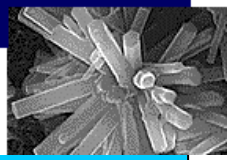
Bauhaus-Universität Weimar



Anaerobic Digestion Technology

Dipl.-Ing. Thomas Haupt
Bauhaus-Universität Weimar

4000 years farming in Asia

Introduction

History

Bauhaus-Universität Weimar

1 farmer + 1ha

8 persons,

2 cows,

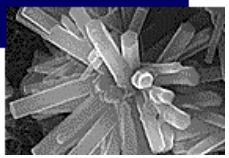
2 donkeys,

8-10 pigs

Demands

Technology

Bauhaus-Universität Weimar



Cambodia

- AD
- Adapation
- Economy
- Product

Demands

Technology

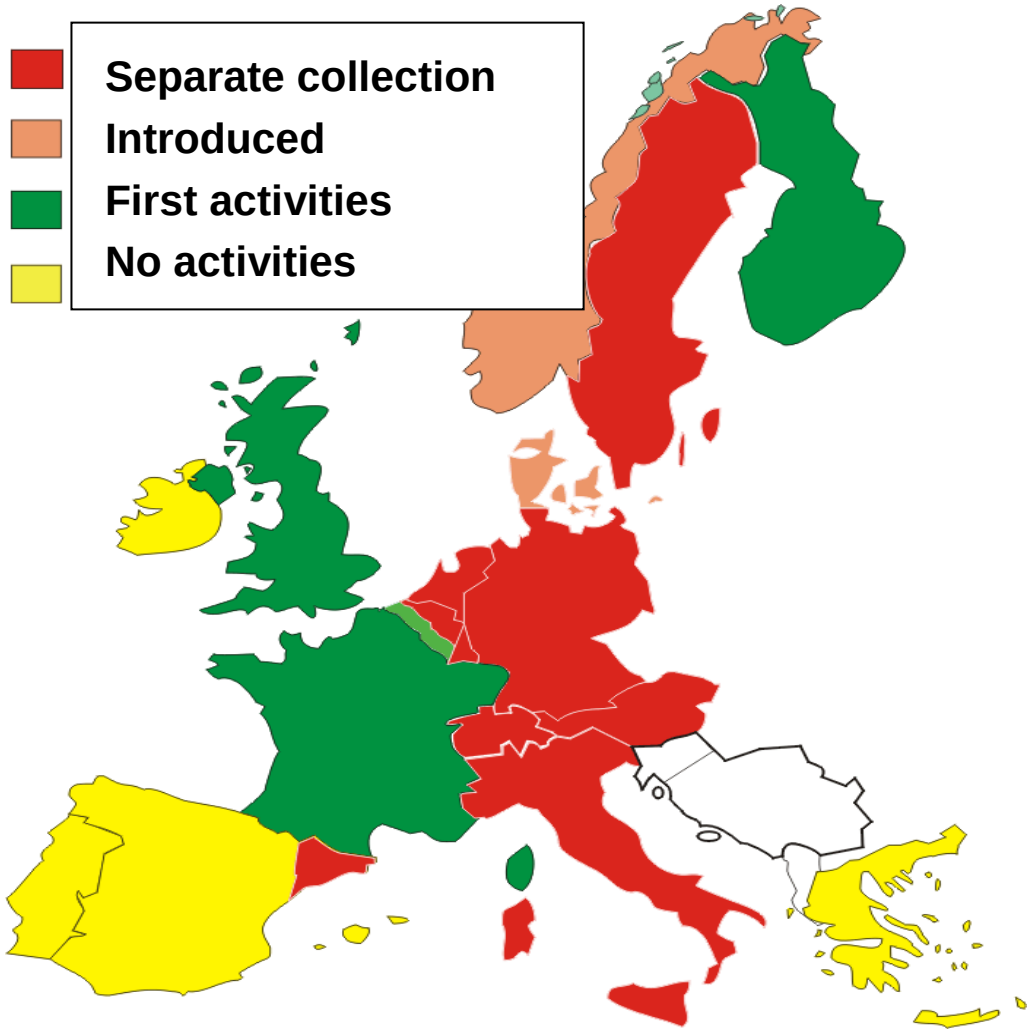
Bauhaus-Universität Weimar

European developing countries

Germany:
10 - 12 Mio. Mg org. waste/a

Potential EU:
35 - 50 Mio. Mg org. waste/a

Potential Eastern Europe:
ca. 45 Mio. Mg org. waste/a



Demands

Technology

Bauhaus-Universität Weimar

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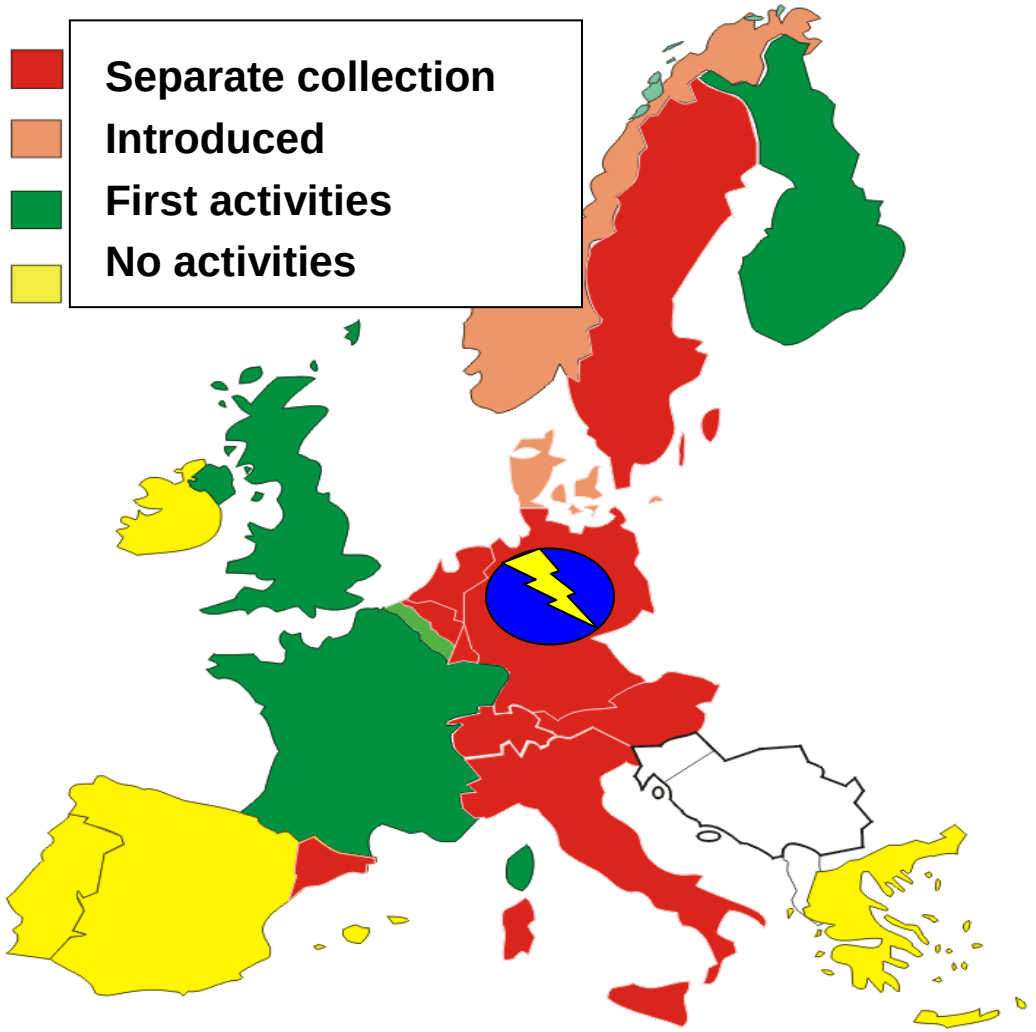

Anaerobic Technology

Theory

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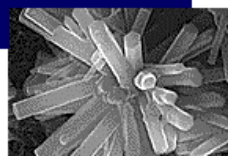


Anaerobic process

$$C_nH_aO_bN_cS_d + (4n–a–2b+3c+2d)\ H_2O \rightarrow$$

$$1/8(4n+a\ –2b–3c–2d)\ CH_4$$

$$+\ 1/8(4n\text{-}a+2b+3c+2d)CO_2$$

$$+\ cNH_3$$

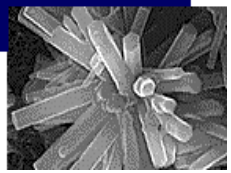
$$+\ dH_2S$$

The anaerobic process

biogas

theory

Bauhaus-Universität Weimar



substrate	methane [Vol.-%]	carbon-dioxid [Vol.-%]	ammonia [Vol.-%]	hydrogene sulfide [Vol.-%]
sugar (glucose)	50	50	-	-
fat	71 - 75	29	-	-
proteine (average)	38 -50	38	18	6

carbohydrate: $C_6H_{12}O_6$

lipids: $C_{16}H_{32}O_2$

protein: $C_{13}H_{25}O_7N_3S$

The anaerobic process

biogas process

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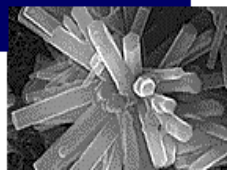

	1. step	2. step	3. step	4. step
name of step	hydrolysis	acidification	acetatification	methane production
start-product	complex sugar, protein, fat	simple sugar	amino acid, organic acids	acetat
micro-organisms		acidogene micro-organisms	acetogene micro-organisms	methanogene micro-organisms
by-product	simple sugar	amino acid, organic acids	acetat	
end-product	CO_2	CO_2, H_2	CO_2, NH_4, H_2,	CO_2, CH_4

The anaerobic process

biogas

energy

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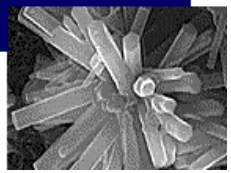


Methane 35 - 55 Vol.-%

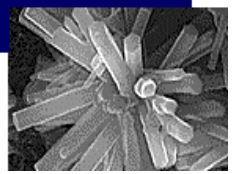
Carbon dioxide 44 Vol.-%

3,5 - 5,5 kWh/m³ biogas

The anaerobic digestion

process possibilities

Bauhaus-Universität Weimar



- thermophilic 50 - 55℃
- mesophilic 30 - 35℃

-stability of process, microorganisms, gas production

- wet 10 mass% dry subst.
- dry 35 mass% dry subst.

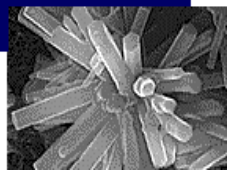
-stability of process, inhibition

The anaerobic digestion

process

technichal

Bauhaus-Universität Weimar



single stage

two stage

single stage	two stage
benefit: - low costs of invest - simple control engineering	benefit: - higher stability of the process - individual solutions - higher efficiency reg. time and volume - better sanitation(lower pH-in hydrolysis)
disadvantage: - no optimisation possible - pH -problem (instability) - general lower stability	disadvantage: - higher costs of invest - more difficult control engineering

The anaerobic digestion

process

condition

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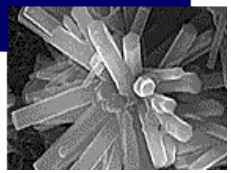

temperature	[°C]	30-35 und 50-55
pH	[-]	6,6-8
water content	mass.-% w.b.	> 50
redox potential	[mV]	<-330
alkalinity	[mg $CaCO_3$/l]	>2000
salt	[g/kg d.b.]	<20
ammonium	[g/l]	<1-2,5
hydrogene sulphide	[mmolar, Vol.-%]	<3, <1
sulphide	[mg/l]	<100-400
organic acids	[mg/l]	<15000

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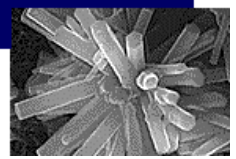
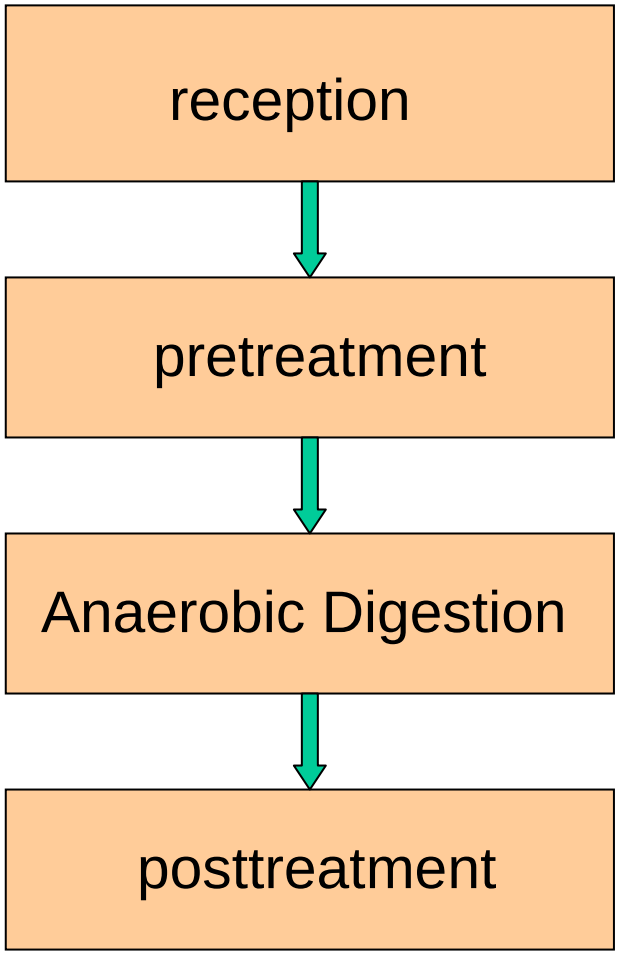


Classic standard procedure



exhaust air

removal mat.

waste water

biogas

The anaerobic digestion

plant

technical

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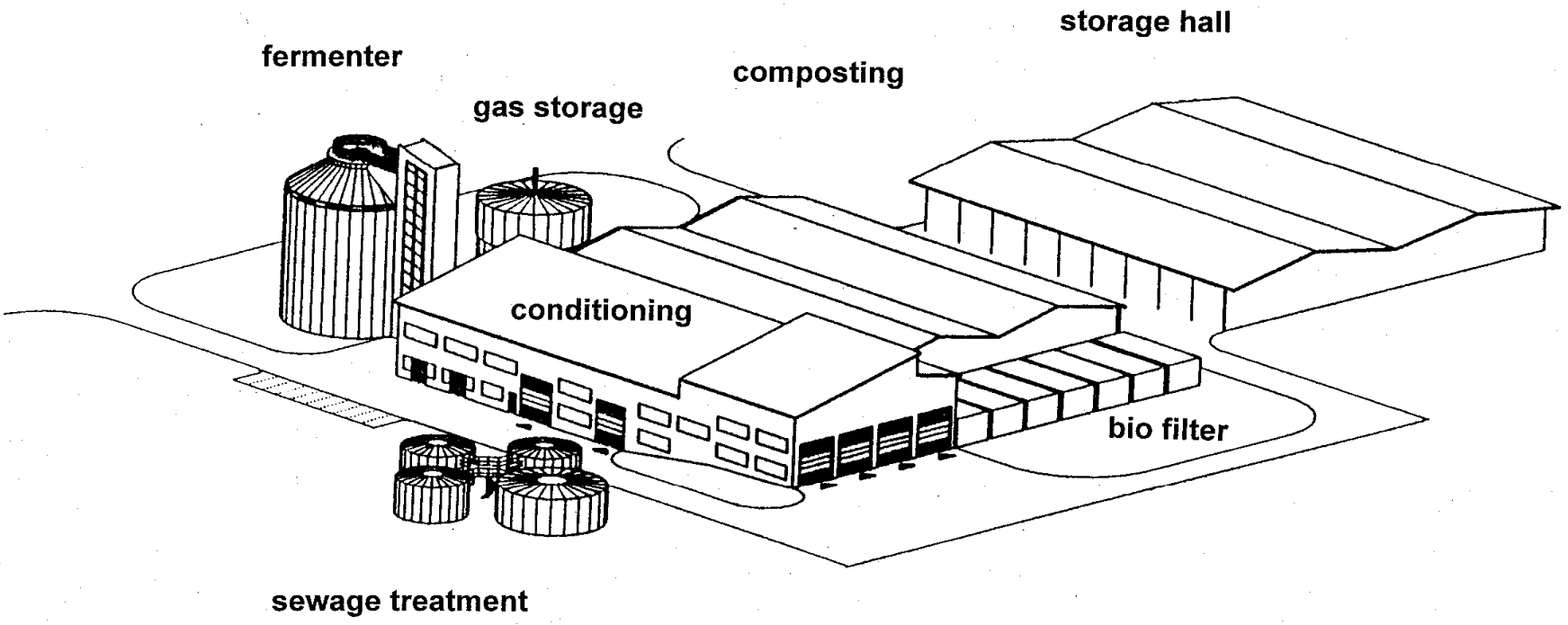

