Anaerobic Digestion of Wastewater

Global Methane Initiative – Wastewater Task Force Meeting

November 11, 2010, Thursday, 15:30 – 16:00

Lettinga Associates Foundation

Delft University of Technology

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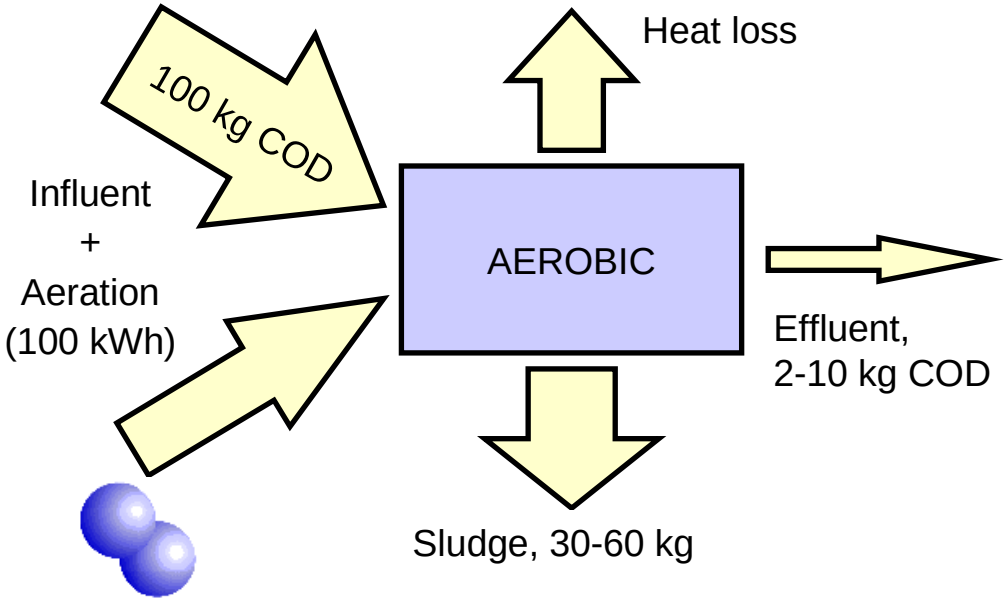
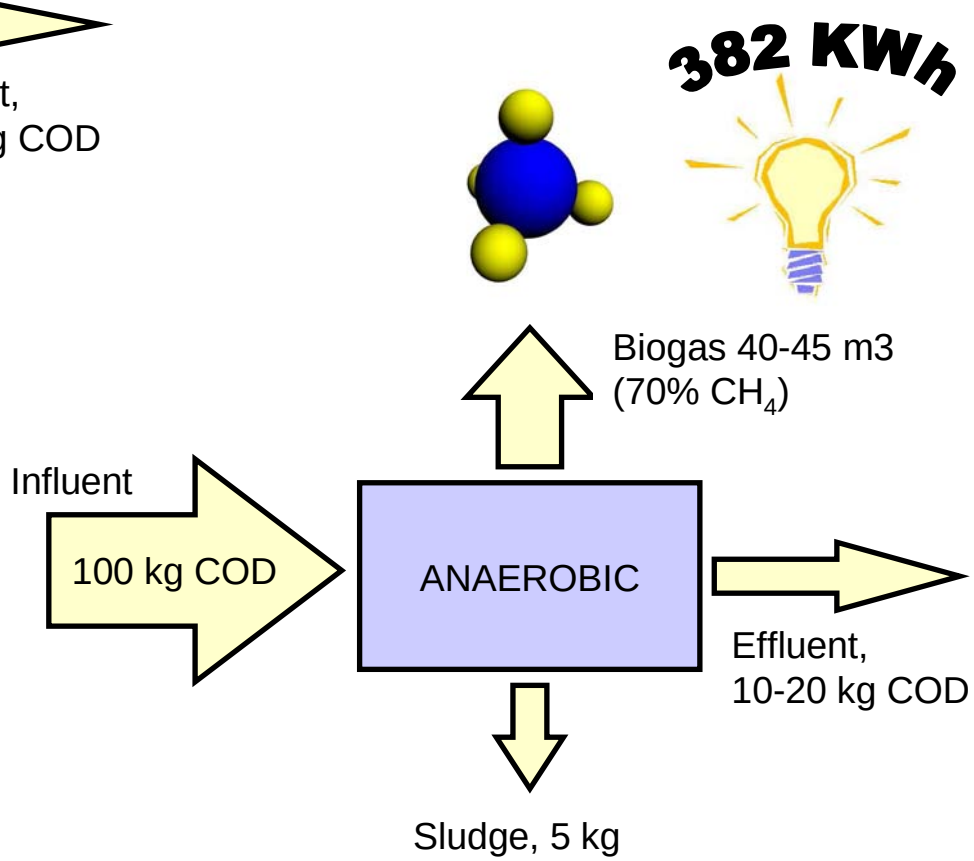
- Basics Anaerobic Digestion
- Reactors
- State of Practice
- Developments

