Overview of anaerobic treatment options for sustainable sanitation systems

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Presentation content

1. Quick basics of anaerobic digestion
2. Anaerobic treatment technologies for sustainable sanitation
3. Two project examples

1. Quick basics of anaerobic digestion

Mantopi Lebofa (from NGO TED) lighting the biogas flame (Lesotho, Dec 2006)

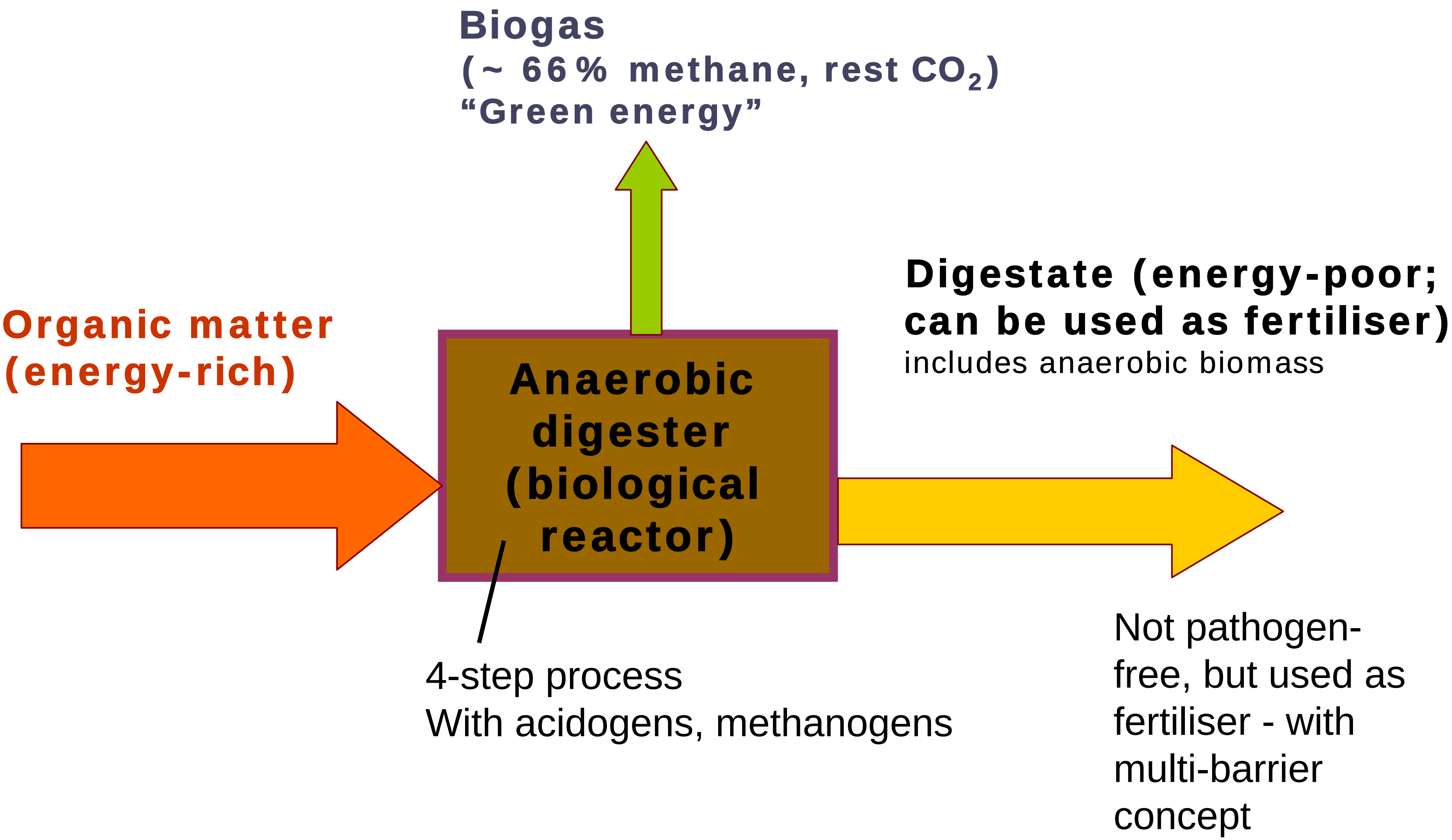
Possible substrates (input materials) in sustainable sanitation context

- High-strength greywater (as a pre-treatment step), rule of thumb: BOD > 400 mg/L (BOD = biological oxygen demand)
- Blackwater / brown water (faeces, urine, small amount of water – e.g. from vacuum toilets)
- Human excreta together with animal excreta and greywater

High-strength grewyater (example from Jordan)

“Blackwater” from vacuum toilets in Sneek, the Netherlands

Anaerobic digestion process schematic



Biogas uses

1. Biogas can be burnt and used for cooking or lighting
2. Biogas can also be converted to electricity and heat (part of the heat can be used to heat the digester) → "Combined heat and power plants" (CHP)

Mantopi Lebofa, Lesotho, Dec. 2006

→ If biogas is not used it should be flared because methane is a greenhouse gas

Removal of different compounds by anaerobic digestion

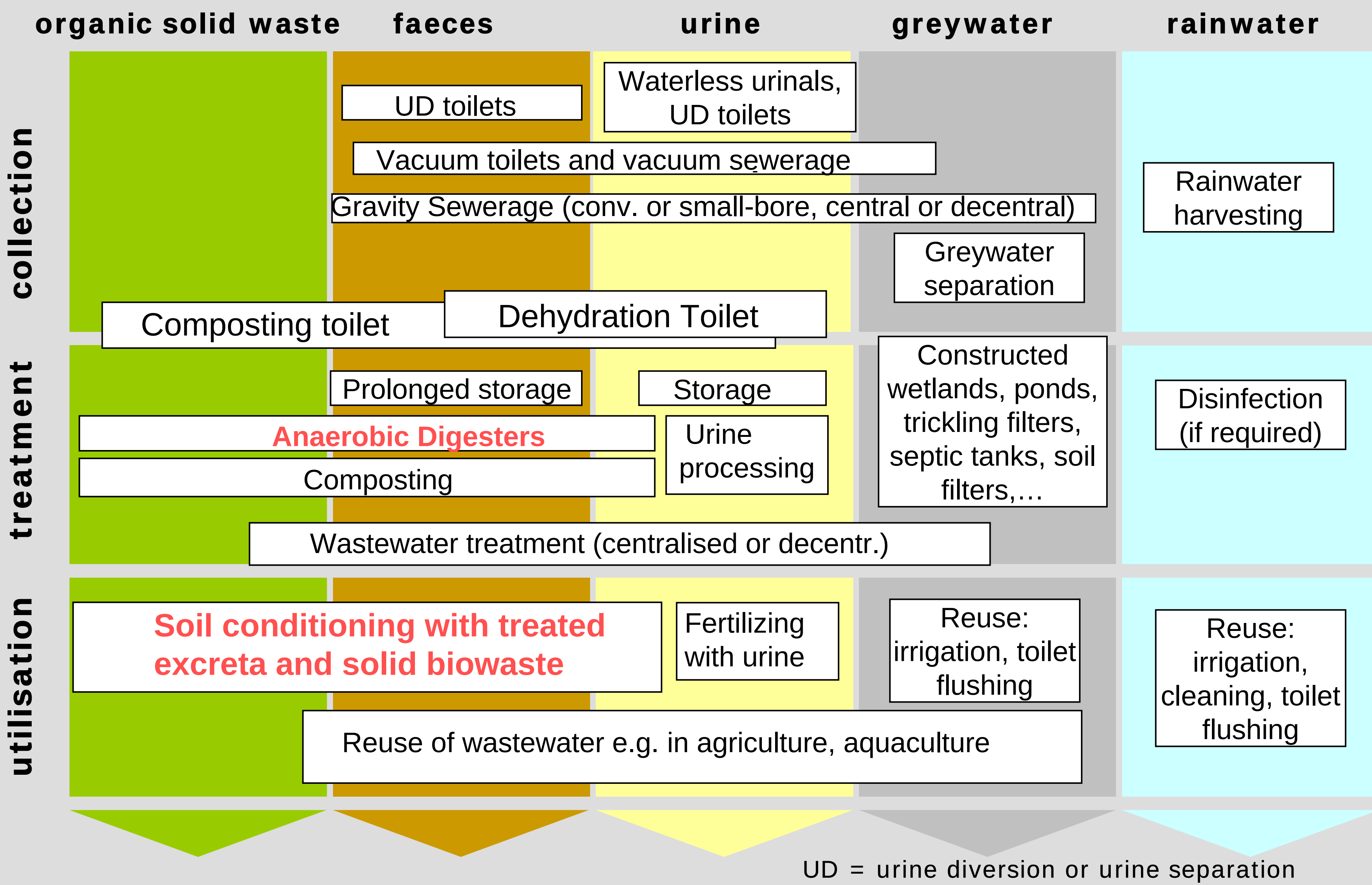
Compound	Removal
Organic matter	High level of removal (but not good enough for direct discharge to surface waters; would need aerobic post-treatment)
Nitrogen and phosphorus	No removal
Pathogens	Not much removal unless operated at thermophilic* temperatures and very long retention times →multi-barrier approach for reuse
Heavy metals	No removal