Demands

Technology

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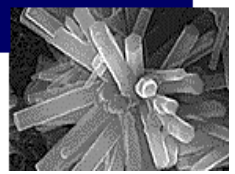
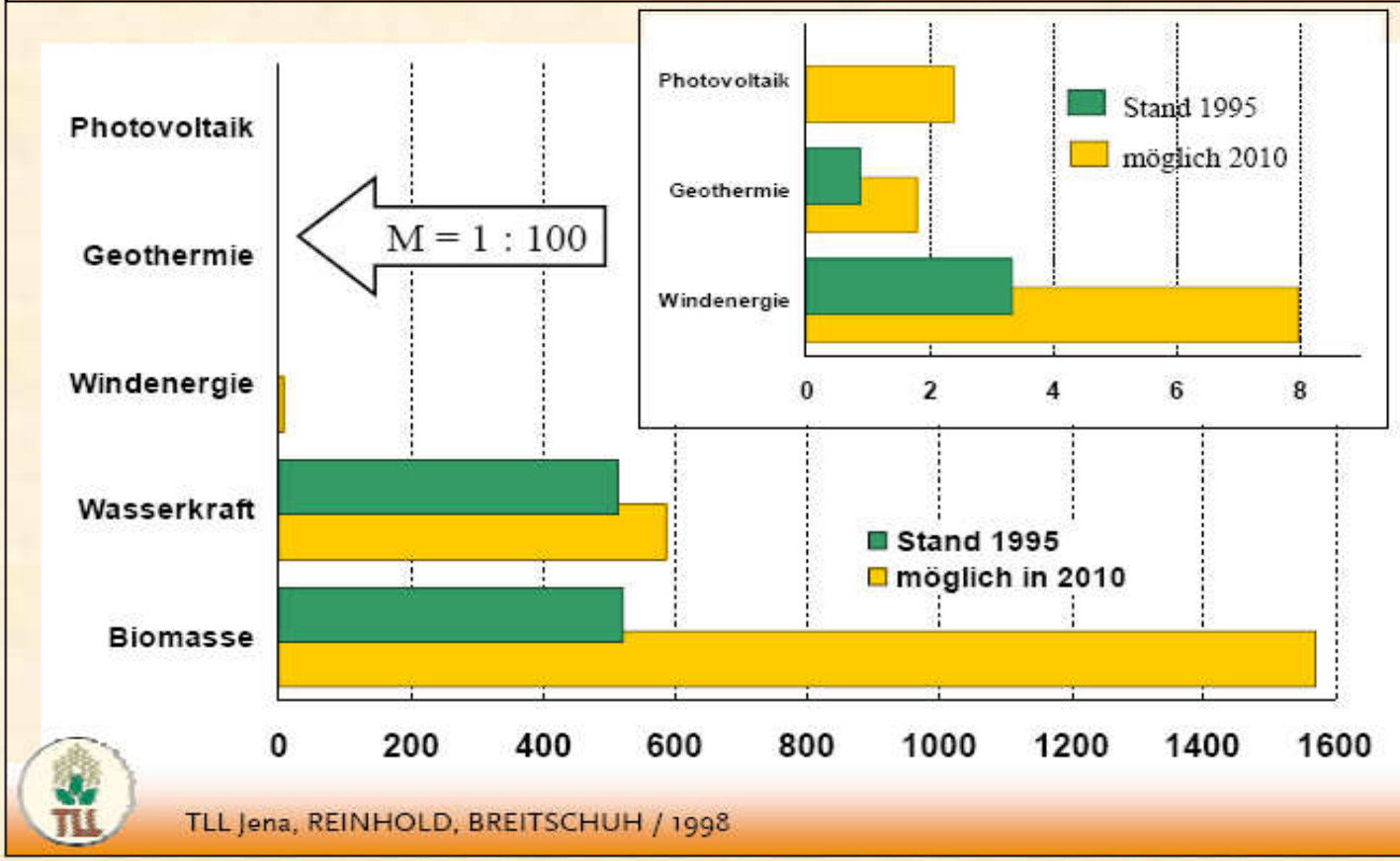


Use of regenerative Energy [TWh/a]



Demands

Technology

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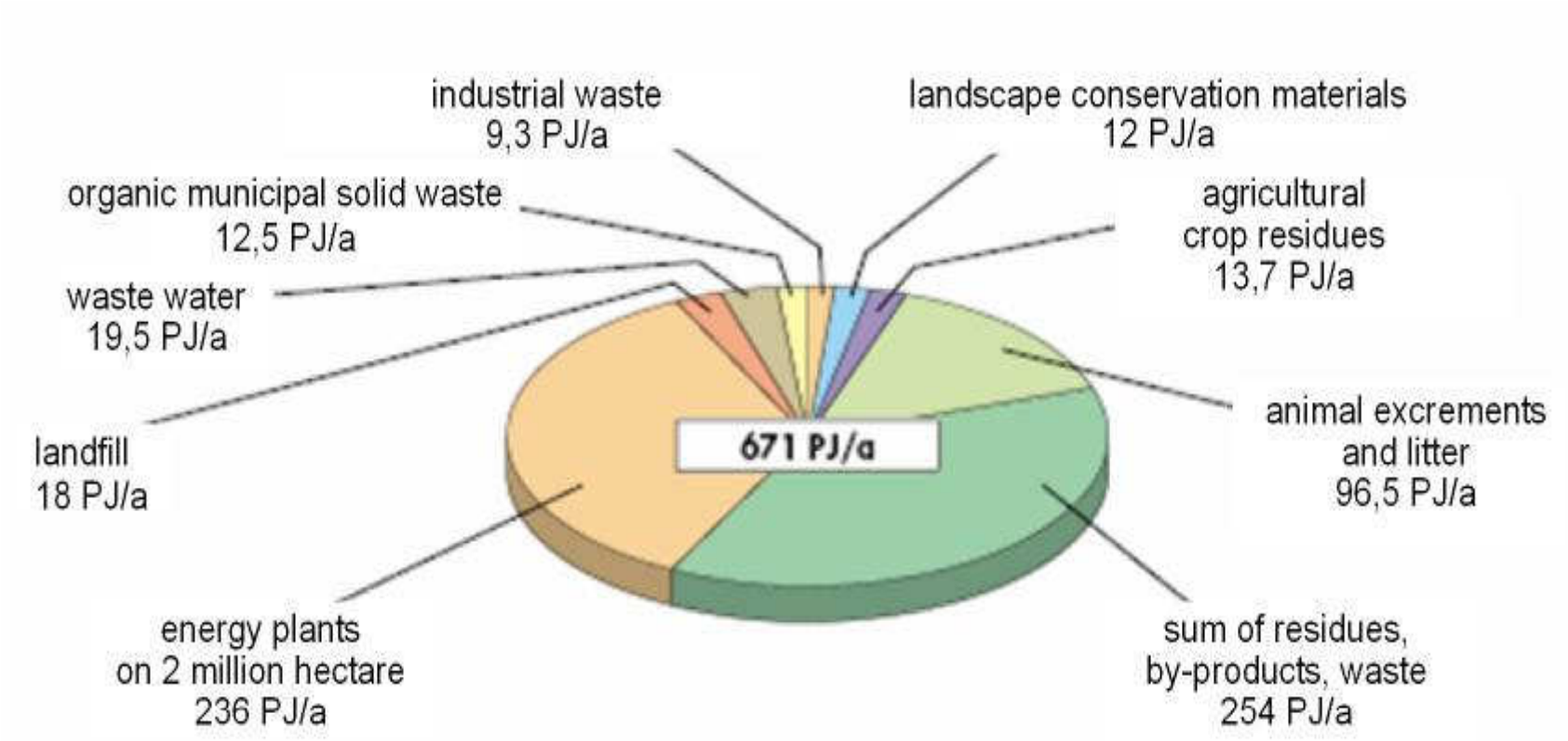
Germany useable energy capability



FNR, 2005

Germany

status

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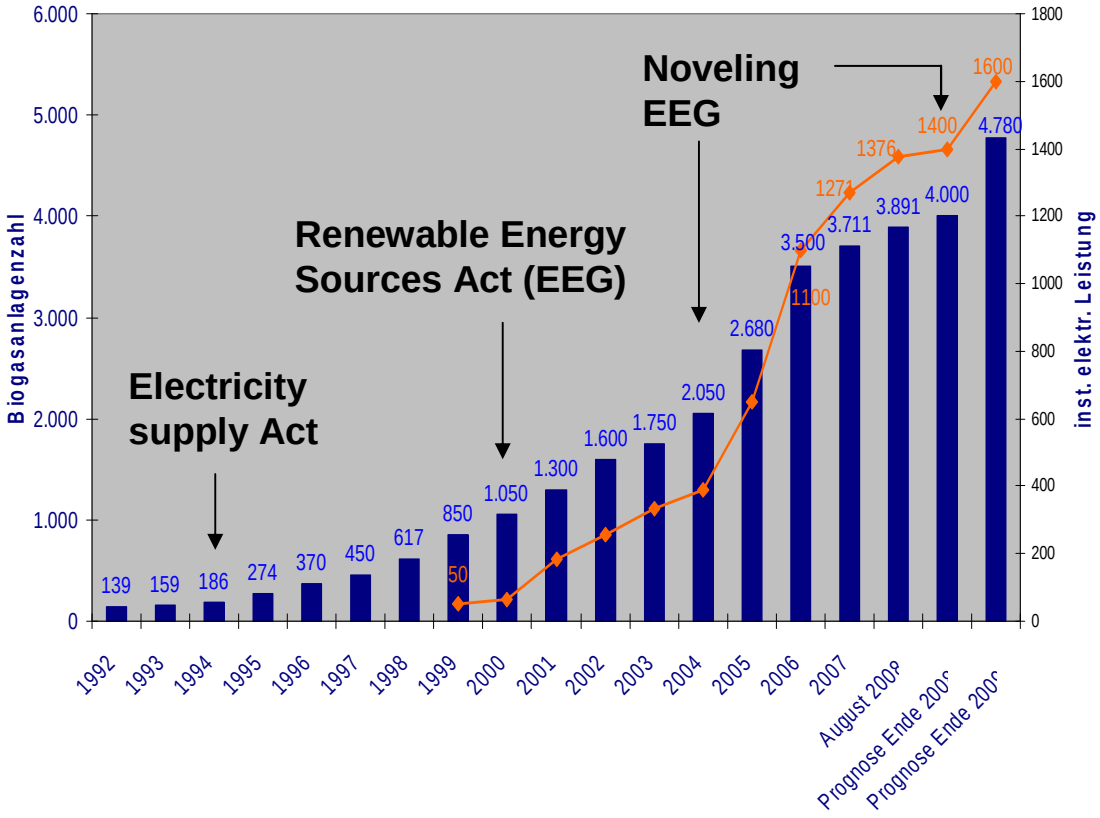
General information

- biological treatment (especially digestion) were pushed by the Act in form of financial support
- entered into force on 29th March 2000
- amendments on 21st July 2004, on 1st January 2009
- in German: Erneuerbare Energien Gesetzt - EEG



Germany

status

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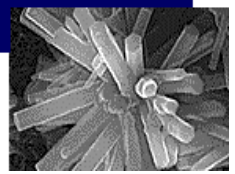

- Relation to energy from biomass

- graded fees paid for electricity produced from biomass

Capacity	Minimum fees in EUR Cent/kWh	Biomass bonus in EUR Cent/kWh
up to and including 150 kW	11,5	6
up to and including 500 kW	9,9	6
up to and including 5 MW	8,9	4
over 5 to including 20 MW	8,4	-
Combined heat and power bonus	-	2
Technology bonus	-	2

- energy from biomass fees shall be paid for a period of 20 years
- decrease of 1,5 % a year

Germany

status

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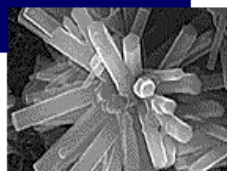
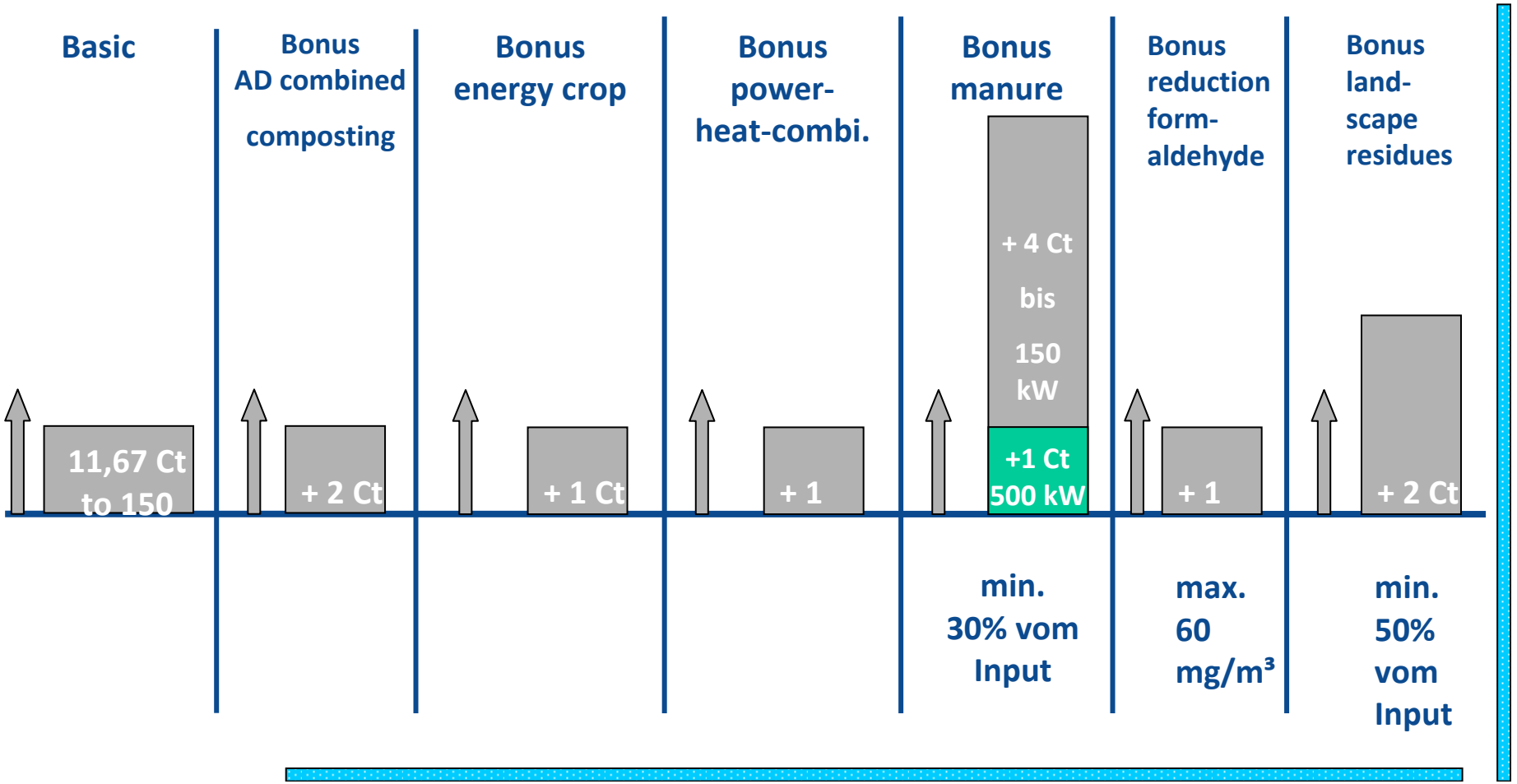


- Novell 2008, starting 01.01.09



Germany

status

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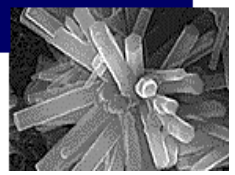


AD general possibilities

Waste water treatment

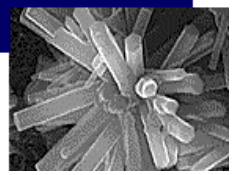
co

wet

Germany

status

Bauhaus-Universität Weimar



AD general possibilities

Waste water treatment

co

wet

agriculture

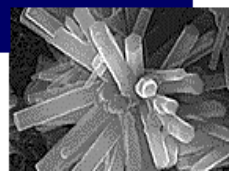
co

wet or dry

Germany

status

Bauhaus-Universität Weimar



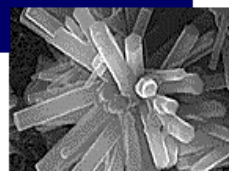
AD general possibilities

Waste water treatment	agriculture	waste
co	co	co
wet	wet or dry	wet or dry

Germany

status

Bauhaus-Universität Weimar



AD general possibilities

Waste water treatment

co

wet

agriculture

co

wet or dry

waste

co

wet or dry

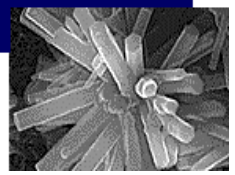
Thermophil

Mesophil

Germany

status

Bauhaus-Universität Weimar



AD general possibilities

Waste water treatment

co

wet

agriculture

co

wet or dry

waste

co

wet or dry

Batch

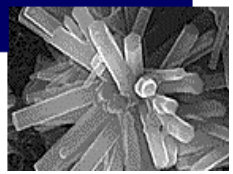
Continous

Thermophil

Mesophil

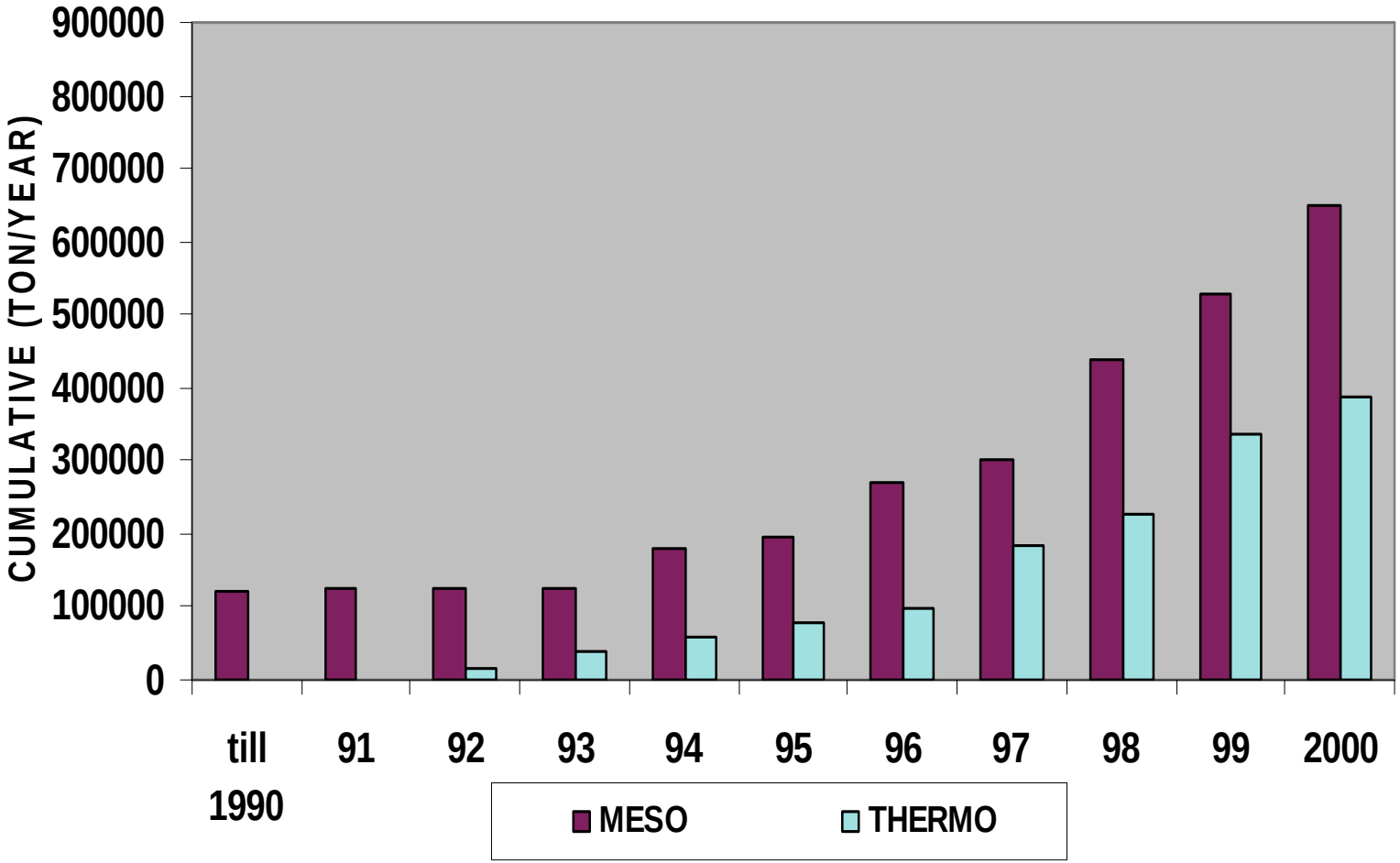
The anaerobic digestion

Bauhaus-Universität Weimar



Europe

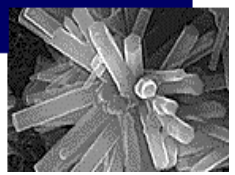
meso-thermo



[de Beare]