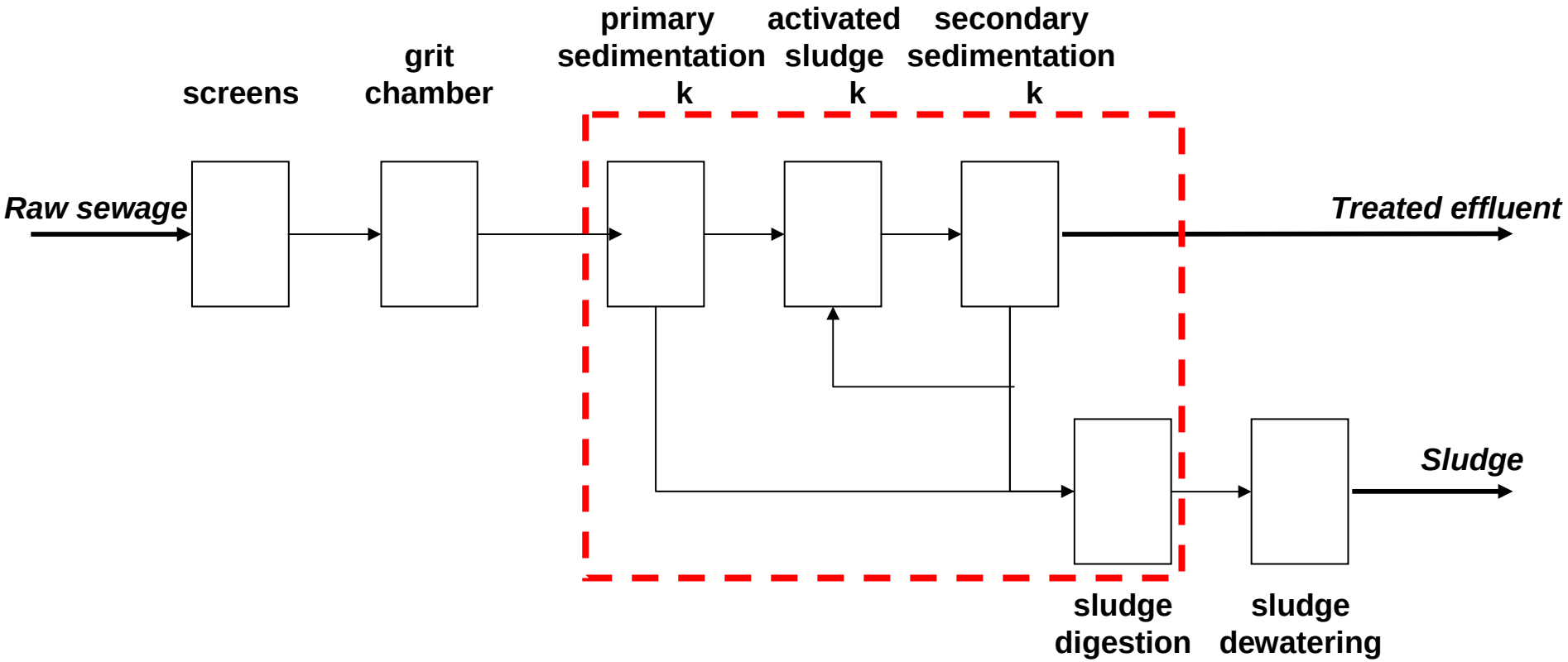
Basics Anaerobic Digestion

Comparison Aerobic - Anaerobic

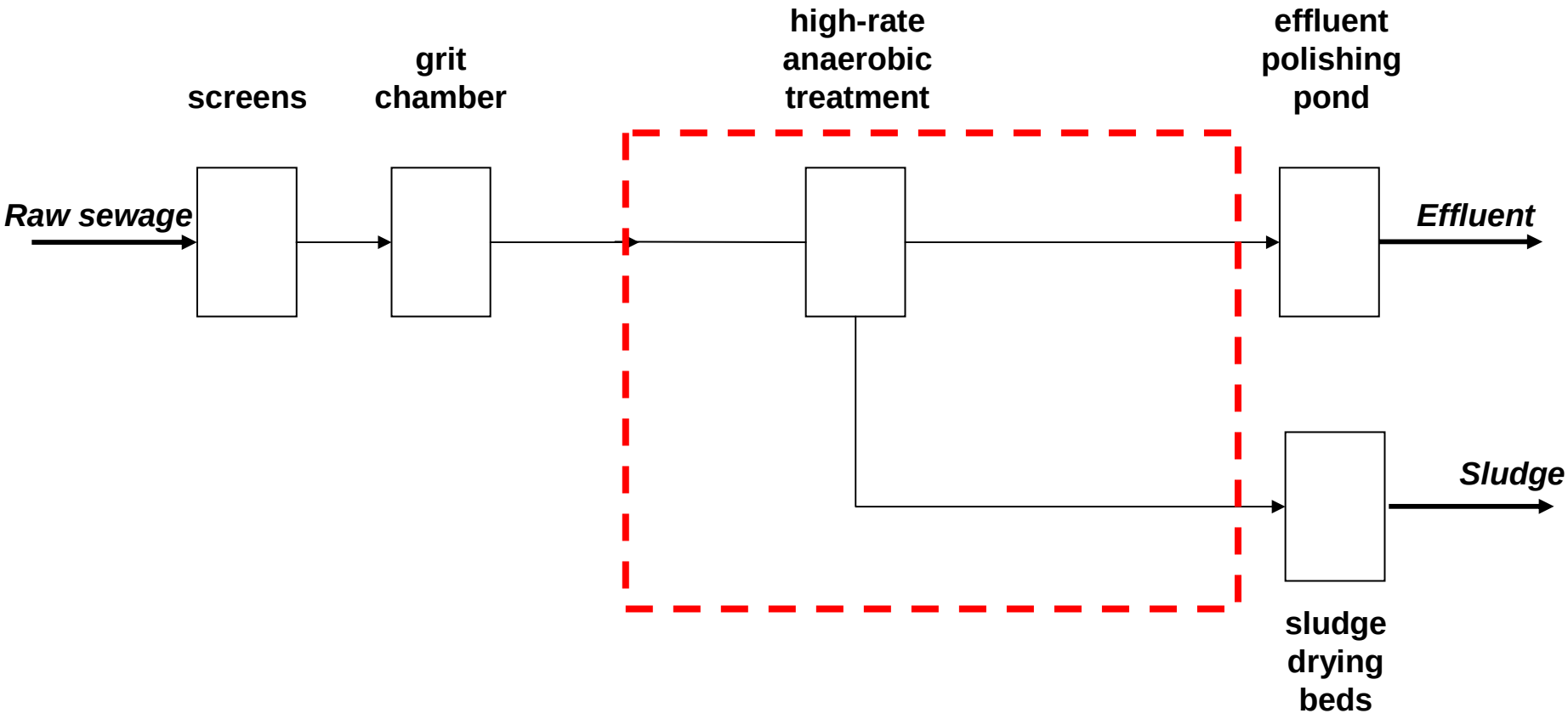




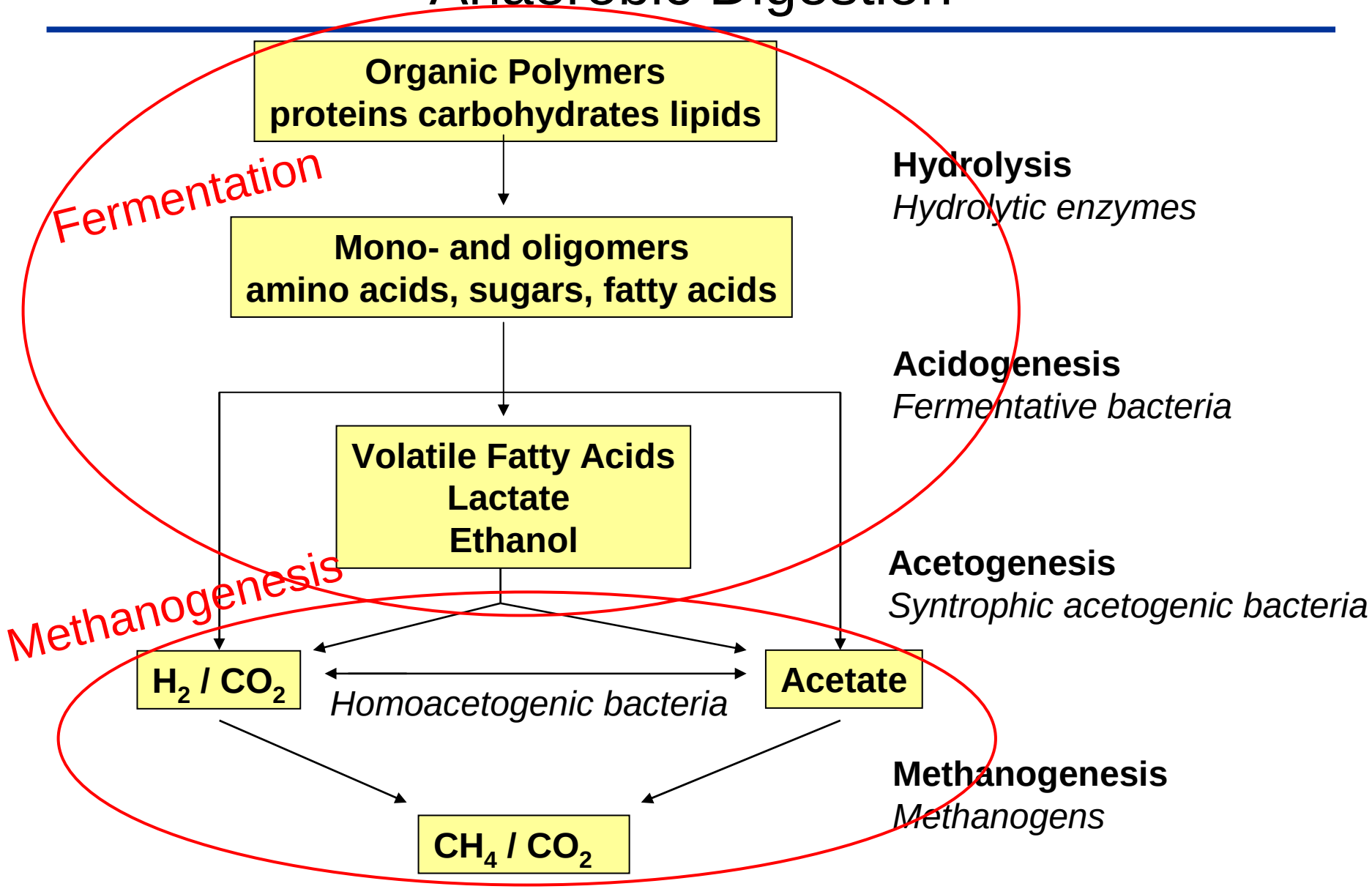
Basic setup of aerobic treatment



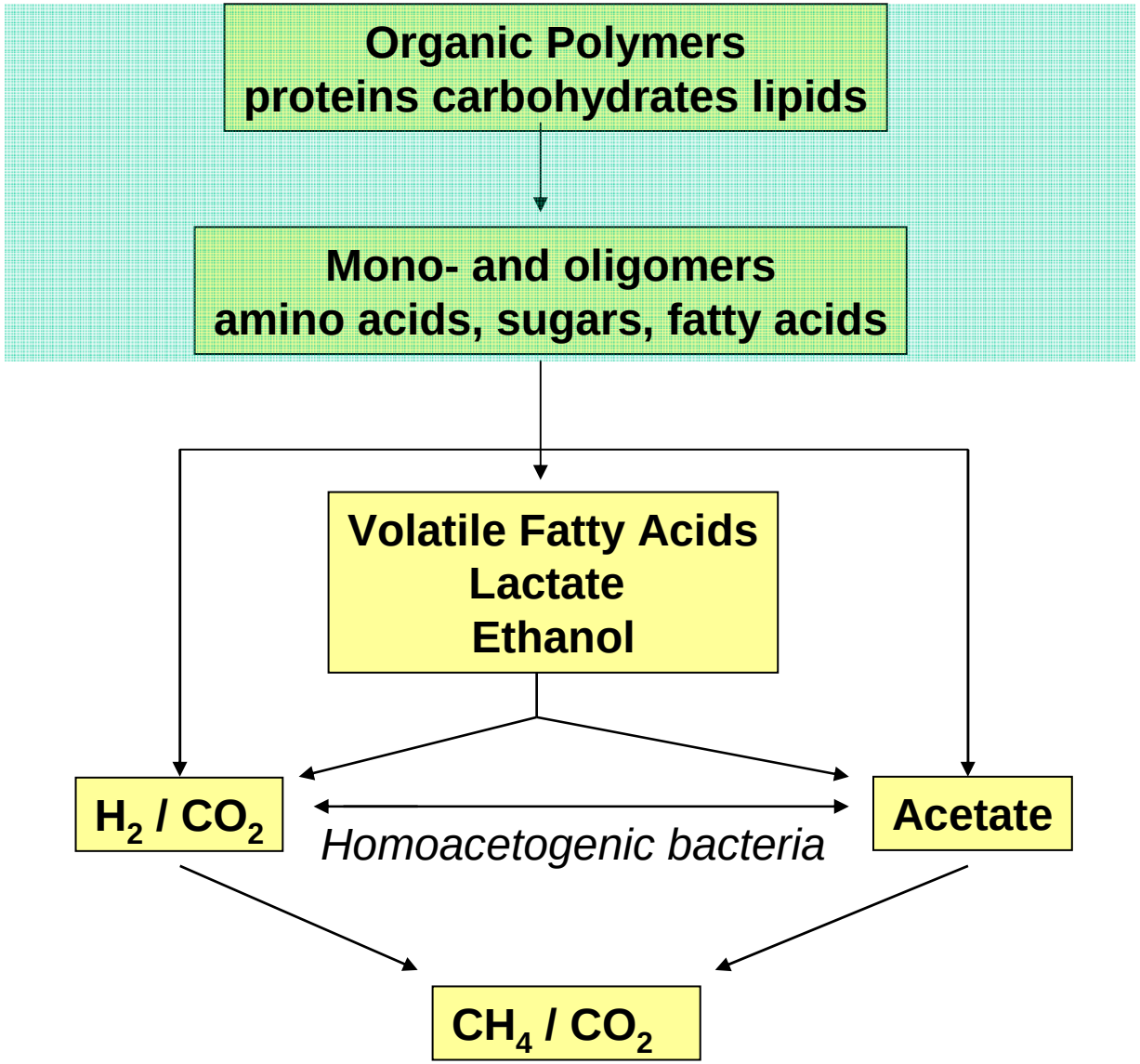
Basic setup of anaerobic treatment



Anaerobic Digestion

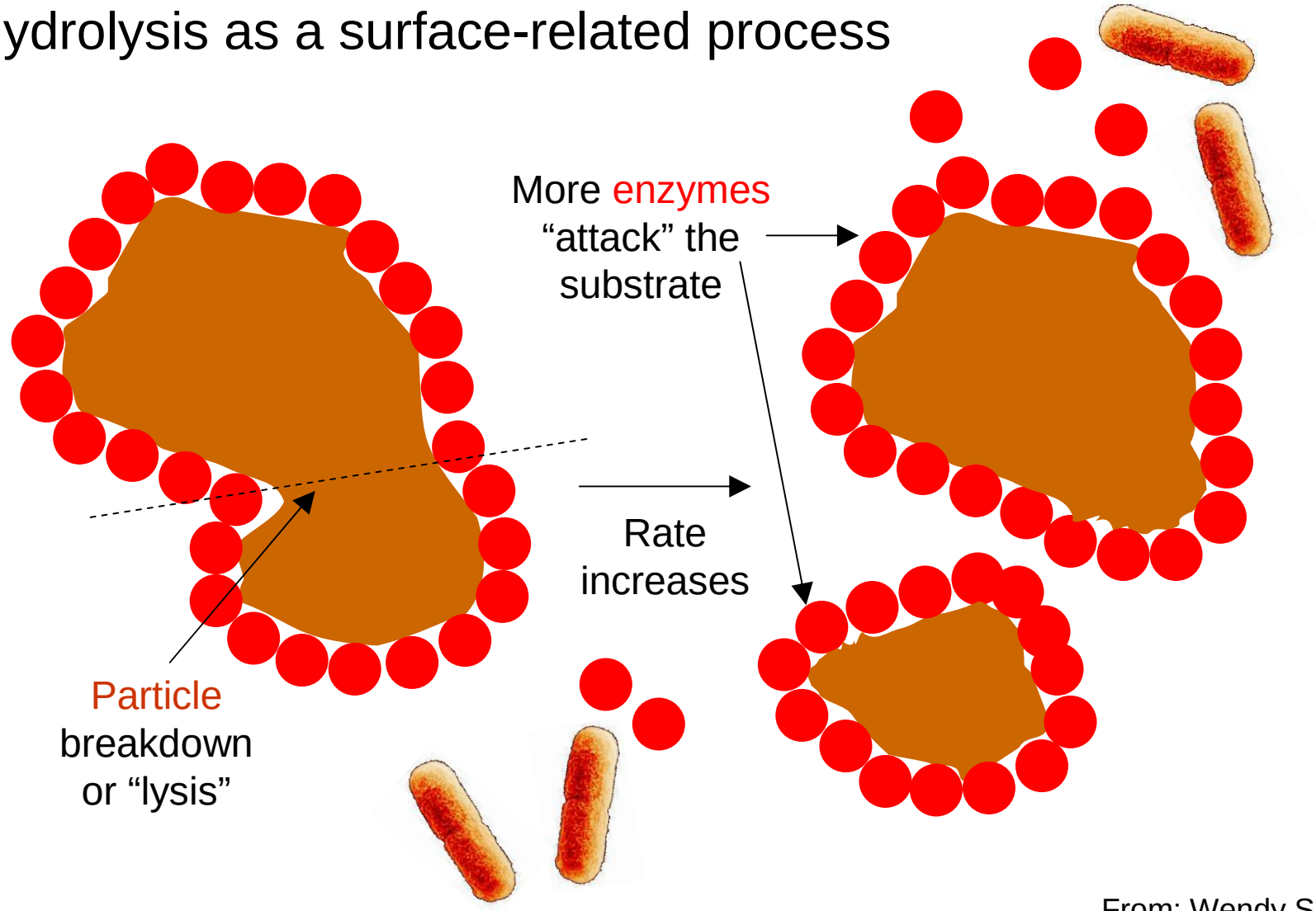


Hydrolysis


Organic Polymers
proteins carbohydrates lipids
Mono- and oligomers
amino acids, sugars, fatty acids
Volatile Fatty Acids
Lactate
Ethanol
H2 / CO2
Homoacetogenic bacteria
Acetate
CH4 / CO2

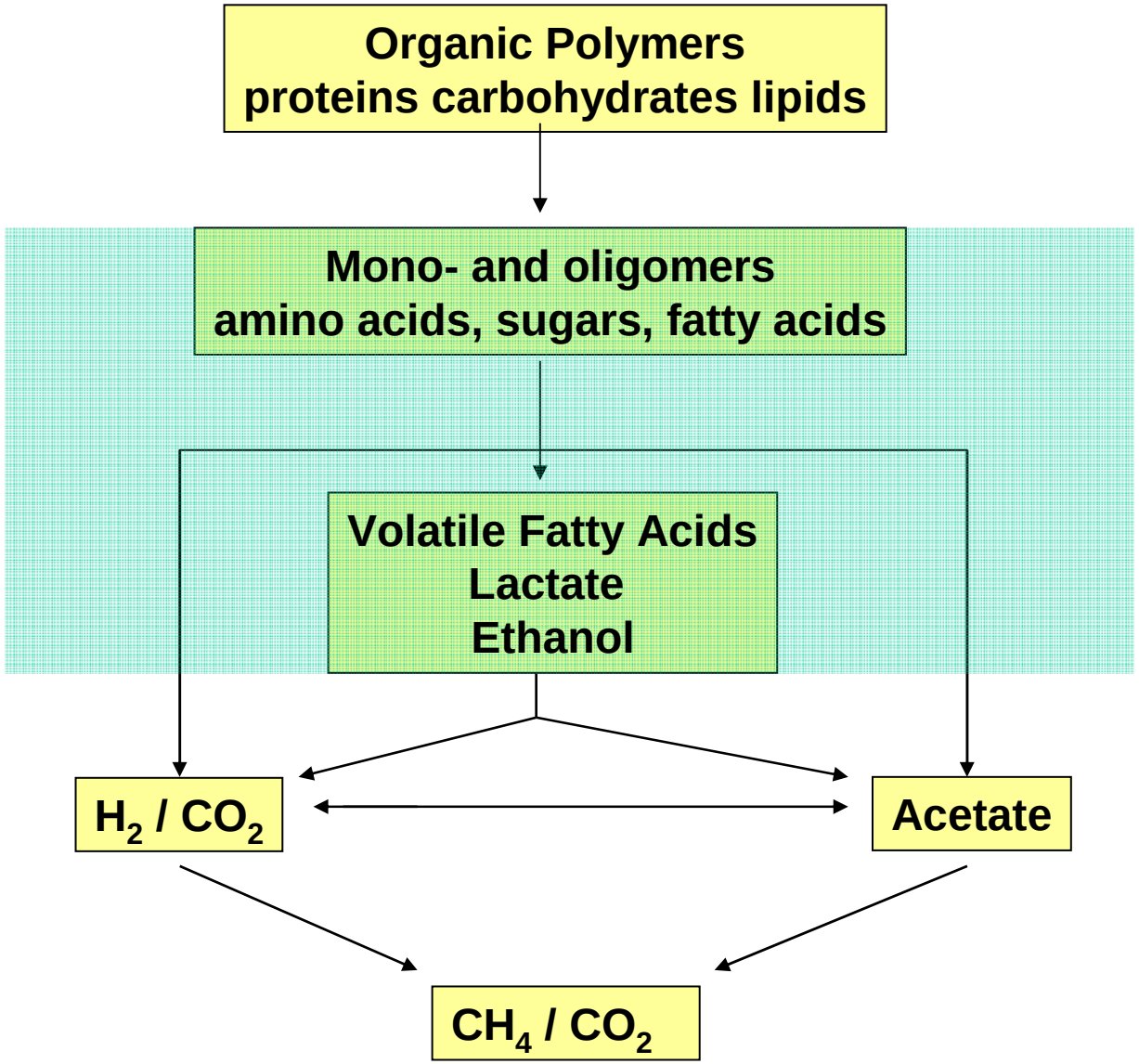
Hydrolysis: Surface related

- Hydrolysis as a surface-related process

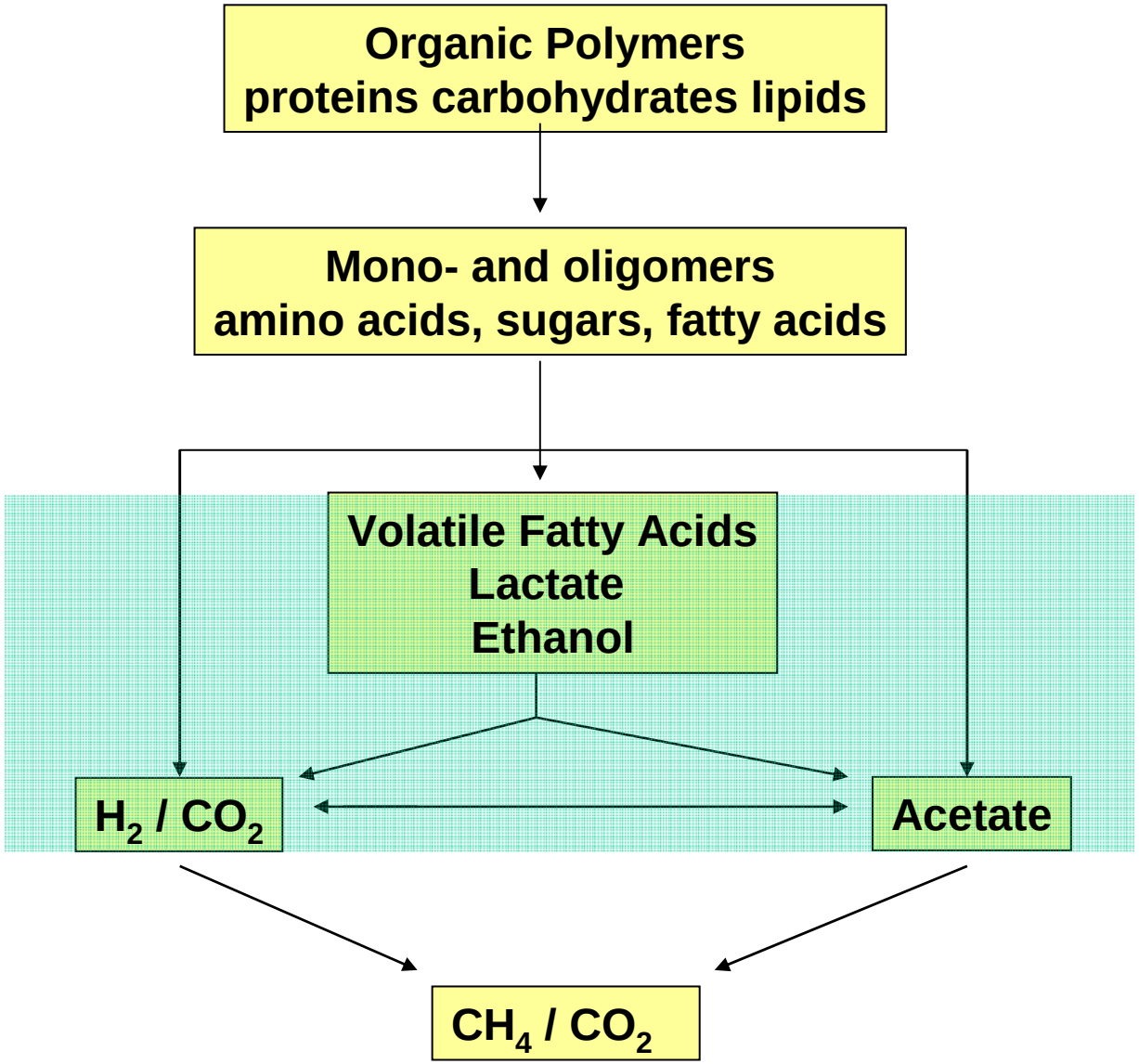


From: Wendy Sanders

Acidogenesis



Acetogenesis



Acetogenesis (Acetate formation)

- Conversion of fermentation products into acetic acid, CO_2, and H_2
- Mainly from propionic acid, butyric acid and ethanol

$propionate^- + 3H_2O \rightarrow acetate^- + HCO_3^- + H^+ + 3H_2$ $\Delta G_0' = +76.1$ kJ/mole

$butyrate^- + 2H_2O \rightarrow 2\ acetate^- + H^+ + 2H_2$ $\Delta G_0' = +48.1$ kJ/mole

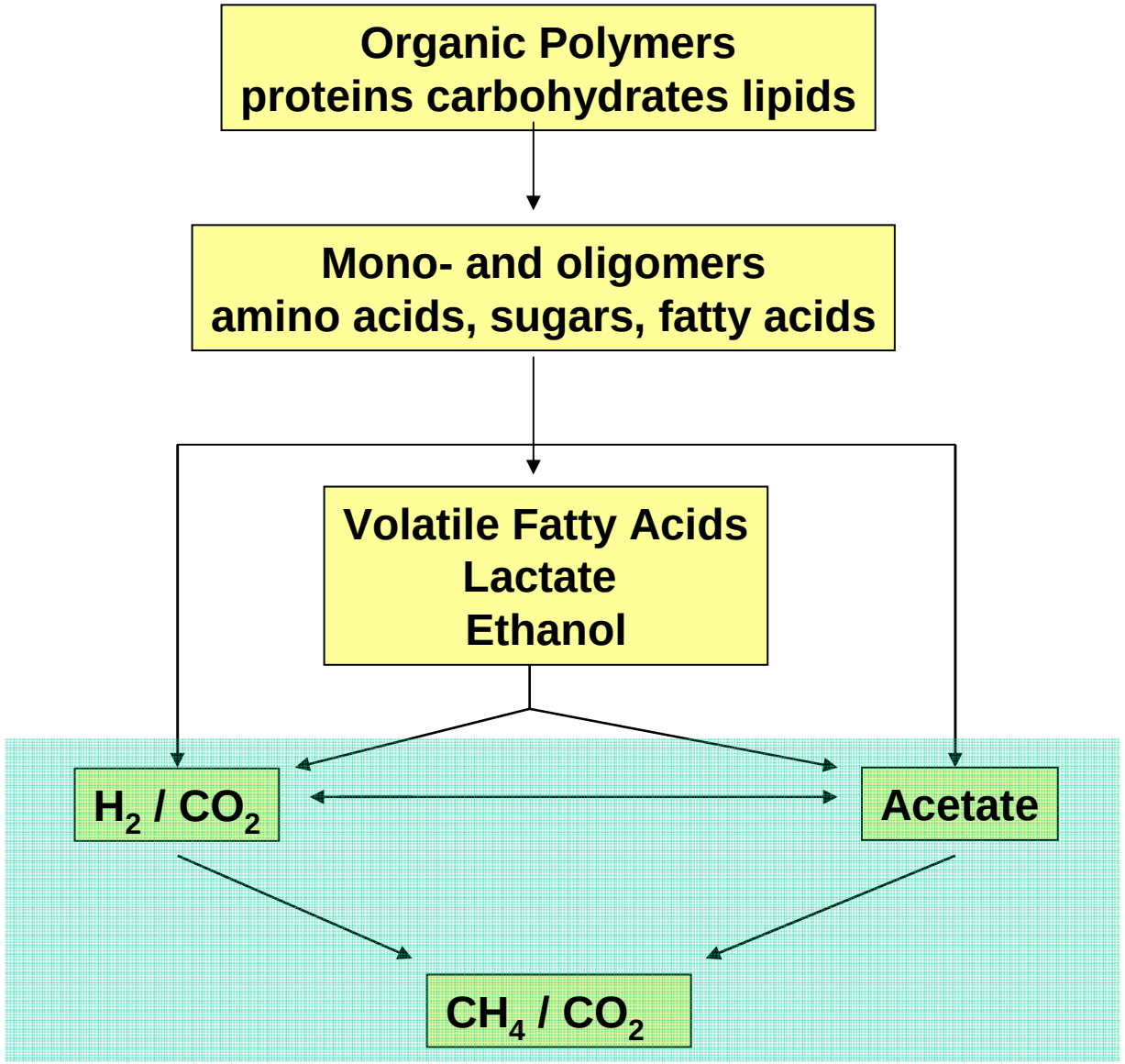
$ethanol + 2H_2O \rightarrow acetate^- + H^+ + 2H_2$ $\Delta G_0' = +9.6$ kJ/mole