* Thermophilic (~55°C) anaerobic digestion will achieve more pathogen removal than mesophilic (~ 35°C) anaerobic digestion

2. Anaerobic treatment technologies for sustainable sanitation

gtz ecosan program recycling oriented wastewater management and sanitation systems

Overview of ecosan technology components

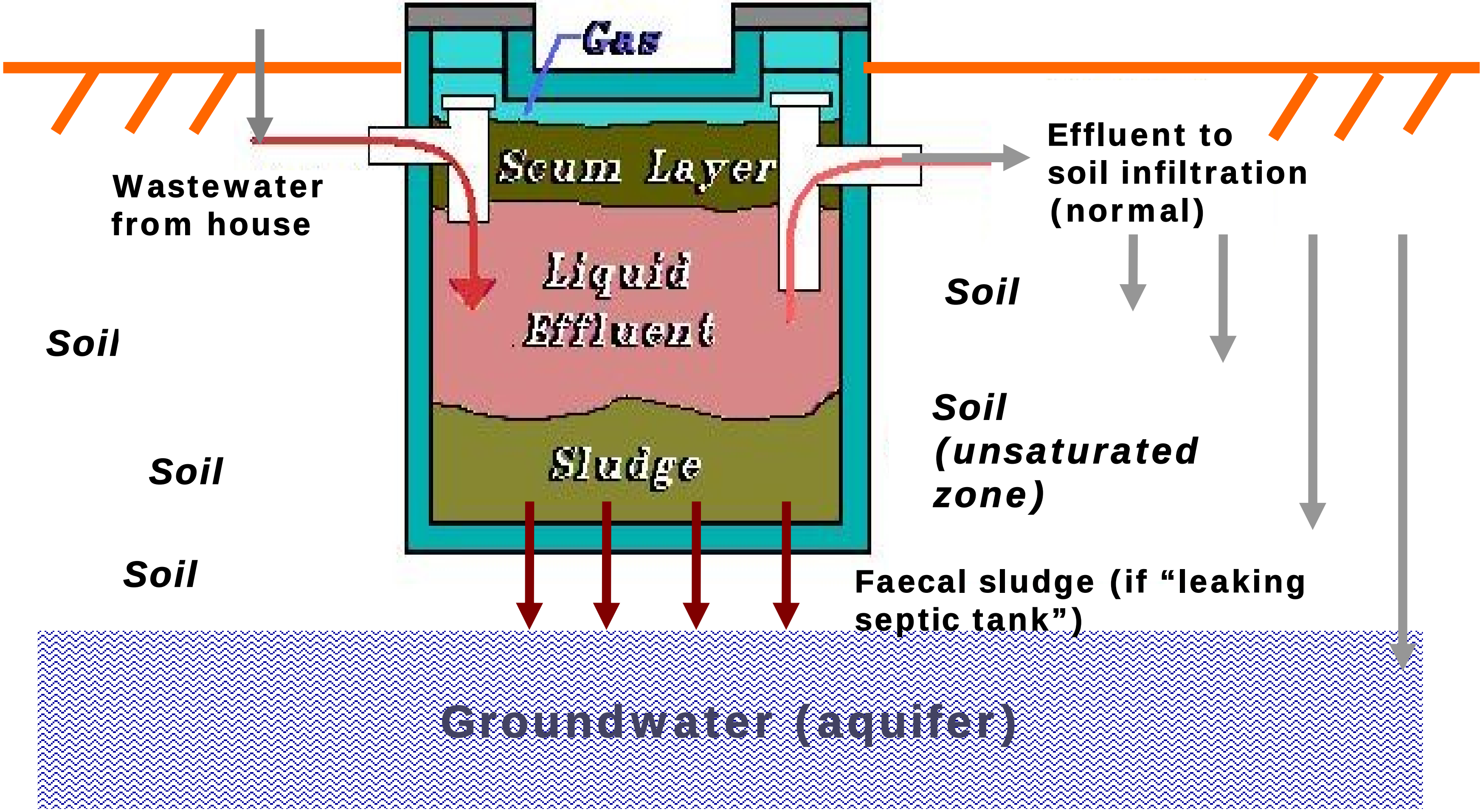


Overview of commonly used anaerobic treatment technologies

#	Process name	Optimised mixing	Covered reactor	Biogas collection	Scale
1, 2	Septic tanks, anaerobic baffled reactors (ABR)	No / somewhat (for ABRs)	Yes	No / rarely	Household or neighbourhood
3	Household biogas plants*	No / somewhat (round shape)	Yes	Yes	Households, neighbourhoods, institutions, farms
4	Anaerobic ponds	No	No / sometimes	No / sometimes	Community
5	Upflow anaerobic sludge blanket reactor (UASB)	Yes	Yes	Yes	Neighbourhood, community, industries

* Also called household biogas digesters or decentralised biogas plants (i.e. not just limited to households) – currently less well-known than the other technologies

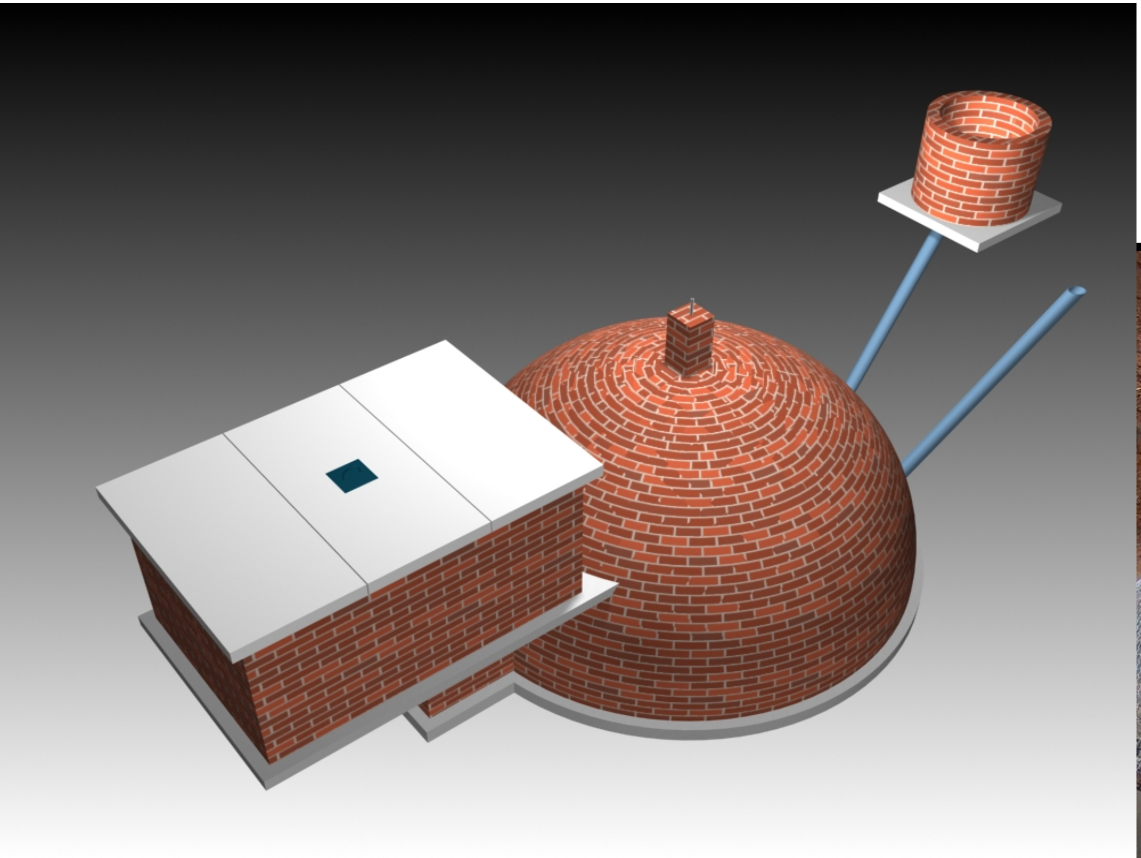
Septic tanks can lead to groundwater pollution



The effluent from septic tanks is commonly infiltrated into the ground (on purpose). But faecal sludge is NOT meant to leak out from the septic tank (but often does if not designed properly).

