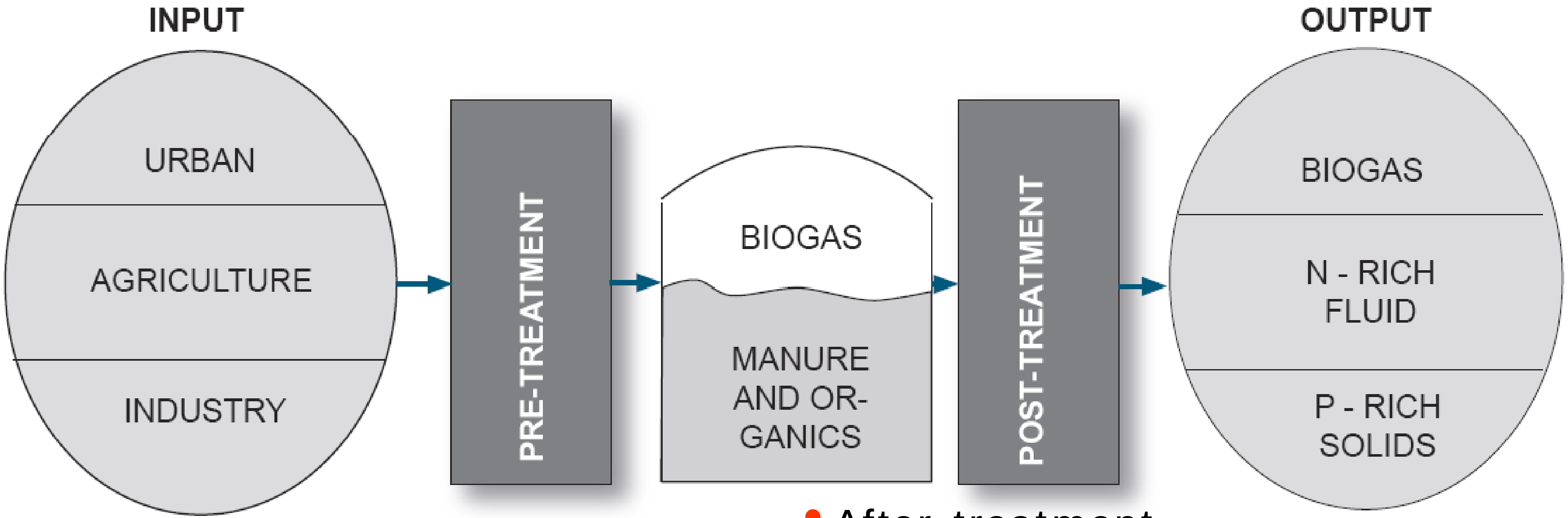
Cycle of matter



Multifunction of biogas

- Power, heat & fuel
- Reduces pathogens
- Weed seed reduction
- Fly control
- Avoidance of methane
- Protects water resources
- Feeding gas into the distribution net
- Reduces odor from land application
- Strong industrial growth
- Saving of mineral manure

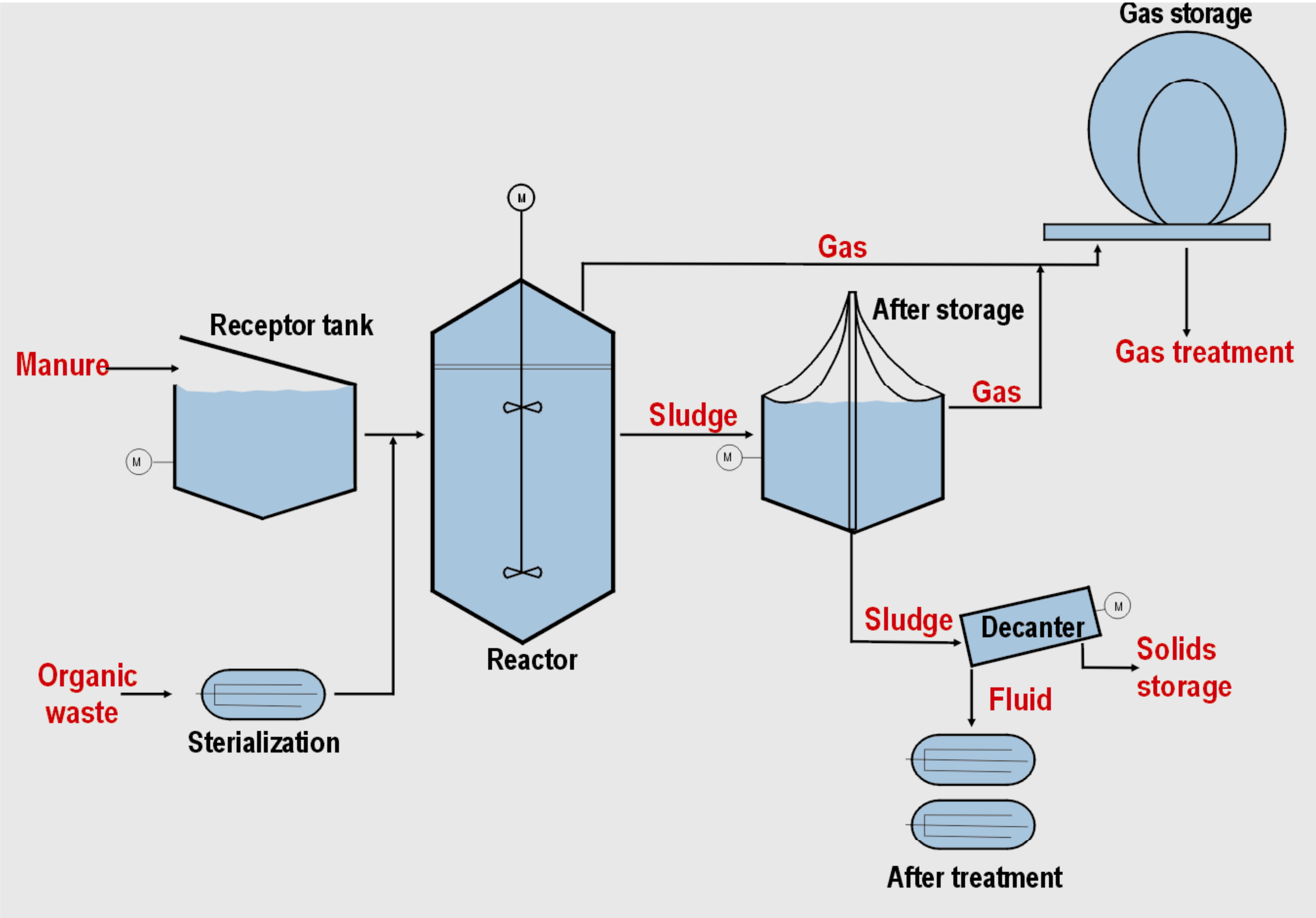
Biogas process



- Pre-treatment
  - Mixing
  - Macerating
  - Hygienisation/ sterilisation
  - +/- other pre-treatment: e.g. concentration
- Digestion
- After-treatment
  - Store
  - Separate
  - Upgrade
- End use
  - Land application
  - Move and apply
  - Transport market / or disposal