---

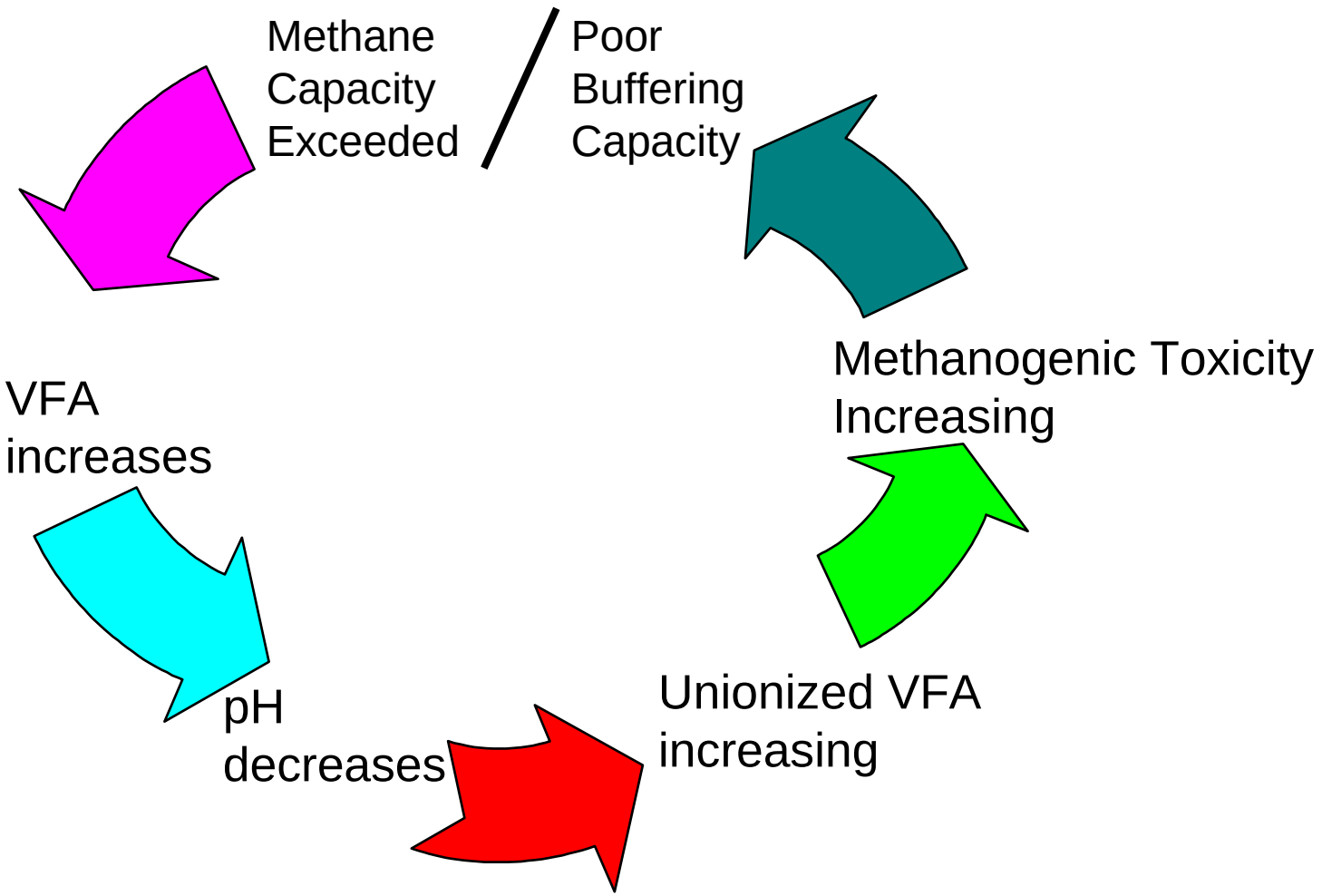
$4\ H_2 + CO_2 \rightarrow CH_4 + 2H_2O$ $\Delta G_0' = -138.9$ kJ/mole

➡ Need for syntrophic associations !!!

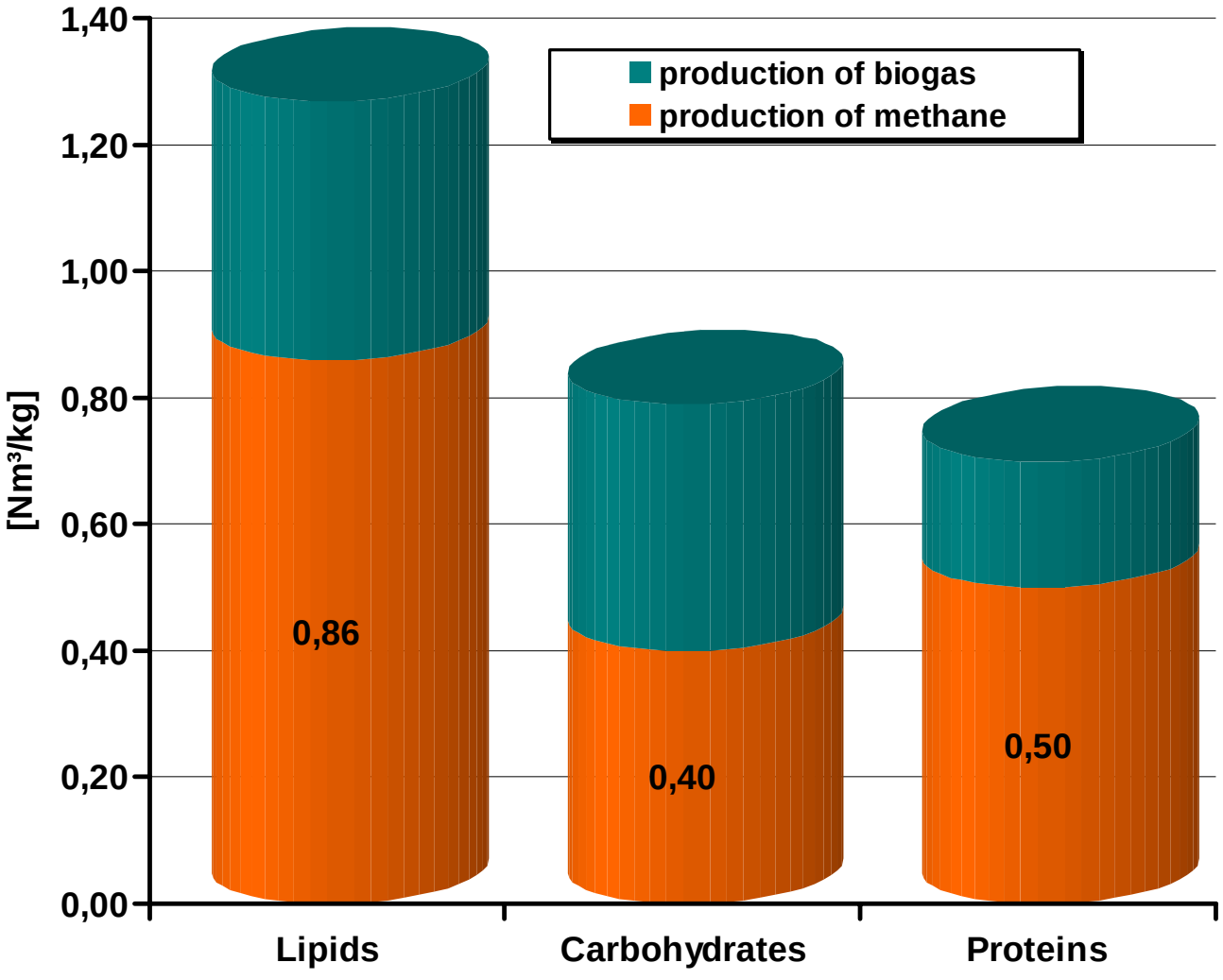
Methanogenesis



Acidogenesis: Acidification



Maximum Production of Biogas



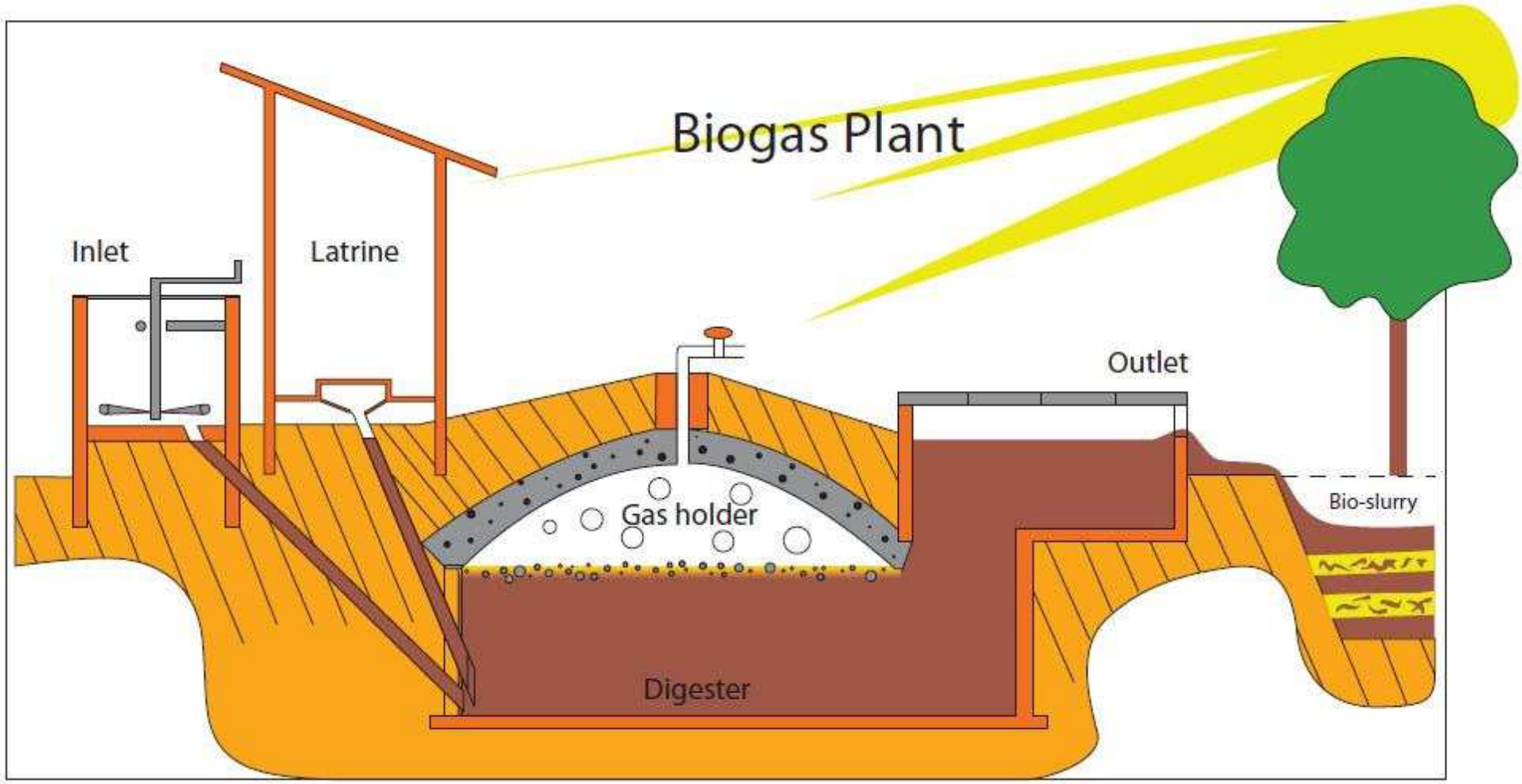
(ATV-DVWK M 363)

Basics Anaerobic Treatment: Summary

- Nett energy production
- No fossil fuel required
- Low sludge production
- Higher effluent COD
- No nitrogen and phosphorus removal
- High loading rates
- Small footprint
- Sewage: Hydrolysis limiting step
- Sewage: Limited biogas production

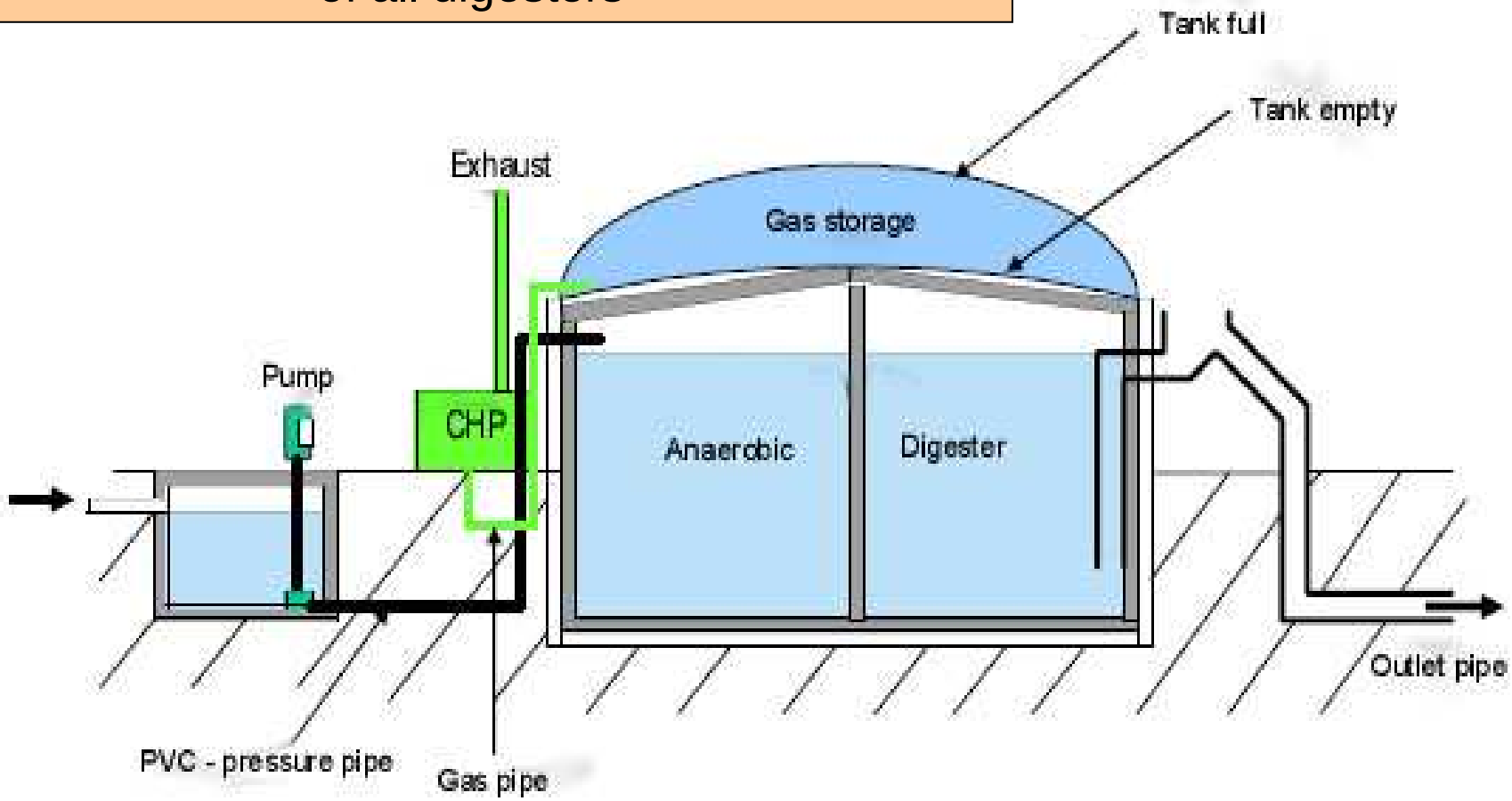
Reactors

Fixed Dome Domestic Digester



Digester: Schematic

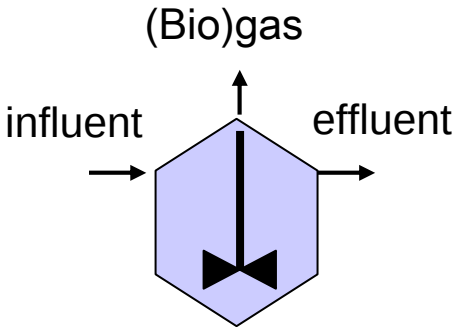
Digester with rubber membrane cover > 50 % of all digesters



