

Wastewater treatment using source separating systems

Petter D. Jenssen

Department of Plant and Environmental Sciences, Norwegian university of Life Sciences

"The development of human society with nature for the benefit of both" *

Closing^{the}Loop

What do the Millennium Development Goals have in common with travelling to Mars?

Both require a functional system for collecting and recycling household wastes in order to reuse water and nutrients.

NASA is using the principle of "closed loop" for the voyage "Man to Mars" in 2013. In a similar way, the Norwegian University of Life Sciences utilizes environmental loops in its contribution towards the UN Millennium Development Target 10:

"To halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation."

The Norwegian **University of Life Sciences** 

RESEARCH • CAPACITY BUILDING • INDUSTRIAL INNOVATION

www.umb.ecosan

*The Norwegian University of Life Sciences is a member of the Norwegian University of Science and Technology (NTNU)



Kathmandu, Nepal

This is Baghmati river in Katmandu. In the dry season the river is literally a sewer (see concentrations in the river water).

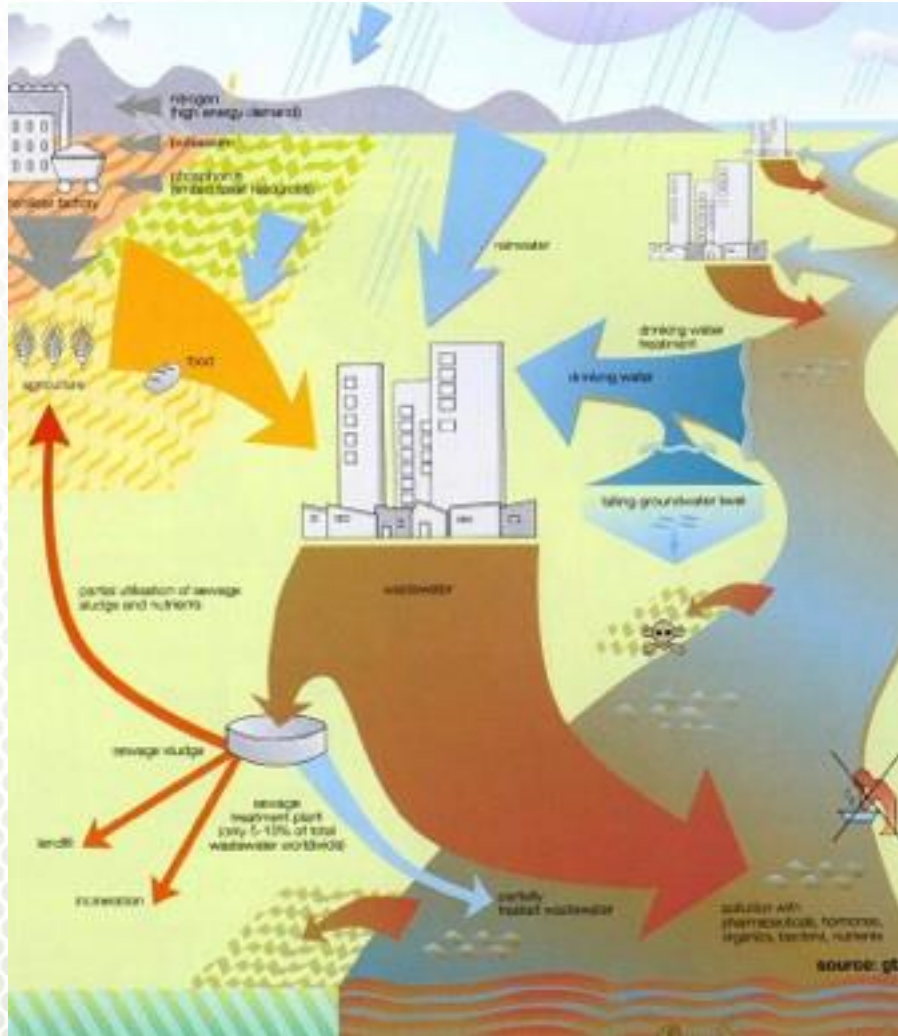
Dry season:

- DO less than 1 mg/l
- BOD - 250 mg

(Pandey et al. 2005)

MAY 11 2005

Current wastewater handling



Unfortunately very many rivers world wide is like the Baghmati. The main reason for the poor water quality in the Baghmati river is the use of water toilets without having treatments plants at the discharge points. Mixing excreta into the water cycle leads to severe water pollution and health problems. This is the result of most of our current sewage handling.

90% of the worlds wastewater is not treated (Corcoran et al. 2010).