Household biogas plants
(here: fixed dome type)

Widespread use e.g. in China, Nepal (SNV program)



Household biogas plant
Source: Jan Lam, SNV (at NBP Dhaka, March 2007)

Source: Mantopi Lebofa, Lesotho, 2006

3. Two project examples

- Housing estate Lübeck-Flintenbreite (**Germany**), partly operational since 2000
  - Similar concept to be built 2010-2013 in Hamburg Jenfeld (HAMBURG WATER cycle: for 700 housing units)
  - Similar concept also operational in Sneek, the Netherlands since 2006
- Vocational Training Institute DSK of Navsarjan Trust in Nani Devti village (Gujarat State, **India**), operational since 2006

Constructed wetlands (for greywater treatment

Terraced and Twin houses

Central building

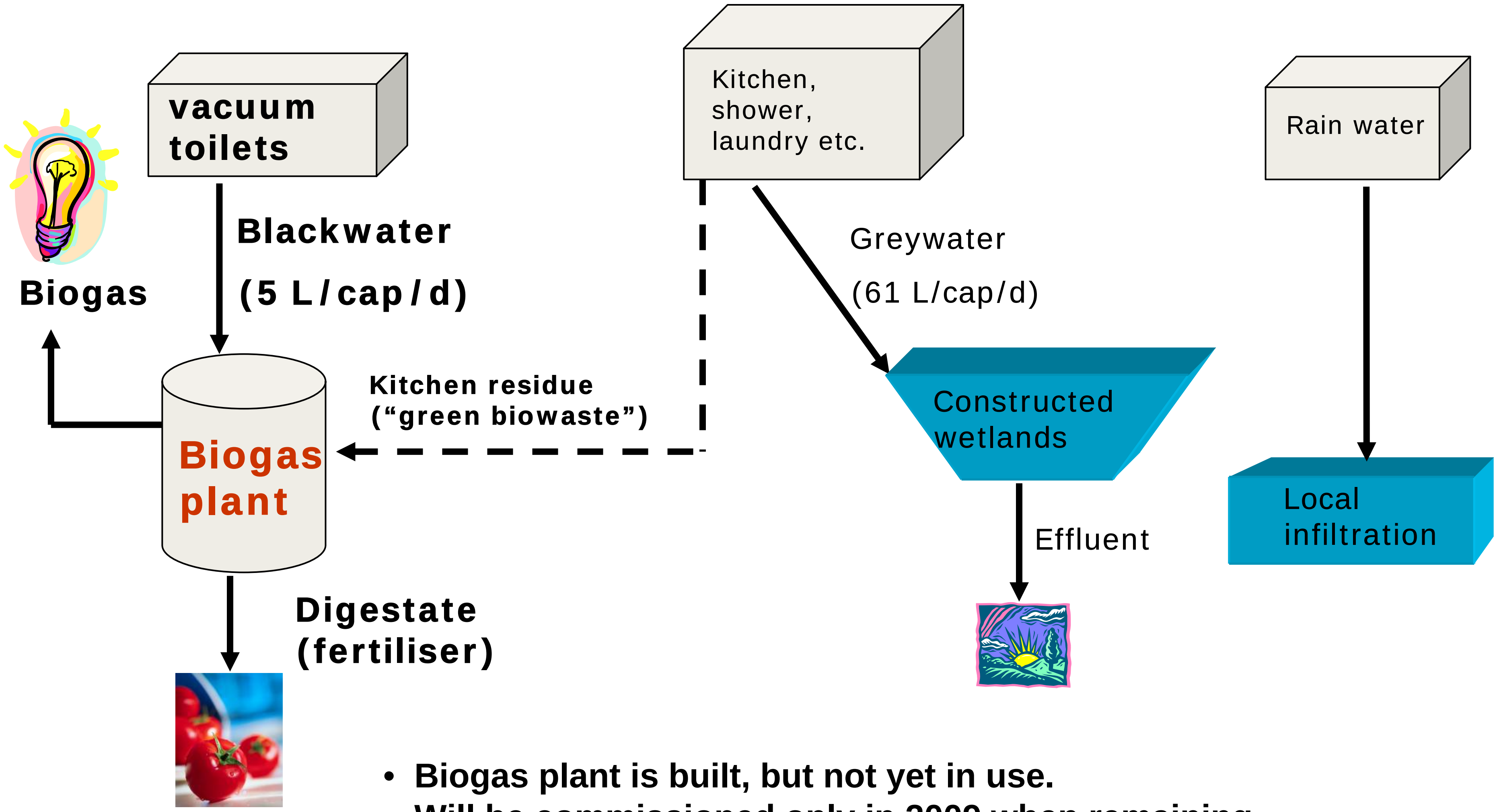
- **In use since year 2000 (111 inhabitants)**

- **2008/2009: new developer to build remaining units (to reach 350 inhabitants in total)**

Source: Claudia Wendland, TUHH, 2008

Process schematic (Flintenbreite)

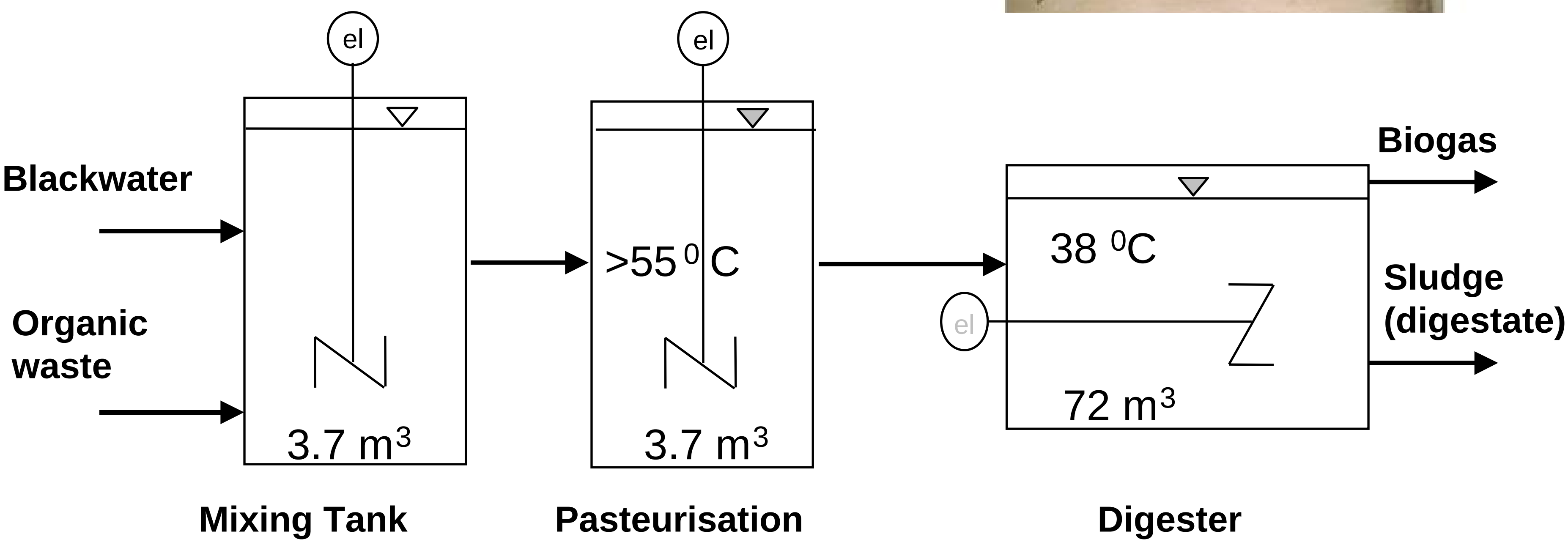
Measured total average per capita water use: 66 L/cap/d



- **Biogas plant is built, but not yet in use.**
- **Will be commissioned only in 2009 when remaining units are built**

Vacuum toilet
Rödiger, Germany

Technical Components of Blackwater Collection and Treatment


el
el
Blackwater
Organic waste
>55 0 C
3.7 m3
3.7 m3
Biogas
38 0C
el
Sludge (digestate)
72 m3
Mixing Tank
Pasteurisation
Digester

Laboratory research with blackwater from Lübeck-Flintenbreite at university TUHH (Hamburg)

- Expected biogas production (vacuum toilets and kitchen waste): 25 L CH_4 / cap/d
- Only 5% of heating requirements of the houses could be met with this biogas
- → Biogas is (only) a by-product of a wastewater treatment process (amount not that significant)