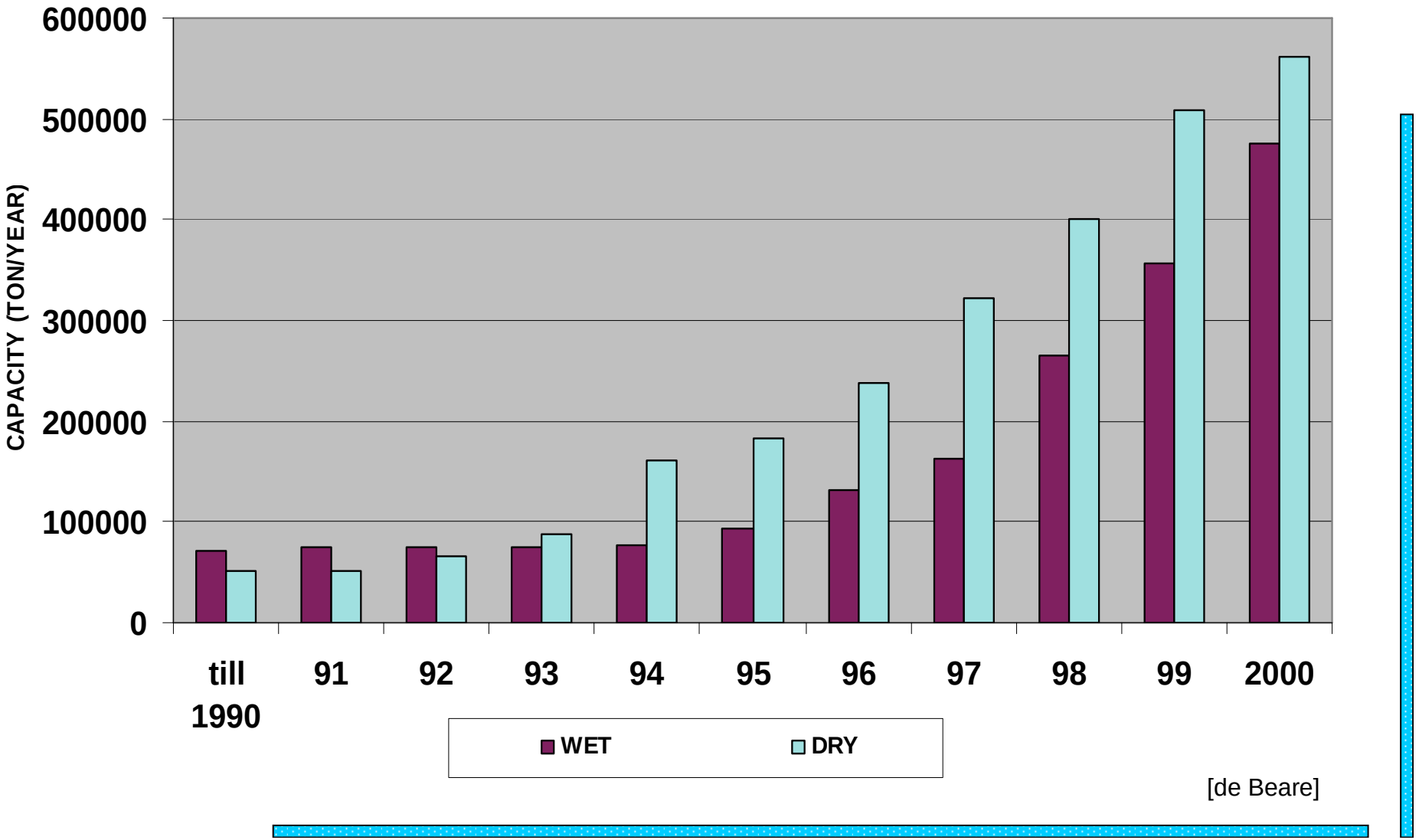
The anaerobic digestion

Bauhaus-Universität Weimar



Europe

wet - dry



[de Beare]

The anaerobic digestion

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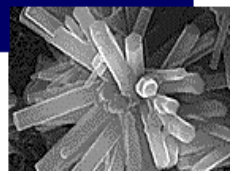
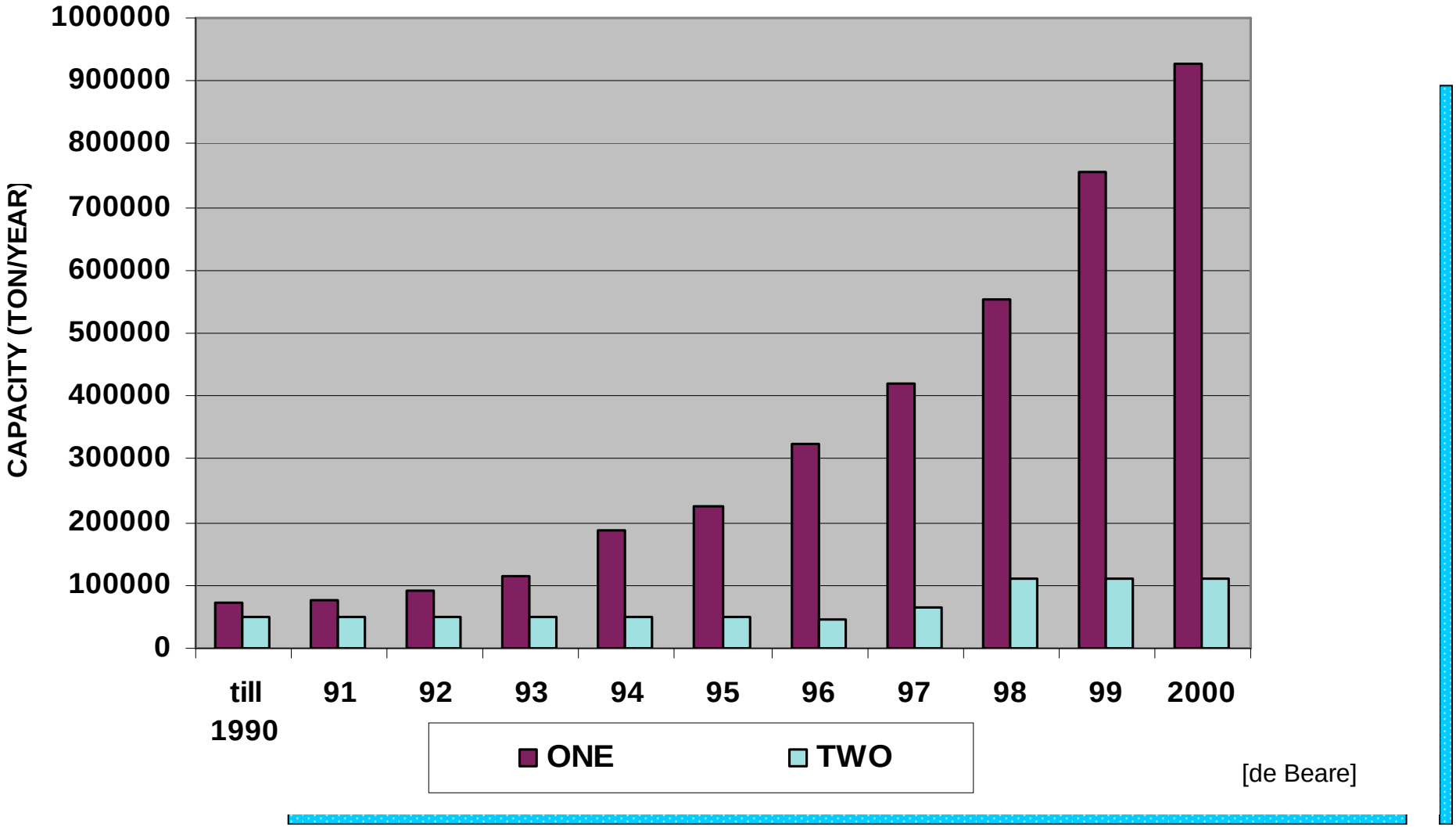


Europe

single - two stage



[de Beare]

The anaerobic digestion

Europe

codigestion

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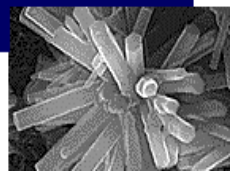

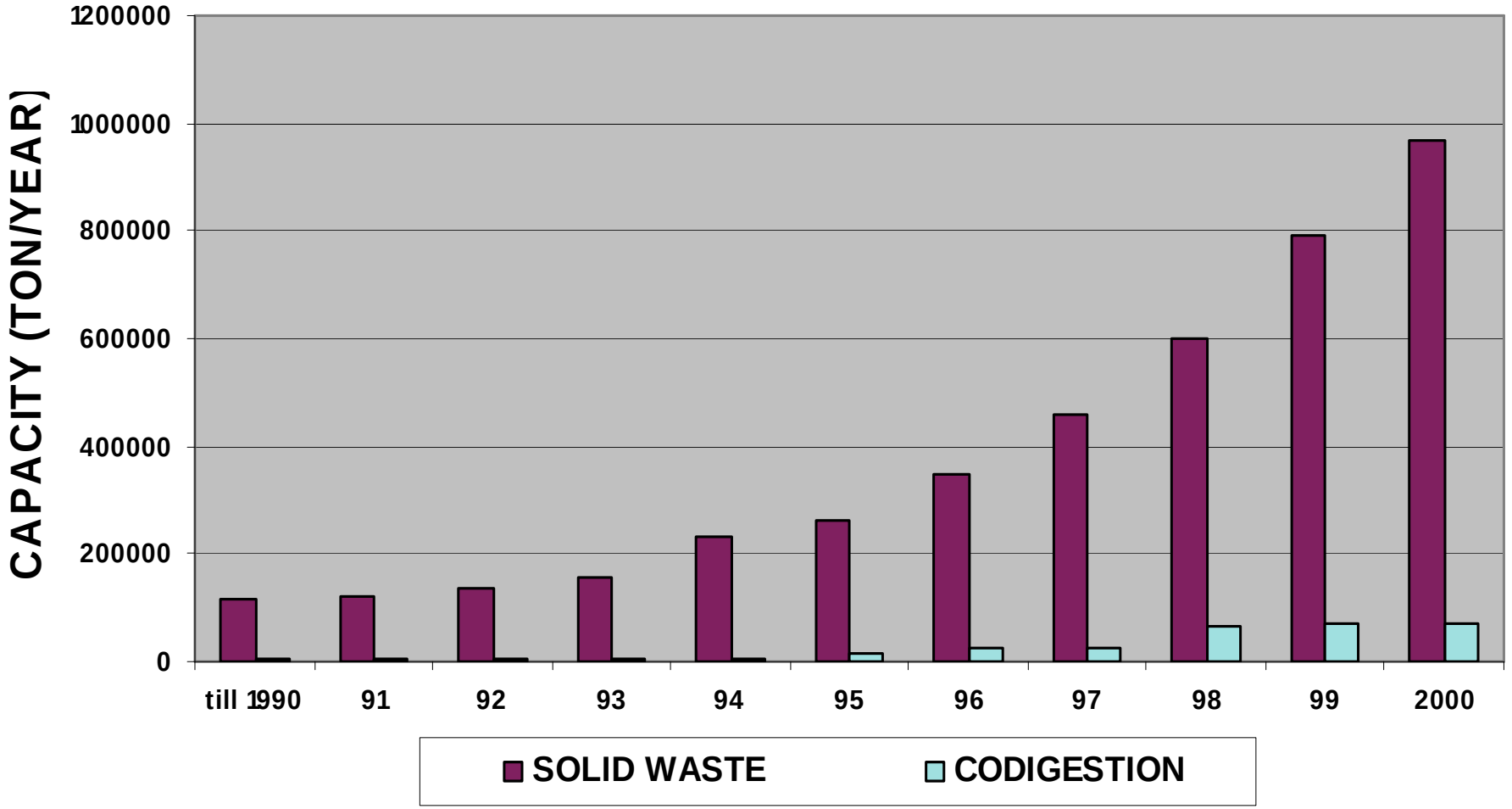

[de Beare]

Europe

status

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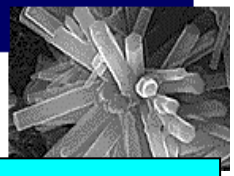

DRANCO [Mg/a]		VALORGA [Mg/a]		KOMPOGAS [Mg/a]	
Brecht I	20.000	Amiens	85.000	Oetwil	10.000
Salzburg	20.000	Tilburg	52.000	Roppen	10.000
Bassum	13.500	Engelskirch.	35.000	Volketswil	5.000
Aarberg	11.000	Freiburg	36.000	Frankfurt	15.000
Kaiserslaut.	20.000	Genf	10.000	Alzey-Worms	24.000
Villeneuve	10.000	Mons	58.000	Kyoto	1.000
Brecht II	50.000	Cadiz	115.000	Niederuzwil	13.000
Alicante	30.000	Varennes	100.000	Hundsrück	10.000
Rom	40.000	Hannover	100.000	Lustenau	10.000
Böblingen	30.000			München	24.000
				Braunschweig	24.000
				Otelfingen	12.000
				Kempten	10.000
				Samstagern	10.000
				Bachenbülach	10.000
				Rümlang	8.500
244.500		**591.000**		**196.500**	

amount 1.032.000 Mg/a

Europe

status

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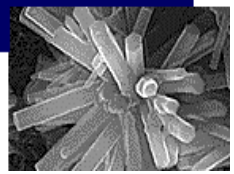

Largest MBT Plants in EU

Location	Throughput (TPD)	Main Outputs
Madrid, Spain	1,300	Soil
Barcelona, Spain	830	Biogas, soil
Calvano, Italy	750	Landfill, RDF
Barcelona, Spain	700	Biogas, soil
Groningen, The Netherlands	650	Biogas
Friesland, The Netherlands	600	Biogas
Leon, Spain	600	Soil, biogas
Valladolid, Spain	600	Soil, biogas