Resources in wastewater

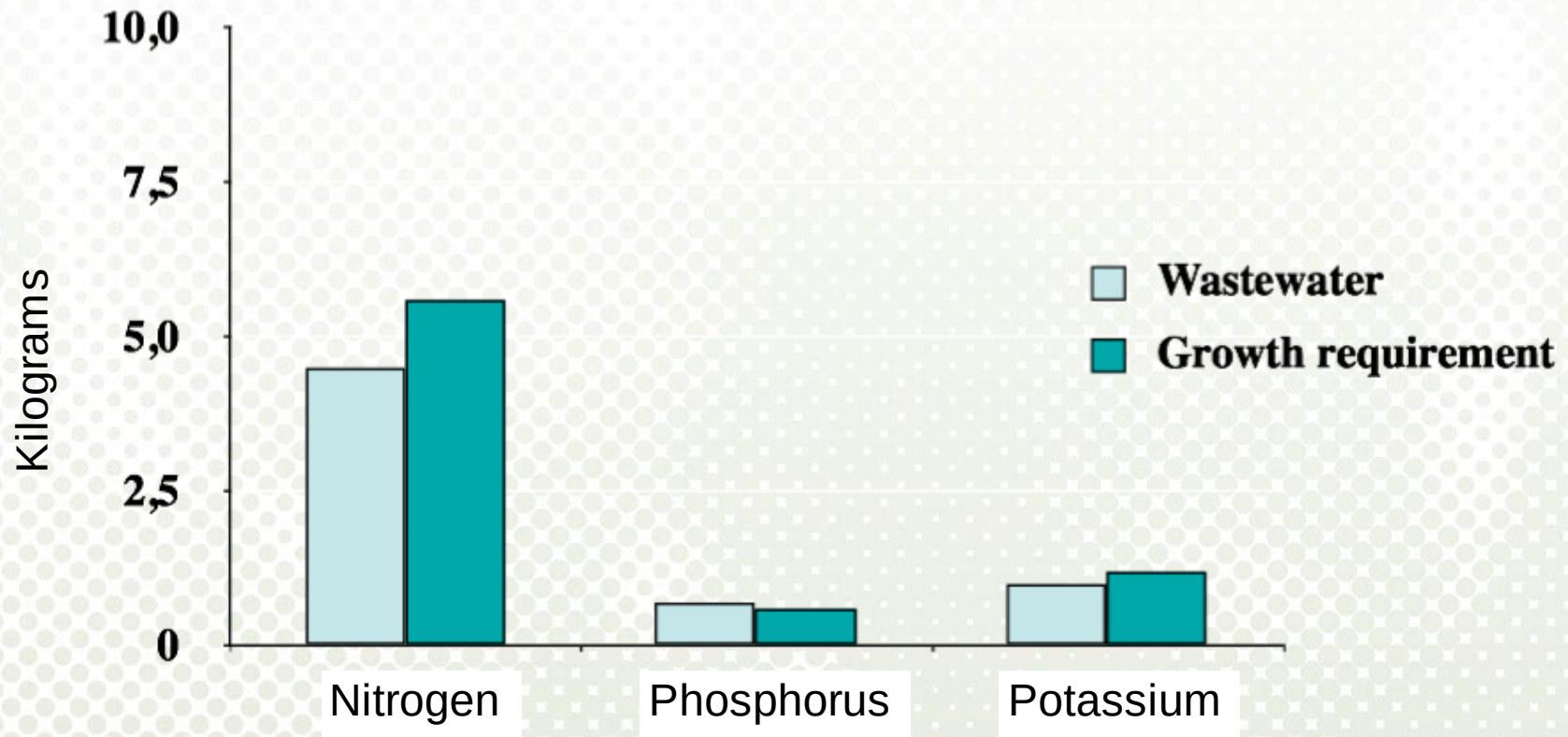
Wastewater is a resource and contains valuable plant nutrients. The ratio between nitrogen phosphorus and potassium (the major elements or macro nutrients for plant growth) in wastewater is close to an optimum ratio for application in agriculture. The yearly discharge from one person is:

- | | |
|------------------------|--------|
| • Nitrogen (N) | 4.5 kg |
| • Phosphorus (P) | 0.6 kg |
| • Potassium (K) | 1.0 |
| • Organic matter (BOD) | 35 kg |

Tekst

The above nutrients are sufficient to fertilize from up to 0.1ha of arable land and can potentially produce nearly enough food to supply one person. The organic matter can be used for production of bioenergy (biogas) and is also a valuable soil amendment.