Biogas Plant in the UK

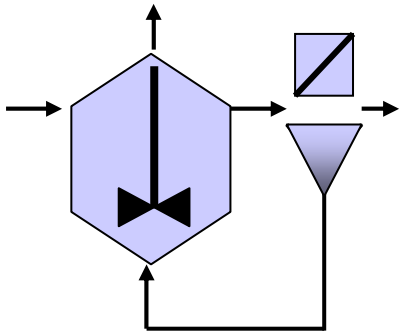
Development of “high-rate” anaerobic treatment systems

Completely mixed



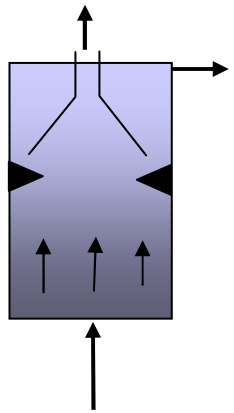
Relative capacity: **1**

Physical retention



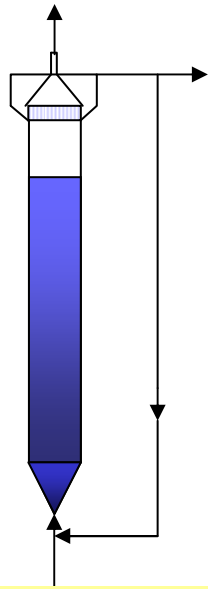
Relative capacity: **5**

Immobilised biomass

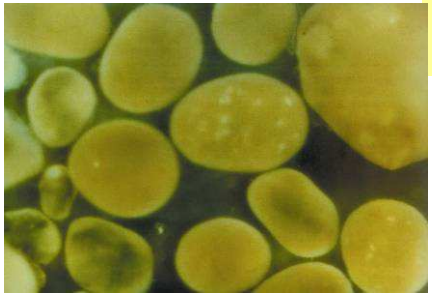


Relative capacity: **25**

Enhanced contact

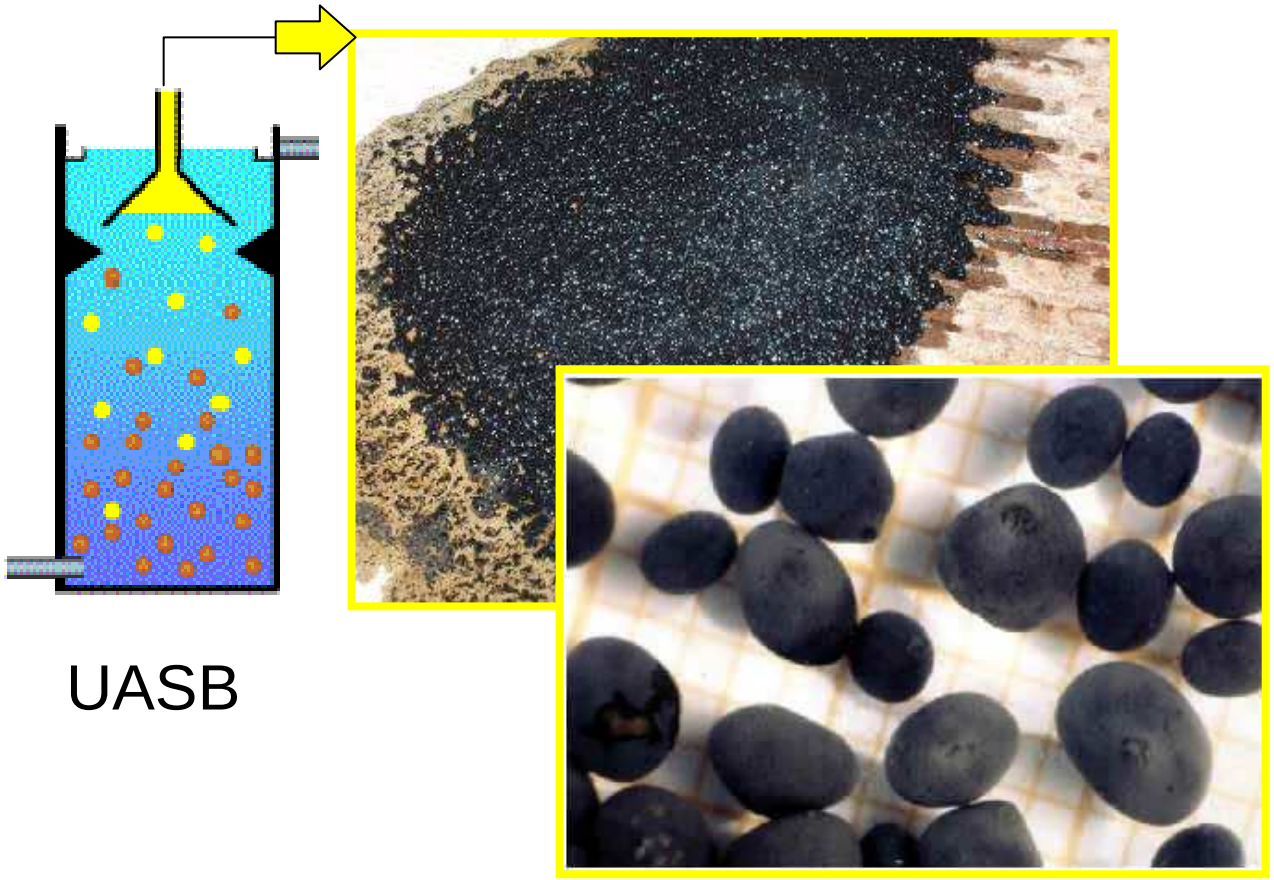


Relative capacity: **75**



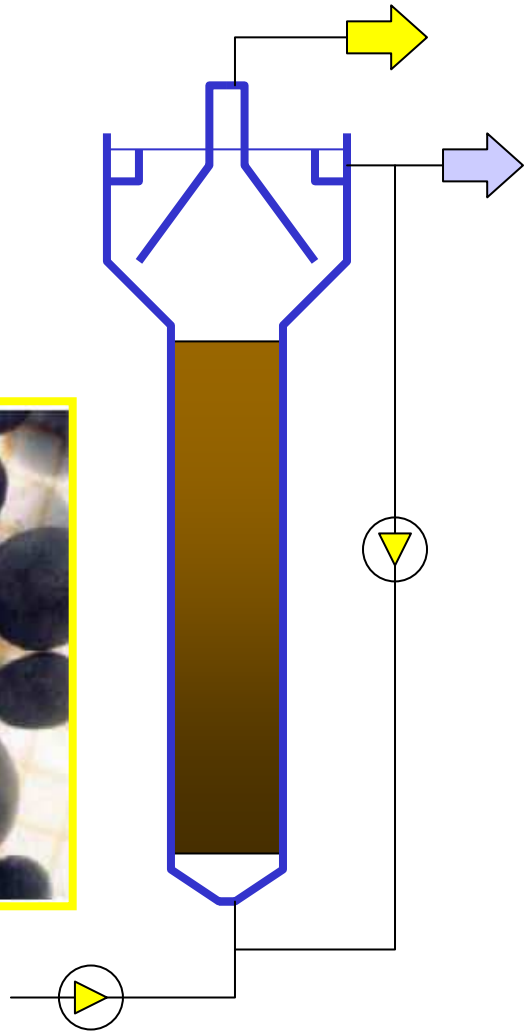
UASB and EGSB

Auto immobilization / granulation

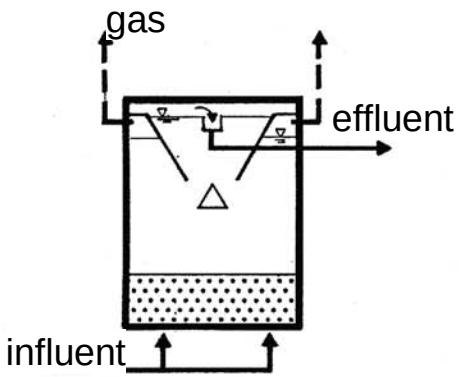


UASB

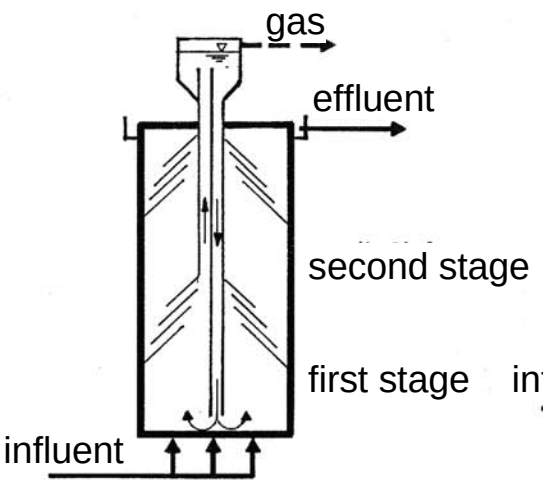
EGSB



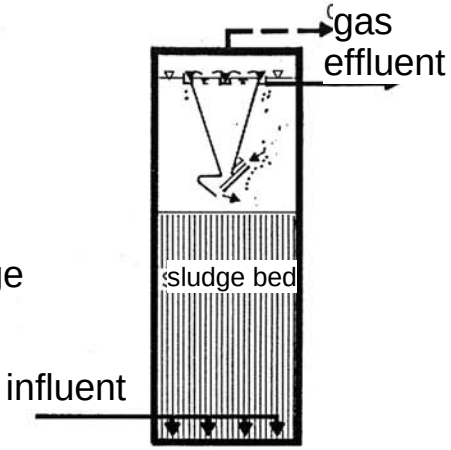
Reactor Technologies for Liquids



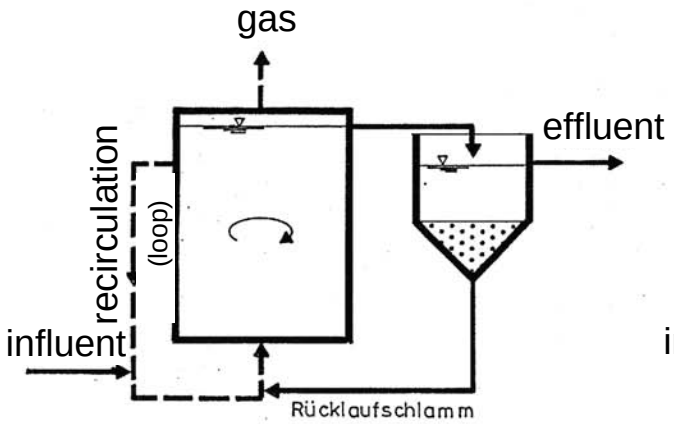
UASB-Reactor



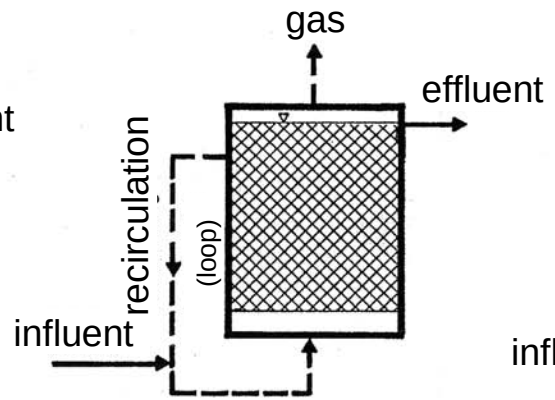
IC-Reactor



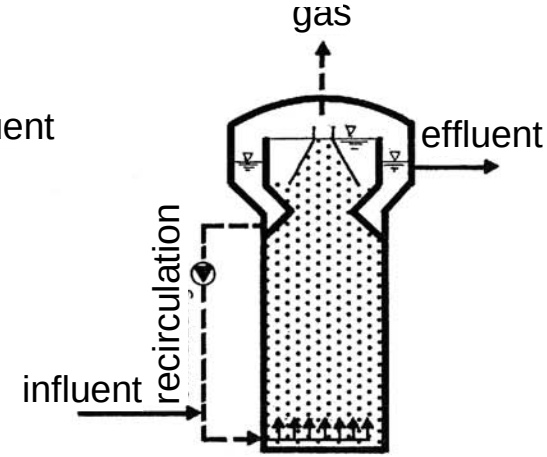
Biobed-Reactor



Anaerobic Contact Reactor