Europe

status

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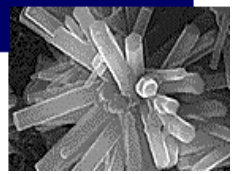
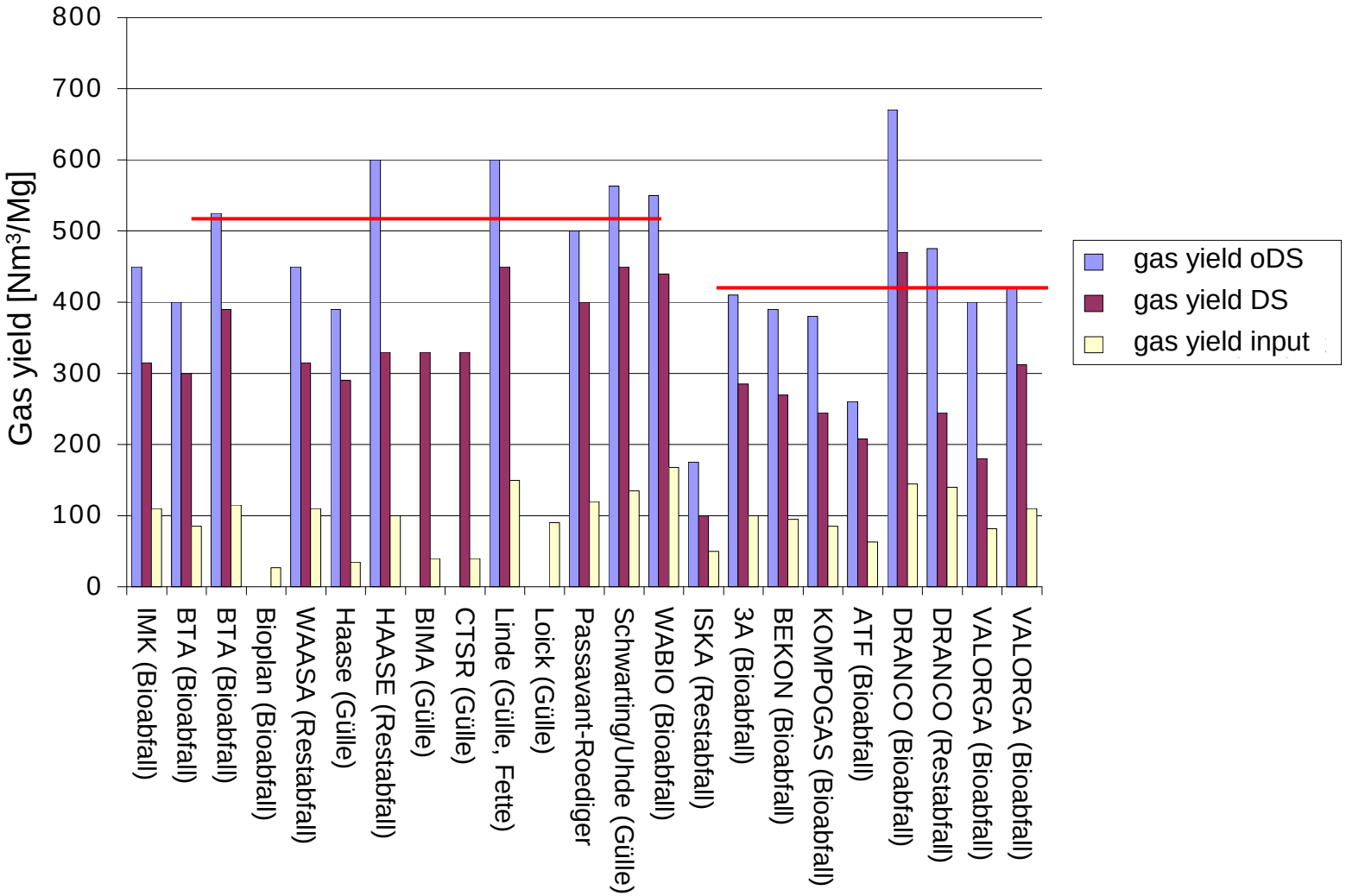


gas production



Europe

status

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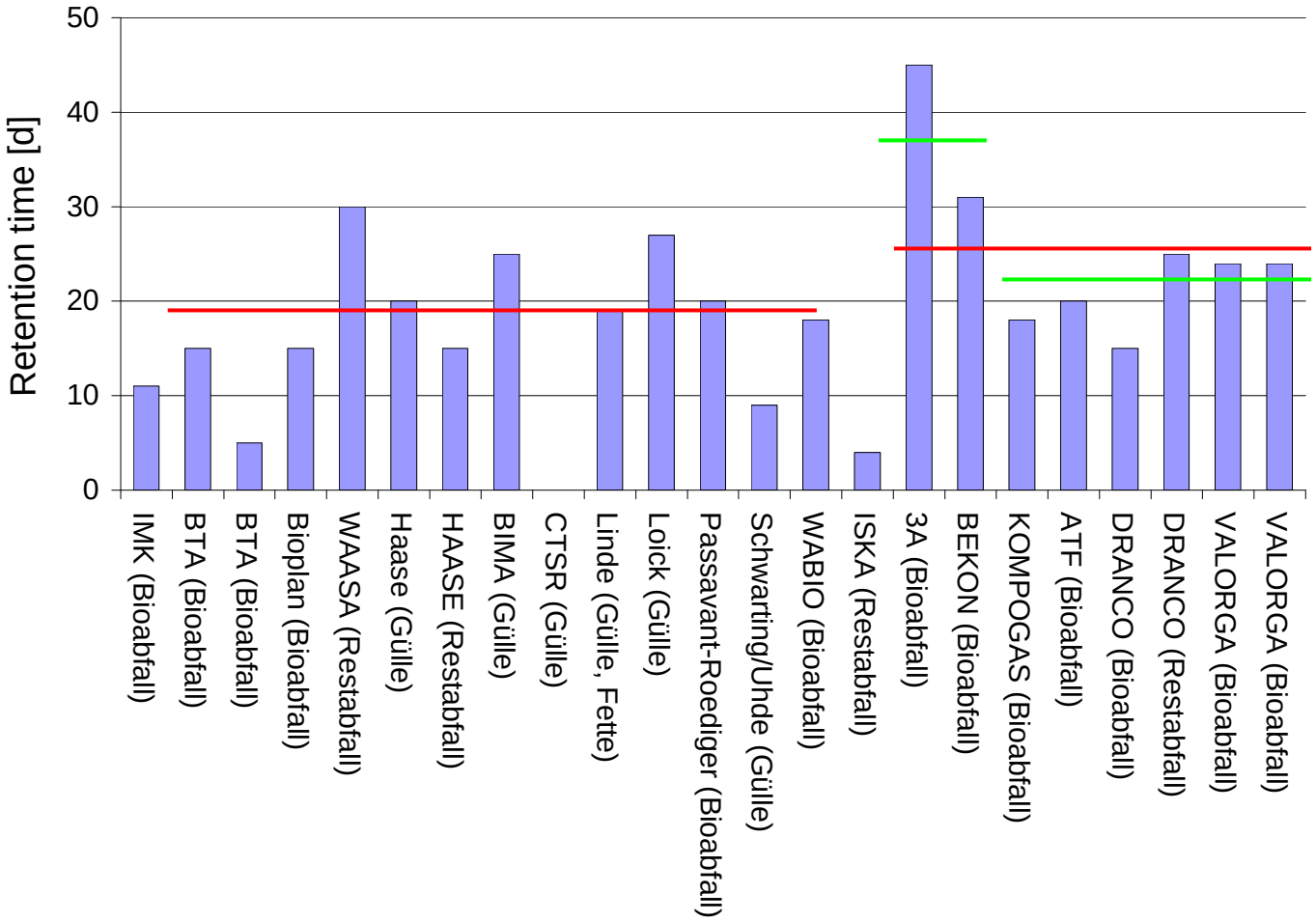
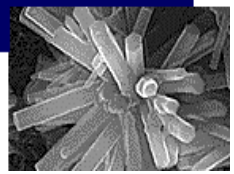
retention time



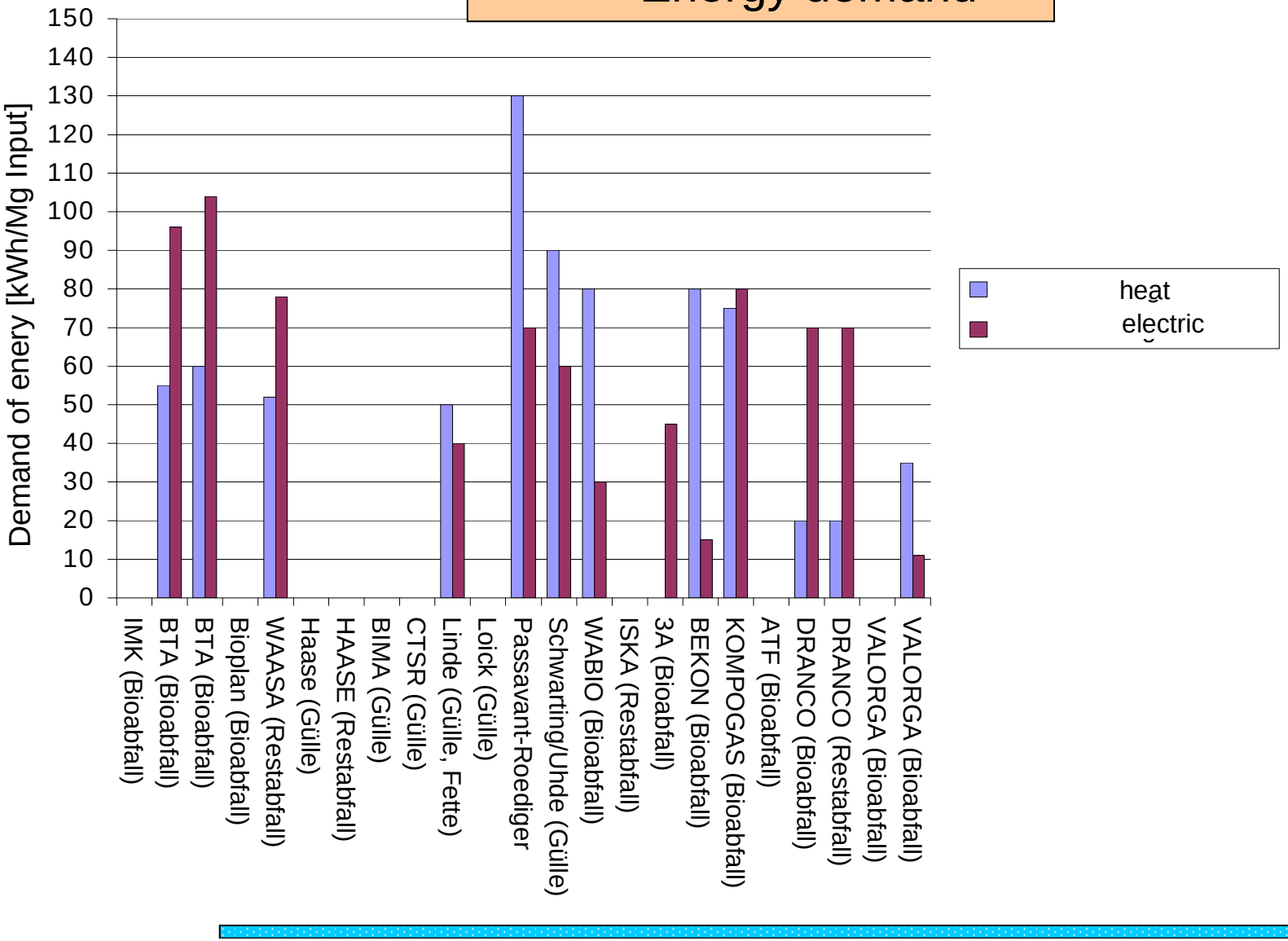
Europe

status

Bauhaus-Universität Weimar



Energy demand



Germany

development

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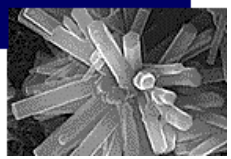
- impulse
- energy generation
- energy farmer
- regional development

- characterisation of input
- Co-AD
- process controll (opt.)
- expert systems
- small, mobil reactors
- automatisation
- spread technology

Anaerobic Technology

Vision

Bauhaus-Universität Weimar



integrated

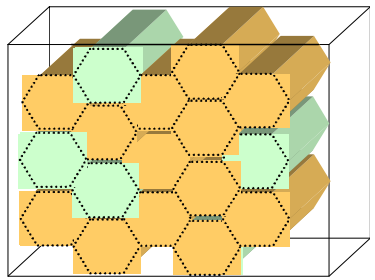
not functional related, but product oriented

fractal

each segment is fullfilling by itself the superordinated aims (schworm intelligent)

dynamic

short time adaptation to the demands of the market (clients)



Anaerobic Technology Vision

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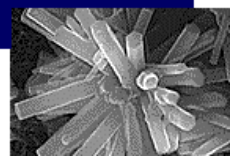

Small reactors

- Small and recurrent technological segments ensure the possibility of specific, material oriented. treatment
- Small segments could be more flexible controlled then bigger once
- Small reactors permit higher specific biogas production
- Small reactors are easier to transport
- Small reactors allow as well aerob or anaerob processes

Europe

status

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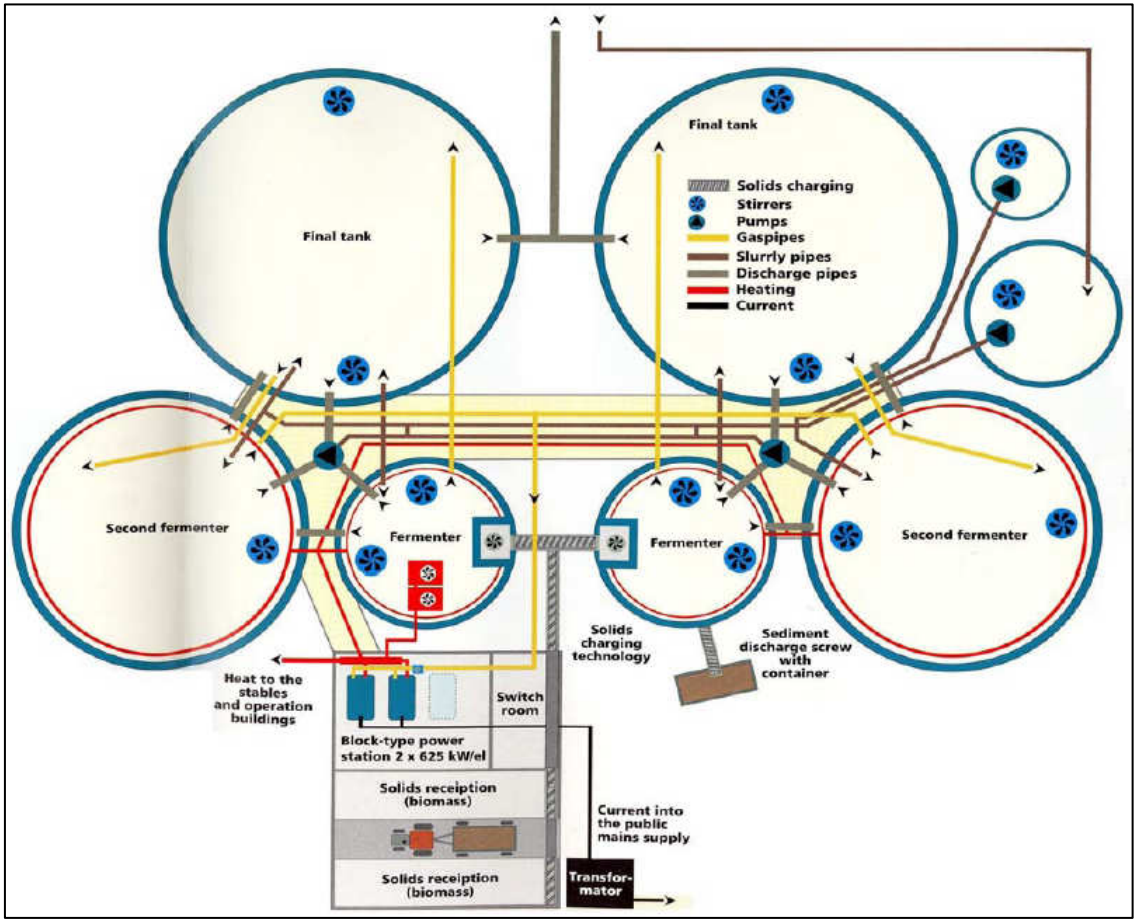
Wet fermentation - Example

General information

- pig farm with more than 13.000 pigs
- fermentation volume: 2 lines each 950 m³ and 2.700 m³ reactors type CompletelyStirredTankReactor, storage tank 4.000 m³
- temperature: mesophil (ca. 40 °C)
- retention time ~ 90 d



Europe

status

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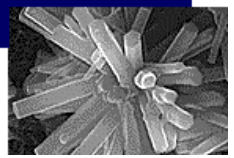

Wet fermentation - Example

General information

- installed electrical capacity: 1,875 MW electr. power (15,8 Mio kWh/a), 3 generators á 625 kW
- use of the heat: temperature of the fermenters (40%), heating of the piggery (30%)
- digestion residues (manure) is used as fertiliser on rented fields
- the biological reduction of H_2S is realised by pressing air into the headspace of the reactor

Europe

status

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Wet fermentation - Example

Pig liquid manure tank

Europe

status

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Wet fermentation - Example

Final disposal of digester residues

Europe

status

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Wet fermentation - Example

Solid entry

Europe

status

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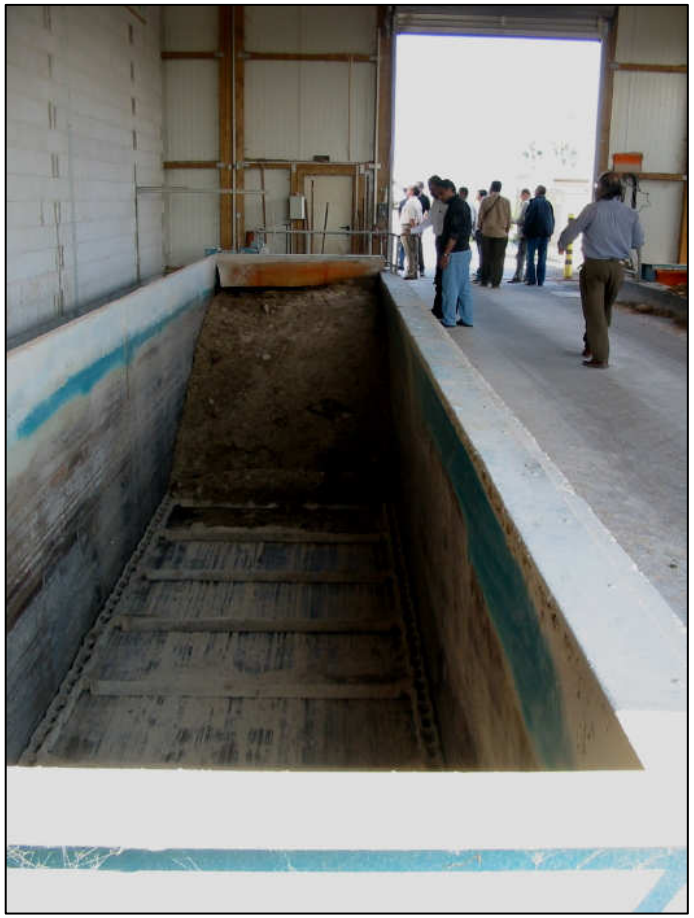
Wet fermentation - Example