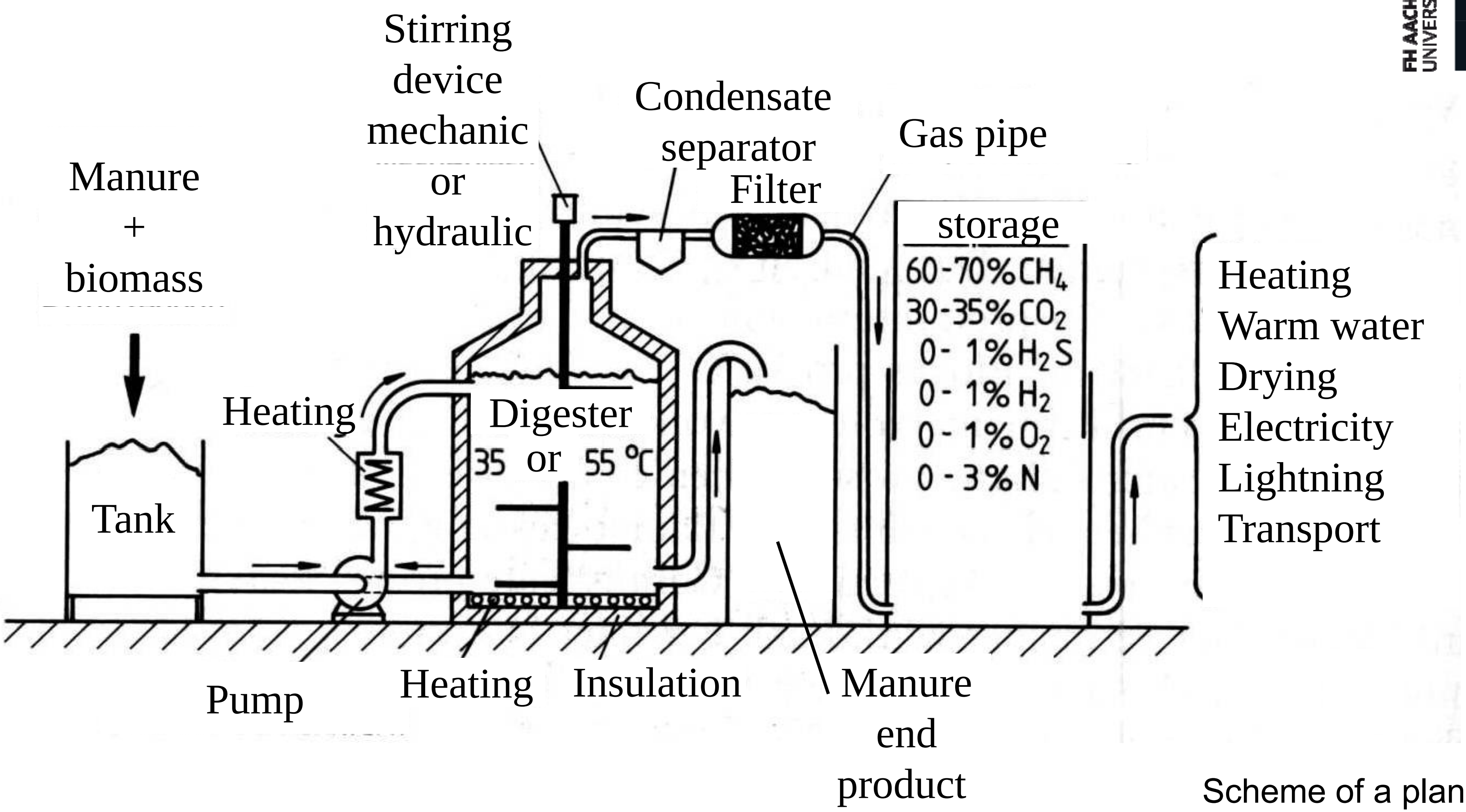
Scheme of a plant

Biogas plant design



Scheme of a plant

Scheme of a continuous biogas plant

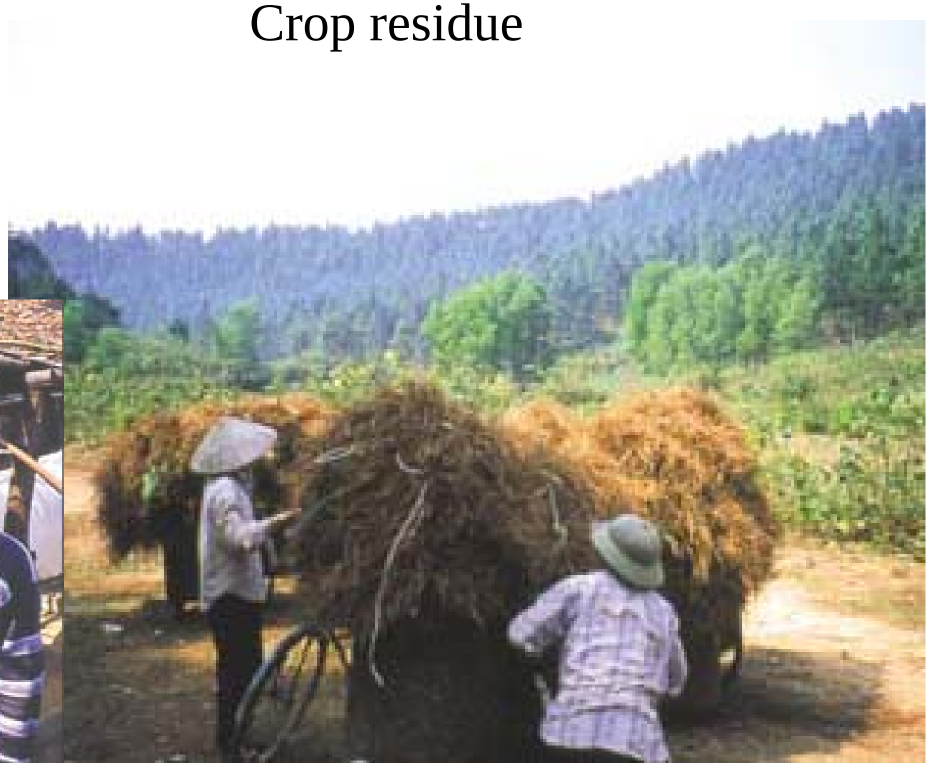


Scheme of a plant

Biomass energy in developing countries

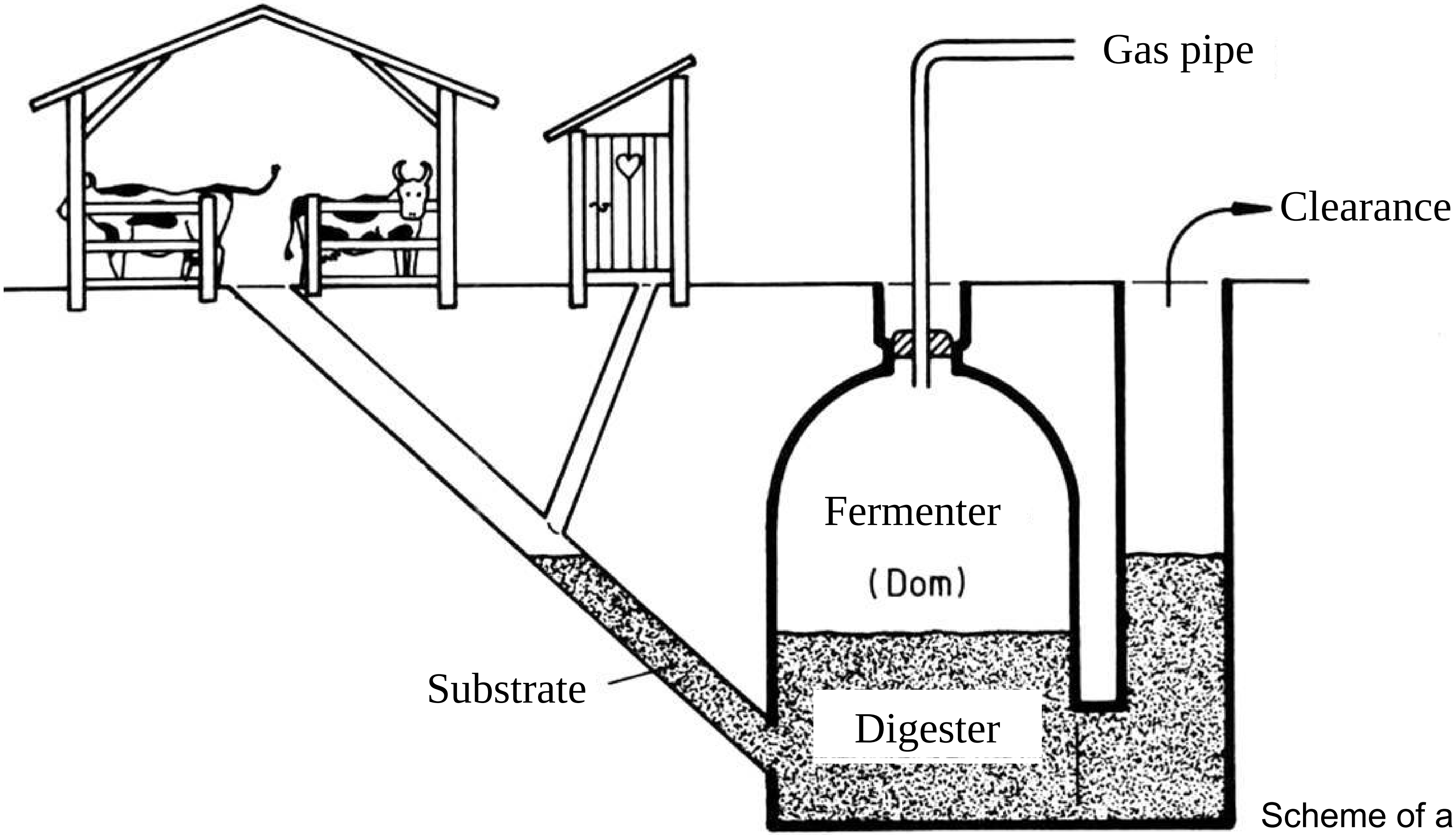
Biogas from
pig waste

Crop residue

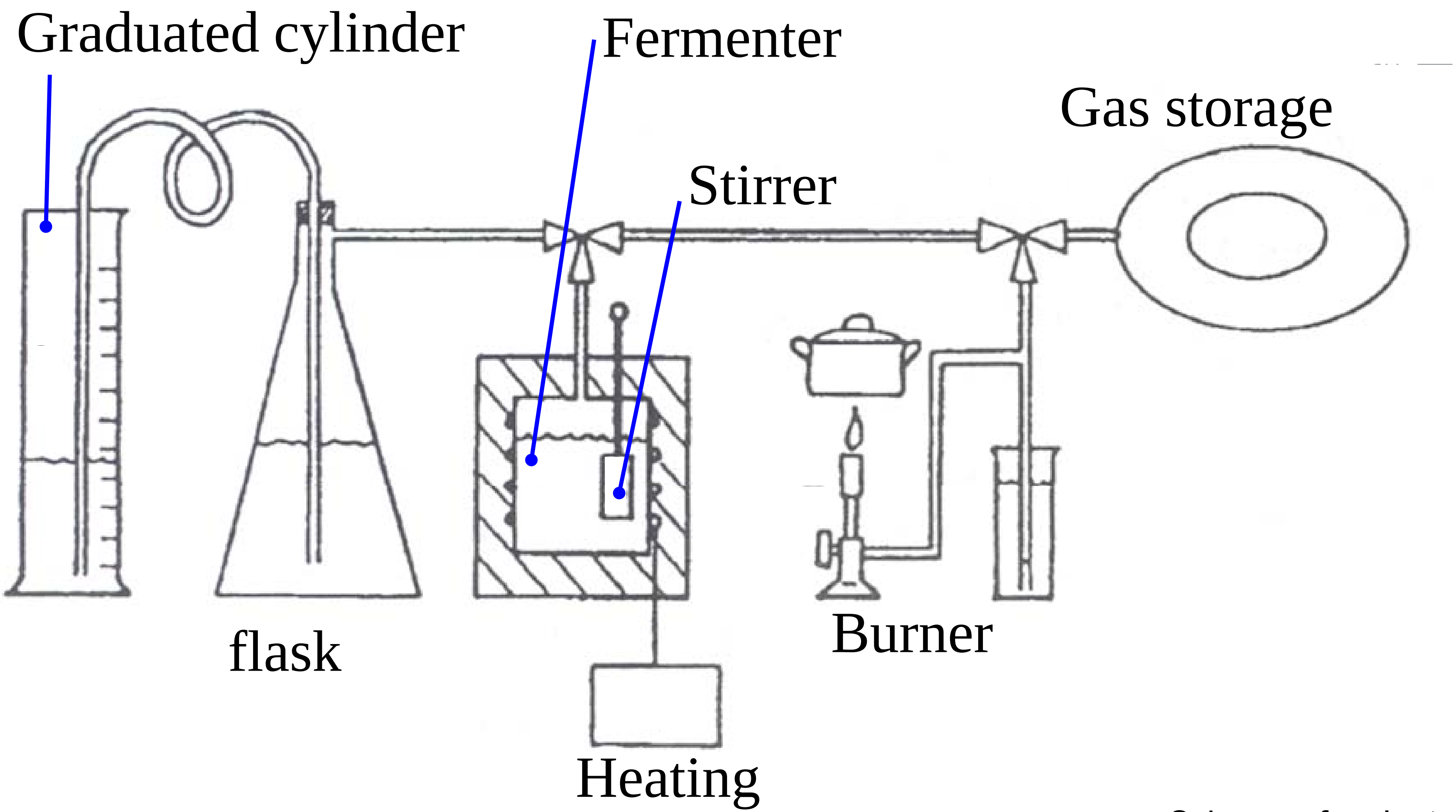


Scheme of a plant

Dom biogas plant for developing countries



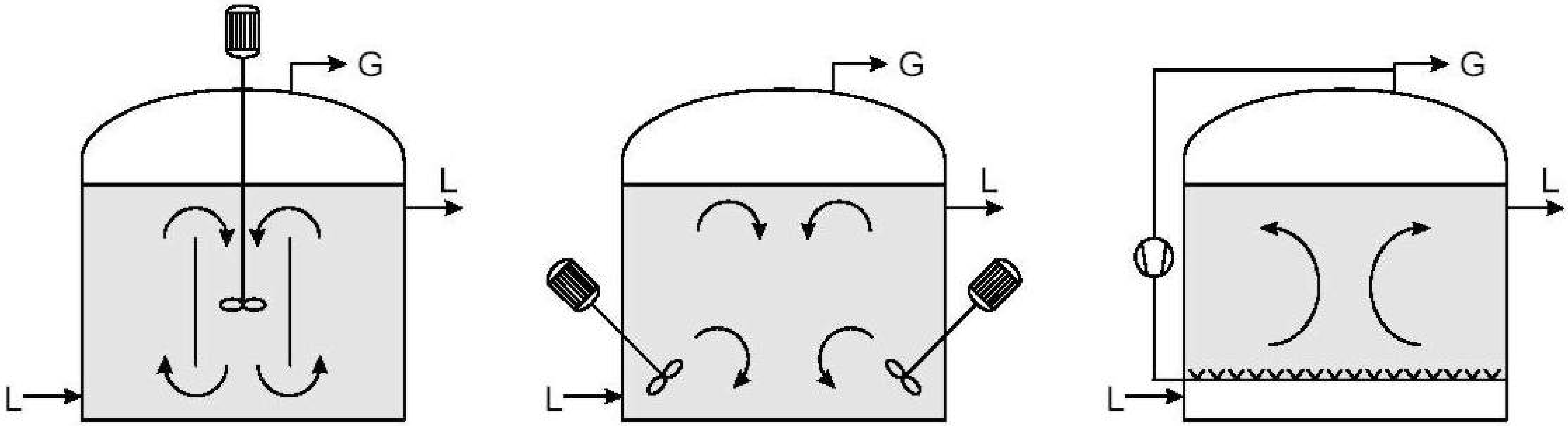
Scheme of a plant



Scheme of a plant

Fermenter types

Complete stirring reactors



Advantages:

- cost-efficiency above 300 m^3
- Variable operation
- Easy maintenance

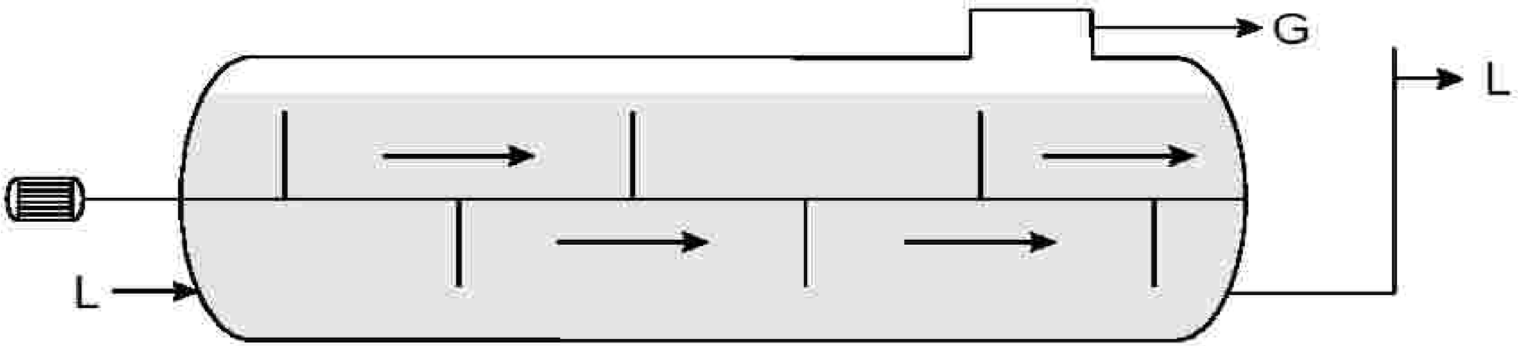
Disadvantages:

- Huge plants need to be covered
- Bypass flow possible
- Swimming and sinking layers possible

Source: Weiland, FAL 2006

Fermenter types

Plug flow reactors



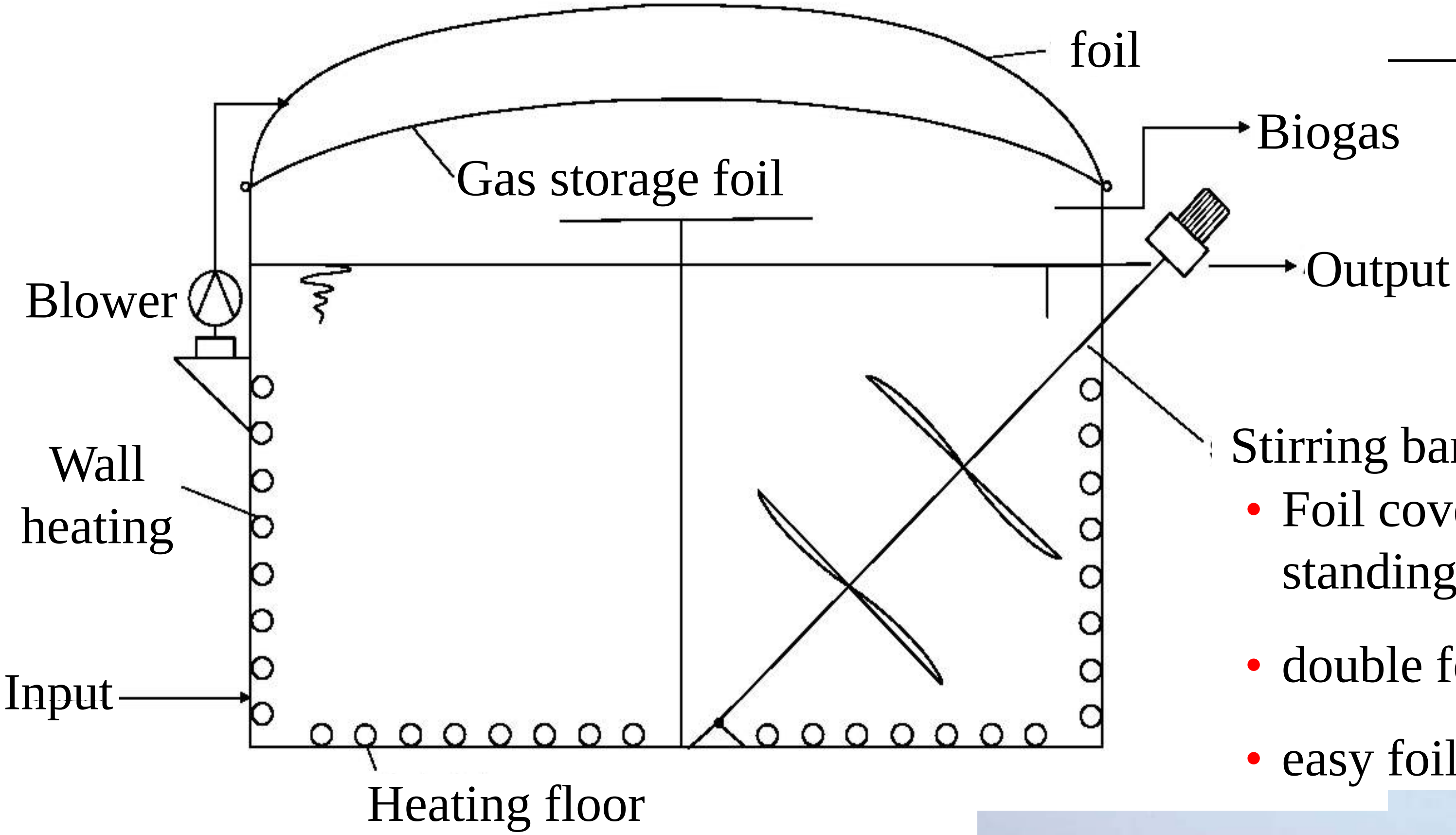
Advantages:

- Pumpable substrates
- Compact system
- Separation of digestion layers in the flow
- Avoidance of swimming and sinking layers
- Avoidance of bypass flow
- Small residence time
- Small heat losses

Disadvantages:

- Cost-effective only in small dimension
- Total emptying of the device needed

Source: Weiland, FAL 2006



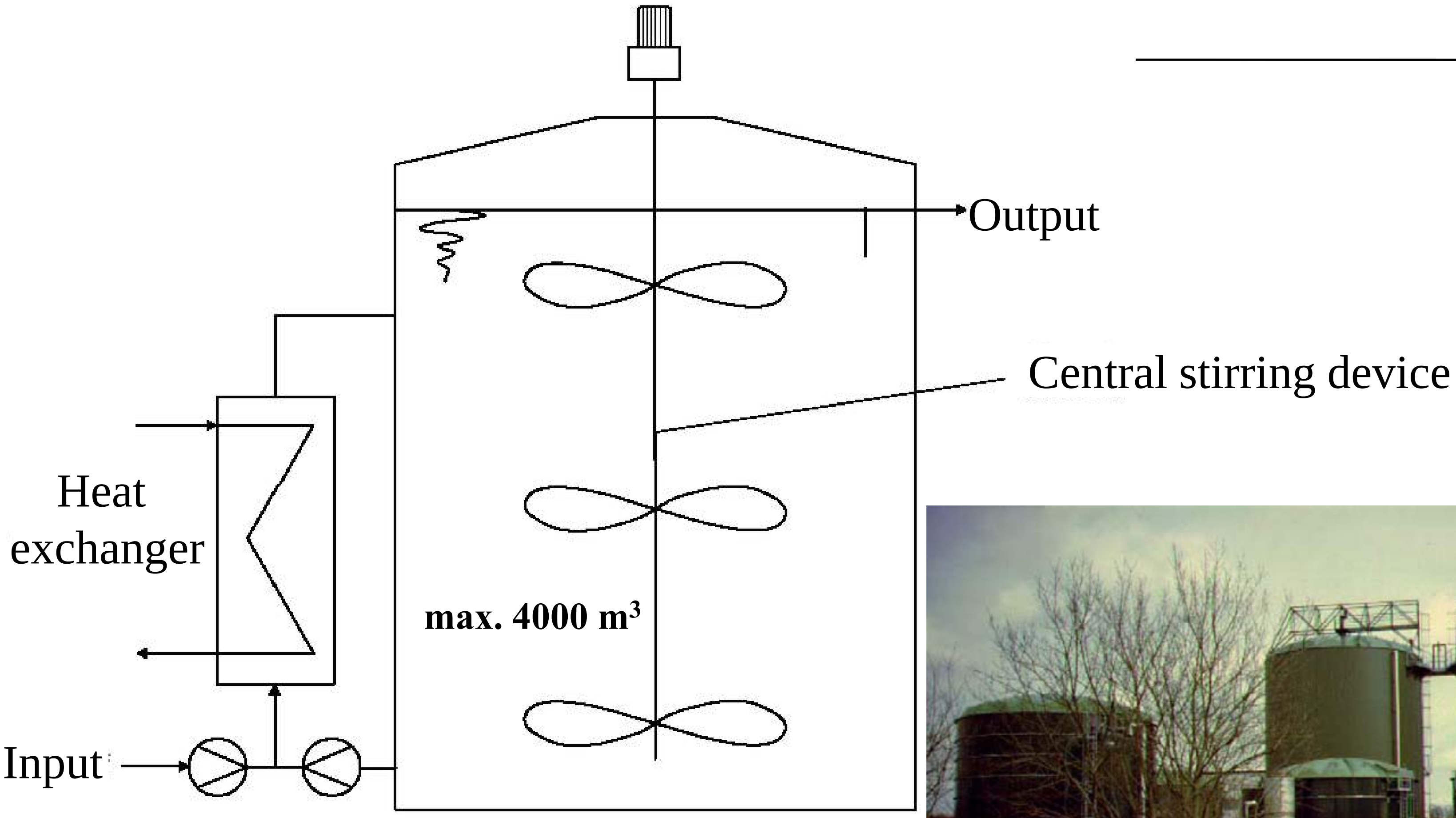
- Foil cover used by 50 % of standing fermenters
- double foil used by 60 %
- easy foil used by 40 %

Source: Weiland, FAL 2006

- Gas-proof cover with up to 34 m fermenter diameter
- Central stirring device not applicable