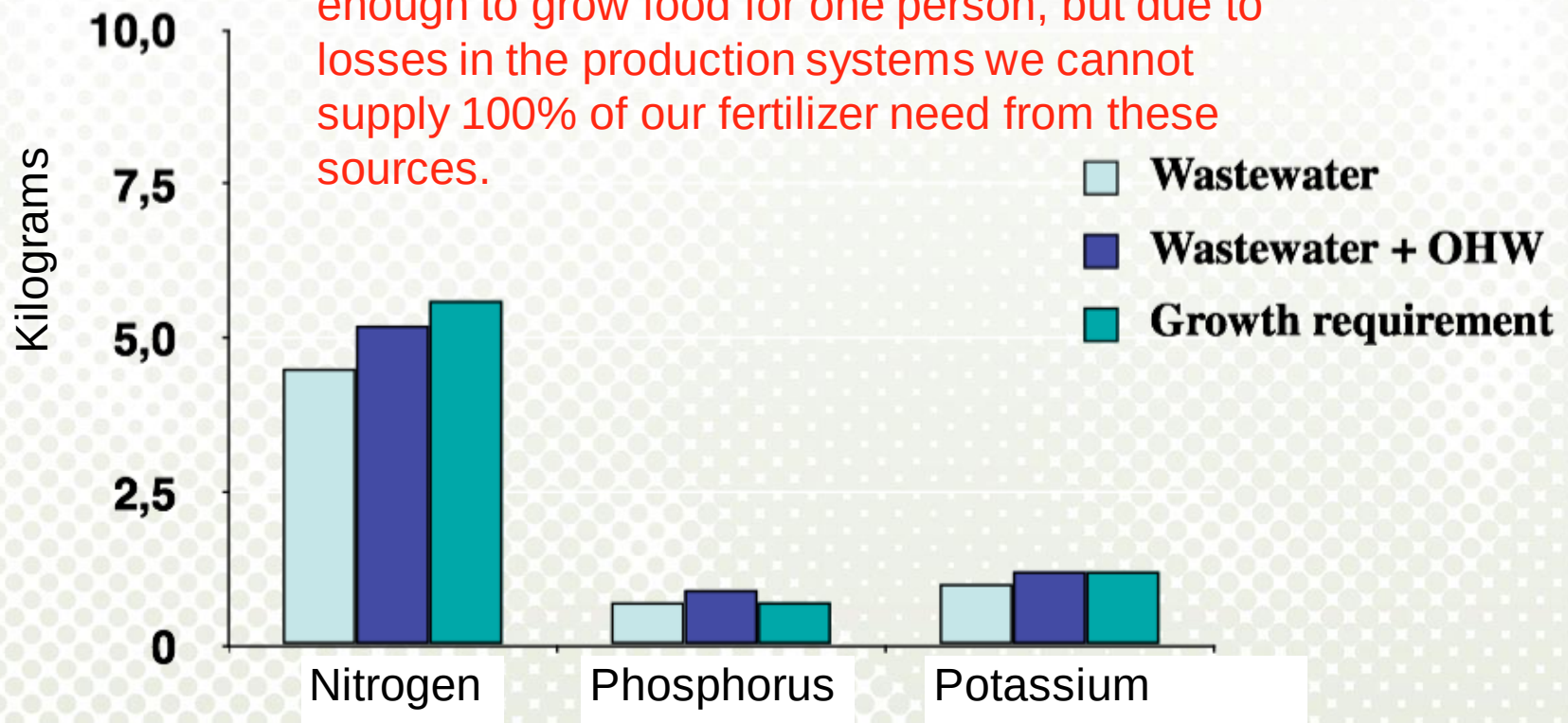
Nutrient content in wastewater + organic household waste vs. nutrient requirement to grow 250 kg wheat



Wolgast (1993), Jenssen & Skjelhaugen (1994)

Nutrient content in wastewater + organic household waste nutrient requirement to grow 250 kg wheat

If we add the nutrients from organic household waste (OHW) and wastewater it is theoretically enough to grow food for one person, but due to losses in the production systems we cannot supply 100% of our fertilizer need from these sources.



Wolgast (1993), Jenssen & Skjelhaugen (1994)