Solid reception: corn and maize silage



poultry chicken dung

Europe

status

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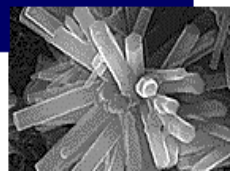

Dry AD

- dry fermentation
  - discontinuous procedures
    - heap procedures
    - percolation proc.
    - dam procedures
  - continuous procedures

[Weiland, 2004]

Europe

status

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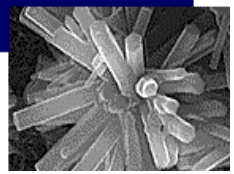

Dry AD

DRANCO

VALORGA

KOMPOGAS

CONTINOUS

BATCH/PERCOLATION

INTRODUCTION

PROBLEM

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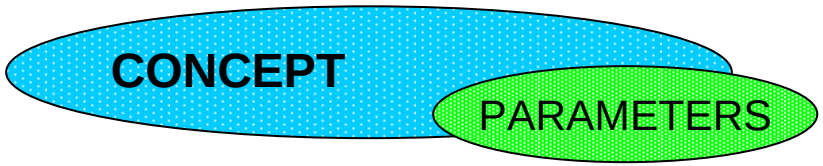
Weimar

3 - phases system

solid fluid gas



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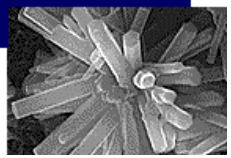

Material	Packed Bed	Flow Pattern
Hydrophobility	Saturation	Retention time
Water content	Pores	Degree of conection
Specific weight	Pore size distribution	Effective pores
Particle size distribution	Particle distribution	Fluid distribution
Form of particles	Specific surface	Load
roughness	Tortuosity	

Europe

status

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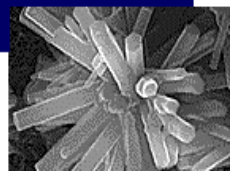

comparison

DRANCO

- reactor stands
- external circulation by pump
- heating by wet steam

VALORGA

- reactor stands
- ciculation by pressed biogas

KOMPOGAS

- reactor laying
- circulation by mixer
- heating by wet process water

Europe

status

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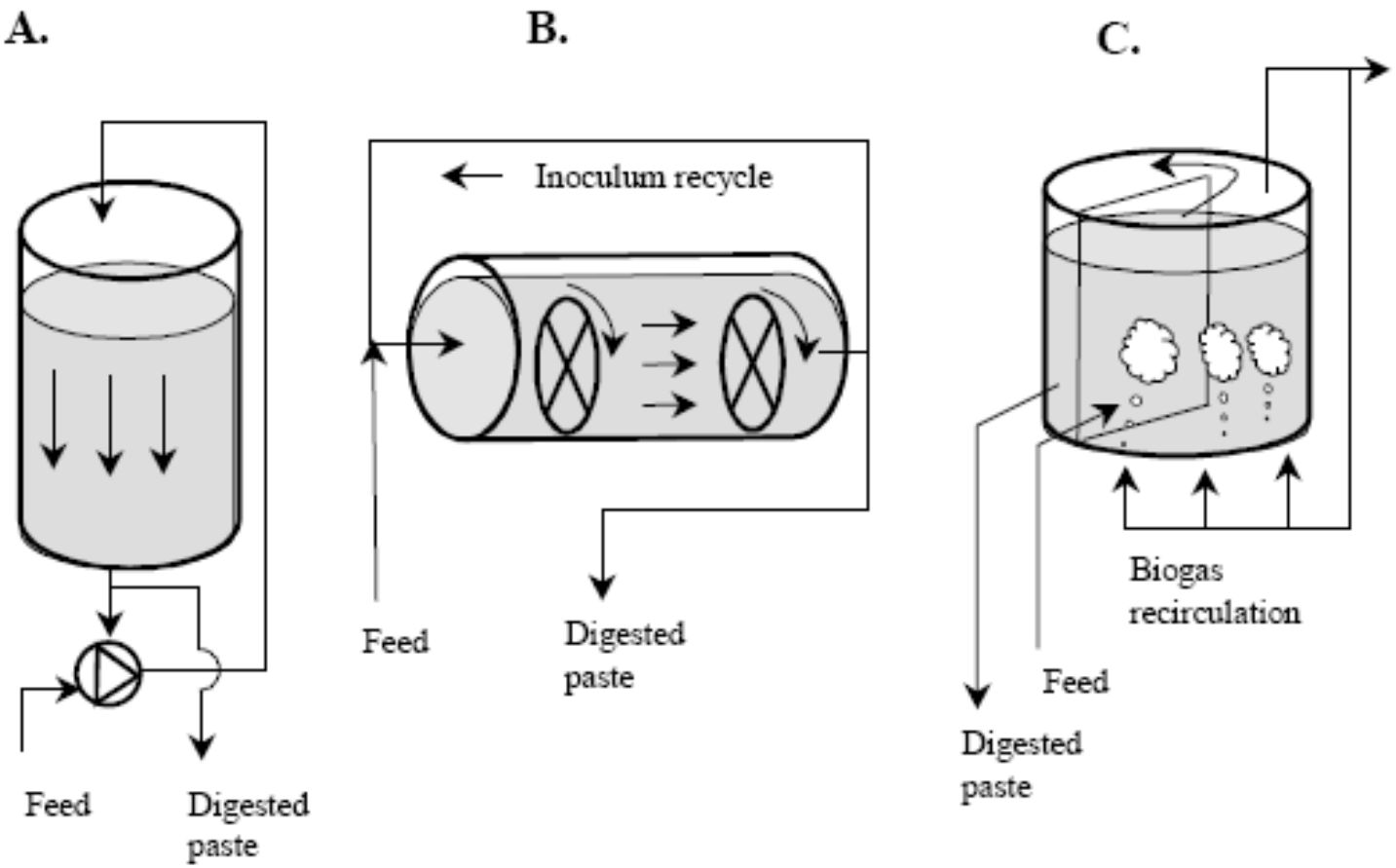
comparison



Dranco

Kompogas

Valorga

Europe

KOMPOGAS

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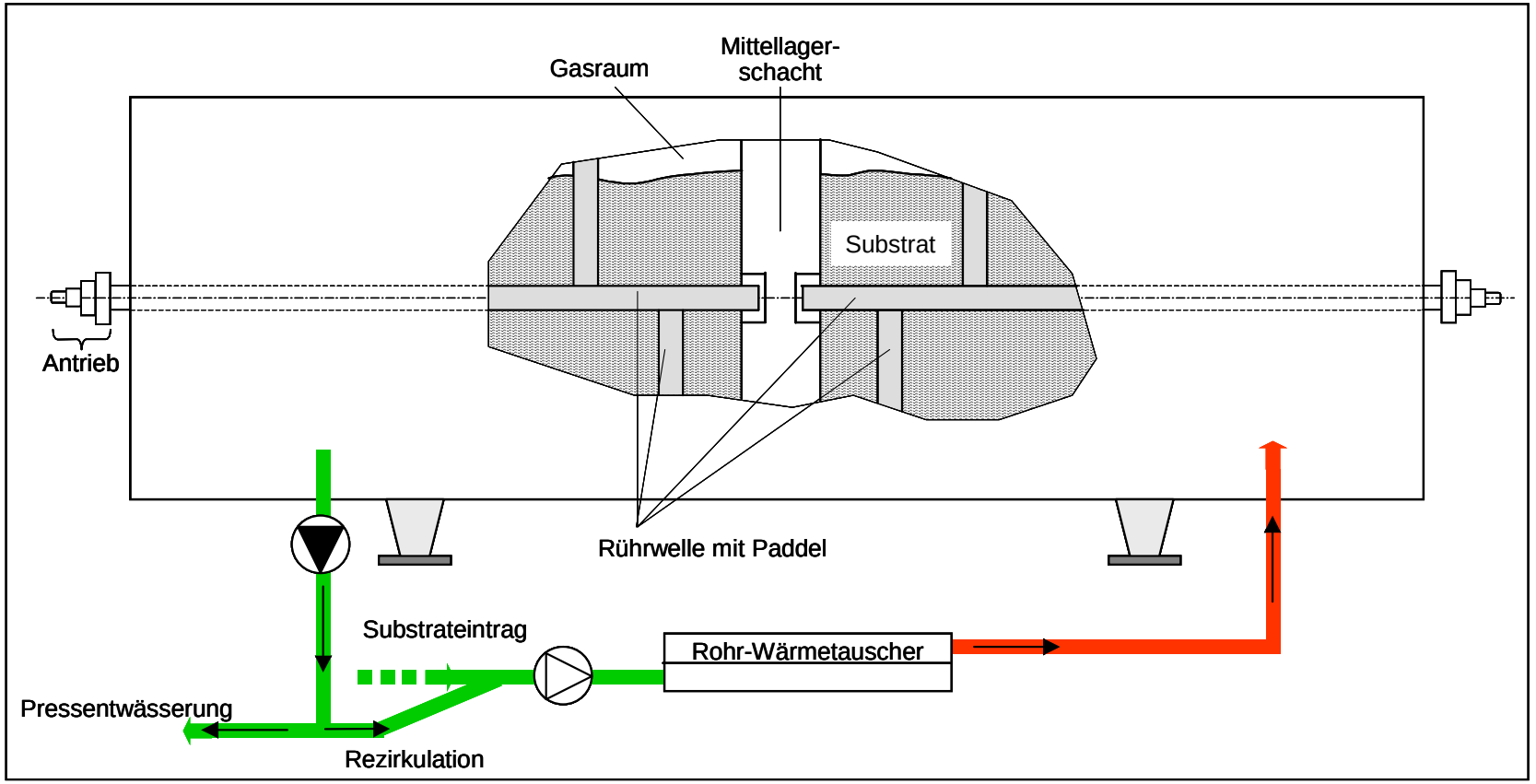

Europe

VALORGA

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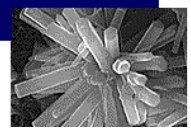

- mixed wastes in form of a thick sludge (20-35% dry matter content)
- feeding via piston pump
- temperatur ranges from mesophilic (40℃) to thermophilic (55℃)
- vertical cylindrical digester with an median inner wall on around 2/3 of its diameter, introduction and extraction orifices at the bottom (forces the matter to a circular movement)
- pneumatic mixing system for homogenizing: a biogas injection into the base of the reactor (a two-level compressor, 8 bar pressure, no mechanical equipment in the fermenter – no maintenance)
- 3 weeks retention time in the one stage process
- gravity extraction
- mechanical pressing resulting in a solid fraction (aerobic post-treatment) and a liquid sludge (separation of suspended solids, then a part is used for dilution, the rest goes to a sewage network)

Europe

VALORGA

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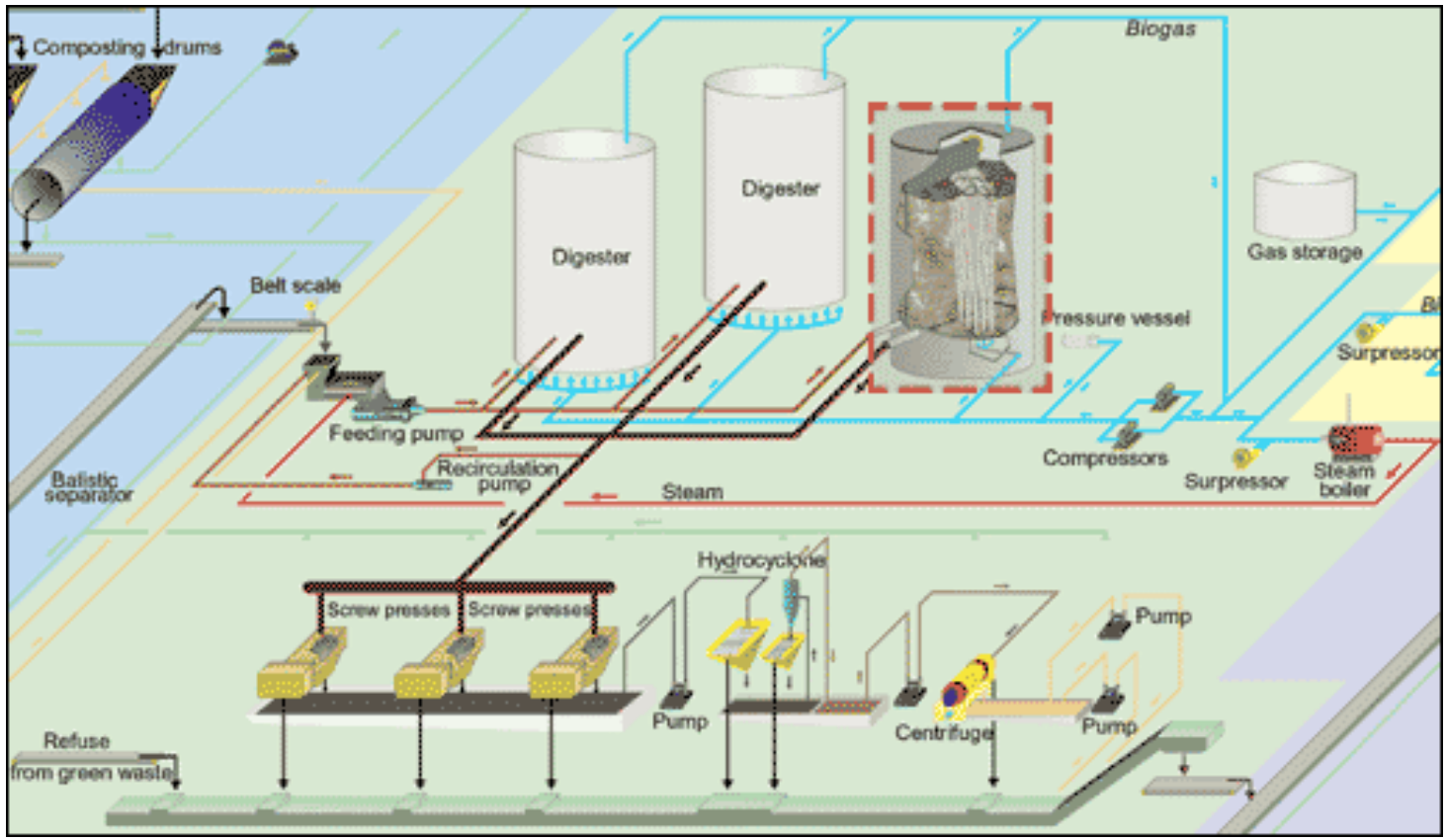

[Valorga, 2006]

Europe

VALORGA

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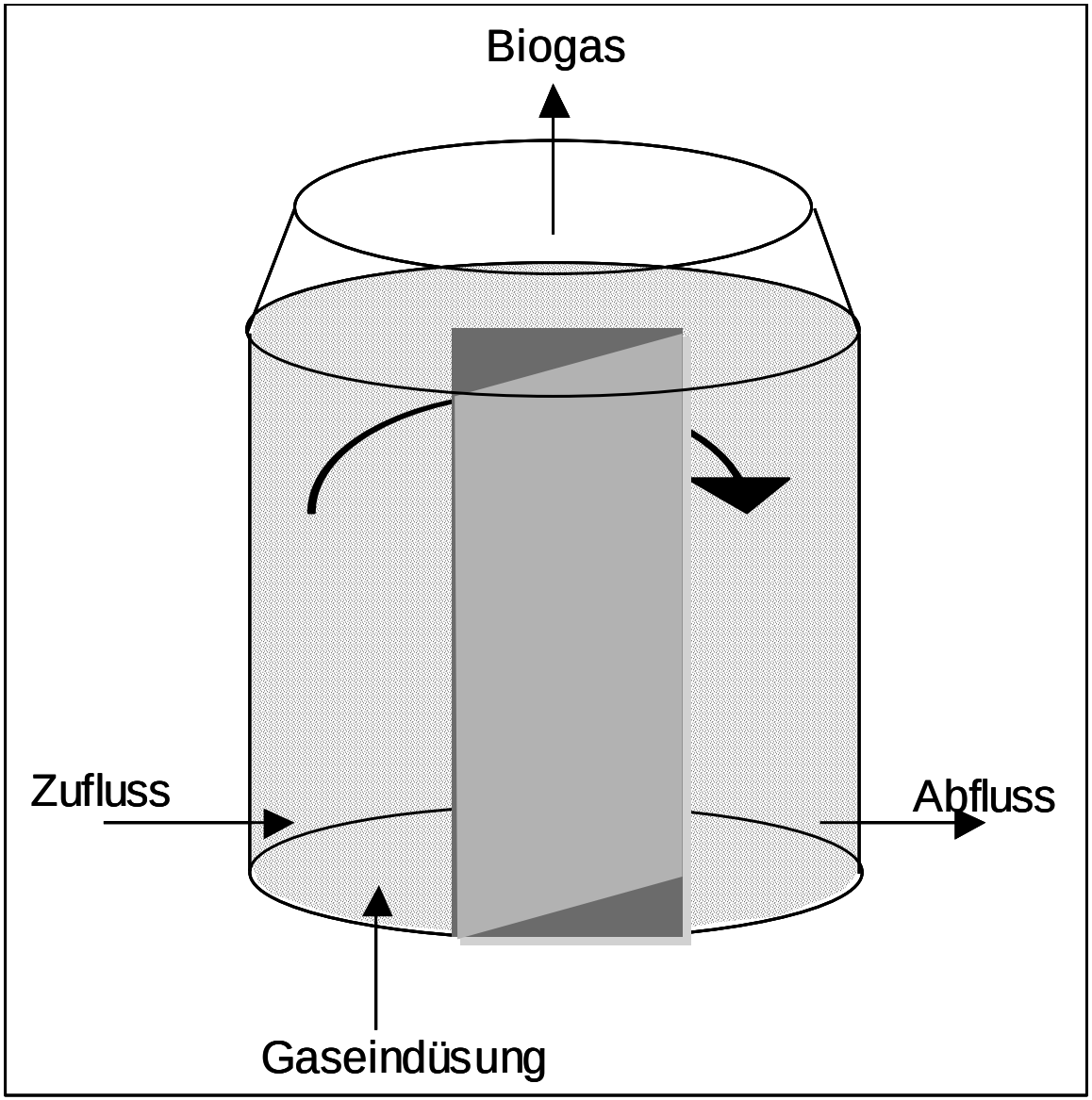