Types of digestion

Huge fermenter with central stirring



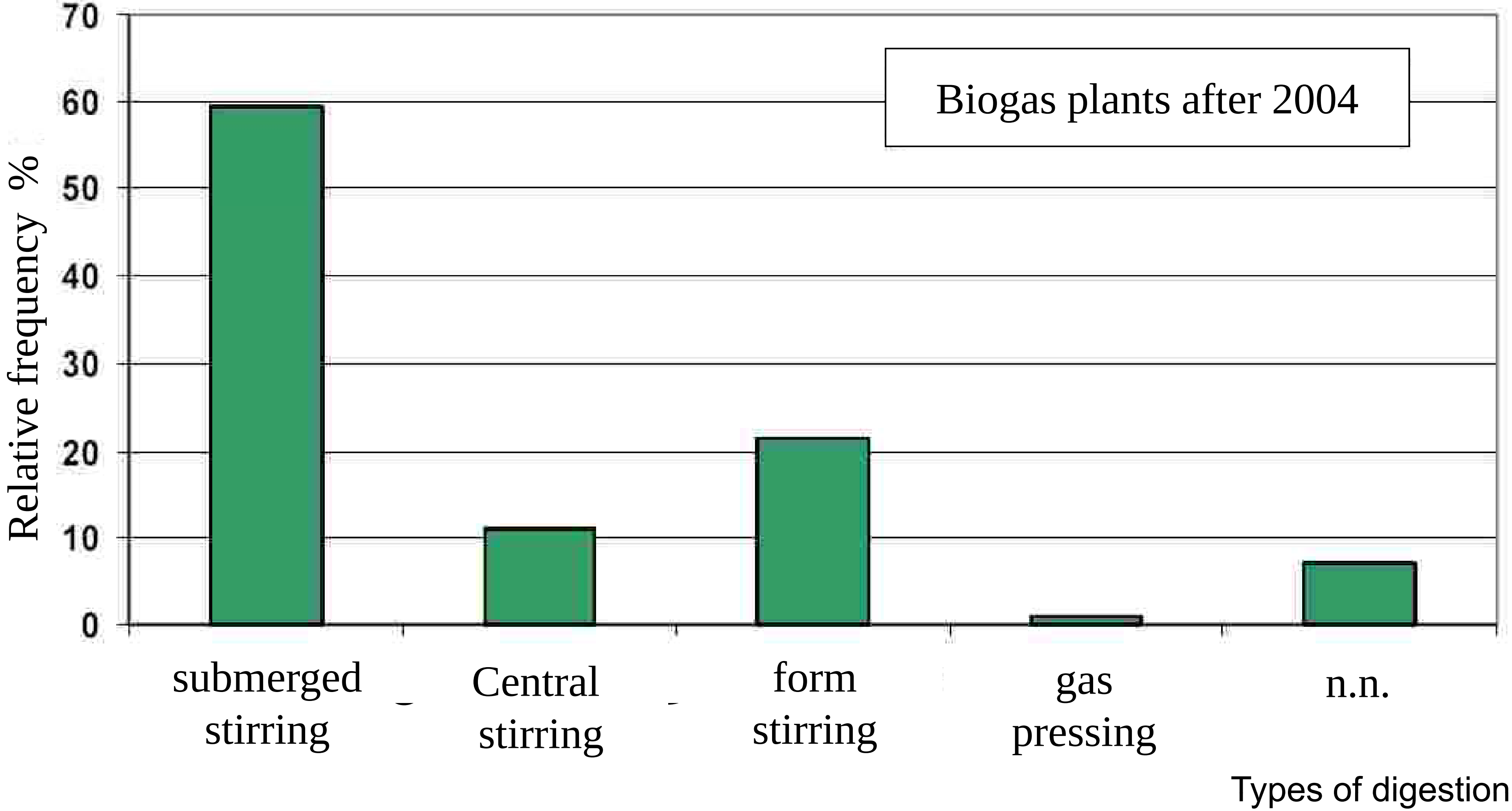
- Odor emission possible
- Use in huge fermenters (up to app. 4000 m^3)

Source: Weiland, FAL 2006

Characteristics of the fermenter types

	Covered Lagoon	Complete Mix	Plug Flow
Level of Technology	Low	Medium/High	Medium
Digestion Vessel	Deep lagoon	Round, square in/above ground	Rectangular in ground
Supplemental Heat	No	Yes	Yes
Solids Concentration	0.5-2%	3-8%	6-11%
HRT (days)	45+	15+	15+
Optimum Location	Warm climates	All climates	All climates

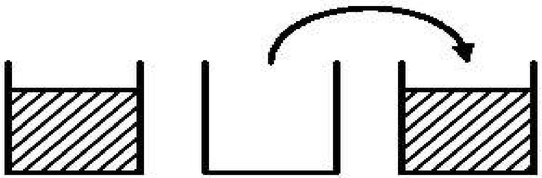
Relative frequency of fermenter types



Source: Weiland, FAL 2006

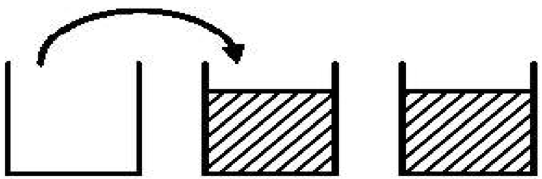
Ways of charging: Two different processes

Phase 1: discharging



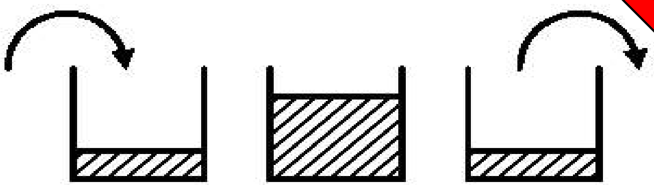
Storage tank full | Fermenter empty | Storage tank full

Phase 2: charging



Storage tank empty | Fermenter full | Storage tank full

Phase 2: fermentation



Fermenter full

Batch process

-charging and discharging phases

-defined residence time

-no constant gas production

Interchangeable tank

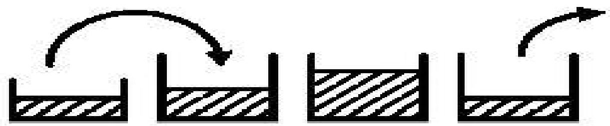
-2 tanks

-defined residence time

-uniform gas production

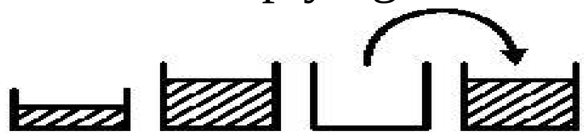
-Important for dry fermentation

Phase 1: fermentation



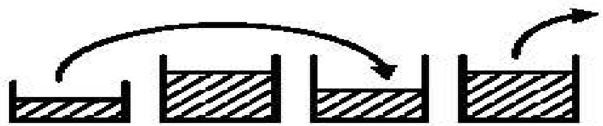
Slurry store | charging tank 1 | fermentation tank 2 | discharging storage tank

Phase 2: emptying tank 2



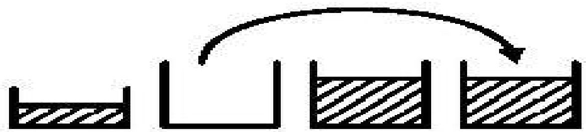
Slurry store | fermentation tank 1 | discharging tank 2 | charging storage tank

Phase 3: fermentation



Slurry store | fermentation tank 1 | charging tank 2 | discharging storage tank

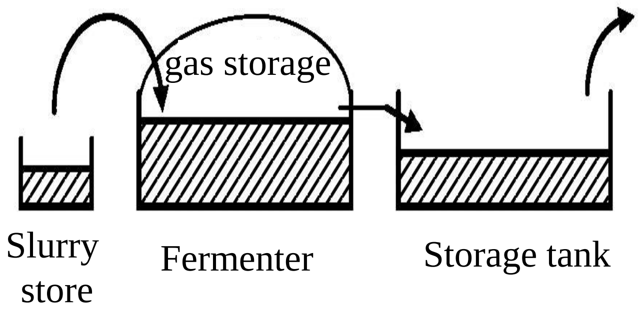
Phase 4: emptying tank 1



Slurry store | discharging tank 1 | fermentation tank 2 | charging storage tank

Continuous ways of charging

Flow-through Process



-one up to multiple daily charging

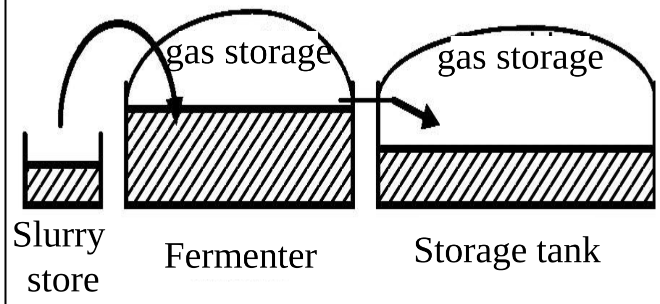
-Fermenter always filled

-uniform gas production

-Good load of the digester

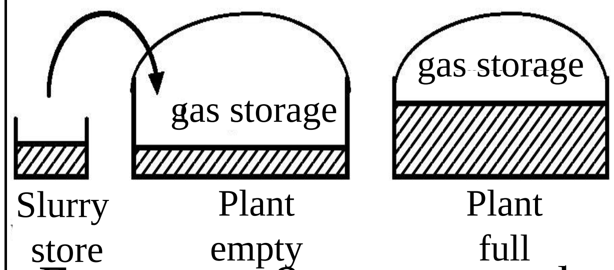
-Danger of bypass

Combined Process



- Fermenter and storage tank covered
- Uniform gas production
- no defined residence time
- possibility of bypass