Source: Claudia Wendland, PhD thesis (2008), TUHH

Navsarjan Trust Vocational Training Institute DSK Campus in Gujarat, India

Biogas plant during construction

- **300 students on the campus (established 1999)**
- **New ecosan sanitation system inaugurated August 2006**
- **Project review Sept. 2008: working satisfactorily**

DSK campus sanitation complex

- **Sanitation complex comprises 22 toilets**
  - **Constructed as a circle with a biogas plant in the centre**
  - **Low-flush pour-flush squatting toilets (design: 2 L, actual: 4 L per flush with cleansing)**
- **Biogas: 2-3 cylinders of biogas per month (only) – used for cooking**
  - **Quantity low (could be increased by adding kitchen waste and cow manure)**
- **Digestate: drying bed, composting, used as compost**

Biogas plant

Waterless urinals for females (squatting type)

Concluding remarks regarding anaerobic digestion for sustainable sanitation

- Great potential: provides for waste treatment, biogas and fertiliser (close nutrient loop)
- Most interesting for:
  - Institutions (e.g. prisons, public toilets, schools, universities)
  - Applications in combination with animal waste (more biogas)
- Remaining issues:
  - Pathogen removal in mesophilic AD is quite low → use multiple-barrier approach for reuse
  - South-South knowledge transfer urgently needed

Thank you!

www.gtz.de/ecosan and www.susana.org

gtz ecosan program recycling oriented wastewater management and sanitation systems

On behalf of
Federal Ministry for Economic Cooperation and Development

Appendix

Overview about anaerobic treatment

- Anaerobic treatment works with organic input materials:
  - liquid organic material
    - »greywater together with excreta
  - solid organic material (with a water content of > 50%), e.g.
    - »slurries/sludges
    - »organic kitchen waste

- Anaerobic digestion “biogas toilets” are particularly suitable for institutions (schools, hospitals, prisons)

- The end product (digested material) is not pathogen-free but still fit for reuse

Anaerobic digestion process overview

- In the anaerobic digestion process, micro-organisms convert complex organic matter to biogas, which consists of methane (CH_4) and carbon dioxide (CO_2)
- Some organic matter remains even after the digestion step, and this is called digestate or digester residue or digested organic matter
- Anaerobic digestion is used to treat high-strength wastewater, organic solid waste, sewage sludges, blackwater, faecal sludge, agricultural waste, food industry waste (e.g. breweries, slaughter houses, dairy), manure,....
- Anaerobic digestion with biogas production also occurs in landfills, septic tanks, cows' rumen, natural or constructed wetlands, dams where vegetation was flooded → all these sites produce methane gas!

Four-steps of AD

(steps 1 – 3 are mediated by bacteria)

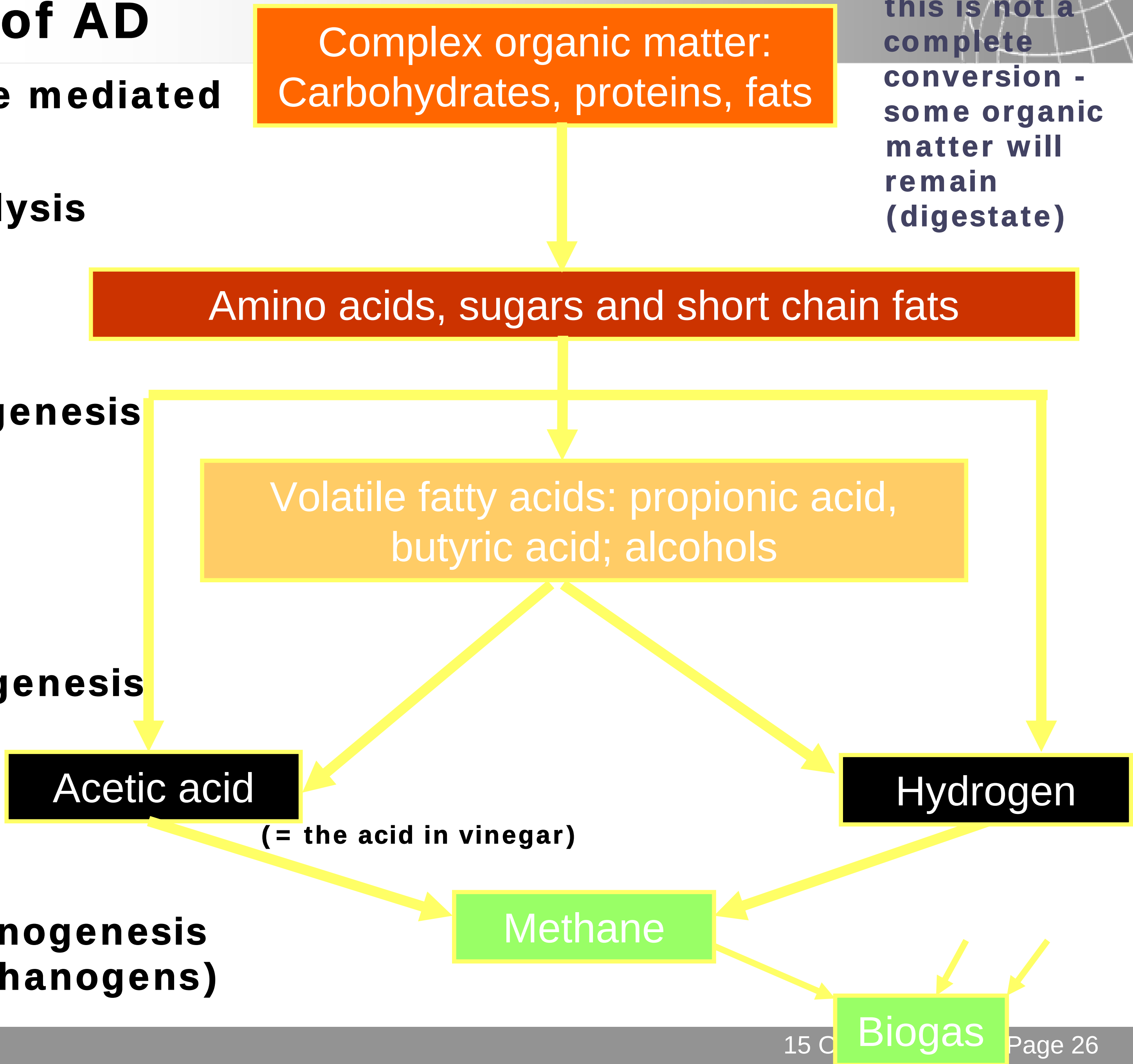
Remember: this is not a complete conversion - some organic matter will remain (digestate)

Step 1 Hydrolysis

Step 2 Acidogenesis

Step 3 Acetogenesis

Step 4 Methanogenesis (by methanogens)



Biogas composition

Compound	Vol %
Methane	**50-75**
Carbon dioxide	**25-50**
Nitrogen	**< 7**
Oxygen	**< 2**
Hydrogen sulfide	**< 1**
Ammonia	**< 1**

Some guidelines for amount of biogas produced per amount of organic material digested

- Sewage sludge: 0.75 – 1.12 Nm^3 per kg of volatile solids destroyed (typical value: 0.95 Nm^3/kg)
- Organic solid waste:
  - 0.38 – 0.42 Nm^3 per kg of volatile solids added (at a retention time of 14 days) for single-stage processes
  - Up to 0.6 Nm^3 per kg of VS added for two-stage processes (two-stage: a process whereby step 1 & 2 is separated (in separate reactors) from step 3 & 4 as shown in slide 24)

Source:
Metcalf & Eddy (2003), p. 1523 (for sewage sludge)
Annette Ochs lecture notes (for organic solid waste), based on "Biologische Abfallbehandlung", Thomé-Kozmienski (editor), chapter "Vergärung", Autor: Scherer (German text book)

Advantages of “biogas toilets” (anaerobic treatment of mixed toilet waste) compared to UDD toilets

- No need to separate urine, hence easier for the toilet user
- Can receive toilet flushwater - hence no need to abandon habit of flushing with water
- Can receive greywater
- Biogas can be used for cooking and lighting
- Can take animal manure and organic solid waste
- Can have the image of a “high-tech” solution

Typical applications for “biogas toilets”

- Public toilets in slums, e.g. in India
- Toilets at schools, universities, prisons and other institutions (e.g. India, Rwanda)
- Situations where animal waste is available and can be combined with human waste (e.g. Nepal, India, China)
- Regions where pour-flush toilets are commonly used (also in combination with anal washing with water)