Fixed bed Reactor

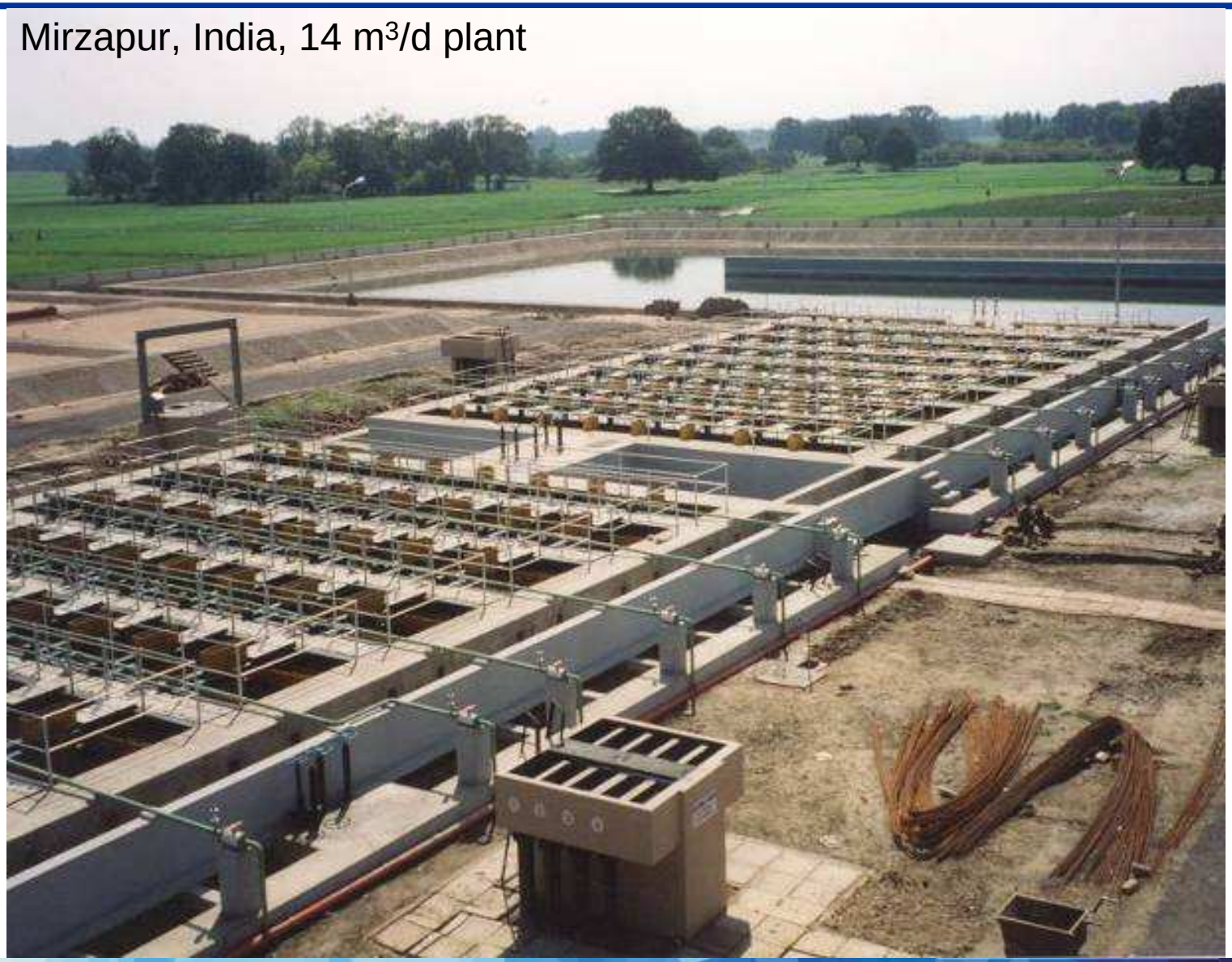


Fluidized bed Reactor

UASB: Sewage

UASB Reactor: Sewage

Mirzapur, India, 14 m^3/d plant



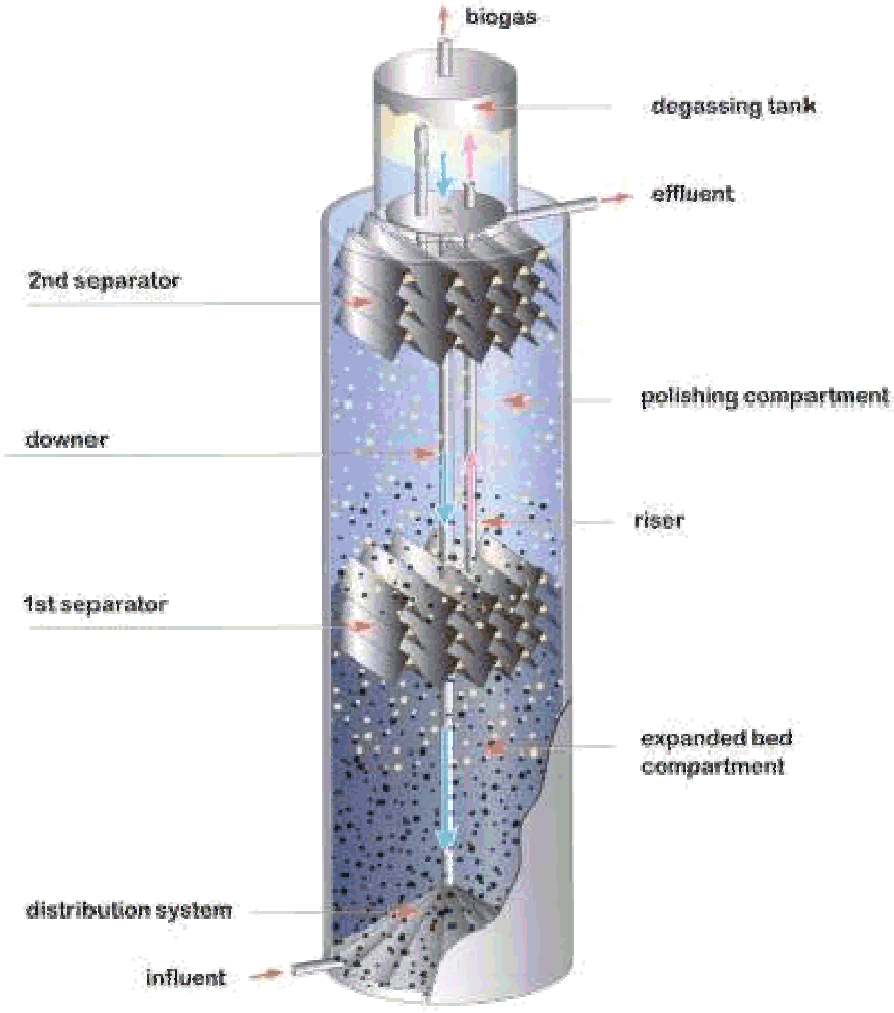
UASB: Sewage

Accra, Ghana

UASB: Industrial

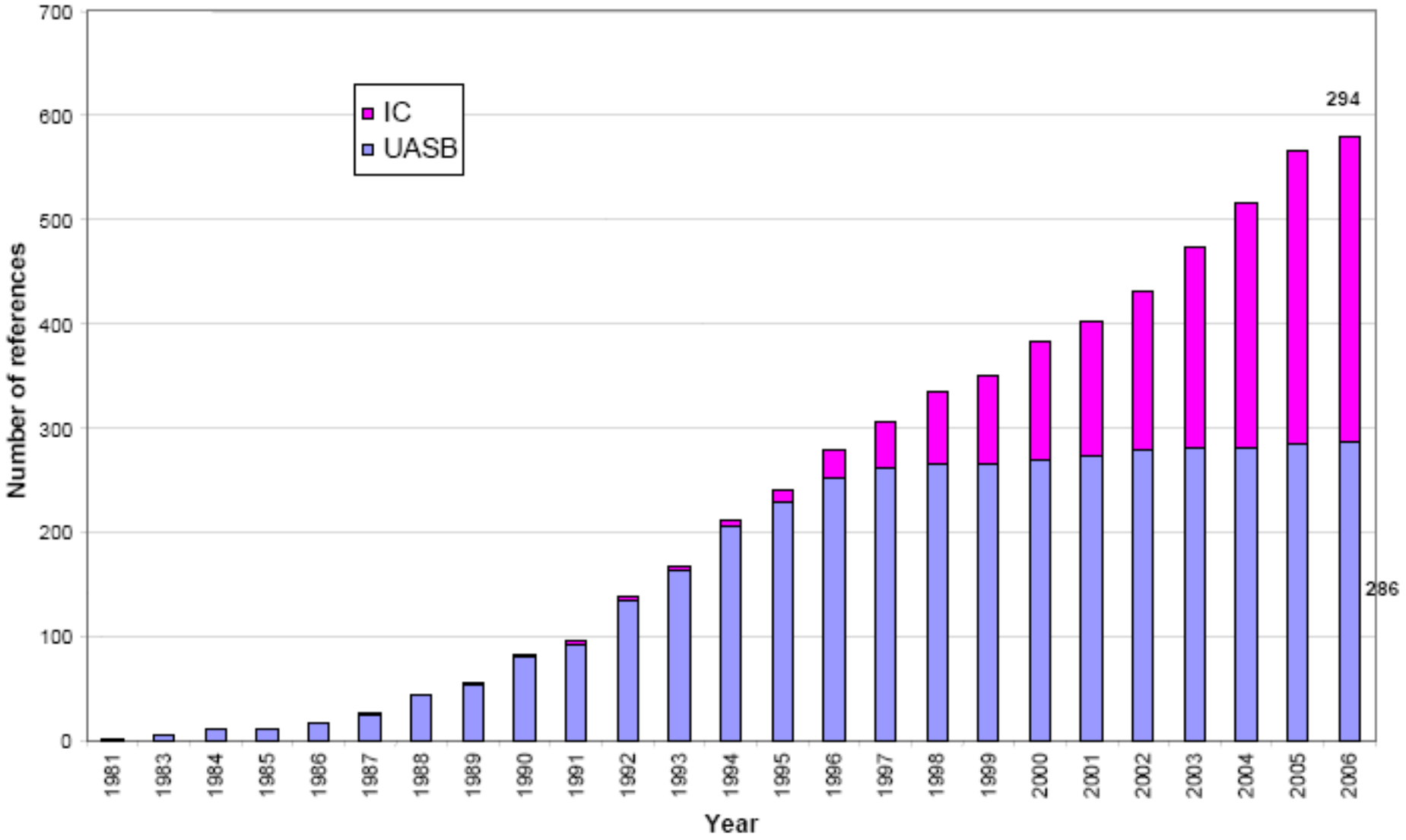
Anaerobic UASB-Reactor CSM

IC-Reactor: Distillery Hanover



(Kraul & Wilkening u. Stelling)

Cumulative BIOPAQ® references N=580

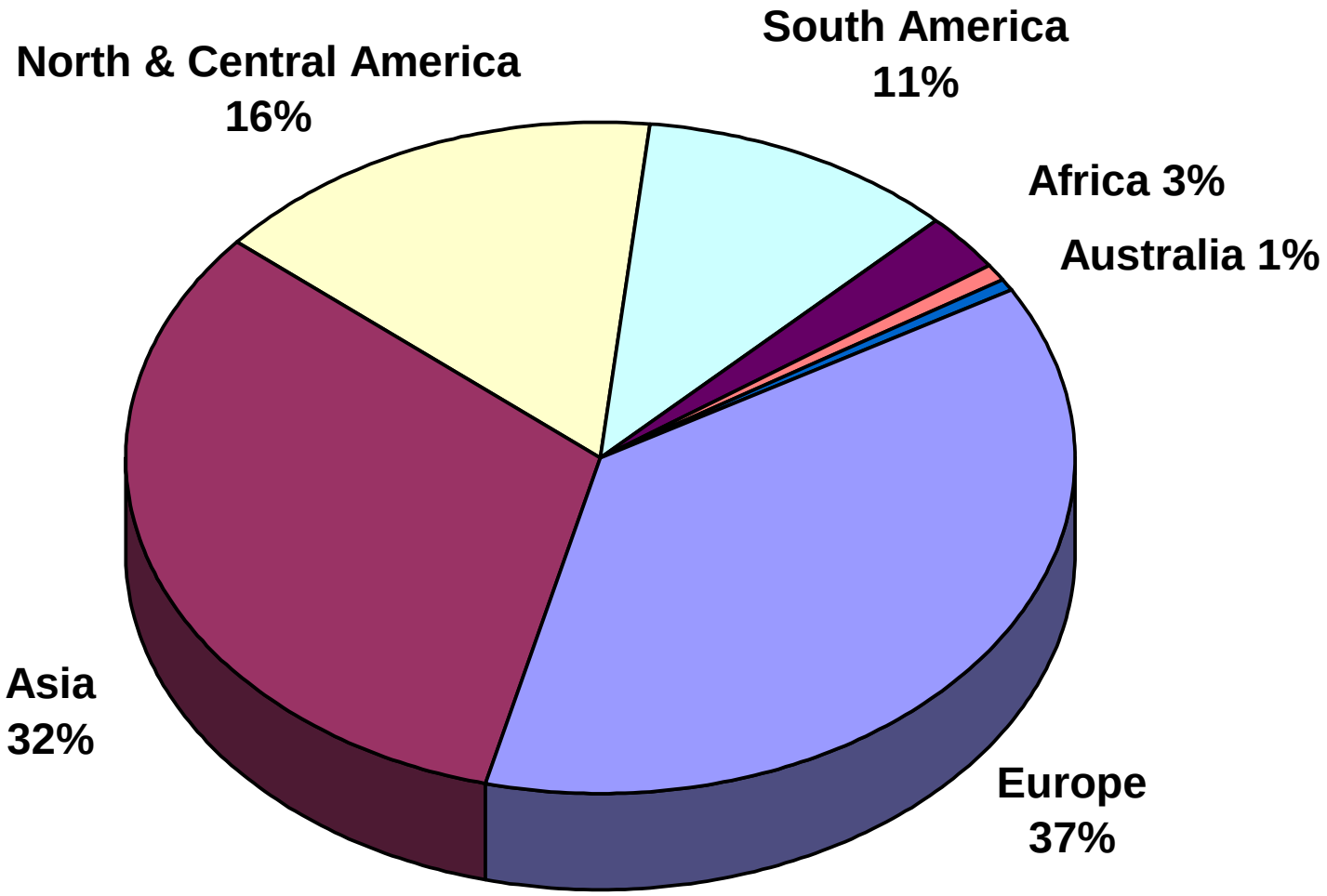


Reactors: Summary

- Sludges and slurries: Digester
  - CSTR, no biomass retention
- Liquids (<~2% solids): High rate reactor
  - Biomass retention
- Sewage: UASB reactors
  - Flocculent biomass
- Industrial wastewater: UASB, EGSB and IC reactors
  - Granular biomass

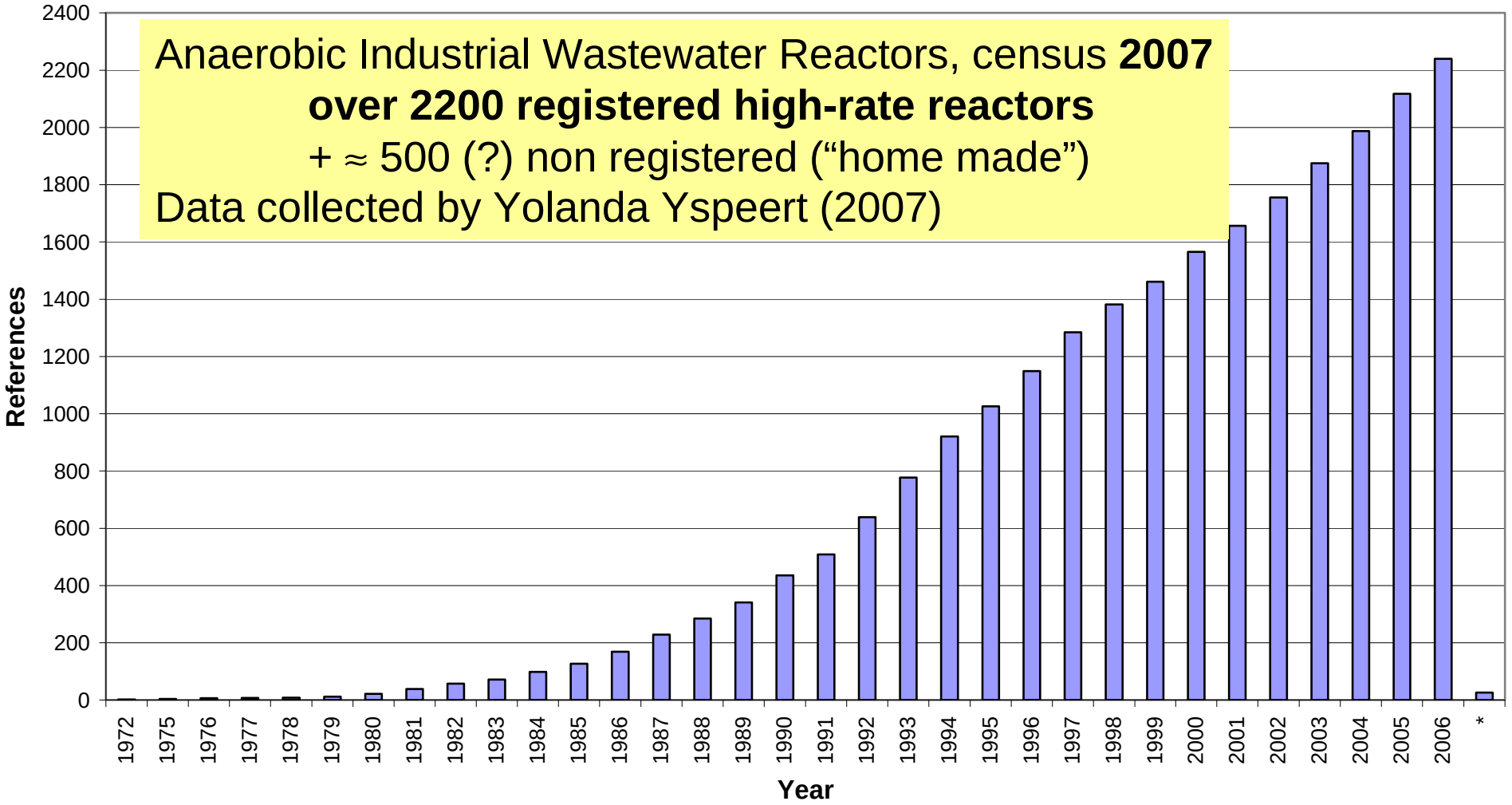
State of Practice

Geographic Distribution of Anaerobic Plants

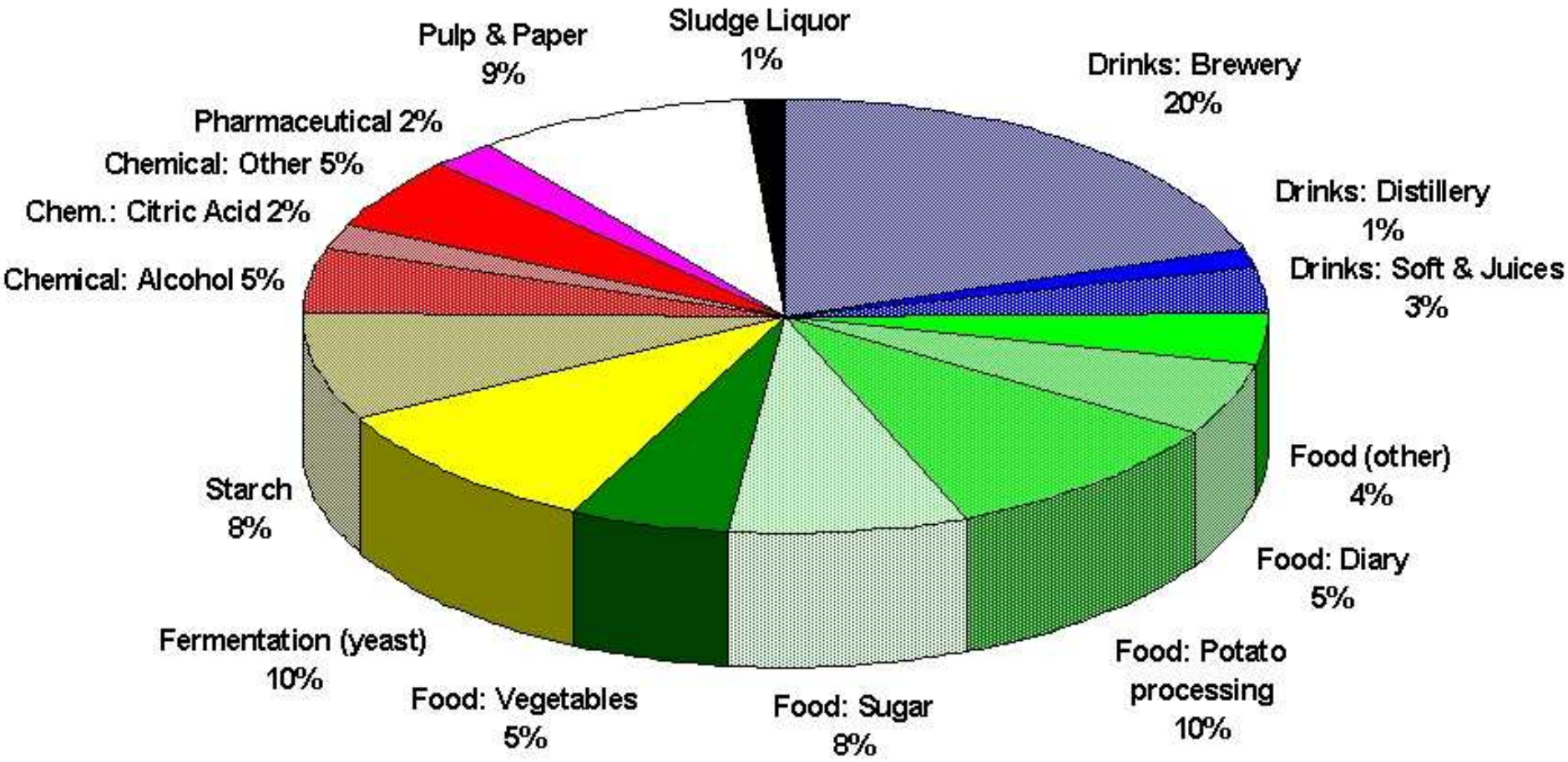


(1981 – 2007, N= 2266, Mainly industrial)