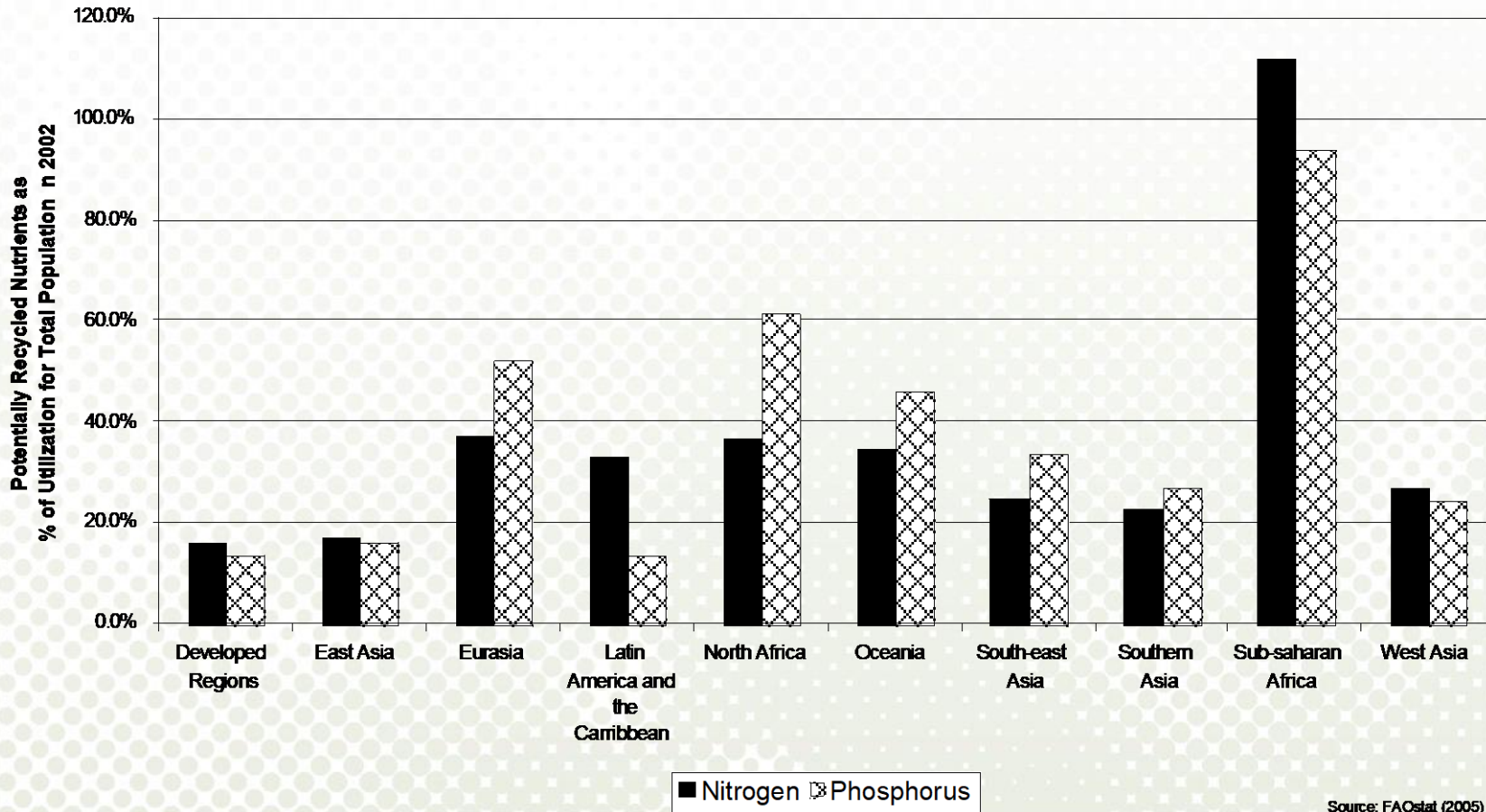
The wastewater resource

The fertilizer value of the nutrients
discharged to the sewer systems in **Norway**

40 million USD per year

(Jenssen and Vatn 1991)

Potentially recycled nutrients from source separating systems as % of currently utilized chemical fertilizer nutrients in 2002



If we could recycle all nutrients in human excreta we could substitute 15-20% of the mineral fertilizer used in rich countries. In most developing countries 40 - 60% could be substituted and in Sub-Saharan Africa excreta could supply all the current fertilizer use.

Why do we need to recycle nutrients from wastewater?



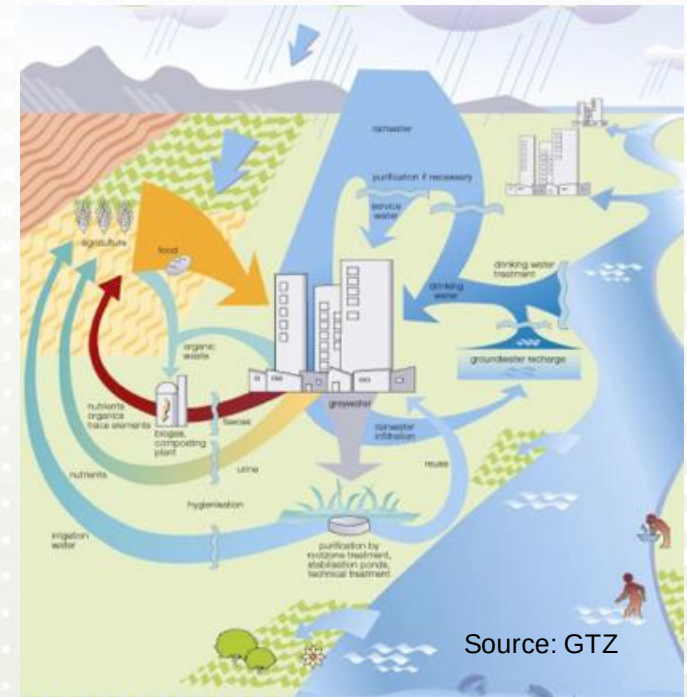
www.umb.no

Source: GTZ

Why do we need to recycle nutrients from wastewater?

The most urgent reason is that the world is running out of mineral phosphorus reserves (Rosemarin 2010). Without phosphorus our future yields will decline. The major future source of phosphorus is human excreta.

It takes 38MJ (megajoule) to produce one kg of nitrogen fertilizer by the current manufacturing process (Refsgaard 1998). If we can bring the nitrogen back to the farm field at a lower energy cost we have a more sustainable system.



Source: GTZ

How can we recycle nutrients from wastewater?

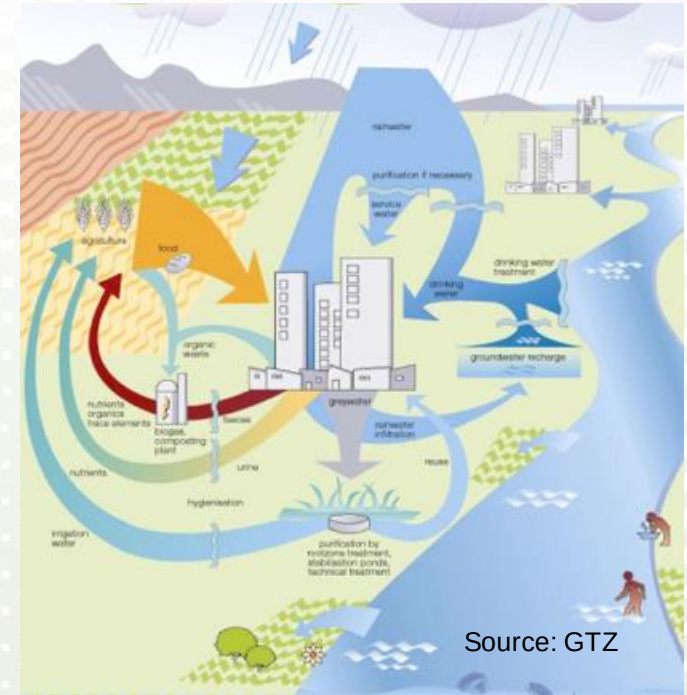


How can we recycle nutrients from wastewater?