Disadvantages of "biogas toilets" compared to UDD toilets

Biogas toilets...:

- Are not suitable for individual households unless the toilets can also receive animal waste (e.g. from cows)
- Have higher capital cost – depending on the number of people served
  - Require more know-how for construction (higher safety precautions)
  - Have a higher process risk since methane is flammable
- Produce digestate which can be relatively high in pathogens
  - OK for use as fertiliser but needs further safety barriers for safe reuse

→ You need to decide on a case-by-case basis which type of toilet is better suited

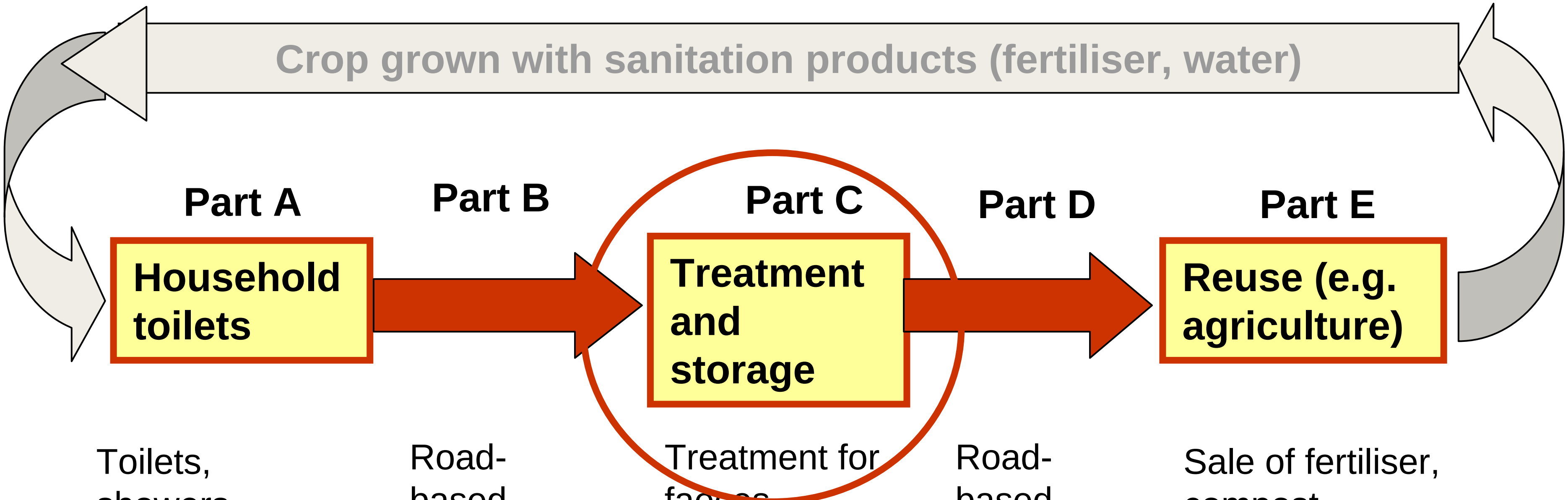
Advantages of anaerobic wastewater treatment (for greywater) compared to aerobic* treatment

- Production of energy-rich methane
- No energy demand for aeration
- No removal of nitrogen and phosphorus (this is an advantage if effluent is to be reused in agriculture)
- High organic loading rates can be applied
  - Suitable for high-strength wastewater (high BOD)
- Low production of excess sludge; the digestate is highly stabilised and can easily be dewatered

Disadvantages of anaerobic wastewater treatment (of greywater) compared to aerobic treatment

- Effluent from anaerobic treatment has higher COD concentration than from aerobic treatment
  - If better effluent quality is required then a second (aerobic) treatment step may be required
- Does not remove nutrients (this is a disadvantage if effluent is discharged to receiving water body)
- Start-up of the process may take long time (slow growth of methanogens)
- Anaerobic microorganisms are sensitive to some toxic compounds
- Can cause odour problems if not operated properly
- Only limited pathogen removal

Sanitation is a system of which anaerobic treatment may form one step



Part A	Part B	Part C	Part D	Part E
Toilets, showers, baths, sinks, washing machines, …	Road-based transport and/or pipes	Treatment for faeces, greywater, urine	Road-based transport and/or pipes	Sale of fertiliser, compost, irrigation water

e.g. anaerobic treatment

Explanation for previous slide:

What is a flare (for biogas) exactly? (slide 1 of 2)

What is a flare (for biogas) exactly? (slide 2 of 2)

- There are many companies who can provide the equipment for a flare (e.g. for landfill gas flares)
  - Just as an example, you can look at this website (photos from the previous slide are from their website): http://www.parnelbiogas.com/products.htm

Pathogen removal in AD processes

- In small biogas digesters, the process is operating at ambient or mesophilic temperatures, and is difficult to control
  - Temperature and retention time therefore vary and sufficient pathogen reduction is difficult to achieve even at long retention times
- Example research results for pathogen removal in AD:

Pathogens	Termophilic (53-55°C)		Mesophilic (35-37°C)		Ambient (8-25°C)	
	fatality	Days*	fatality	days	fatality	days
Salmonella	100 %	1-2	100 %	7	100 %	44
Shigella	100 %	1	100 %	5	100 %	30
Polivirus	-	-	100 %	9	-	-
Schistosoma ova	100 %	<1	100 %	7	100 %	7-22
Hookworm	100 %	1	100 %	10	90 %	30
Ascaris ova	100 %	2	98.8 %	36	53 %	100

*** This refers to the residence time in the digester, see next slide**

Source: Zhang Wudi *et al.* (2001) - slide from Heeb *et al.* (2007)

Important design parameter: residence time (τ or HRT)

- The residence time in a digester is also called hydraulic residence time (HRT), or retention time (τ)
- It is the length of time that the liquid stays in the reactor
- Once you know the design residence time for your process, you can calculate the required volume of the digester

$$V = Q \cdot \tau_{design}$$

With:

Q: Flowrate (m^3/d), e.g. 0.5 m^3/d

τ_{design}: design residence time, e.g. 30 days

Then required volume is: 15 m^3

- Examples (see also Part B):
  - Anaerobic baffled reactor: HRT = 2-3 days
  - Sewage sludge digestion: HRT = 15 – 20 days

Degradability of organic materials

Easy to degrade

Lots of biogas in short time (short residence time)

Not so much biogas and long residence times needed

Hard to degrade

Classification of anaerobic digestion processes

- By temperature:
  - Mesophilic (35°C)
  - Thermophilic (55°C)
- By operation:
  - Batch
  - Continuous
  - Fed-batch or semi-continuous
- By water content of input material:
  - Wet systems: TS content < 15% d.s.
  - “Dry” systems: TS content 25-50% d.s.
  - → rule of thumb: AD does <u>not</u> work if all input material has TS > 50% d.s (too dry)

Remember: 15% d.s. means 150,000 mg/L dry solids content and TS stands for total solids (same as d.s. which stands for dry solids)

Example for anaerobic digestion operating and performance parameters

Operating parameters

- Hydraulic retention time in digesters (also called treatment time): 15 – 20 days
- Operating temperature:
  - Ambient
  - Mesophilic (35°C)
  - Thermophilic (55°C)
- Type and composition of feed (input material)
  - TS and VS content of feed
  - Degradability

Performance parameters

- VS loading rate: 1.6 – 4.8 kg/m^3/d
- VS destroyed: 56 – 66%
- Methane content in biogas (%) – expect 50 – 75%
- Gas production per kg VS destroyed (m^3 /kg VS destroyed)

Values provided on this slide are for high-rate complete-mix mesophilic anaerobic digestion (Metcalf & Eddy, page 1513 and 1514)

How to detect a failing anaerobic treatment process

- Odour
- Explosion (worst case !! – extremely rare) – see next slide
- Foaming
- Low pH value (step 4 of 4-step process on slide 24 is inhibited)
- No or low biogas production
- Low methane content in biogas
- Volatile solids (VS) fraction in effluent close to the VS fraction in the influent, indicating no VS removal

How could an explosion of an anaerobic digester occur?