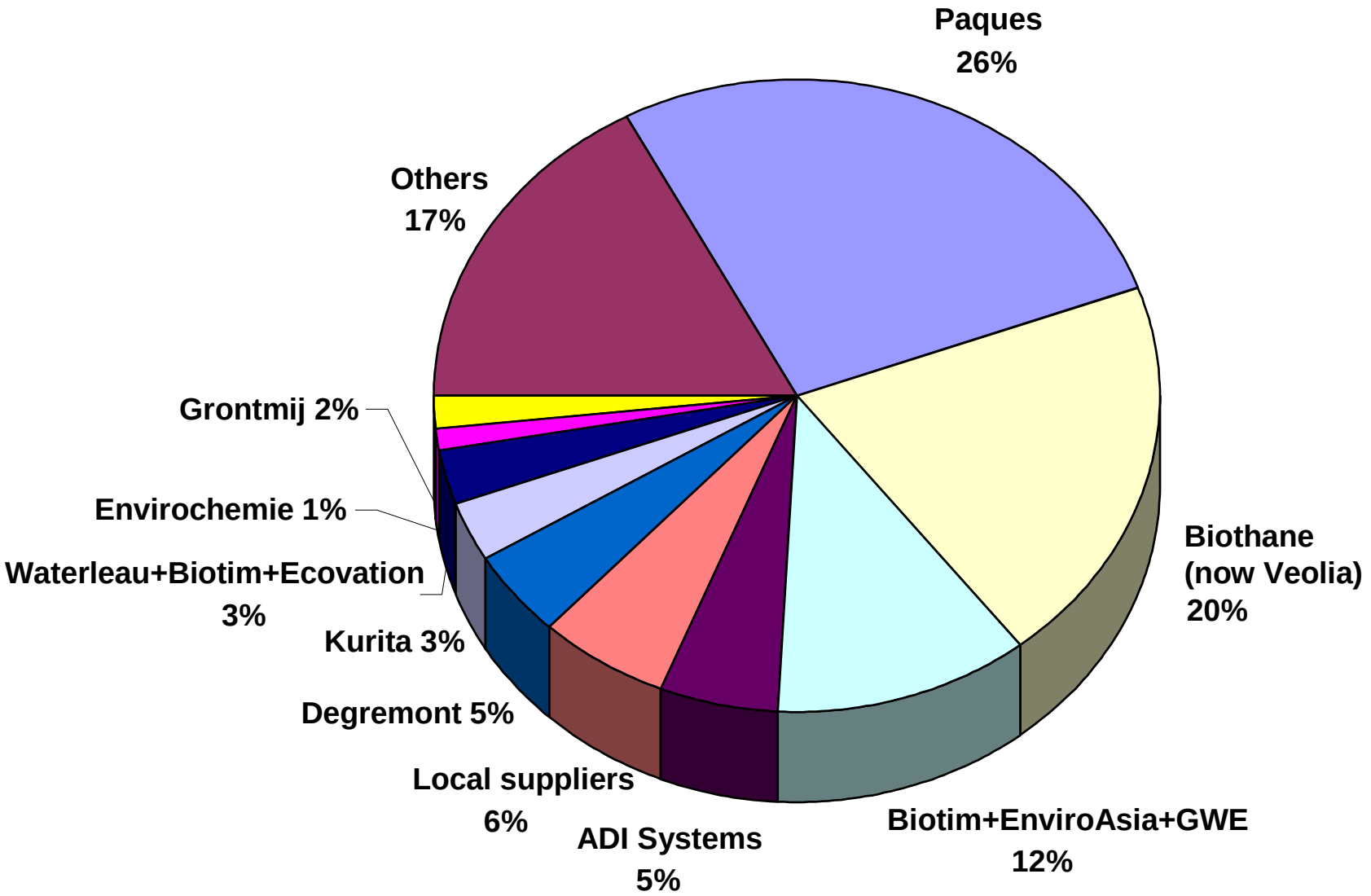
Worldwide cumulative anaerobic references

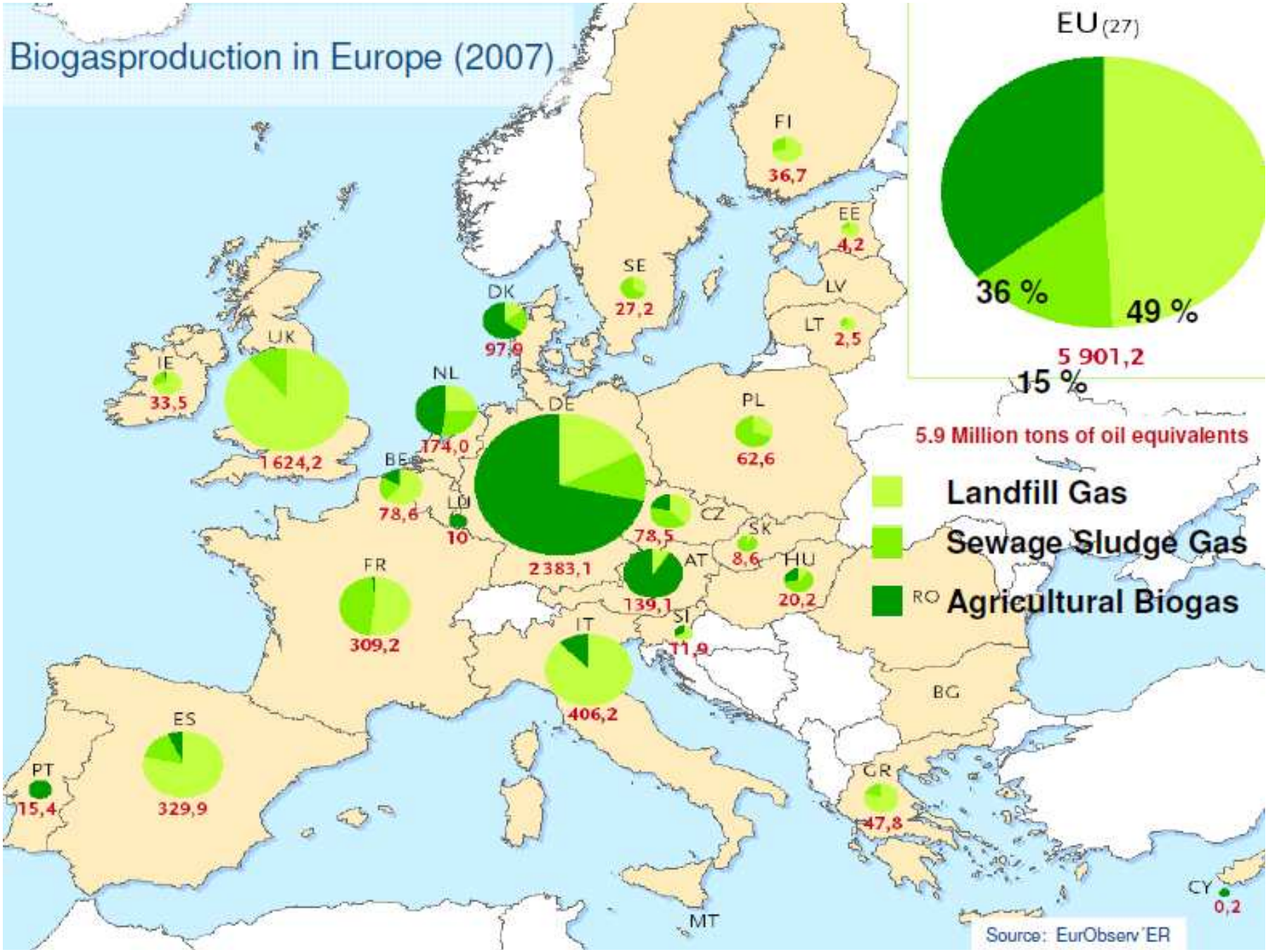


Types of industries

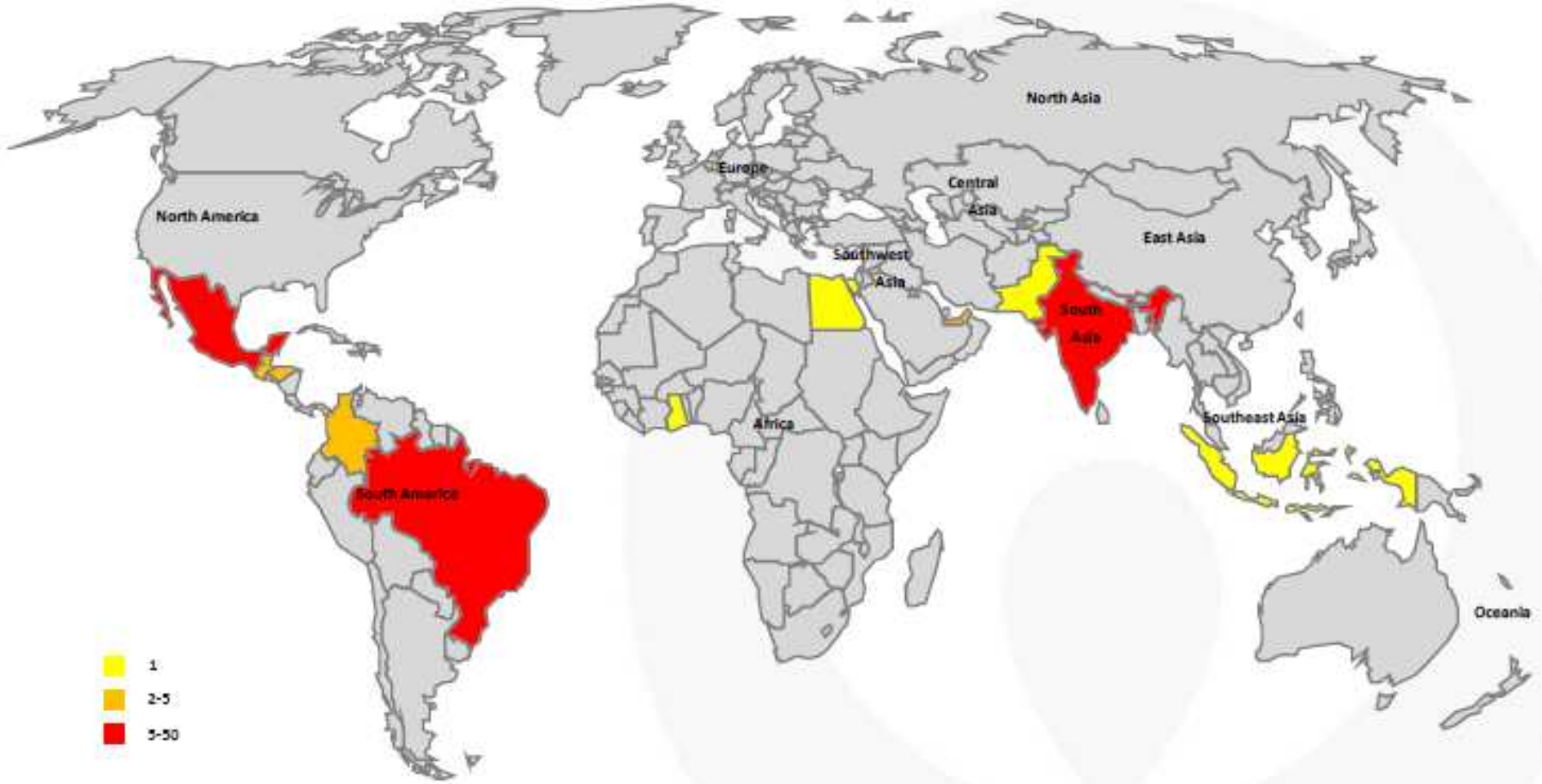


Major Technology Suppliers (1981 – 2007, N= 2266)




Biogasproduction in Europe (2007)
EU (27)
36 %
49 %
15 %
5 901,2
5.9 Million tons of oil equivalents
Landfill Gas
Sewage Sludge Gas
Agricultural Biogas
FI
36,7
EE
4,2
LV
LT
2,5
SE
27,2
DK
97,9
UK
1 624,2
IE
33,5
NL
174,0
DE
2 383,1
PL
62,6
BE
78,6
LU
10
CZ
78,5
SK
8,6
HU
20,2
AT
139,1
FR
309,2
SI
11,9
IT
406,2
BG
ES
329,9
PT
15,4
GR
47,8
CY
0,2
MT
Source: EurObserv'ER

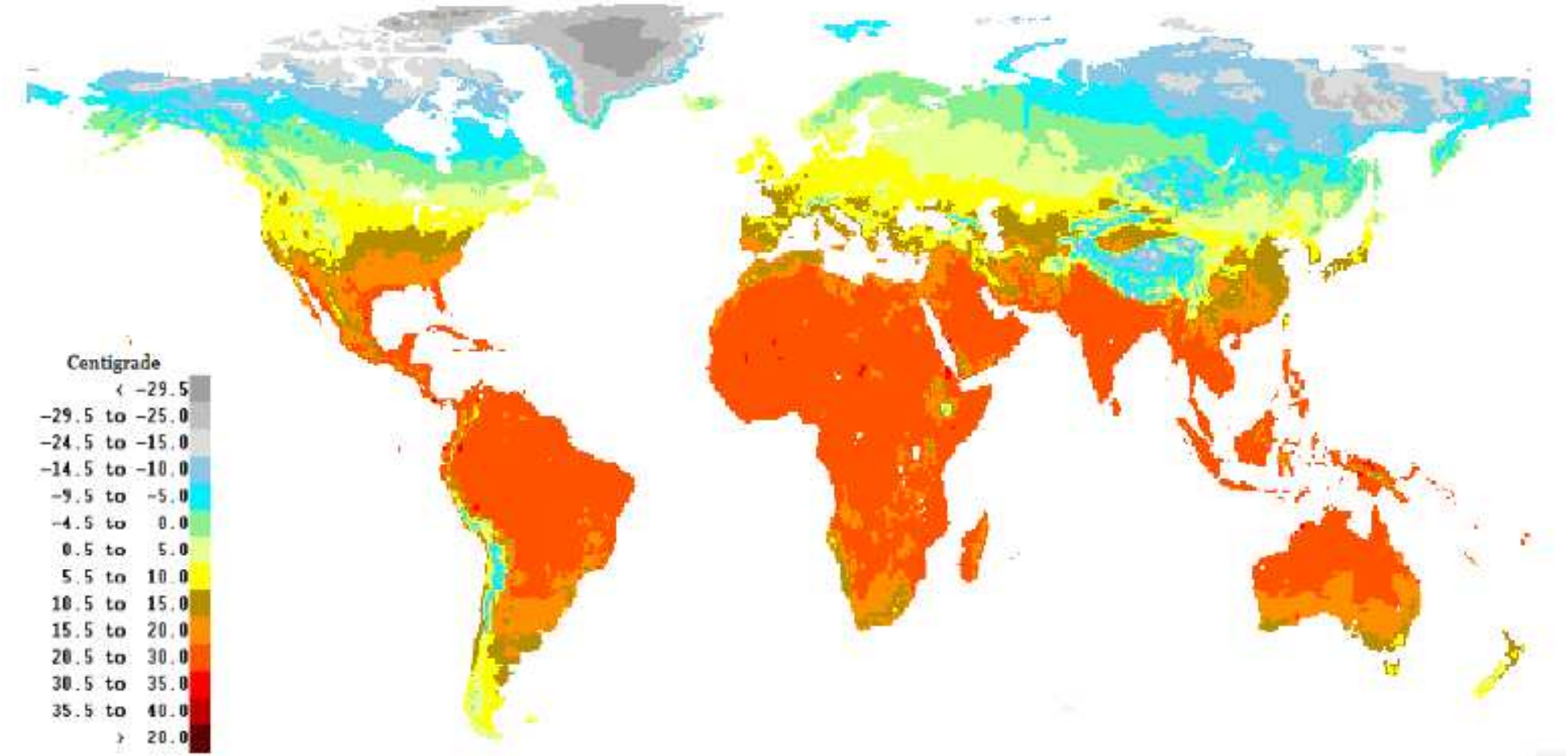
Countries where large municipal UASB plants have been built