There are several technical options for recycling of nutrients:

- ☐ Reuse of sewage sludge from current treatment plants
- ☐ Precipitation of struvite from wastewater
- ☐ Recycle human excreta by the use of **source separating systems**

In this presentation we explore the use of **source separating systems**



Source: GTZ

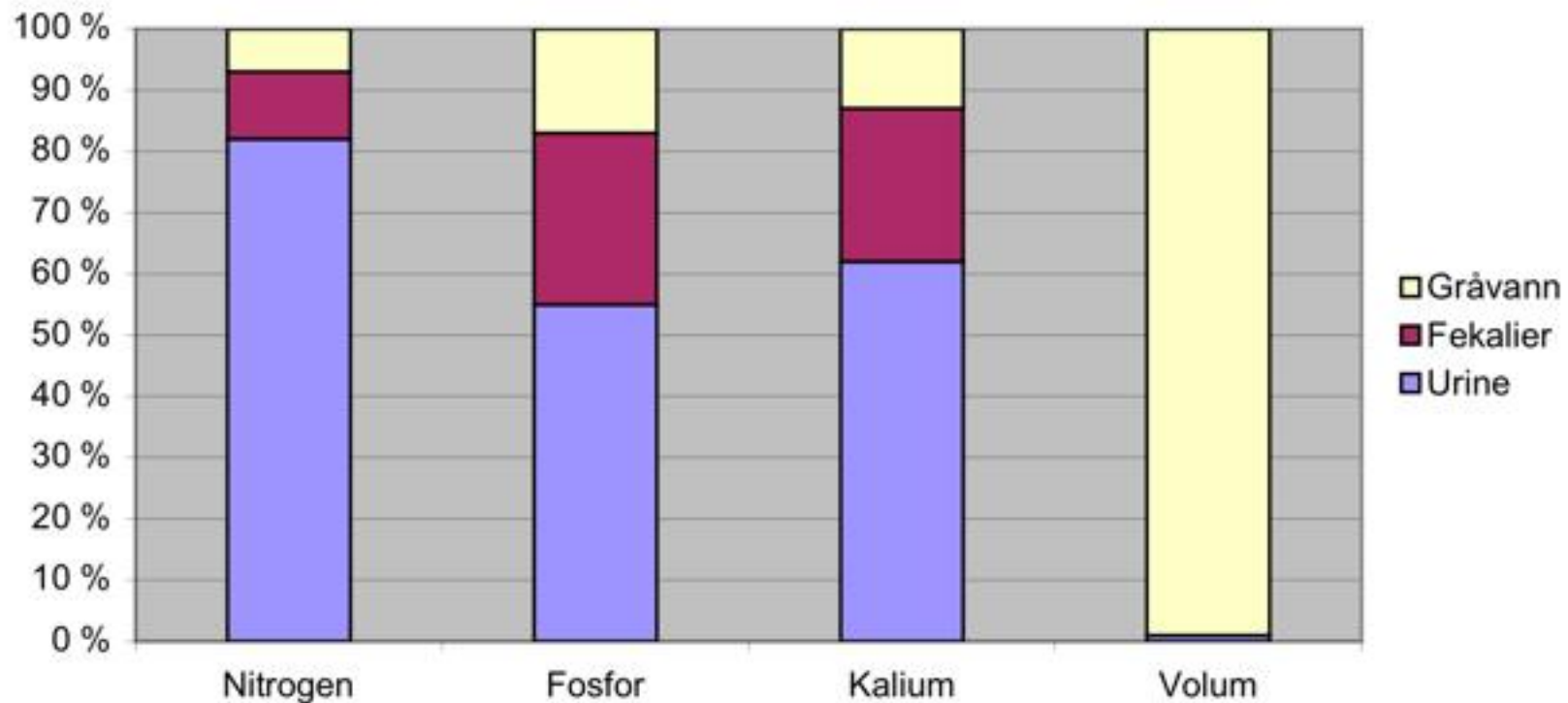
The majority of the nutrients and the organic matter is in our excreta or toilet waste. The toilet waste is often termed **blackwater**.



- * 90 % of N
- * 80 % of P
- * 80 % of K
- * 40-75 % of org. matter
- * Majority of the pathogens

Content of nutrients and volume in wastewater fractions

Urine is the most valuable fraction of our wastewater. Urine can be termed **yellow-water** and the faeces **brownwater**