Storage Process



-Fermenter & storage tank combined and covered

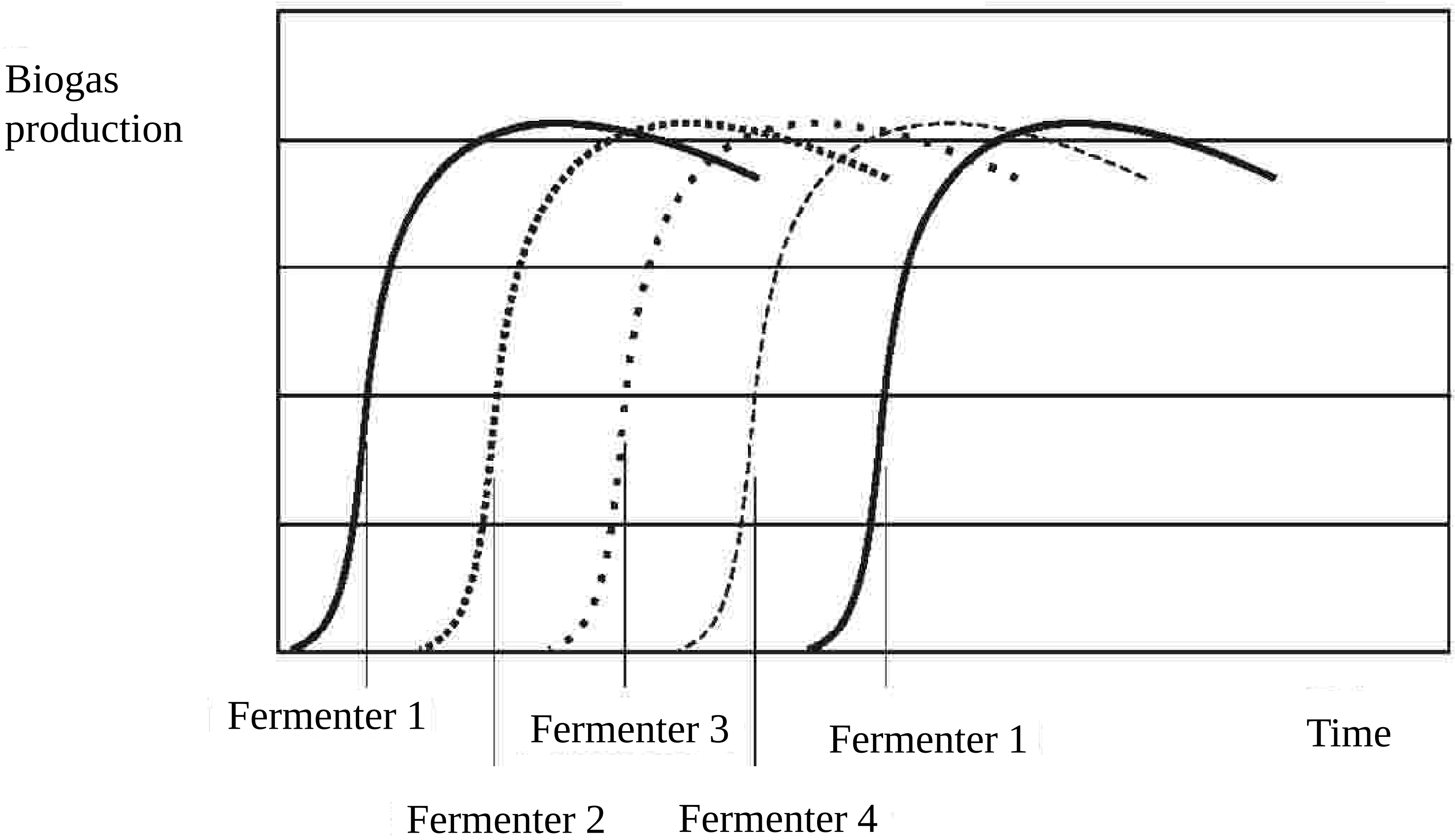
-Complete discharging

-Slowly advancing continuous charging

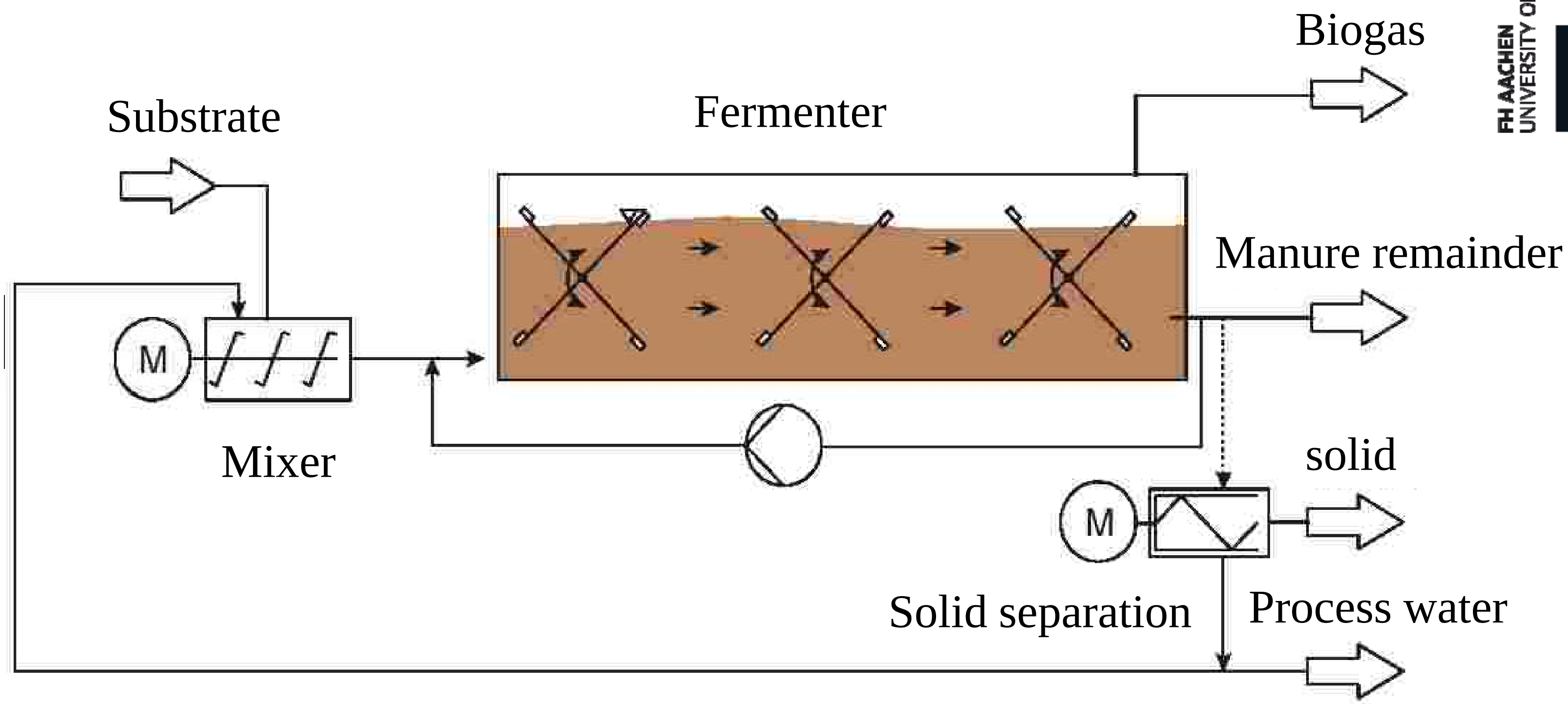
-Less uniform gas production

-Longer residence time

Dry fermentation



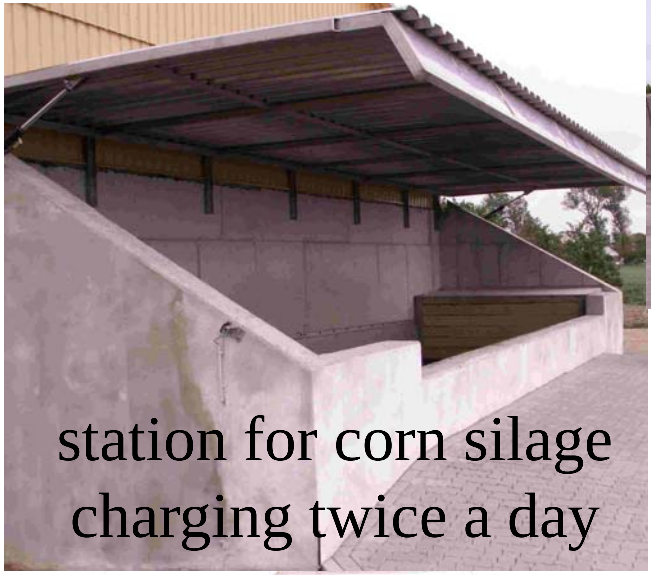
Dry fermentation



→ high capacity (> 20.000 t/a)

Operation

Components of a biogas plant



station for corn silage charging twice a day

Storage of 5000 t corn silage

Tank mixer for the homogenization of corn silage and manure

continuous corn feeding in premixed tank (20 t/day)

Heat exchanger

Operation

Gas processing

Problem: Biogas is steam saturated and contains beside of CH_4 and CO_2 also small amounts of H_2S

→ **H_2SO_4 corrodes components!**

→ desulphurization und drying of the biogas!

Desulphurization:

biological: $H_2S + O_2$ + Bacteria → S

chemical: H_2S + chemical additives → Sulfides,..

Additives: e.g. caustic soda, iron chlorate

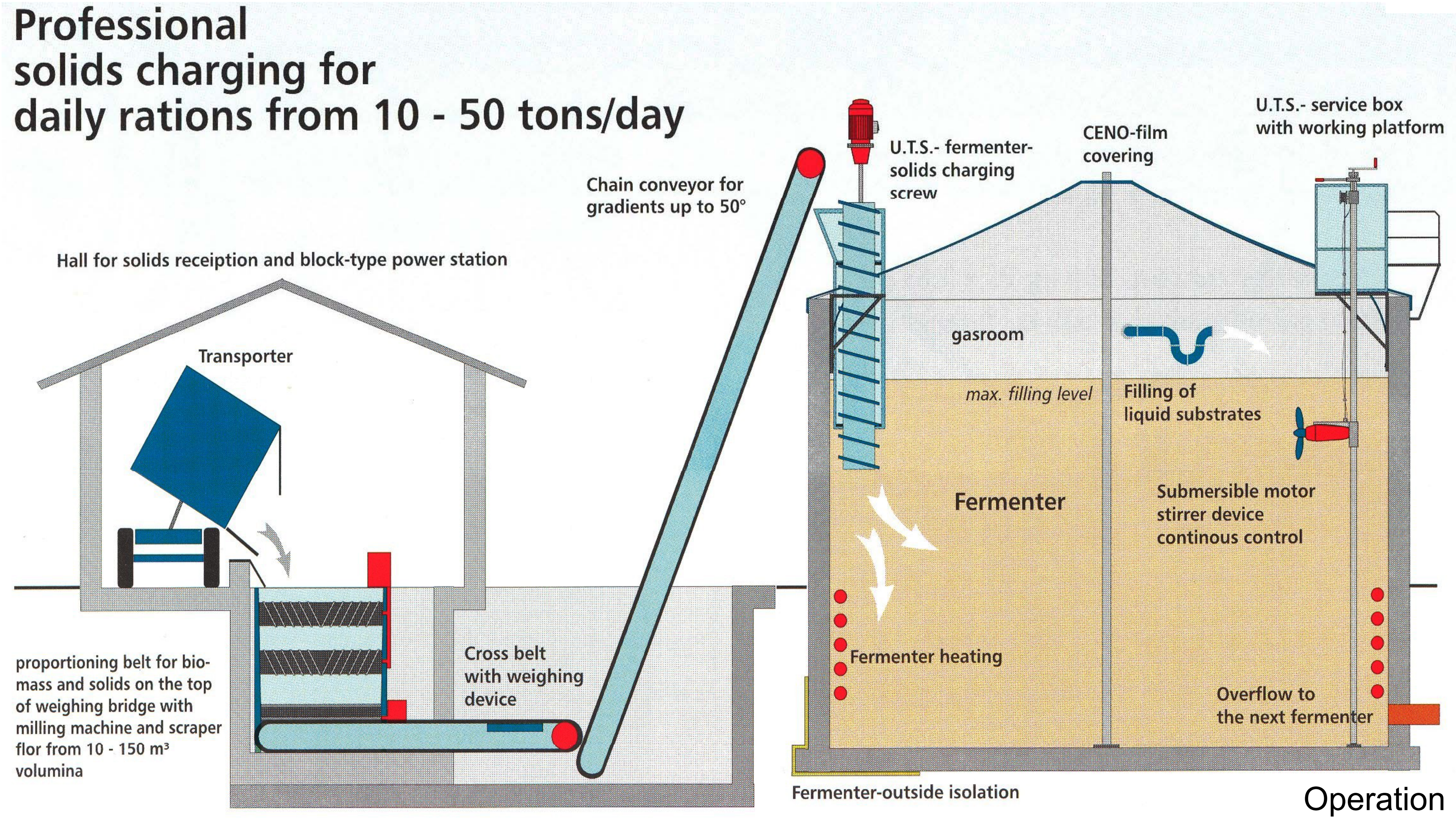
Example

Capacity:	32,000-35,000 tons & fermenter
Volumetric capacity:	1000 m^3
Biogas production:	485 Nm^3 / h
Treatment capacity per year:	approx. 3,9 Mio. Nm^3 biogas
capacity per year:	approx. 40.000.000 kWh into gas net
Supply:	Gas net of Munich
Investment:	approx. 9,800,000 Euro
Start of Construction:	June 2006
Starting up:	December 2006