- If a vacuum develops in the digester (e.g. leaks of liquid): → air is sucked in → if methane content is 5-15% in air, and there is a spark, then there could be an explosion
- If digester is in an enclosed building and biogas leaks out: → if there is a lack of ventilation and a spark, then there could be an explosion
- → Checking for liquid and gas leaks is an important operational maintenance task
- *Having said all this, I have never heard of such an explosion actually having taken place (have you?)*

Main possible causes of process failure

- Organic overload (too much BOD added per m^3 and day)
  - This applies particularly to easily degradable substrate, e.g. brewery wastewater
- Insufficient alkalinity and therefore a drop in pH (could add alkalinity, e.g. lime)
- Toxic substances in influent are inhibiting methanogens (this applies only to industrial wastewater)

Two principal types of construction to deal with gas development

- Fixed dome in which a pressure builds up (see Lesotho example)
  - Common for small-scale plants
  - Needs skilled workers for construction but less attention during operation (no moving parts)
- Floating or moveable dome/cover which allows an expansion of the gas volume in the digester
  - A “gas bubble” can be used
  - This type is more common for large-scale plants

What does ecosan stand for?

- ecosan = ecological sanitation
- is no specific technology but a new philosophy that sees substances as resources instead of waste
- applies the natural principle of closing the loop by reuse-oriented wastewater management
- flow streams are often collected separately
- unnecessary dilution with water is avoided
- both low-tech and high-tech technologies are used

Important treatment technologies often used as part of ecosan concepts

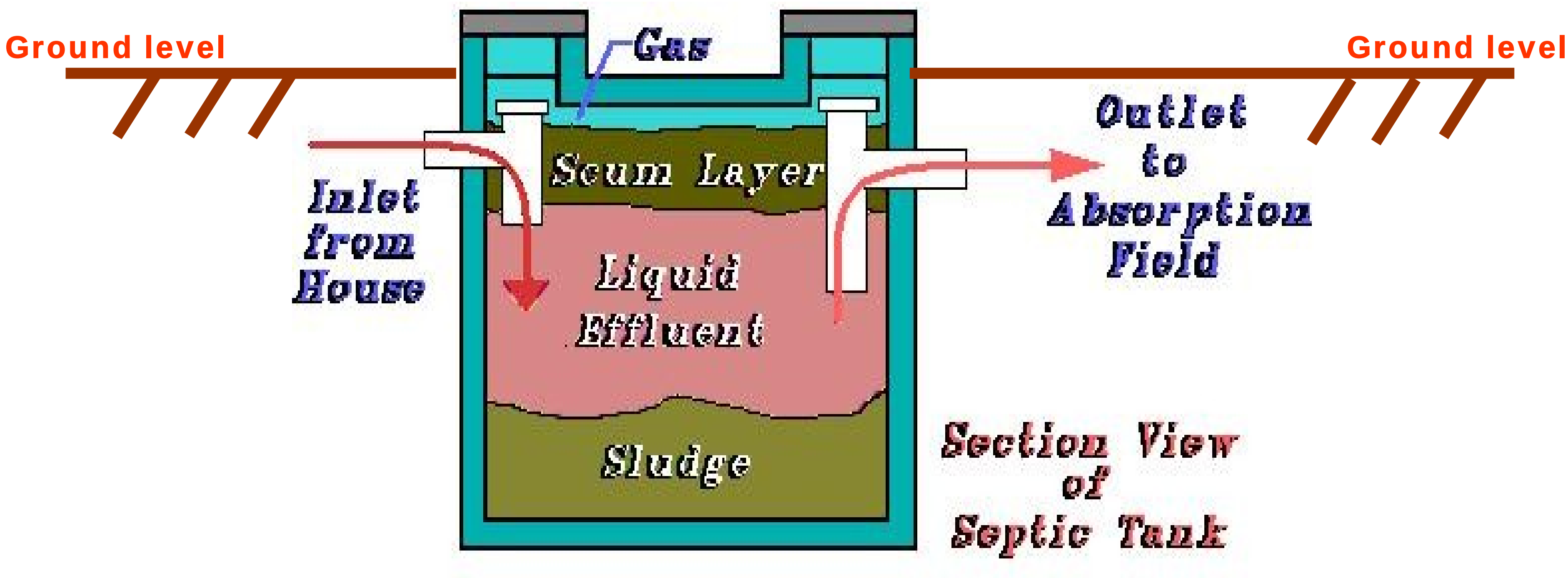
- Technical options
  - Septic tanks
  - UASB
  - Anaerobic ponds
  - Anaerobic digesters

- Reasons for use
  - Suitable for faecal sludge, blackwater, faeces (e.g. together with manure), organic solid waste
  - Preserves nitrogen (unlike aerobic wastewater treatment)
  - Produced biogas for cooking, lighting, heating

1- Septic Tanks

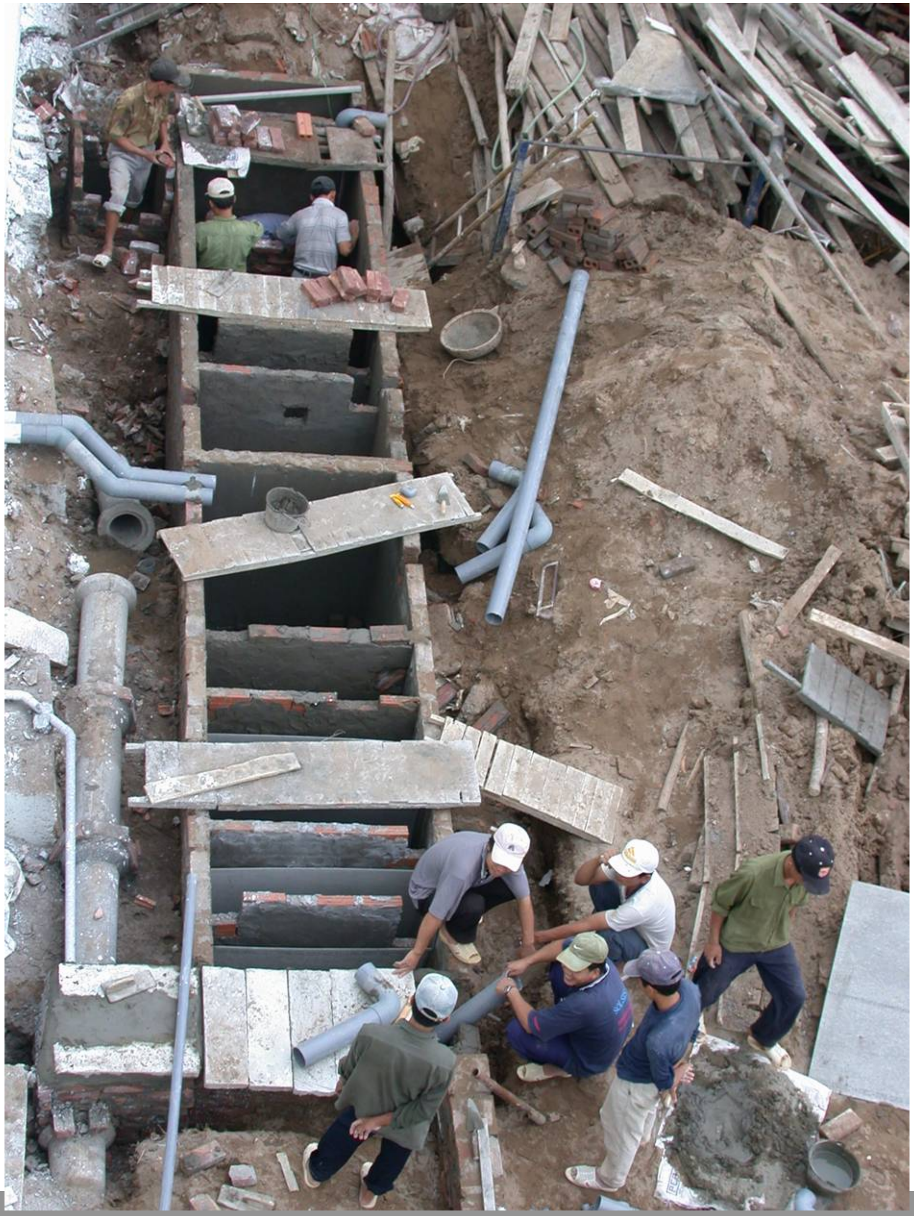
- Very common on-site sanitation system for excreta and greywater
- Relatively common also in some high-income countries: Australia, USA
- In most cases, biogas is not collected (amount is small unless animal manure is digested as well; in that case it is no longer called a septic tank)