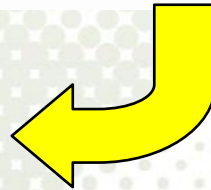
Source: Jönsson et al. 1999

Blackwater fractions

Blackwater = Yellowwater + Brownwater



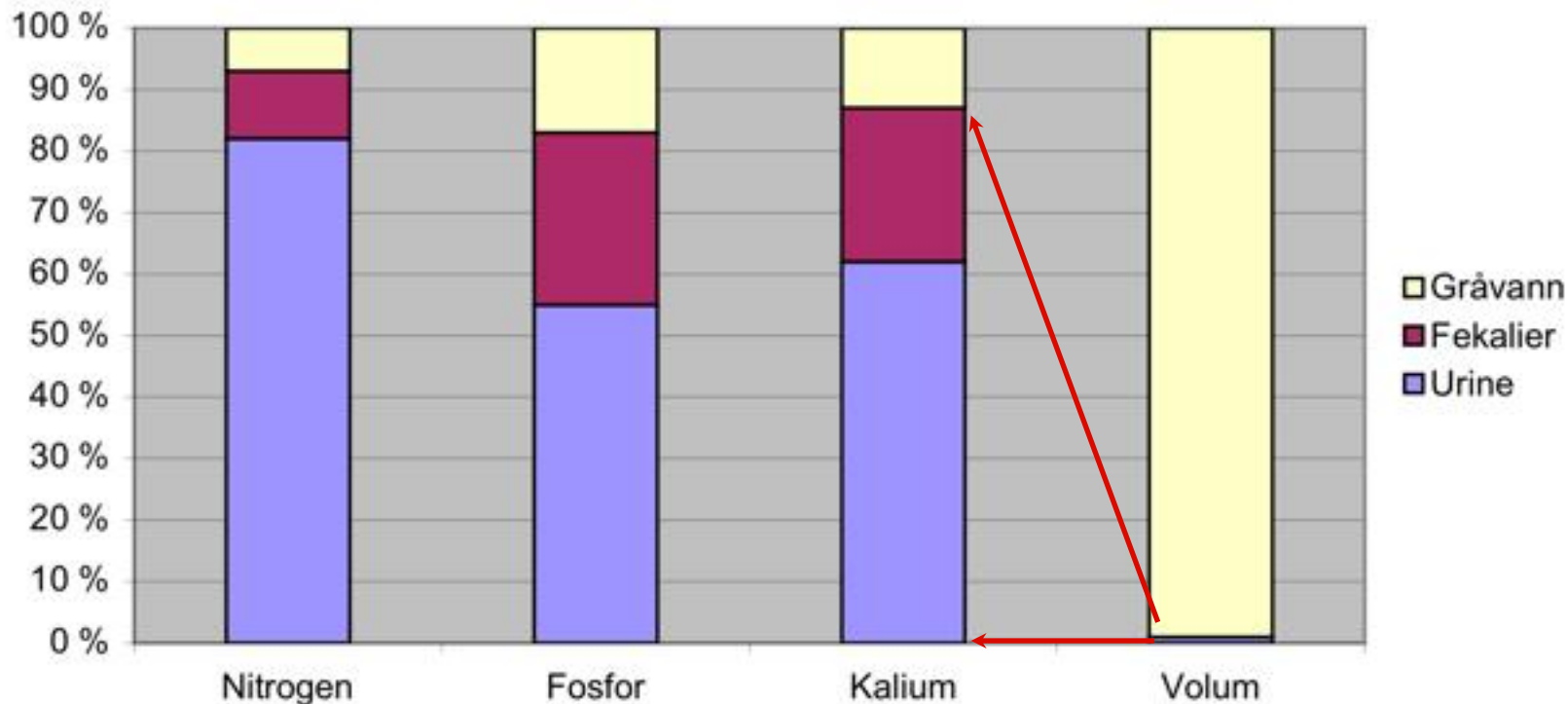
Yellow-water
(urine)



Brownwater
(faeces)

Content of nutrients and volume in wastewater fractions

Our excreta constitute about 1,5 liter per person per day. In Norway we use an average of 150 liter of water per day. This means our excreta is 1% of the total wastewater volume but contains more than 80% of the resources.