BIOTHANE

VEOLIA WATER
Solutions & Technologies

Average daytime air temperature



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VEOLIA WATER
Solutions & Technologies

Large Municipal Anaerobic WWTPs

Country	City	pe	Year	℃	m3	HRT (h)	COD	BOD	TSS
Colombia	Bucaramanga				35	5-19			
Colombia	Cali	1000		25.2	64	6-8	267	95	215
Brazil	Sumare City	1410	1992	16-23	67.5	7	402	515	379
Brazil			1987	18-28	120	5.15	188-459	104-255	67-236
Brazil	Sao Paulo				120	4			
Brazil	Pedegral				160	6	799		
Italy				7-27	336	12-42	205-326	55-153	100-250
Brazil					477	13	600		303
Brazil	Mangueira	18000		30	810	9.4	549 ± 150		196 ± 100
India	Kanpur		1989	20-30	1200	6	563	214	418
Egypt	Fayoum	105000	2007		2304				
Colombia	Bucaramanga		1990	24	3360	5	380	160	240
India	Yamunanagar	55000	2002	17.3	3500	8.4	939	318	374
India	Panipat	69000	1999	18.6	3500	8.4	985		411
Brazil	Minas Gerais - Laboreauz	70000	2007		4840	8			
India	Mirzapur	100000	1994	18-32	6000	8	404	205	362
Ghana	Accra		2000		6500	10	150-16550	1500	500-22000
Colombia	Bucaramanga	160000	1990		6600	5.2	380		
India	Faridabad	110000	1998	22.5	7000	8.4	1194		

Large Municipal Anaerobic WWTPs (con'd)

Country	City	pe	Year	℃	m3	HRT (h)	COD	BOD	TSS
India	Yamunanagar	130000	2000	18.4	9000	8.4	702	250	372
India	Agra	570000	2004	18.8	10000	9.3	762	264	514
India	Sonepat	200000	1999	18.5	11000	8.4	481	160	189
India	Gurgaon	150000	1998	18.6	11000	8.4	870	318	435
India				18-32	12000	8	1183	484	1000
India	Panipat	240000	2000	23.8	13000	8.4	487	196	320
India	Karnal	270000	2000	19.7	14000	8.4	443	141	236
India	Noida	190000	2000	20.0	14000	10.9	674	247	558
India	Faridabad	250000	1998	23.8	16000	8.4	1055	318	920
Brazil	Campinas			25	16464	14.3	522 ± 80	257±30	266±70
UAE	Ajman	490000	2008		17600	8.6			
India	Faridabad	270000	1999	23.7	18000	8.4	1113	365	593
India	Ghaziabad	350000	2002	21.7	20000	10.7	418		185
India	Ghaziabad	430000	2002	21.2	26000	10.7	829	293	458
India	Saharanpur	310000	2000	21.6	28000	10.4	363		169
Brazil	Piracicamirim	92000	1998			18-32			
Brazil	Minas Gerais - Onca	1000000	2006		53088	8			

Gas Utilization

Plant	Capacity (actual)	Gas Utilisation
Brazil	164 (95)	-
Brazil	100 (43)	-
Brazil	90 (69)	--
Brazil	70 (41)	--
Brazil	48 (25)	-
Brazil	38 (22)	--
Brazil	30 (17)	-
India	120 (60)	-
India	43 (53)	+
Middle East	49 (43)	-

Biothane-Veolia, 2010

Issues

- Lower COD/BOD removal than expected
- Biogas yield lower than expected (0.1-0.2 Nm^3 instead of 0.35 Nm^3 per kgCOD removed)
- Sludge production higher than anticipated (0.3-0.4 kgTSS per kg COD applied, instead of 0.15)
- Significant operator attendance required

Survey Biothane-Veolia 2010

10 Large scale (>10 ML/d) UASB STPs

Current Projects: Summary

- Industry: many reactors
- Large (>10 ML/d) municipal UASB STPs
  - India 45
  - Brazil 15
  - Ghana, Egypt, UAE
- Large scale: lower performance than early pilot and full scale
- Many small UASB STPs
  - Brazil, India, China, ...
- Large number of small systems mostly without biogas capture
- Decentralized sanitation (less/no dilution, no sewer):
  - Domestic biogas plants: India, China, Nepal, ...
  - New reactor concepts: Germany, Sweden, Netherlands

Developments

Developments

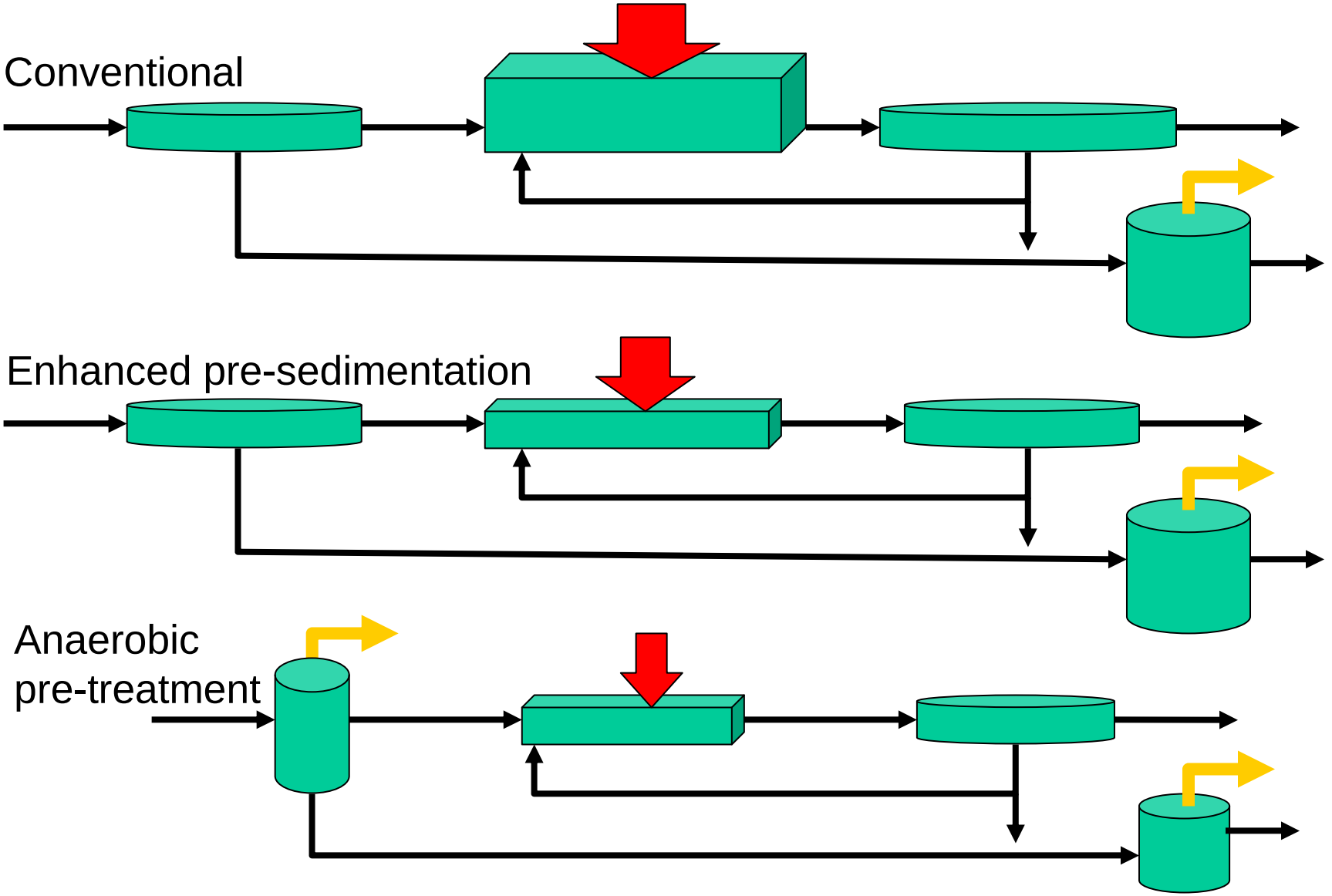
Anaerobic treatment of sewage in colder climates

- Challenge: treat municipal sewage to achieve net energy production while meeting effluent standards
- Two approaches:
  - enhanced pre-sedimentation
  - direct anaerobic treatment

Anaerobic treatment of domestic solids

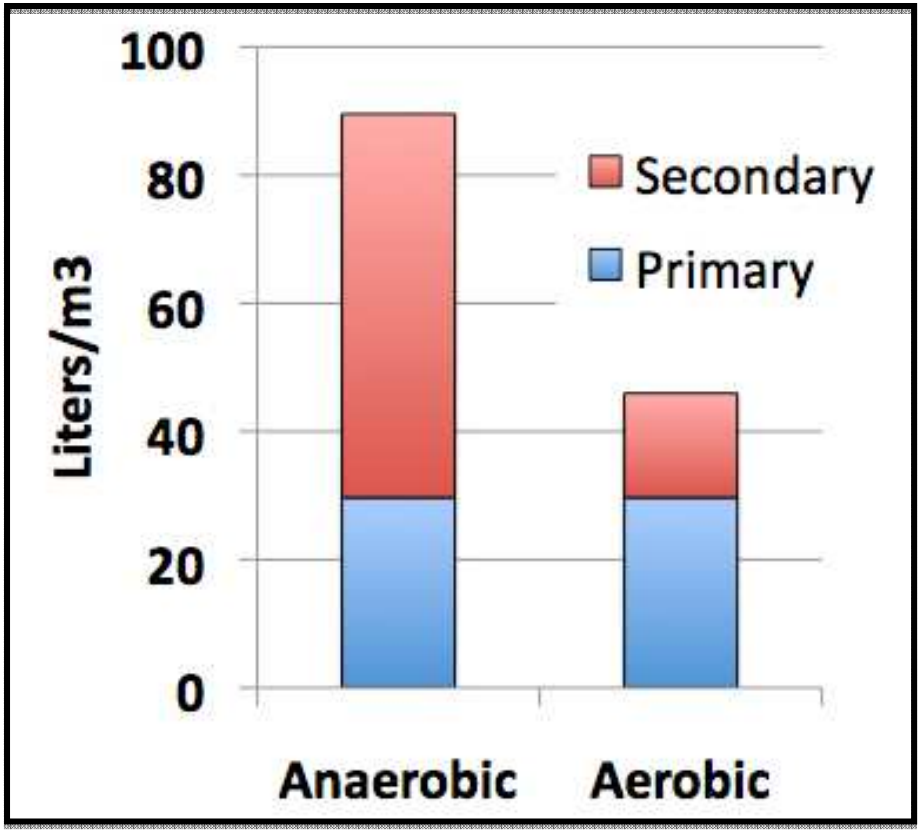
- Decentralized sanitation (less/no dilution, no sewer):
  - Domestic biogas plants: India, China, Nepal, ...
  - New reactor concepts: Germany, Sweden, Netherlands