Europe

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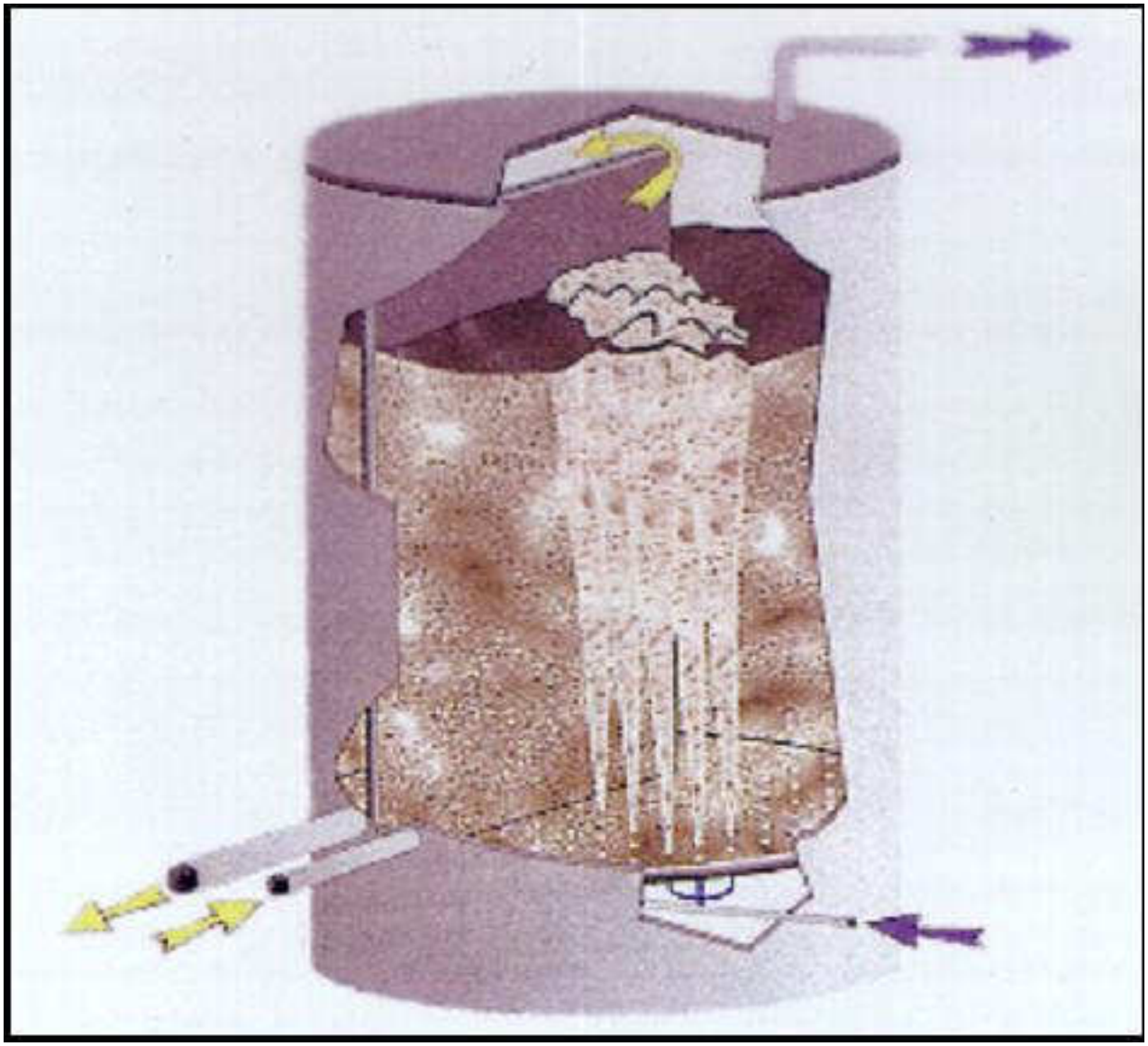

Europe

status

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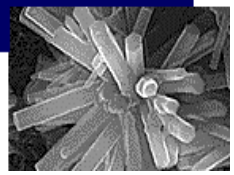

DRANCO - OWS Brecht II

Organic waste characteristic

- Dry Sub. 40 mass.-%
- o Dry Sub. in Dry Sub. 55 mass.-%

composition mass.-%w.b

garden waste	75
kitchen waste	10
wet paper	10
industrial waste	3,5
disturbing material	1,5

Europe

status

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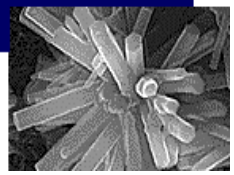

DRANCO - OWS Brecht II

Process parameter

- load	7 - 14 kg org. dry sub./m³ d
- biogas	90 - 120 Nm³/Mg Input
- biogas	4 - 8 Nm³/m³ d
- content of methane	50 - 60 Vol.-%
- retention time	15 - 25 d (20 d)
- dry Sub.	28 - 40 mass.-%(25 - 33 mass.-%)

Europe

status

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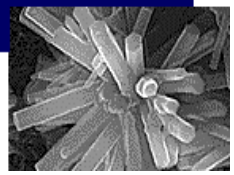

DRANCO - OWS Brecht II

additional information

- produced	2 x 650 kWh
- own consumption	450 kWh
- including Pump	250 kWh
- homogenisation drum	1h
- fresh substrat : rest	1: 5
- polymer	3,5 kg/Mg
- 3 worker; 2 shifts	
- price	83 €/Mg

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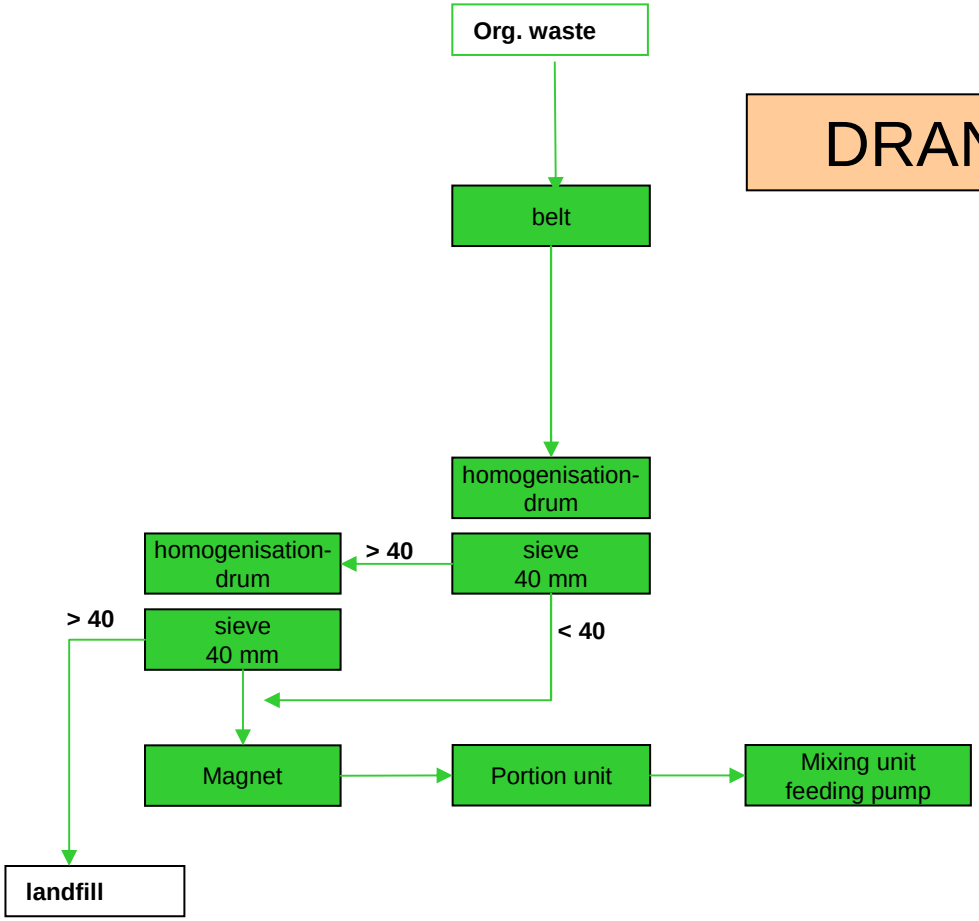
DRANCO - OWS Brecht II



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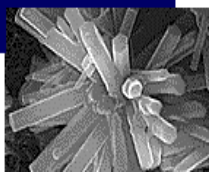

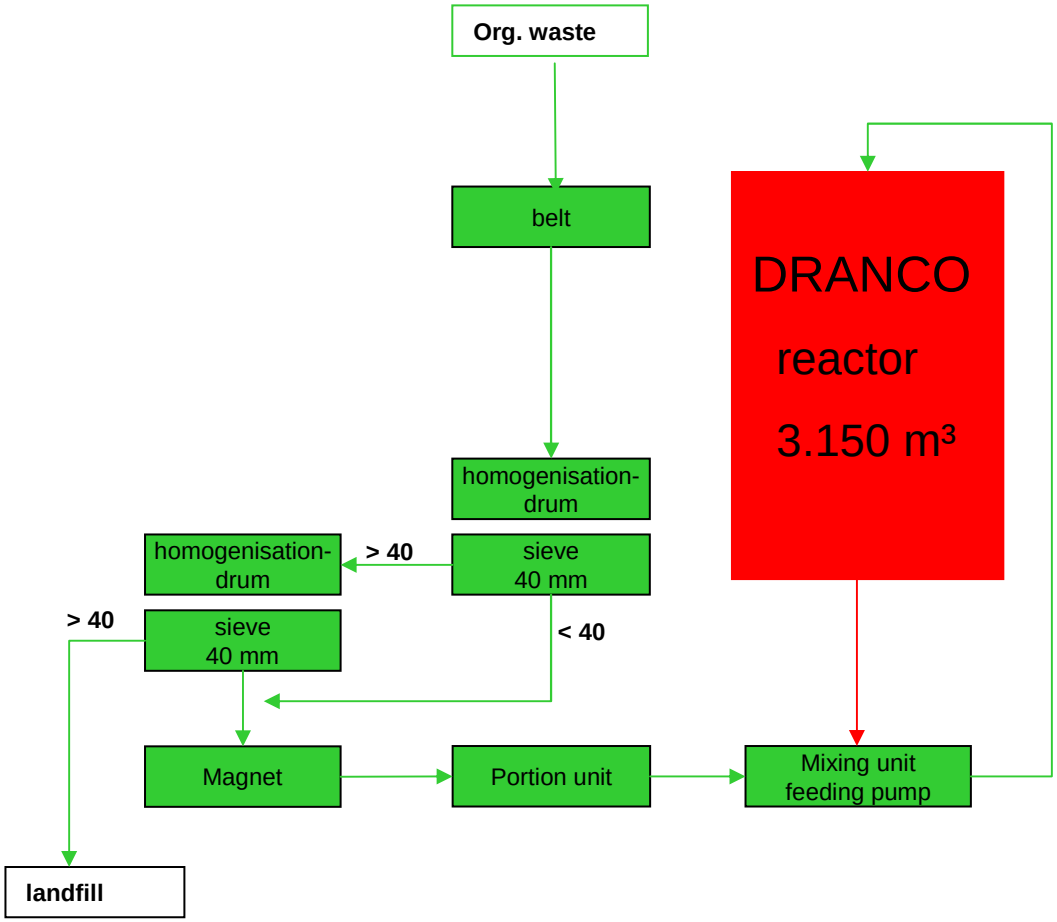

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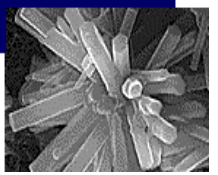

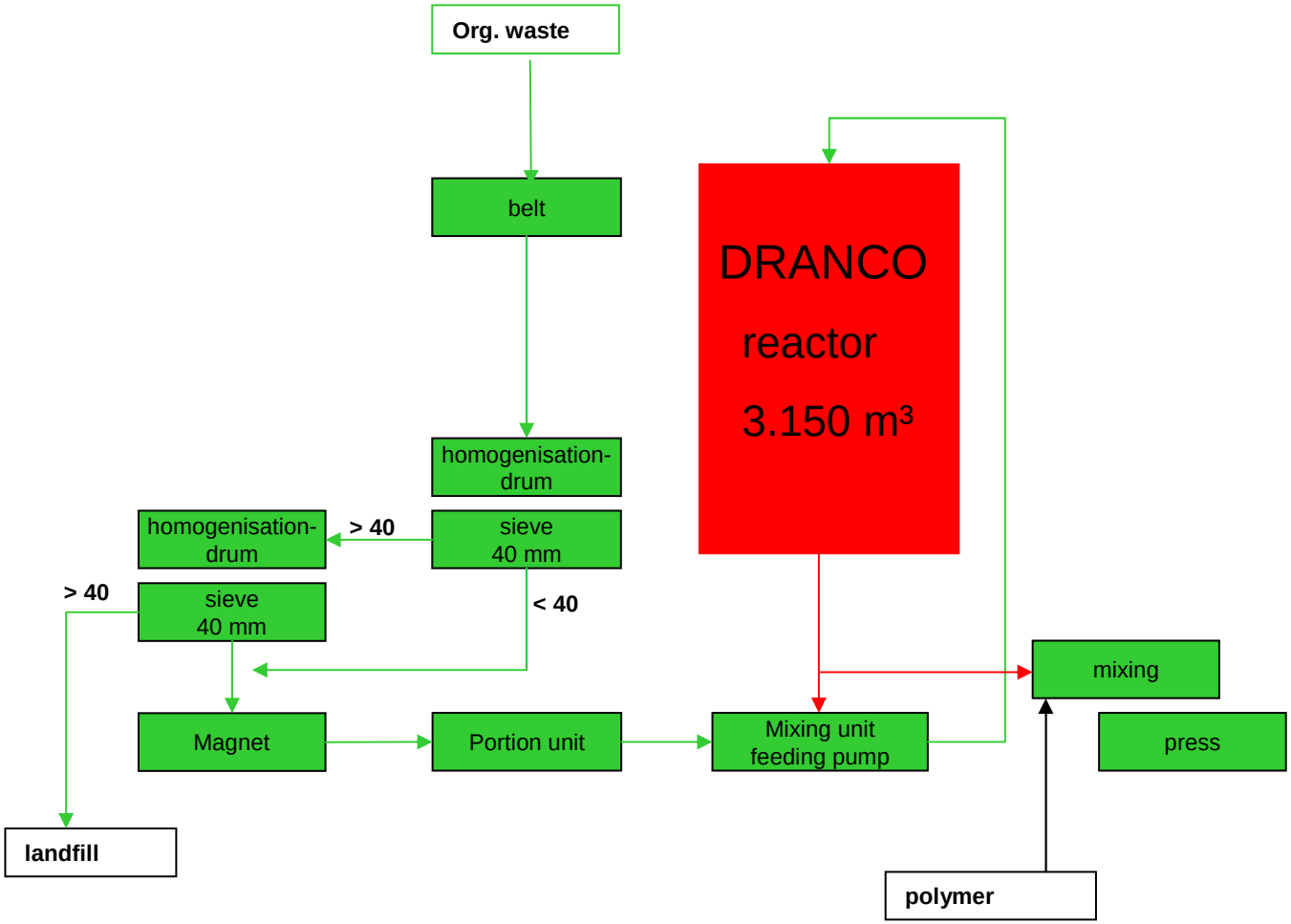

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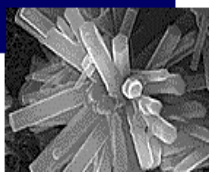

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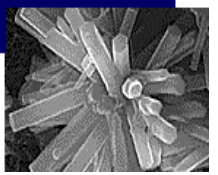