Source: www.biogas-netzeinspeisung.at/anlagenbeispiele

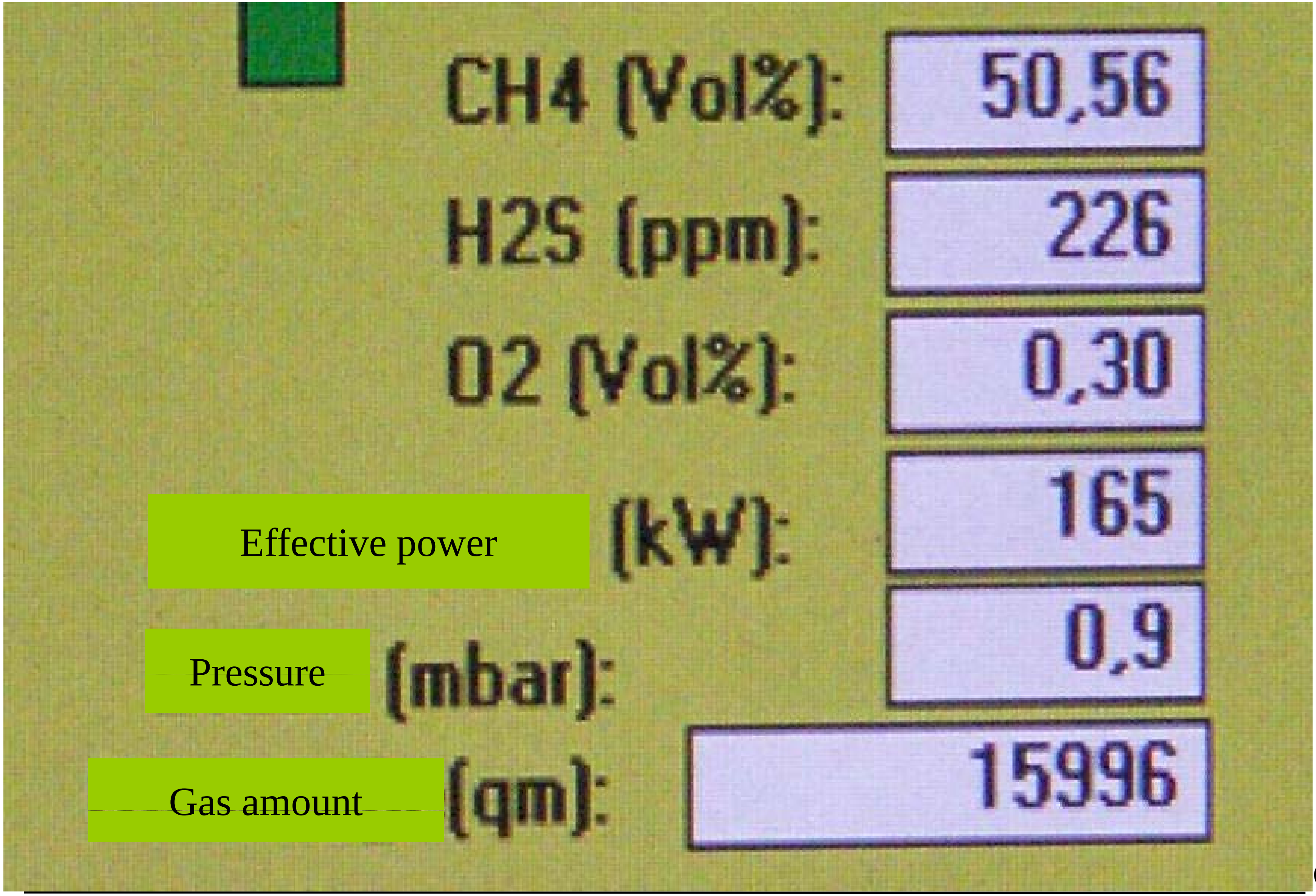
Operation

Solid biomass charging



Operation

PC control of a biogas plant



Control

Example

Construction		Dimension of Fermenter	460 m^3		98.000	€
Motor		Residence time	50 d		3.000	€
Total Investment					**101.000**	**€**
Amortisation					7.500	€/y
Interest		6%			3.000	€/y
Insurance		0,50%			500	€/y
Maintanance					3.000	€/y
Costs of labour		275 h	15 €/h		4.000	€/y
Electricity & ignition					2.500	€/y
Costs of operation					**20.500**	**€/y**
		Utilizable energy production		122,000 kWh/y		
Remuneration	standard	11.5 cent/kWh			14.000	€/y
Renumeration	bonus	6 cent/kWh			7.500	€/y
Renumeration	CHP	2 cent/kWh			500	€/y
Gains					**22.000**	**€/y**
Earnings					**1.500**	**€/y**

Application of biogas

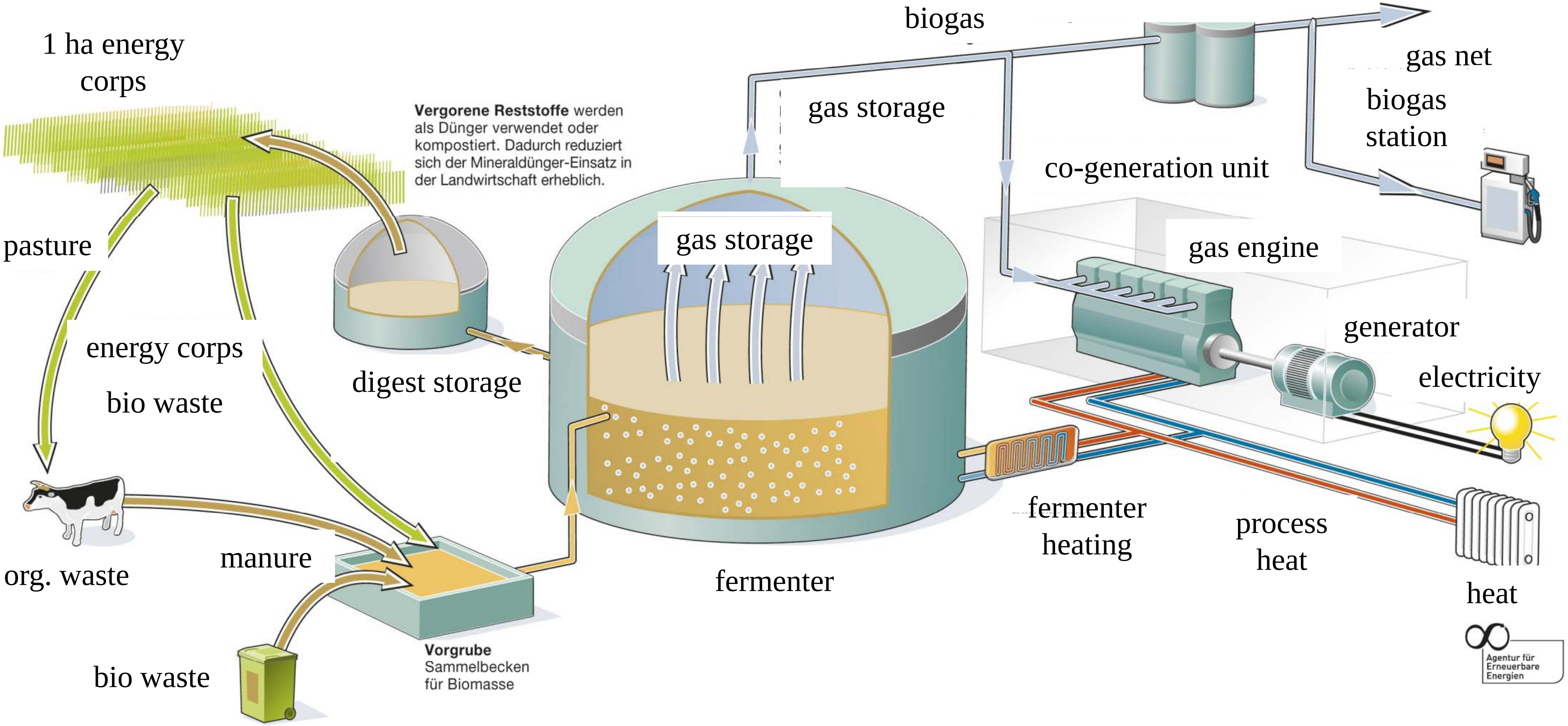
- Block heat and power block
- Micro turbines
- Fuel cells
- Gas supply net
- Fuel
- Power plants

biogas plant

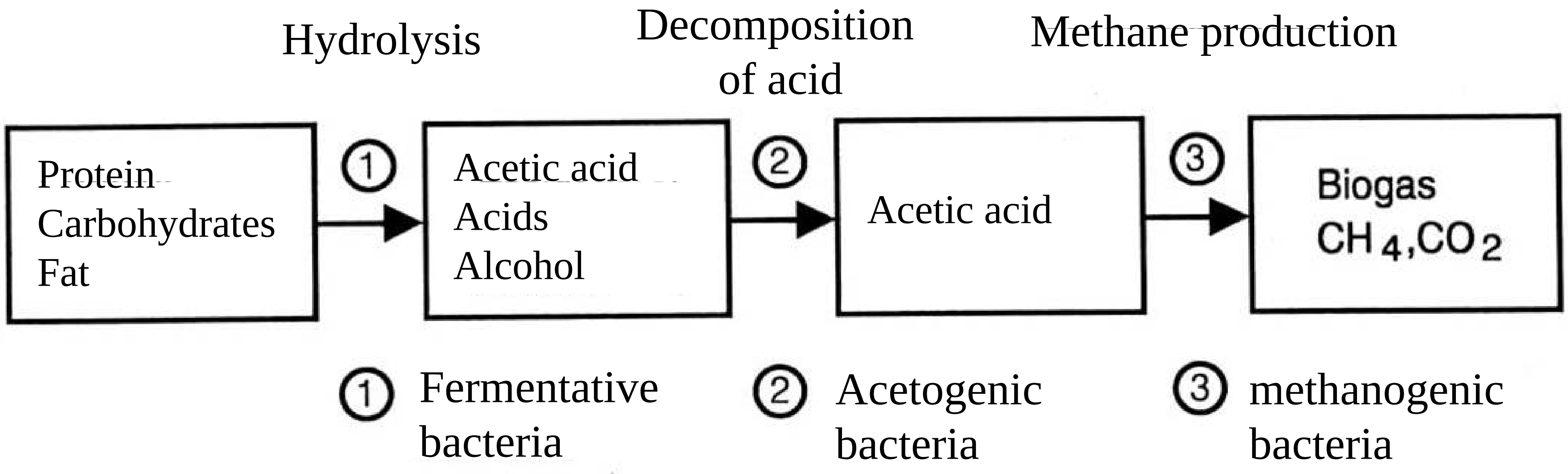
From 500 kg cow per day 1.5 m³ biogas

From 1 ha grass 6,000 m³ biogas

From 1 ha 12,000 m³ biogas

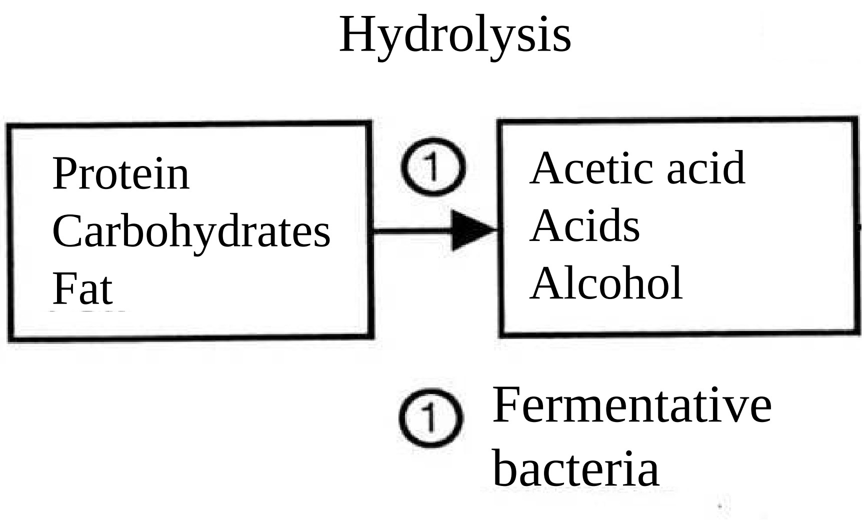


Process of fermentation



Principle of the fermentation

Stage I



Polymers → Monomers

Fat → Fatty acids

Protein → Amino acid

Carbohydrates → Saccharide

Intermediate products:

Acetic acid CH_3COOH

Alcohol

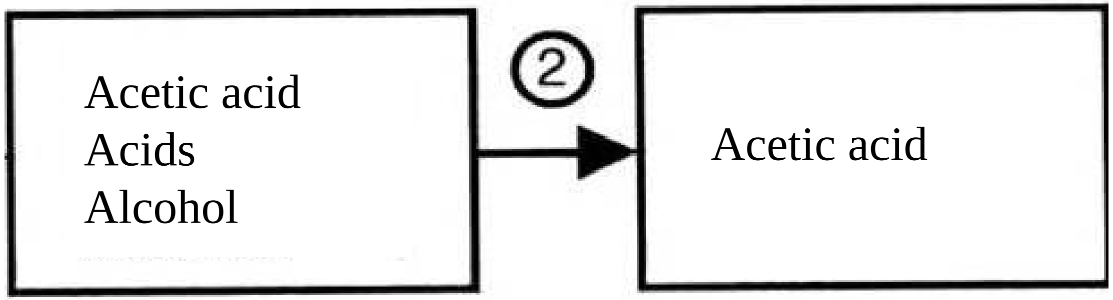
H_2O CO_2

H_2 NH_4

Principle of the fermentation

Stage II

Decomposition of acid



Protein
Carbohydrates
Fat

② Acetogenic bacteria

Products

H_2O

H_2

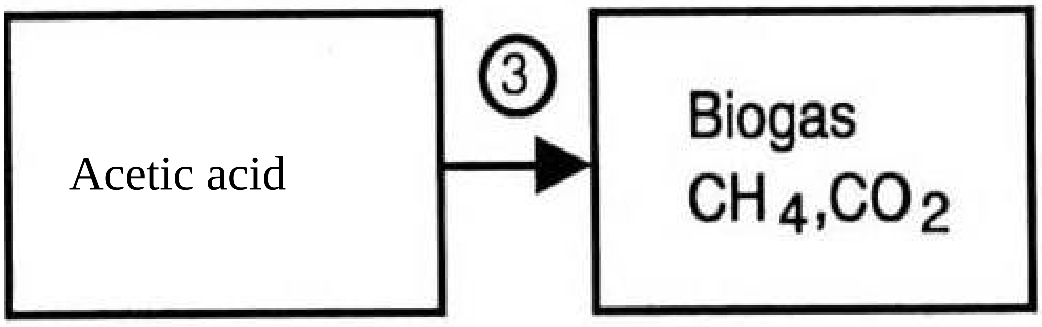
CO_2

Brew end product CH_3COOH

Principle of the fermentation

Stage III

Methane production



(3) methanogenic bacteria

Acetic acid from stage I → CH_4 H_2 H_2S NH_3

Acetic acid from stage II→ CH_4 H_2 H_2S NH_3

Ecology of the Methanogens

- Methanogens require **anaerobic conditions**
- In the digestive systems of herbivores, marshes or lake bottoms.
- Many require **warm conditions** to work best.
- They are associated with a **source of organic matter** (e.g. plant remains or sewage) and with **heterotrophic bacteria**
- The heterotrophs break down this organic matter to release compounds such as ethanoic acid (acetic acid or vinegar) and hydrogen
- The ethanoate ions are a substrate for the methanogens

Biochemistry of the methanogens

- Methanogens are **chemoautotrophs**
- Methanogens produce methane:

- Using ethanoate (acetate) that may be derived from the decomposition of cellulose:

$$CH_3COO^+ + H^- \rightarrow CH_4 + CO_2 \qquad +36\ kJ\ mol^{-1}$$

- Or using hydrogen and carbon dioxide produced by the decomposers:

$$4\ H_2 + CO_2 \rightarrow CH_4 + 2\ H_2O \quad +130.4\ kJ\ mol^{-1}$$

Impact parameters

- Substrate form
- Concentration of organic dry matter
- pH
- Temperature
- Digestion time (residence time in the fermenter)
- Substrate charging

Substrate

- must be degradable
- must/should be available at a constant mass/volume flow
- should have a nearly constant composition
- Concentration of organic dry matter should be higher than 2 %
- should be a liquid slurry
- Digester volume should be more than 100 m^3

Composition of manure

Biogas potential: substrate	**total organic solids (%)**	**m^3 CH_4 / m^3**
Waste water, municipal	0.05	0.15
Waste water, food industry	0.15	0.5
Sewage sludge	2	5 to 10
Cow manure	8	20 to 30
Pig manure	6 to 8	30 to 50

	Pig manure [%]	Cow manure [%]	Chicken manure [%]
Carbohydrates	38	20	25
Fat	4	4	4
Protein	19	15	29
Crude fiber	20	40	15
Ash	19	21	27

Fertility and retention time

Material	Biogas m^3/kg ODM	Retention time Days
Wheat	0.367	78
Sugar beet	0.501	14
Haulm	0.606	53
Corn	0.514	52
Clover	0.445	28
Grass	0.557	25

optimum substrate with: 70 % manure
30 % biomass

Negative und optimum impact parameters

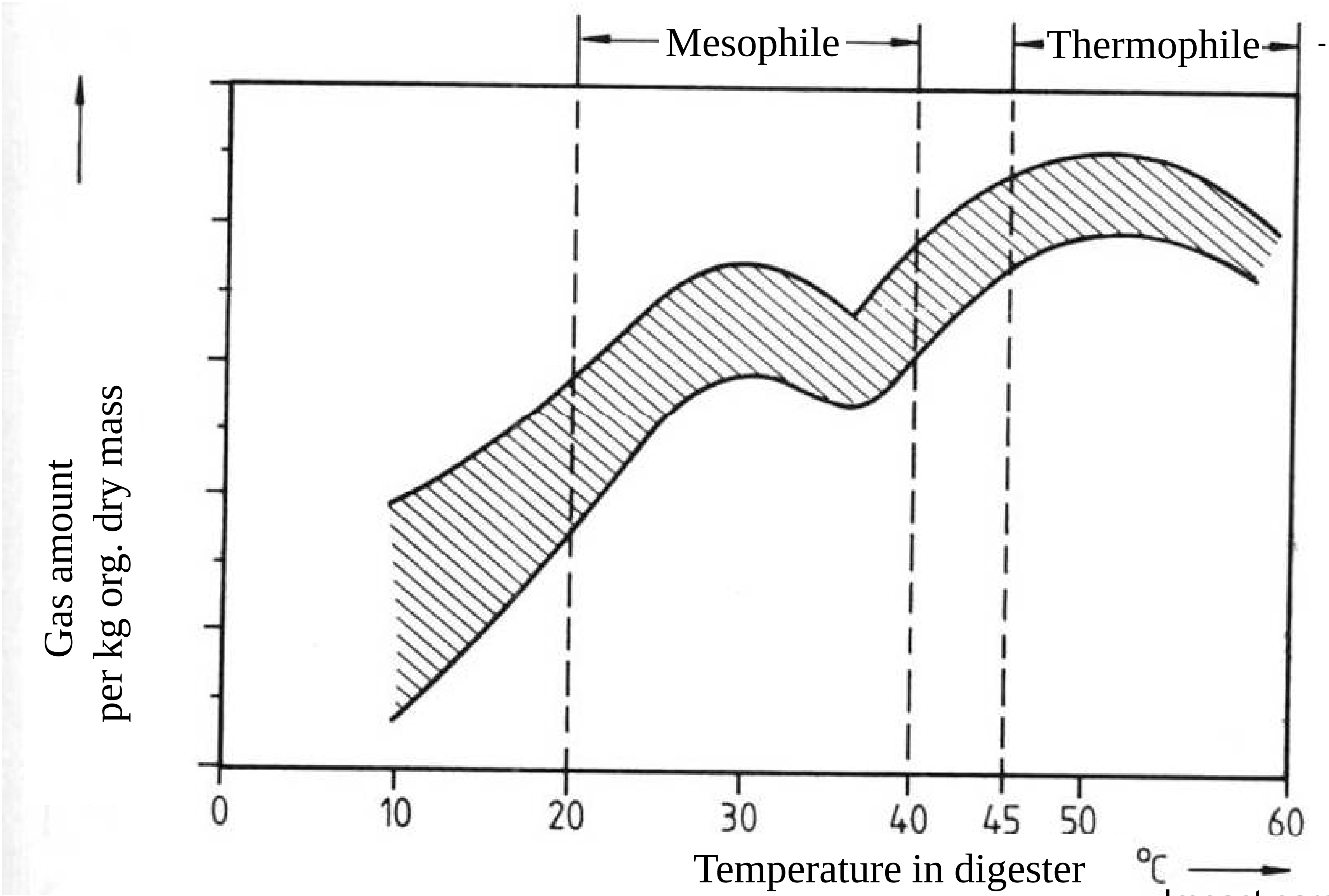
Substances with antibacterial impact:

- Heavy metals
- Mediums for the disinfection of stables
- Antibiotics for the animals

Optimum impact parameters:

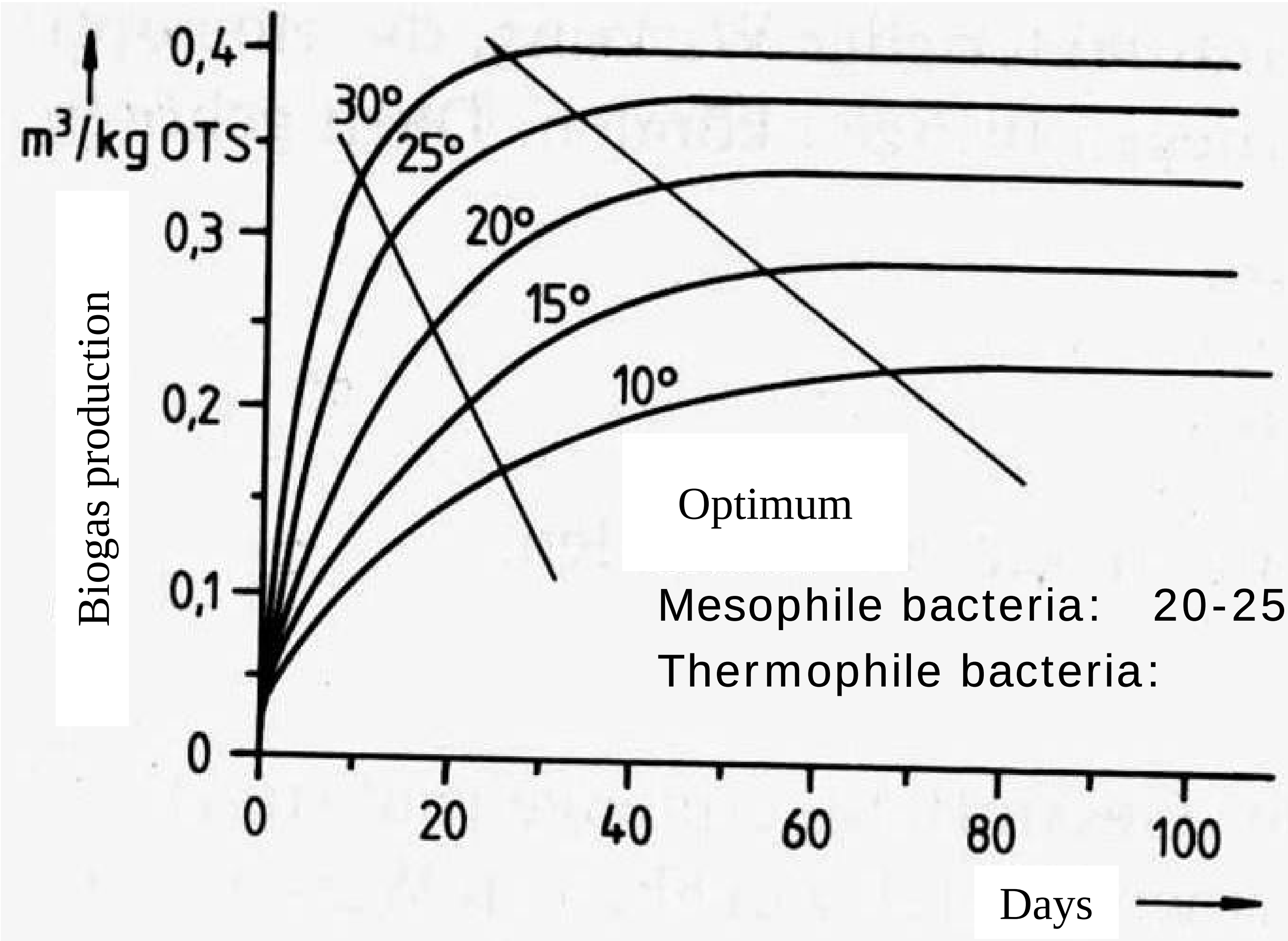
Dry substance concentration:	3 % -10 %
pH-value:	6.5-7.2

Temperature impact on gas production



Impact parameters

Residence time



Mesophile bacteria: 20-25 days

Thermophile bacteria: 3-10 days

Substrate supply

$$R_b = \frac{\dot{m}_{Su} C_{ODM}}{V_R}$$

R_b indicates quantity in kg of organic dry matter loaded per day

R_b: volume load
m_{Su}: mass of substrate
V_{Su}: volume of substrate
V_R: reactor volume
C_{ODM}: concentration of organic dry mass

- Complete digestion requires long residence time in the fermenter
- Long residence time require huge fermenters

$$V_R \approx V_{Su}$$

$$C_{ODM} = \frac{m_{ODM}}{m_{Su}} = \frac{V_{ODM}\,\rho_{ODM}}{V_{Su}\,\rho_{Su}}$$

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Substrate supply

$$t_{Vw} = \frac{V_{Su}}{\dot{V}_{Su}} = \frac{m_{Su}}{\dot{m}_{Su}}$$

t_{Vw}: residence time of the substrate

$$t_{Vw} \approx \rho_{Su} \frac{C_{ODM}}{R_b}$$

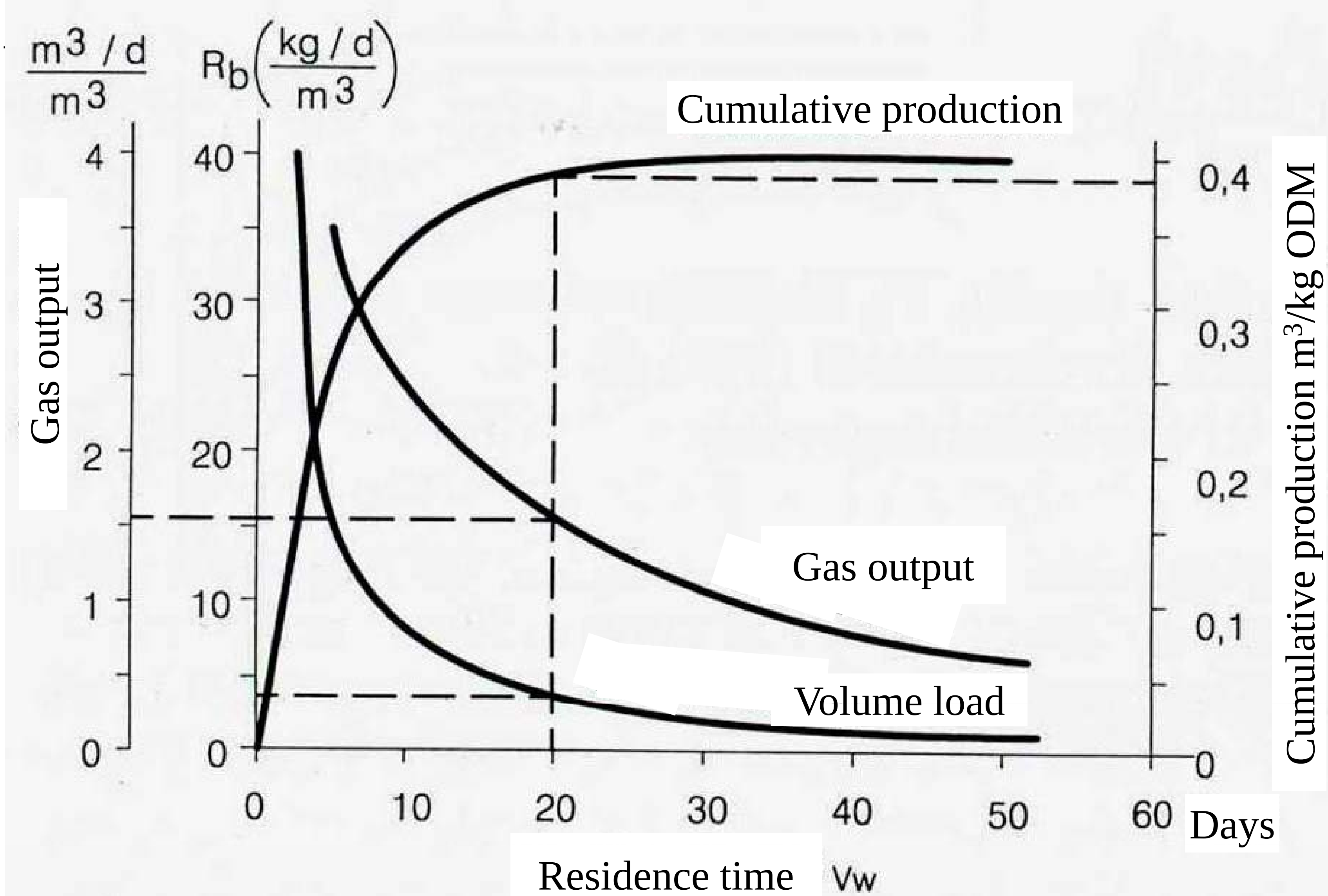
$R_b \downarrow \quad t_{Vw} \uparrow$

Example: C_{ODM} = 0.08 substrate density: 1000 kg/m³
residence time of the substrate: 20 days

$$R_b = \rho_{Su} \frac{C_{ODM}}{t_{Vw}} = 1000 \cdot \frac{0.08}{20} = 4\,\mathrm{kg\,ODM/m^3}$$

Impact parameters

Parameters of the biogas production



Impact parameters

Stirring device

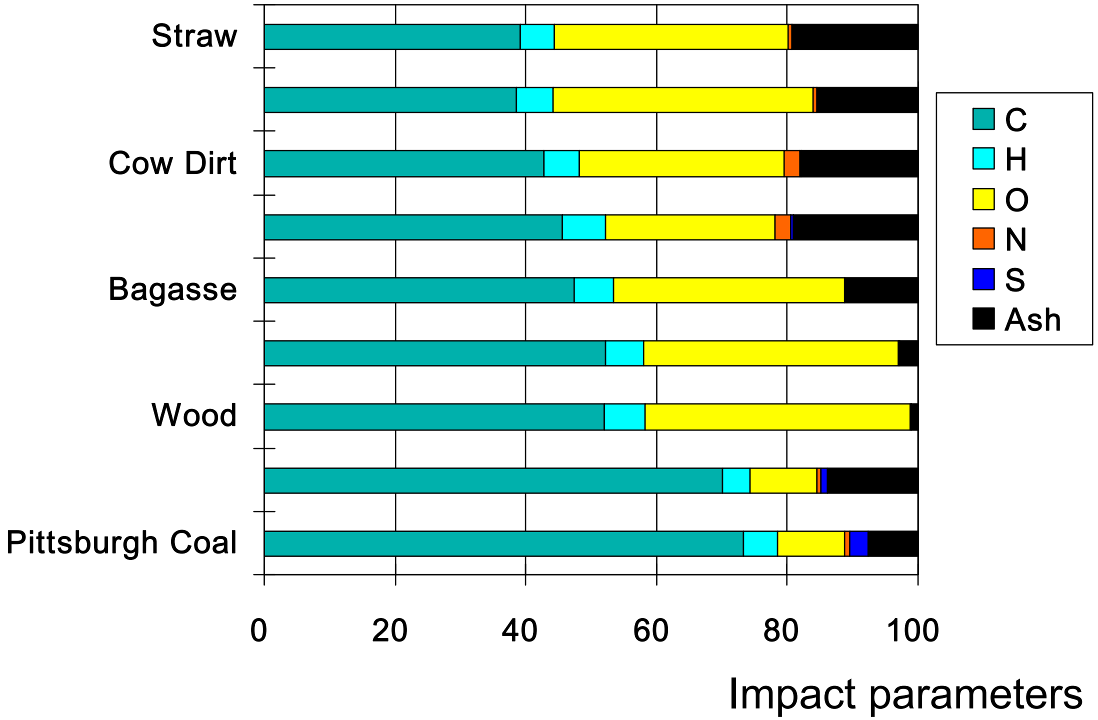
Why stirring is necessary in the digester:

- Prevents sinking layers on the bottom of the fermenter
- Prevents swimming layers on the surface of the substrate
- Secures uniform temperature distribution
- Supplies bacteria uniformly with nutrients

Requirements

- A fermenter, supplied with bacteria (methanogens and decomposers)
- Moisture & anaerobic conditions
- Optimum uniform temperature of 35°C
- Optimum pH of 6.5 to 8
- Organic uniform waste (biomass) charging e.g. sewage, wood pulp
- C:N:P:S-ratio:

recommended:	600:15:5:3
cattle manure:	600:40:2:4
corn:	600:20:4:2
grass:	600:17:4:2
crop:	600:7:2:11



Methanogens and the greenhouse effect

- Half of the methane produced by methanogens is used up as an energy source by other bacteria
- Half is lost to the atmosphere (600 M tonnes/a) where it acts as an important greenhouse gas
- As more land is converted to rice paddy fields and pasture for grazing animals more methane will be produced

DAF Shiga Pref.

Global warming

- As global warming progresses the permafrost with thaw in the tundra regions
- Tundra contains frozen peat
- As the peat warms and melts, it will provide a huge source of material for methanogens
- Methanogens will produce high amounts of methane
- Increase of methane in the atmosphere
- Further increase of global warming

UNEP

Impact parameters

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Literature