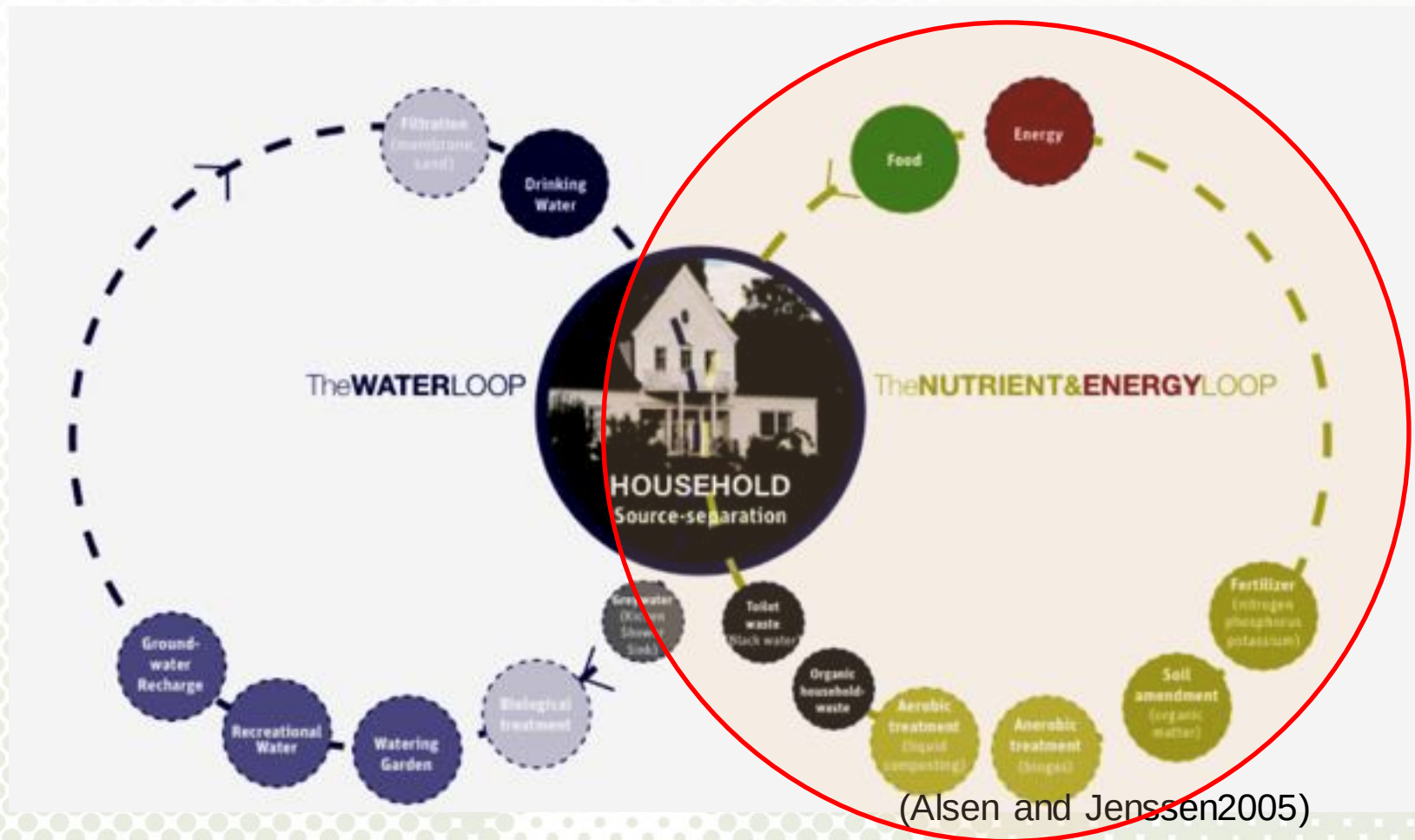


Source: Jönsson et al. 1999

1% of the volume contains 80 - 90% of the resources

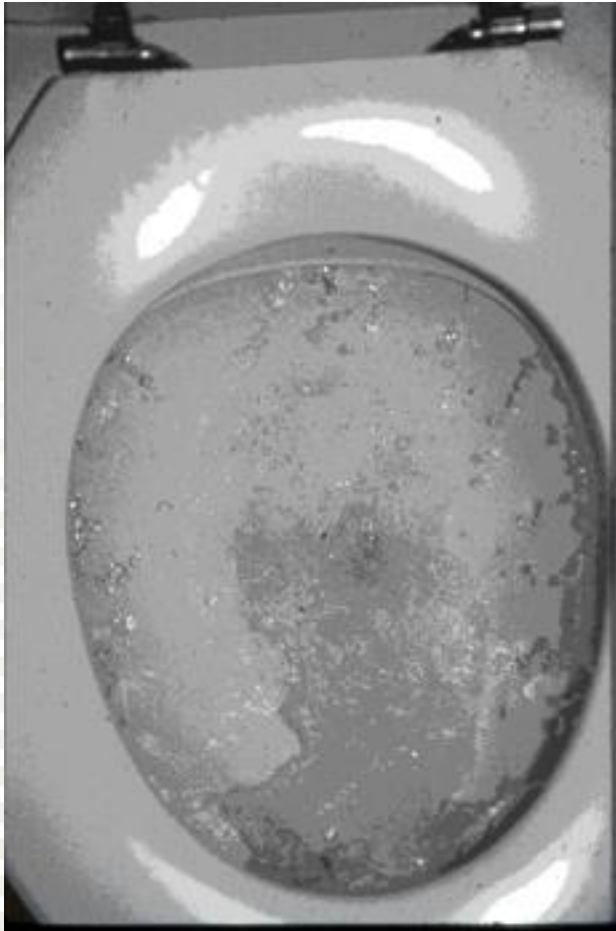
Source separation of wastewater

The high amount of resources in our excreta makes source separation of wastewater an interesting option. In the «nutrient and energy loop» excreta is converted to fertilizer and bioenergy. In the «water loop» greywater (all water except toilet waste) can be easily be treated to meet irrigation water standards or for a quality suitable for recharge of groundwater. It is also possible to produce drinking water quality.



(Alsen and Jenssen 2005)

The water toilet



An ordinary water toilet uses 4 -20 liters per flush. This is too much if we are going to collect and reuse our excreta.

Did you know that 20 - 40% water consumption in sewered cities is due to use of the water toilet?