Org. waste

belt

DRANCO reactor 3.150 m³

homogenisation-drum

sieve 40 mm

> 40

homogenisation-drum

> 40

sieve 40 mm

< 40

landfill

Magnet

Portion unit

Mixing unit feeding pump

mixing

press

Spannwellen-sieve 10 mm

Überlauf

landfill

polymer

Press water storage

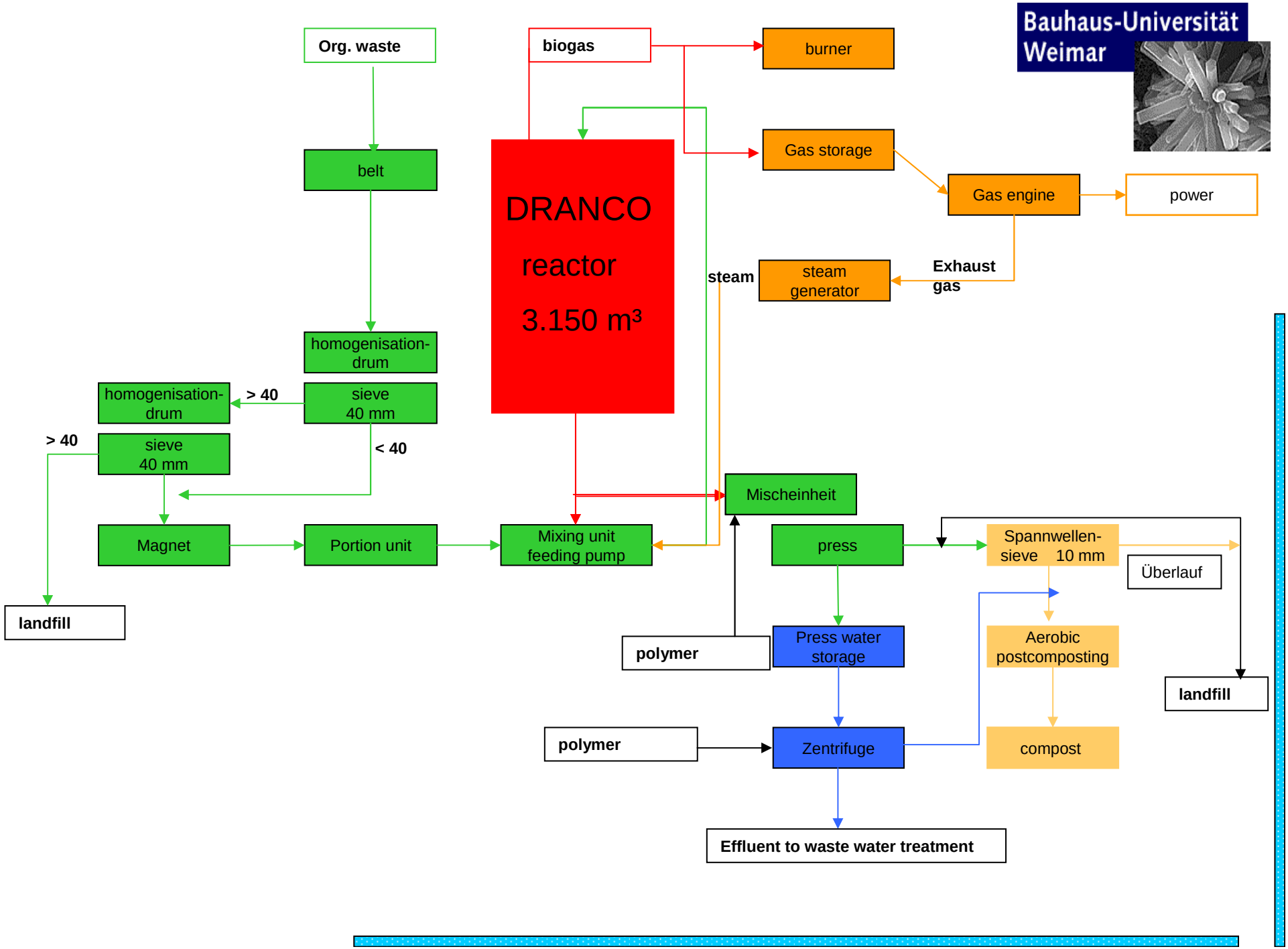
Aerobic postcomposting

polymer

Zentrifuge

compost

Effluent to waste water treatment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Org. waste
biogas
burner
belt
DRANCO
reactor
3.150 m³
Gas storage
Gas engine
power
steam
steam generator
Exhaust gas
homogenisation-drum
homogenisation-drum
> 40
sieve 40 mm
> 40
sieve 40 mm
< 40
Mischeinheit
Magnet
Portion unit
Mixing unit feeding pump
press
Spannwellen-sieve 10 mm
Überlauf
landfill
polymer
Press water storage
Aerobic postcomposting
landfill
polymer
Zentrifuge
compost
Effluent to waste water treatment

Germany

development

Bauhaus-Universität Weimar

Dranco

Germany development

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Dranco

Germany development

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Germany development

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Kompogas

Germany development

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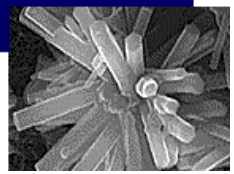

Dry - Batch

- Percolation is dynamic element

- no mixing/circulation within the reactor

- higher density of energy

Germany development

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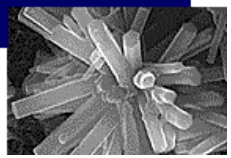

biomass

biomass and energy crop

- diff. silages
- diff. kinds of manure
- organic waste of markets
- sep. collected organic waste
- organic industrial waste (tabaco, potato)
- waste

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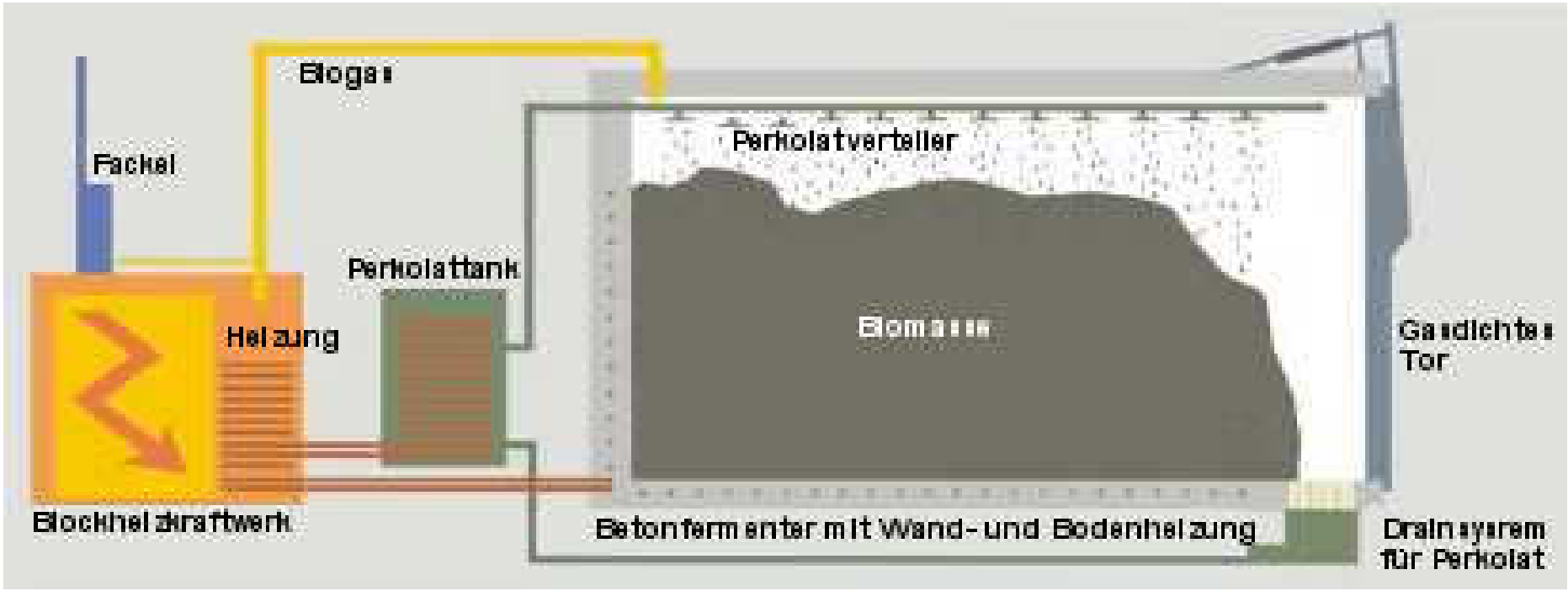
schematic



[Bekon, 2005]

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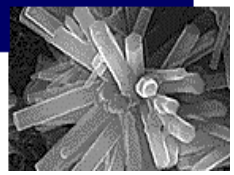
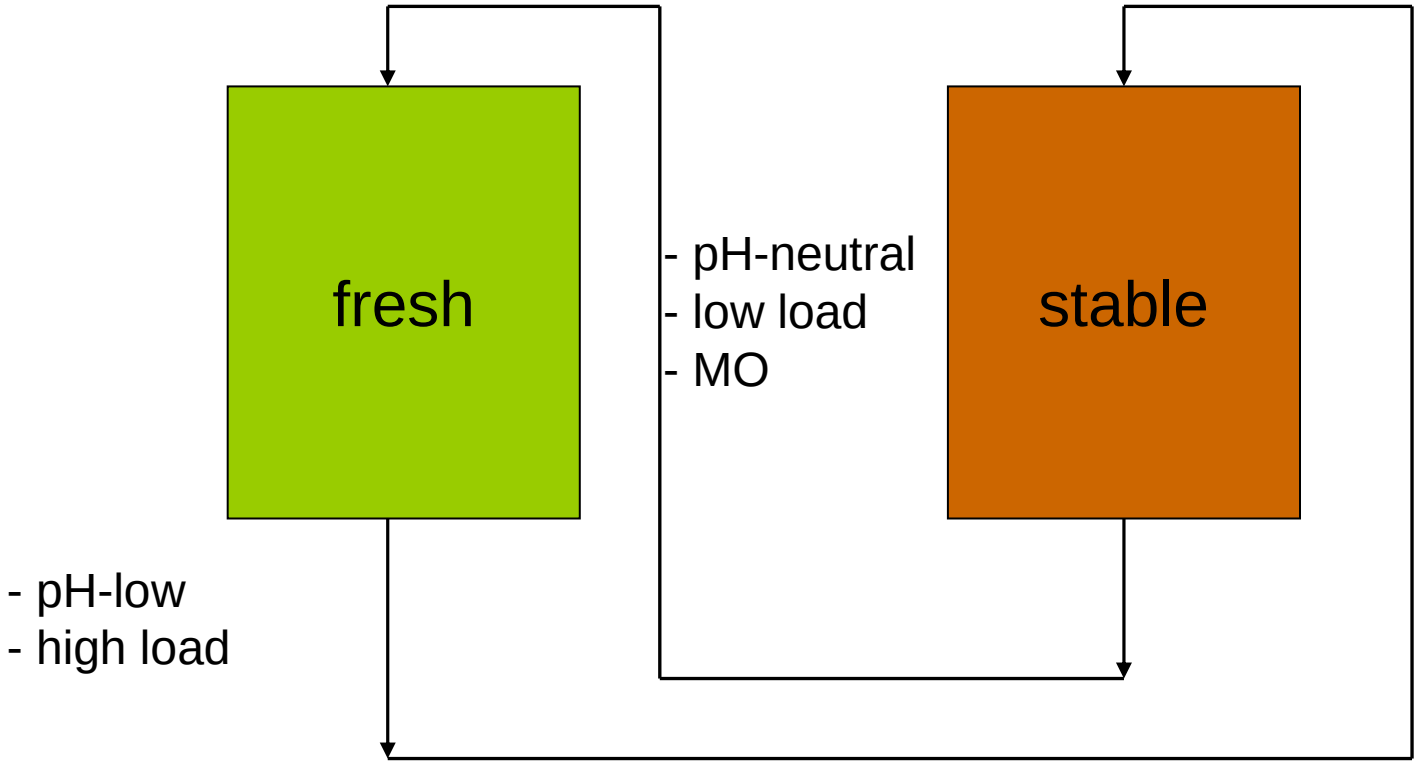


Batch



Germany development

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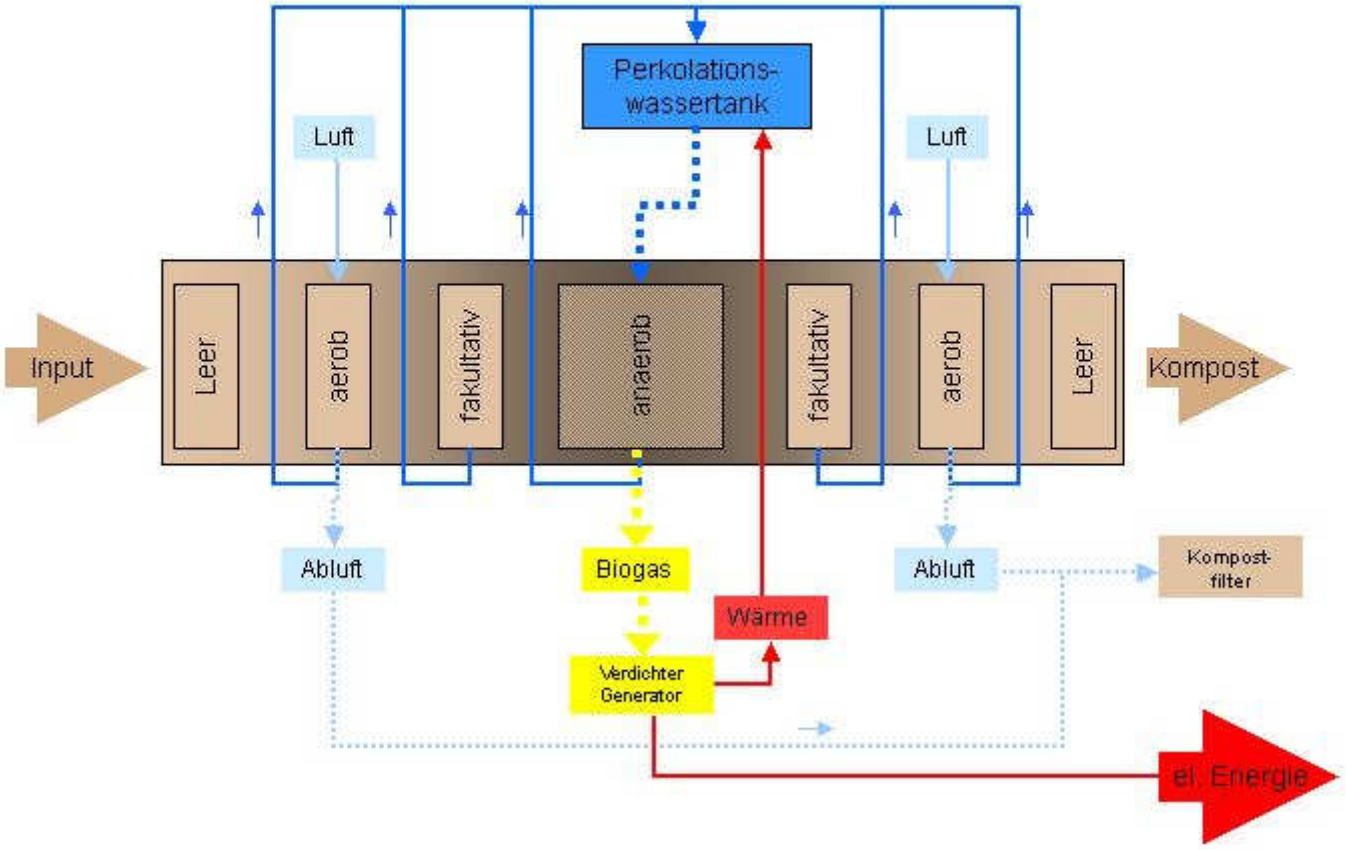
3A

Verfahrensfließbild



[SIG i. M.V.]

Germany development

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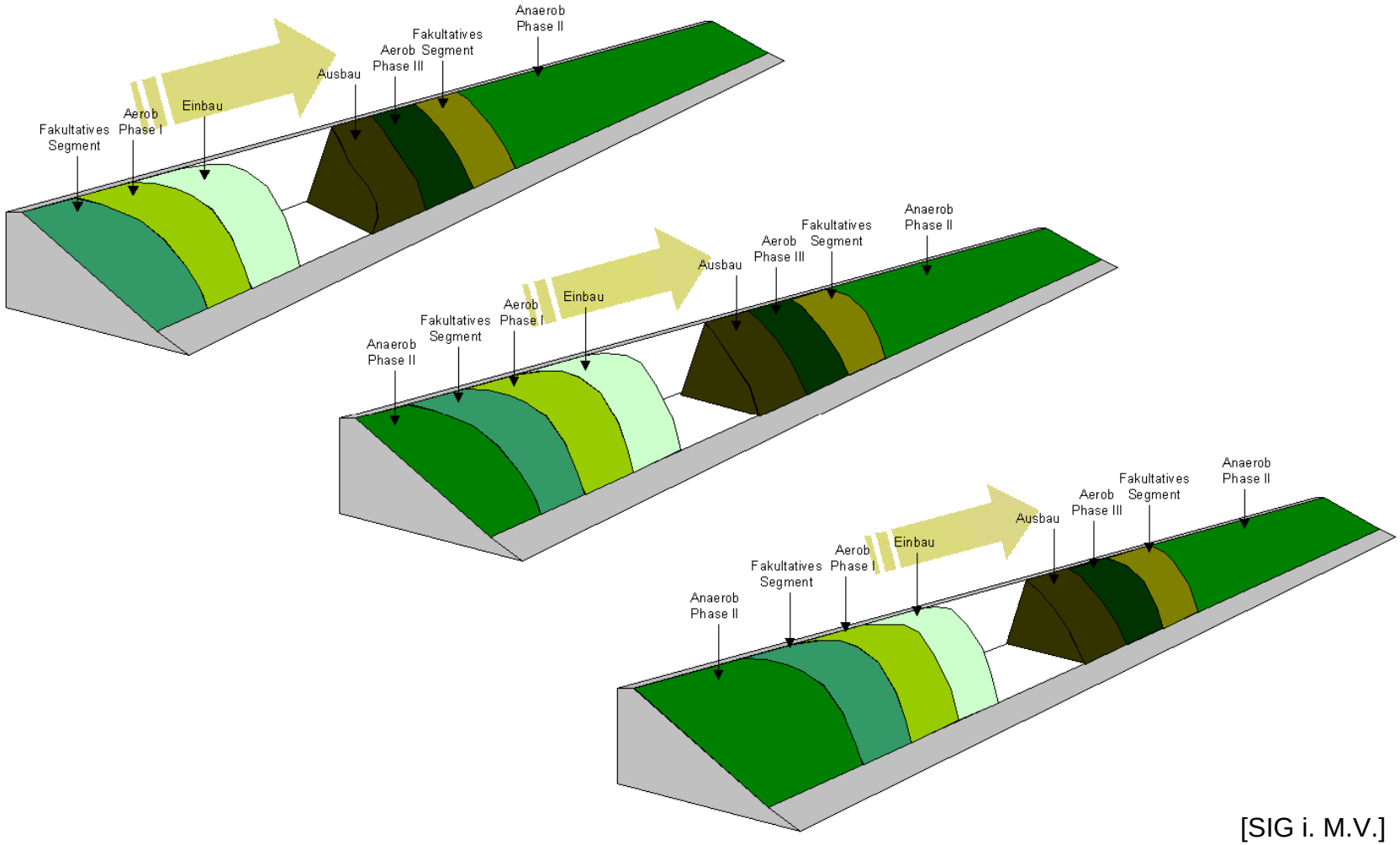

[SIG i. M.V.]