Anaerobic Sewage Treatment

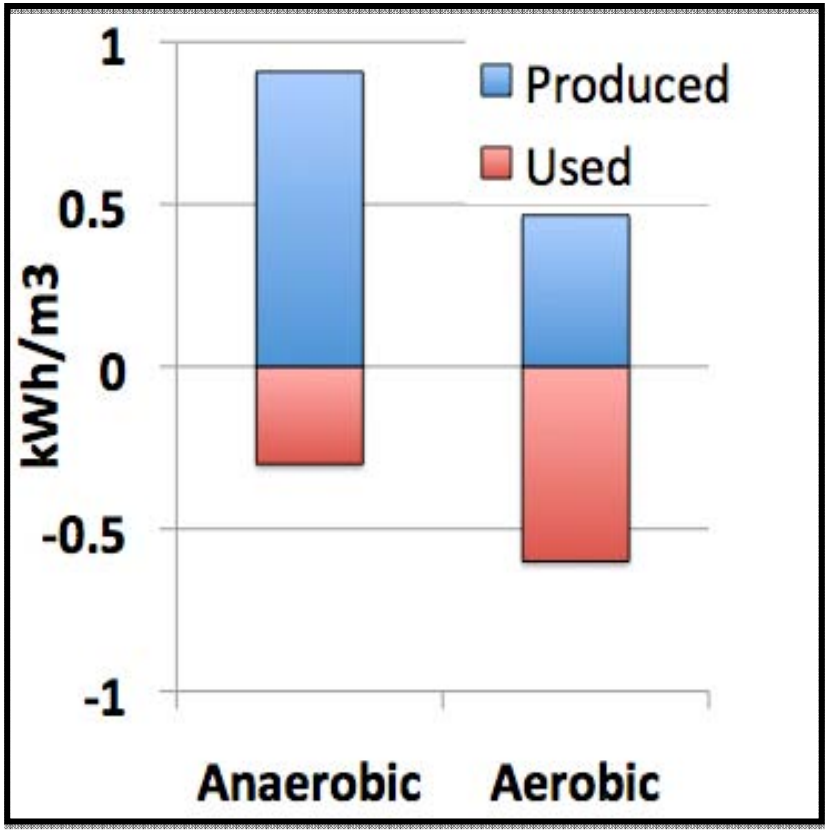


Aerobic/Anaerobic Comparison

Methane Production



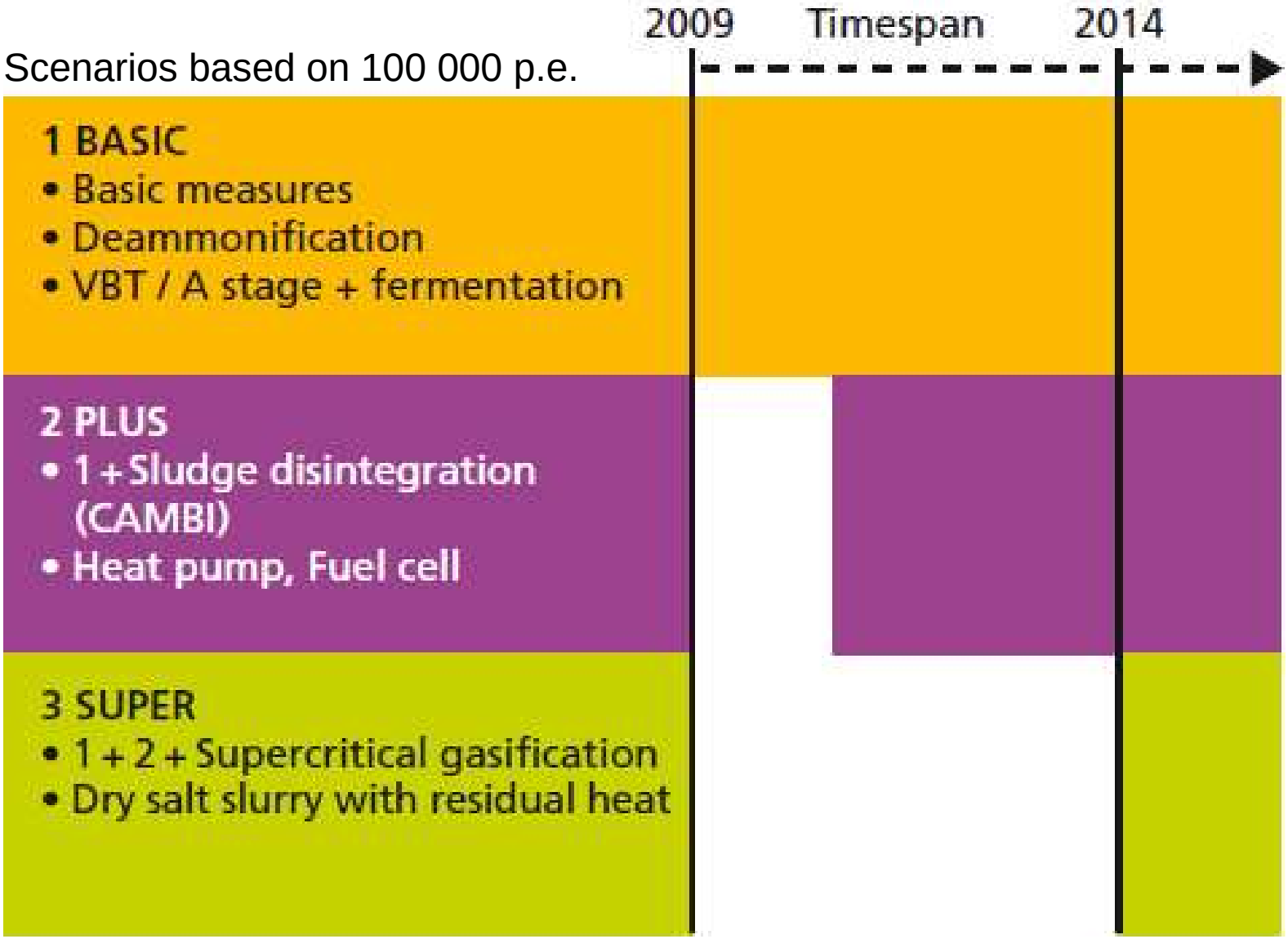
Net Energy Production



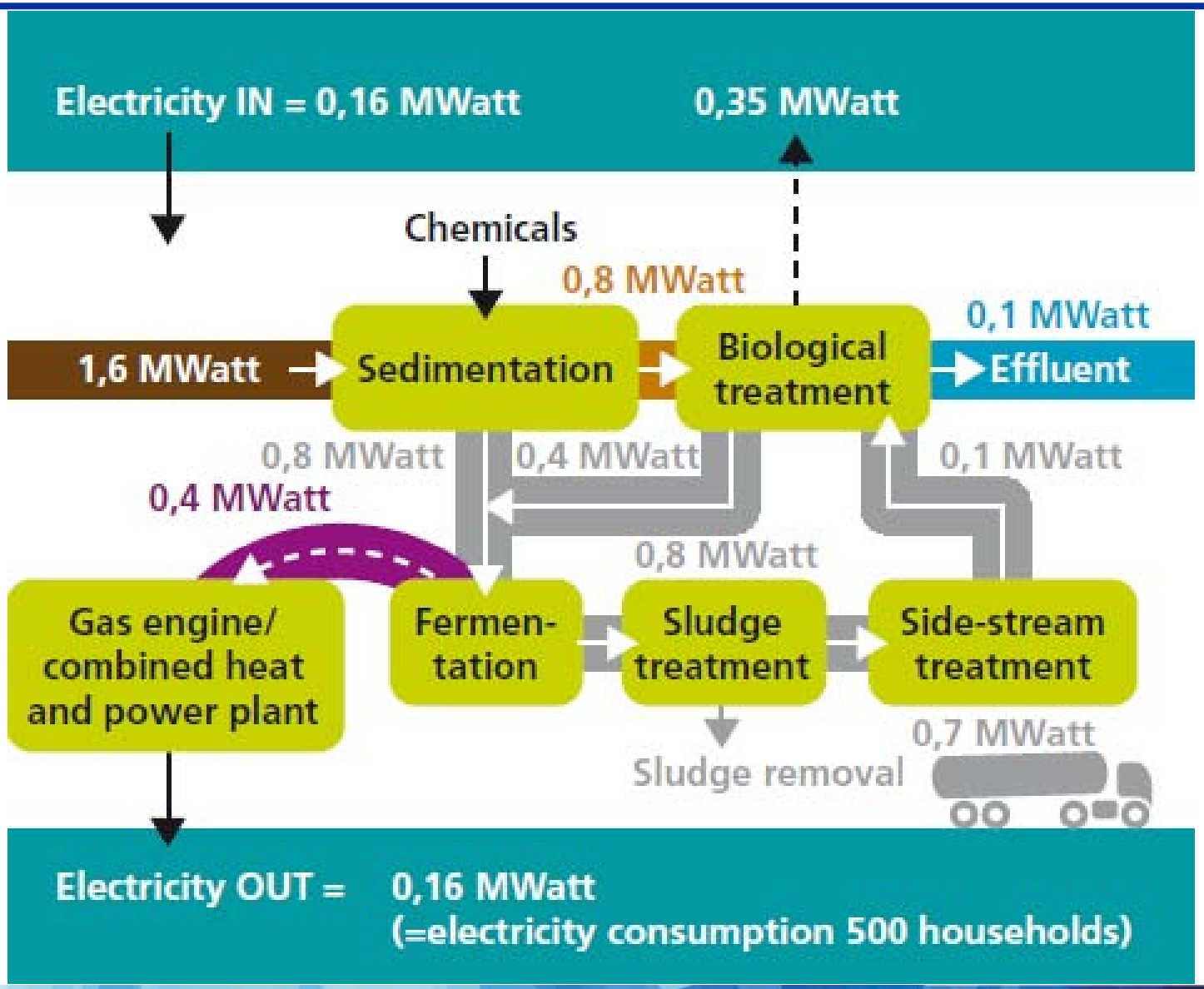
Perry L. McCarty, 2010

The Energy Factory

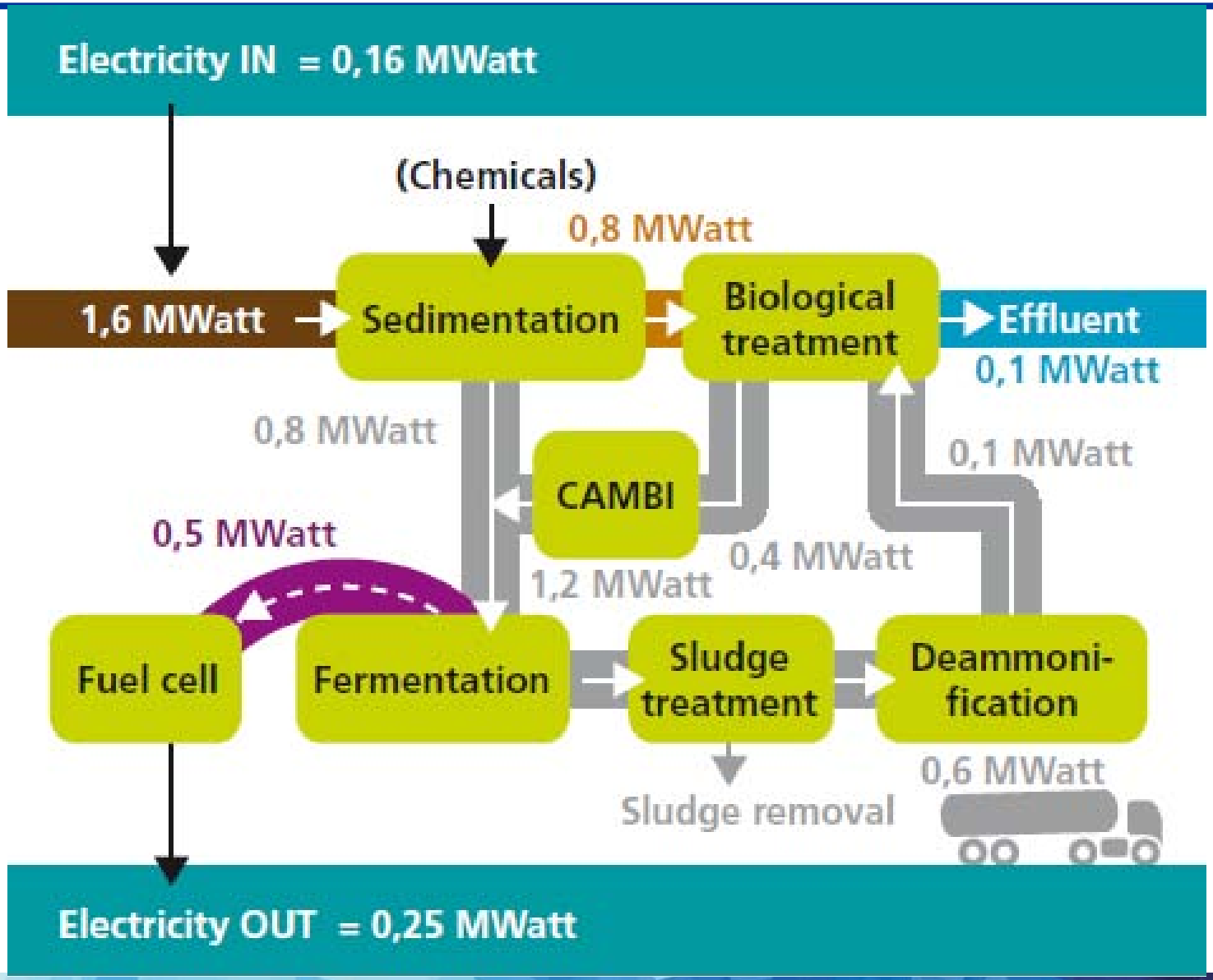
Scenarios based on 100 000 p.e.



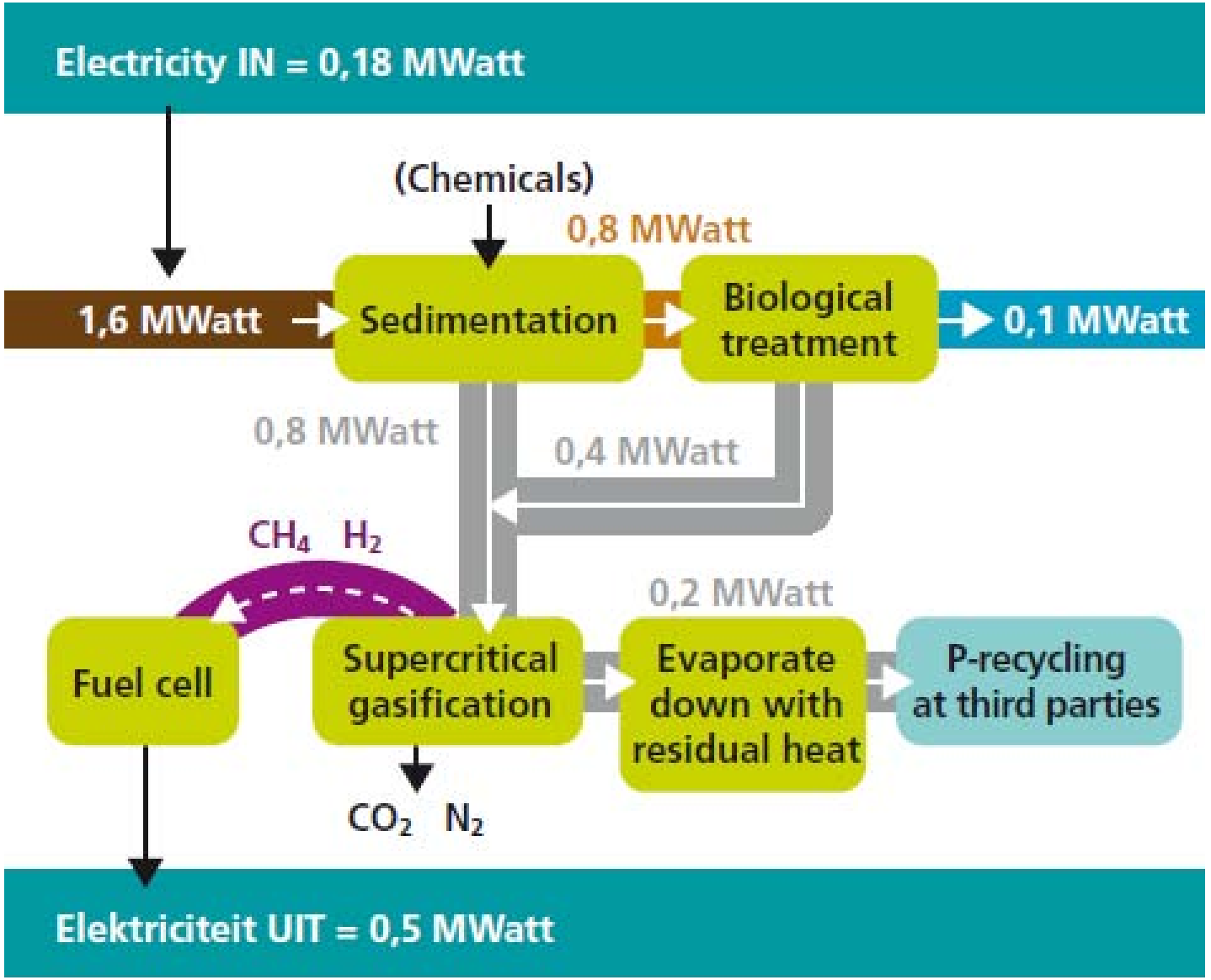
Basic scenario



Plus scenario

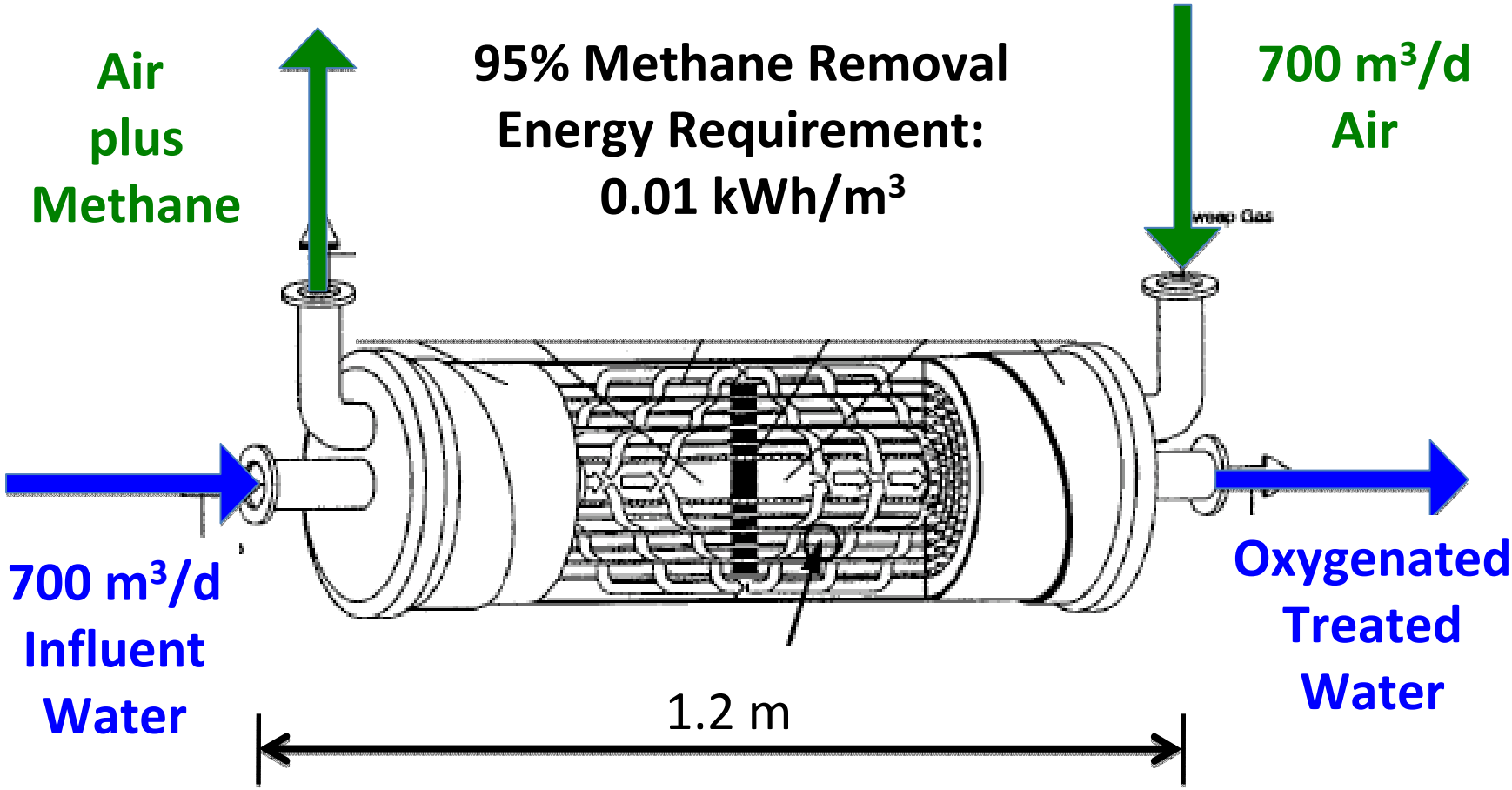


Super scenario



50% of Methane lost via Effluent!

Liqui-Cel Membrane Contactor for Air Stripping of Methane



Perry L. McCarty, 2010

Developments: Summary

- Anaerobic sewage treatment in colder climates
- The Energy Factory
- Anaerobic sewage treatment: 50% loss of methane
- Decentralized sanitation