Septic tank process principles



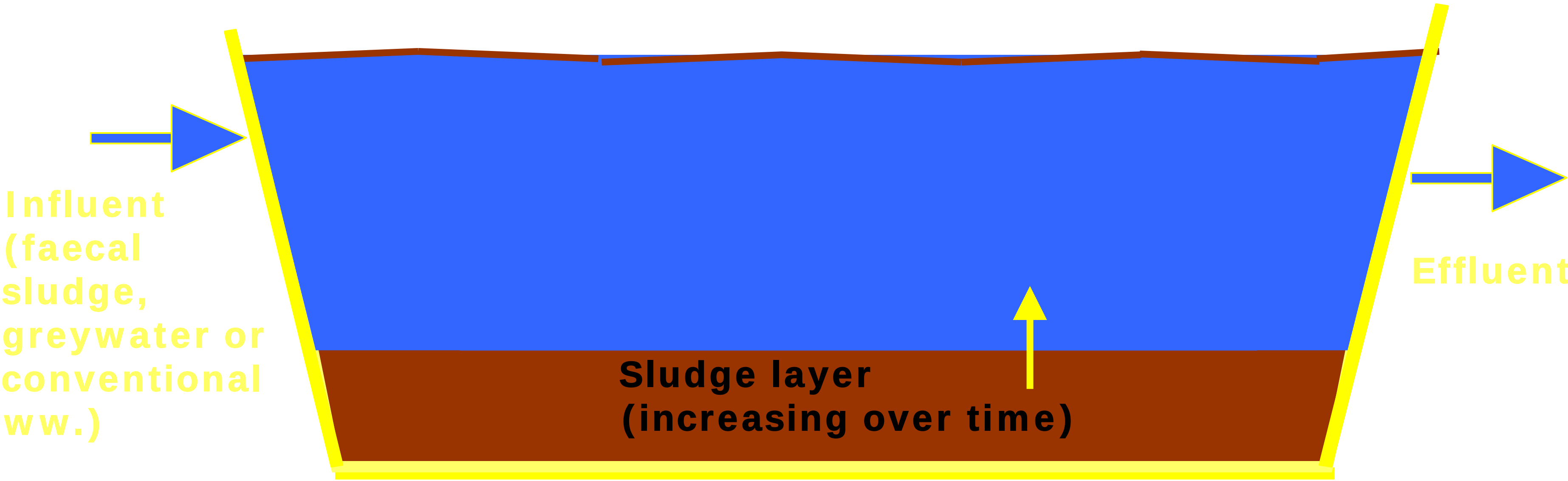
- Combined settling, skimming and anaerobic digestion
- Commonly followed by filtration of effluent (e.g. sub-surface soil disposal field)
- No mechanical equipment (no moving parts)

Anarobic baffled reactors during construction



4 - Anaerobic ponds

- Also called lagoons (in the US) or waste stabilisation ponds
- Low-rate anaerobic process (e.g. 1 – 2 kgCOD/m^3/d)
- Solids settling and anaerobic decomposition
- Depth: 5-10 m
- Could be covered for odour control and gas collection (but most of them are not covered)
- Usually several ponds in series (last pond: aerobic maturation pond with algae; pathogen kill by sunlight)



This slide was provided by Peter van der Steen (UNESCO-IHE)

Anaerobic ponds

5 - Principles of UASB reactors

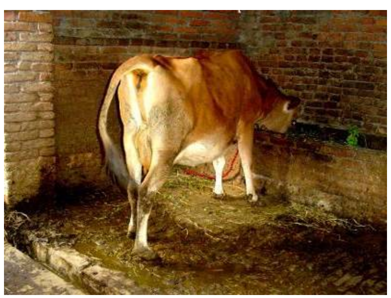
- UASB = Upflow anaerobic sludge blanket reactor
  - Inflow flows in vertical direction (from bottom up – upflow)
- A high sludge concentration is maintained in the reactor, which results in long solid retention times
- Short hydraulic retention times
- Good contact between substrates (COD) and the sludge (bacteria)
- High-rate system (high organic loading rates, e.g. 2 -24 kgCOD/m^3/d)
- UASBs can treat:
  - Blackwater (faeces and urine), manure
  - Conventional wastewater (high strength), greywater
  - Industrial effluent
  - Agricultural organic waste

A UASB reactor for the treatment of 6000 PE (person equivalents) domestic wastewater

The biogas contains sulphide, which can be removed in iron filters (FeS precipitation)

Biogas for a better life (supported by SNV, DGIS, UEMOA and GTZ)

- is an **African initiative**, launched by SNV and other partners, which will offer investment and business opportunities
- relies on **Nepalese Model case**: successful Nepalese biogas programme (20.000 biogas systems per year, supported by SNV and KfW)



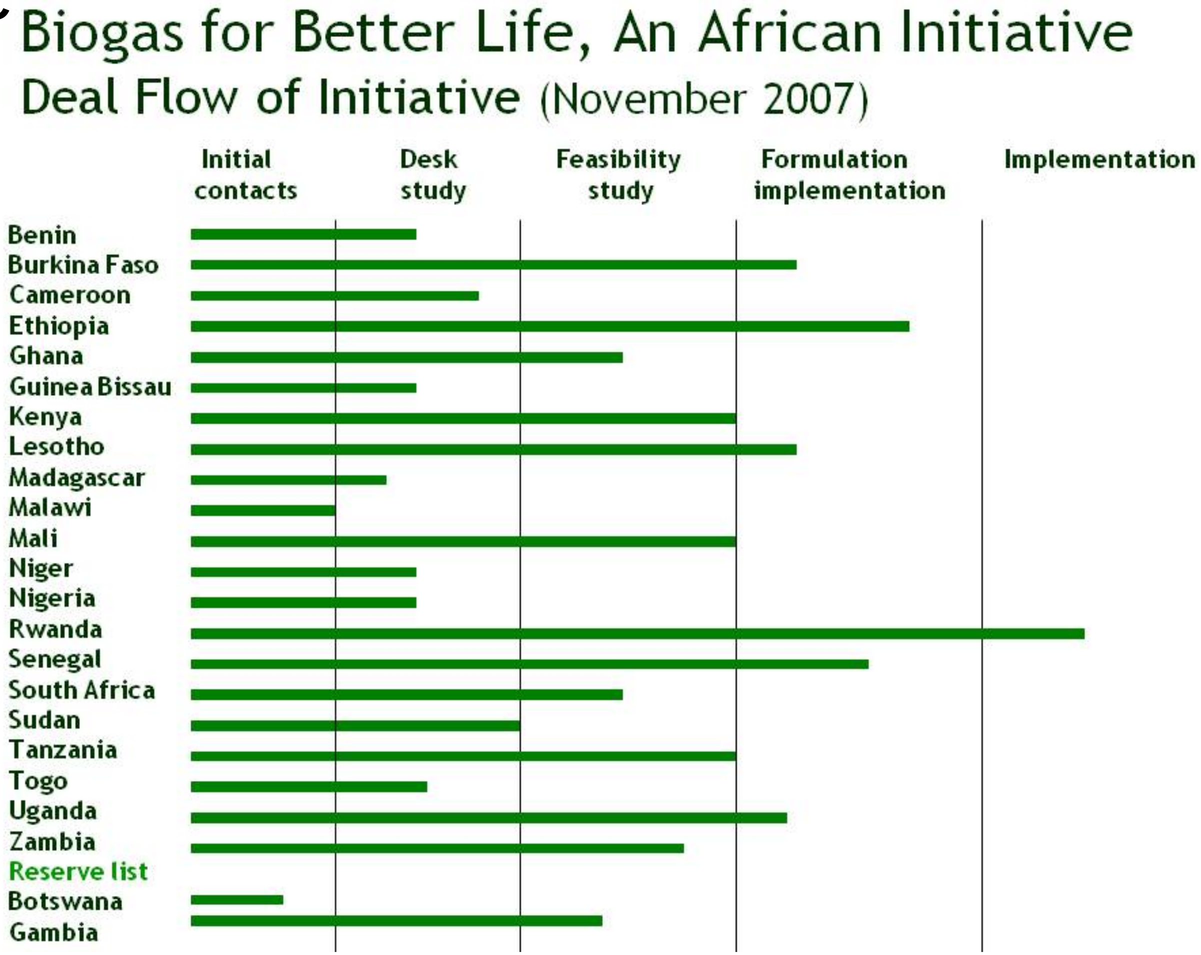
Aim: 2 million domestic biogas installations sold and 95% in daily operation within 10 years.