Germany

development

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3A

Germany development

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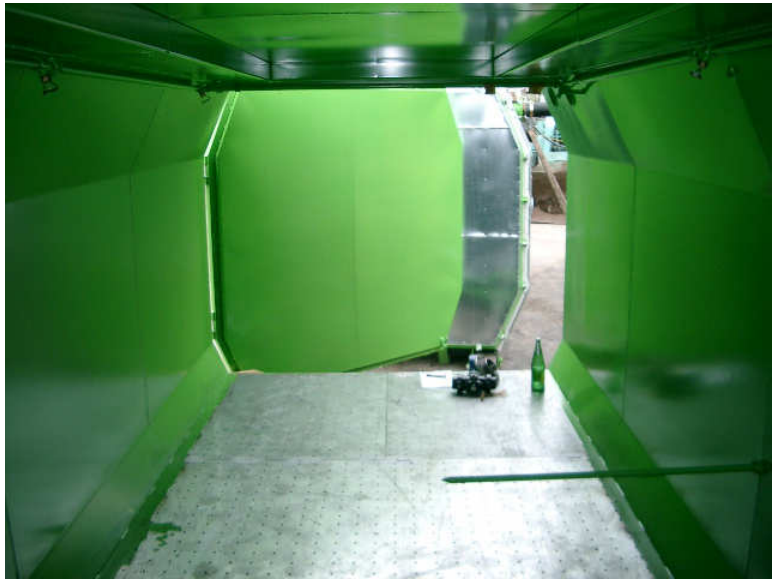
3A



Germany development

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Bekon

Germany development

Bauhaus-Universität Weimar

Bekon

Germany development

Bauhaus-Universität Weimar

Bioferm

Germany development

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Bioferm

Germany development

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State of the art -agriculture

- of the majority pilot plant character
- mesophilic batch operation in garages/boxes
- insertion by wheel loader
- continuous and undisturbed operation depends on experience of staff members
- mostly use of inoculum combined with percolation processes
- instructions and dimensioning facilities are missing

Germany development

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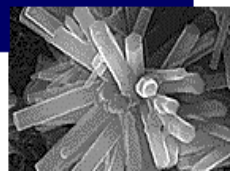

batch -dry-benefit

- biomass with high dry solid matter (DS) contents; no disturbances by woody or fibrous constituents
- dilution, stirrer, pumps are not to apply; less accident-sensitive equipment, less maintenance effort
- modular design feasible; lower investment costs
- lower process energy demand comparatively
- biogas with minor content of hydrogen sulphide; no gas purification
- storage of fermentation residues not necessary

Germany development

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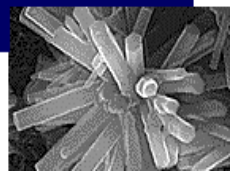

batch -dry-challenge

- difficult to generate continuous gas yields; possibility of phase displaced operation exists
- partly decreased gas discharge by zoning, because of missing complete mixing
- dispersed provision of substrate is not given
- nutrient supply is more difficult, because of less water in the system
- large amounts of inoculum necessary to keep the biological activity on a level

Germany development

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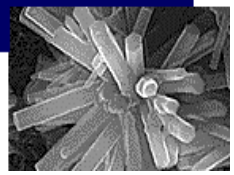

Initial point

- in a heap leaking gases, pressed water and percolated fluid share provided pore space in a competitive situation
- high packing densities promise increased biogas yields (additional material insertion) = economical gain
- too high packing densities leads to process failures or incomplete substrate degradation
- it is valid to find a density optimum
- systematic tests of packed beds consists of renewable raw materials and different physical parameters

Germany development

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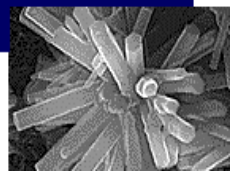

Initial point

- substrates:
  - by-products (e.g. apple pulp, straw)
  - cattle dung
  - energy crops (e.g. maize silage, grass, triticale)

- investigation of physical properties, namely:
  - densities (d.b. and w.b.)
  - hydraulic conductivity (permeability)
  - particle size distribution
  - pore space

Germany development

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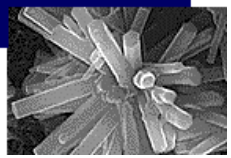

Yield of biogas

- between 150 and 600 m³/Mg :
  - appel 150 m³/Mg
  - silage of maize 200 m³/Mg
  - straw 350 m³/Mg
  - triticale 600 m³/Mg
- between 50 and 150 m³/Mg for organic waste

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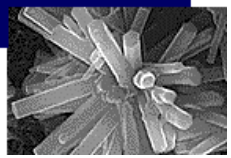

substrate characterisation

substrate	*water content*	*water capacity*	*degree of saturation*	*pore space*	
	WC	AWC	S_w	n_w	n_g
	[mass-%]	[mass-%]	[-]	[-]	[-]
apple pulp	86	86	1,0	0,89	0,00
maize silage	72	73	0,9	0,70	0,04
straw	61	78	0,3	0,26	0,83

substrate	*bulk density*	*proctor density*	*compacted density* *	*particle density*
	r_b	r_{pr}	r_{max}	r_p
	[g*(cm^3)$^{-1}$]	[g*(cm^3)$^{-1}$]	[g*(cm^3)$^{-1}$]	[g*(cm^3)$^{-1}$]
apple pulp	0,98	0,14	1,04	1,1
maize silage	0,42	0,28	0,98	1,1
straw	0,02	0,17	0,43	1,0

* w.b. - wet basis

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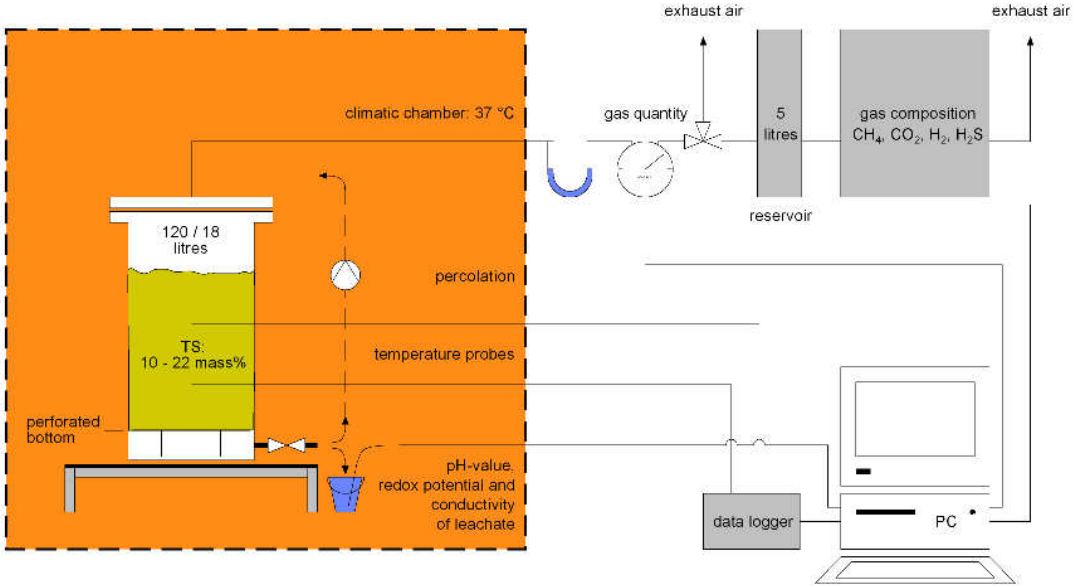
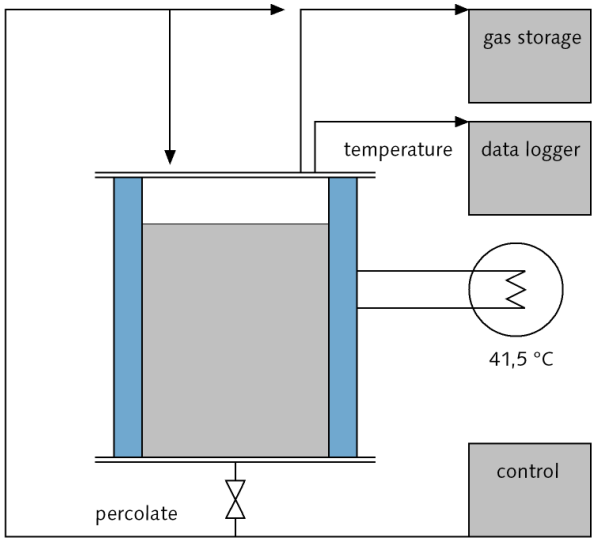
experimental set-up



inoculation / percolation



combination

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pictures

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pictures

- inoculation / percolation
- mixing ratio = 0,65 ($TS_{substrate}$ to $TS_{inoculum}$)
- different densities

- combined tests
- different mixing ratios (finding the optimum)
- different densities

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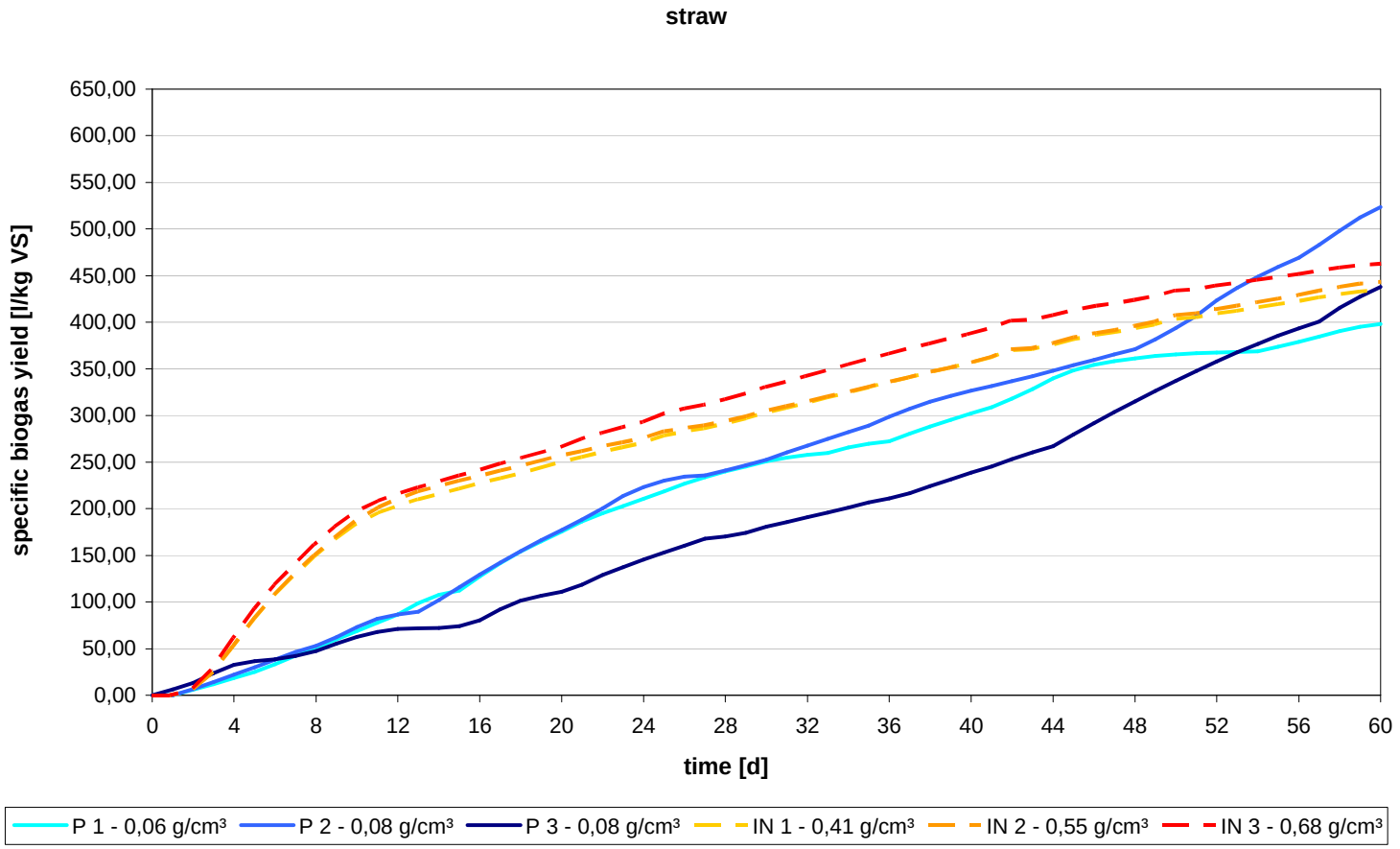
fermentation process data - straw



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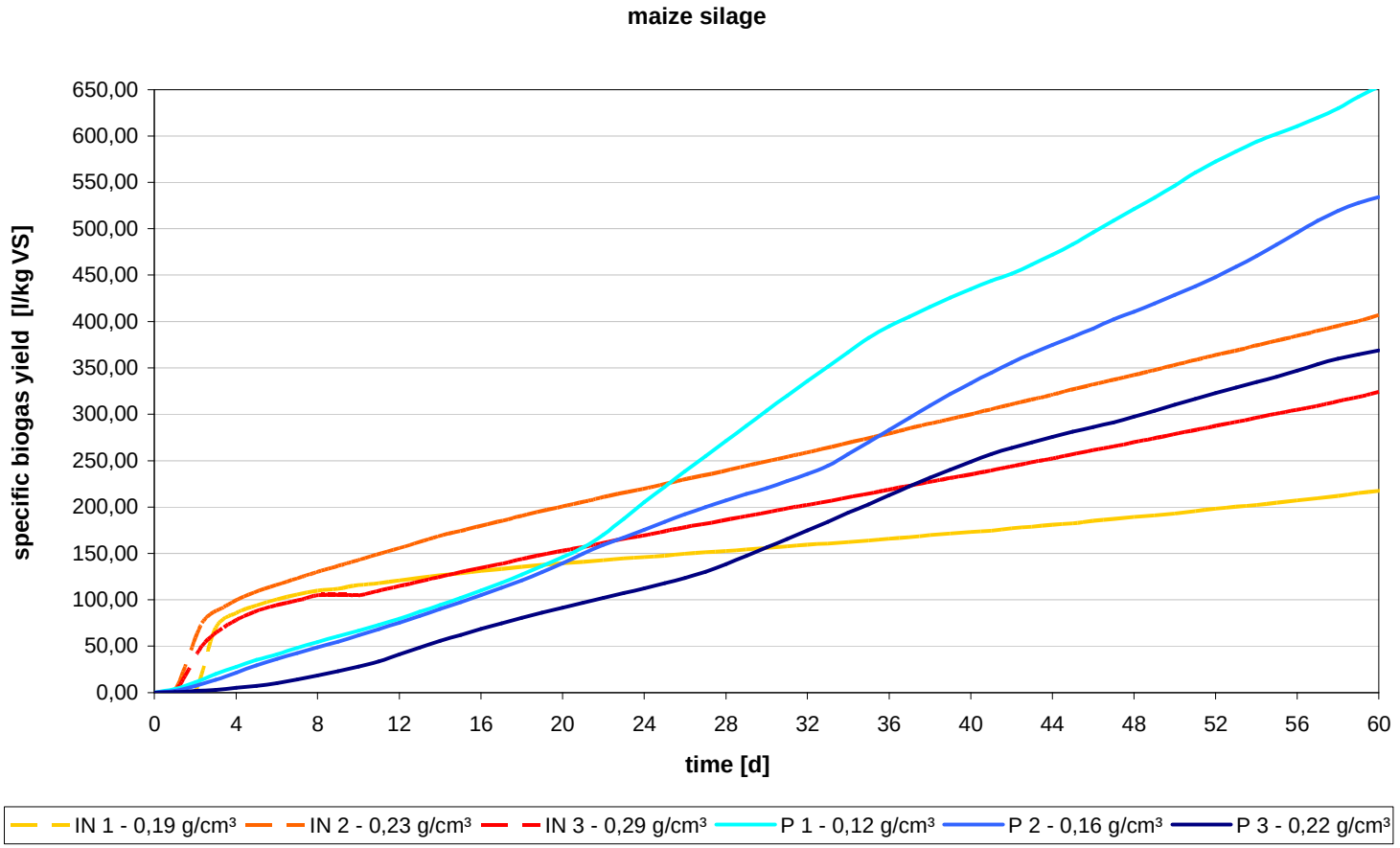
fermentation process data – maize silage



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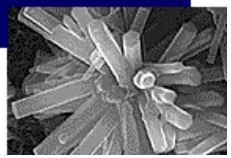

fermentation process data – maize silage

	percolated fermentation			*literature **	
substrate	*density*	*biogas yield*		*biogas yield*	
	low, middle, high	[l/kg input]	[l/kg VS]	[l/kg input]	[l/kg VS]
apple pulp	low	135,6	607,8	150	670
maize silage	low	178,3	653,3	185	575
straw	low, middle	260,5	523,5	292	369
triticale	low	176	539,8	171	615

	inoculated fermentation			*literature **	
substrate	*density*	*biogas yield*		*biogas yield*	
	low, middle, high	[l/kg input]	[l/kg VS]	[l/kg input]	[l/kg VS]
apple pulp	high	30,2	171,9	150	670
maize silage	middle	113	407	185	575
straw	high	371,7	462,6	292	369
triticale	high	285,9	540,9	171	615
		marks inhibited processes			

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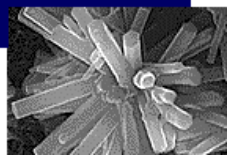

conclusions

- after introducing stable inoculum the biomass bed performed well
- increasing density does not mean inevitably increased biogas yield
- at this moment it is not possible to constitute optimal packing densities
- it is expected to achieve consolidated expertises regarding process duration, substrate characterisation and suitability = meets the current demand