Specific achievements to reach by 2020

- 2 million biogas plants installed and being used
- 800 private biogas companies established and operational
- 200 biogas appliances manufacturing workshops developed and operational
- Comprehensive quality standards and quality control systems developed
- Minimum 90% of constructed plants are operational
- 1 million toilets constructed (motivated for construction) and connected with biogas plants
- 80% of bio-slurry is utilized as organic compost fertilizer
- Biogas programme fully developed as a first CDM project in Africa
- Biogas programme fully ISO certified for quality and environmental performance
- 1,500 micro finance organizations mobilized on biogas lending
- 10 million persons directly benefiting from the programme
- Over 140,000 persons get employment in the programme

Status of the Initiative

Feasibility studies initiated or completed in 13 African countries (e.g. Rwanda, Kenia, Ethiopia, Tanzania, Burkina Faso) conducted by Dutch and Gernam DC



India: Adarsh College of Arts and Commerce, Badlapur

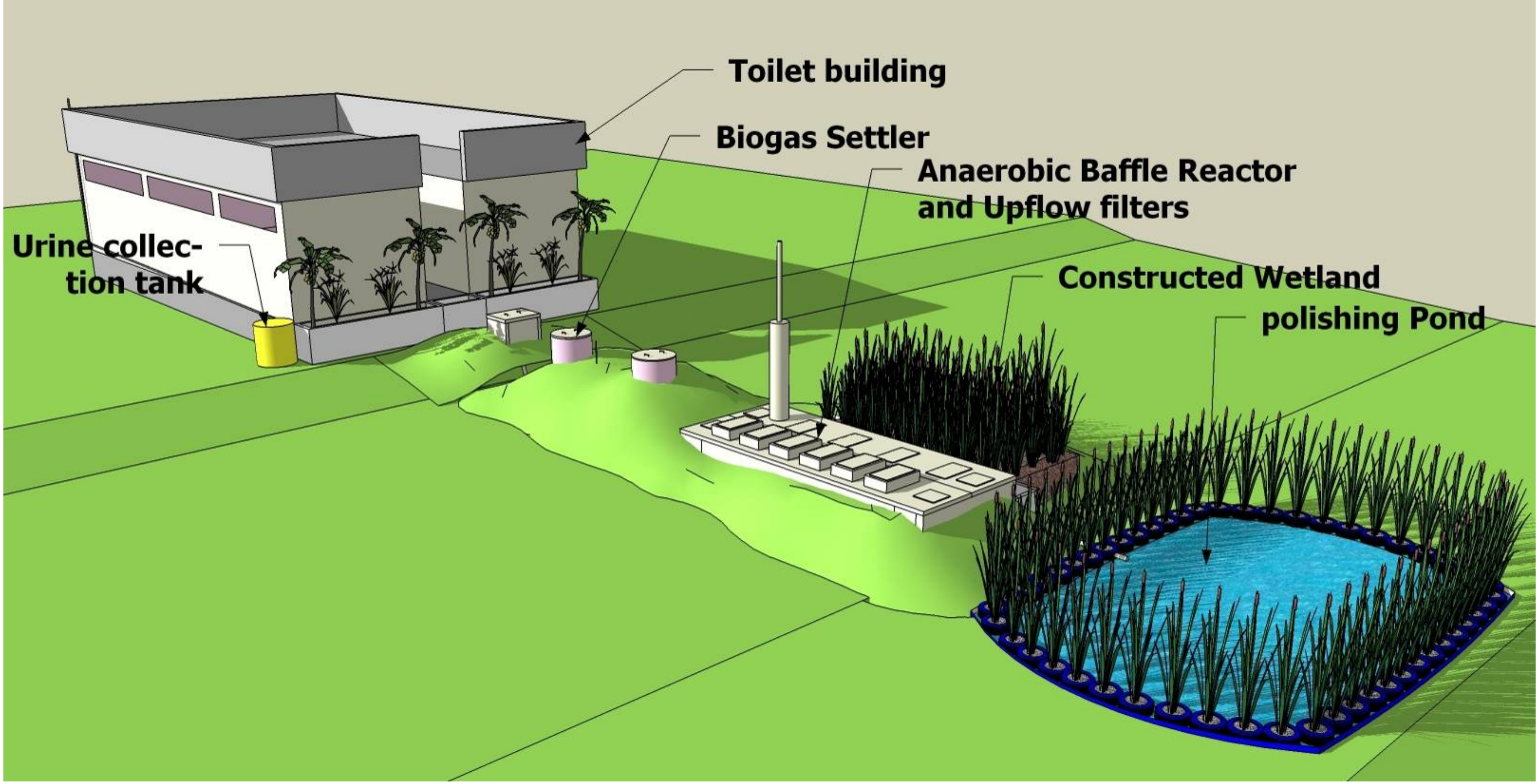
2600 students per day (1300 morning + 1300 afternoon)

Front view of Adarsh College

Existing toilets are in bad condition

India: Adarsh College of Arts and Commerce, Badlapur

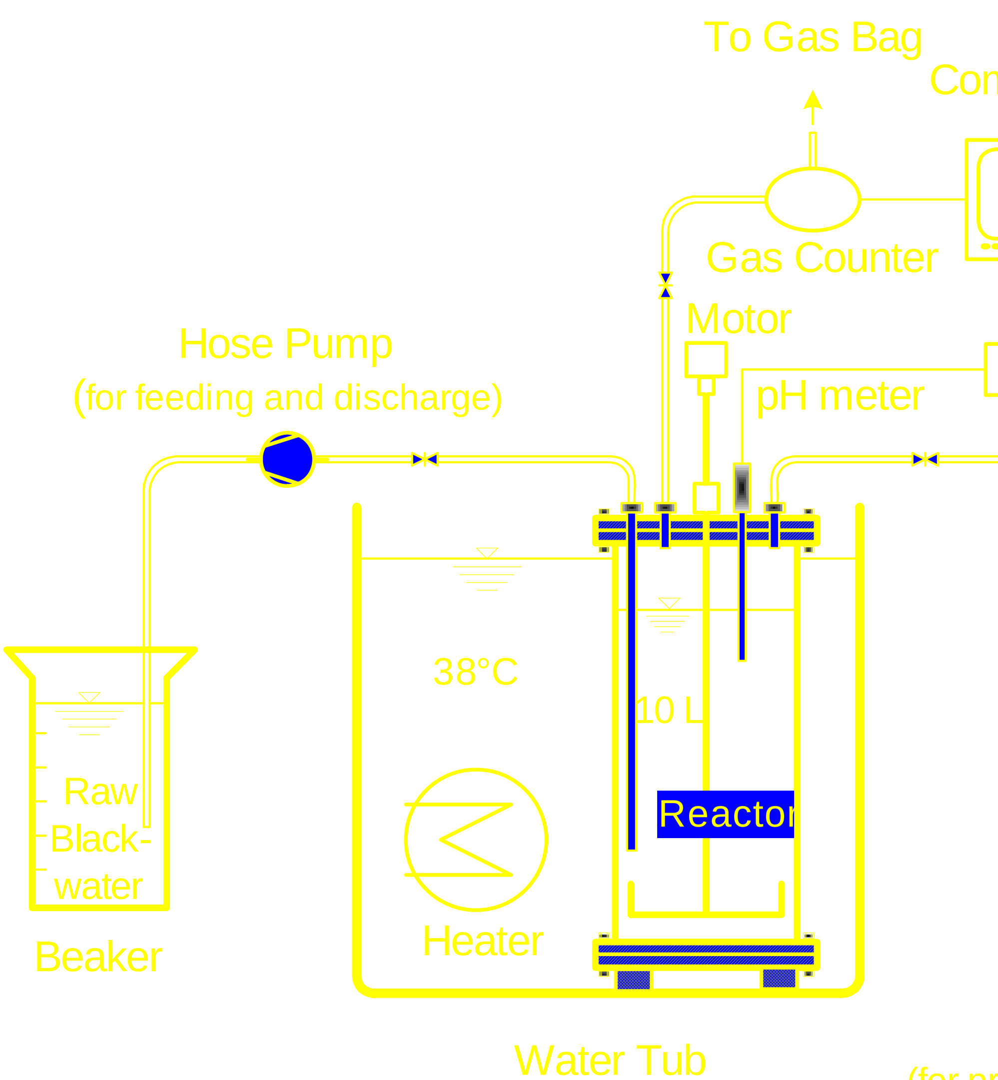
Anaerobic treatment system



Navsarjan Vocational Training Institute: System components

- Hand washing facilities
- Existing toilet centre converted into urinal centre
- Urine collected in subsurface tank and reused in gardens
- Water from dishwashing stand collected and reused in the garden

ecosan program recycling oriented wastewater management and sanitation systems



U – Tube
(for pressure balance during feeding and discharge)

Example: Blackwater treatment in Sneek, The Netherlands

- The next slide is from myself and the remaining slides for this examples are from Brendo Meulman, Landustrie, the project leader (provided in Sept 2007)

Neighbourhood “UASB-septic tank” for blackwater in Sneek, The Netherlands

- Vacuum toilets are used, they flush with 1L water and 100L of air. Reduction of 36 L/cap/d water, is 25% of total water consumption

Vacuum toilet

Vacuum station (pump)