(Gardner 1997)

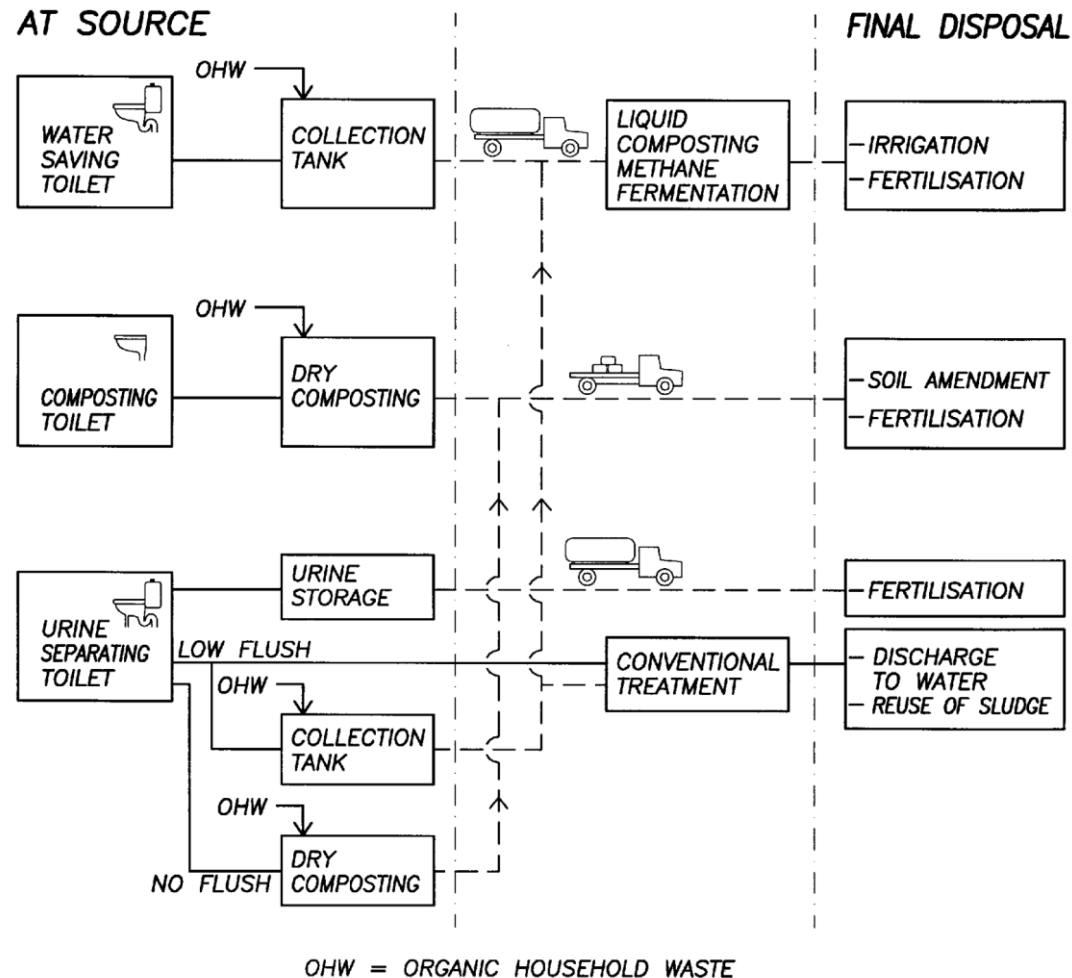
Future toilet types

In order to collect excreta we have to use very water efficient toilets. Such «future toilet types» are commercially available today.

- | | |
|------------------------------|-----------------------|
| • Composting /dry sanitation | 0 - 0.1 liter/visit |
| • Urine diverting | 0.1 - 4.0 liter/visit |
| • Water saving* | 0.5 - 1.5 liter/visit |
- *(vacuum&gravity)

Toilets and corresponding logistics

The use of the «future toilet types» changes the logistics of wastewater handling

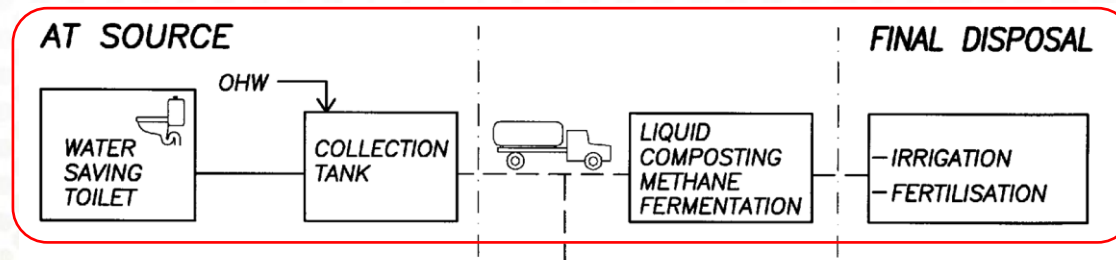


See: Jenssen et al. (2004) for more comments to the logistics

www.umb.no

Toilets and corresponding logistics

The use of the «future toilet types» changes the logistics of wastewater handling



Using a low flush toilet and separate collection of the blackwater requires a dual plumbing system for the wastewater. The blackwater is transported to a holding tank. The holding tank may be fitted inside the basement of the building or buried adjacent to the building. In urban areas, especially, a basement tank may be convenient because of space and conflict with other infrastructure outside the building. In existing buildings where water saving toilet system is retrofitted a flexible tank may be used. A flexible tank of reinforced plastic fabric can be folded and carried into the building without having to modify doors or other building structures. What is needed is to prepare a corner or other suitable space by constructing watertight walls as support for the tank. The watertight space should also be connected to a drain in case of leaks or for cleaning and maintenance. The flexible tank must be custom made to the available space. The tank should be vented through the normal ventilation of the plumbing system. The tank should be equipped with a suction pipe that emerges at street level at a convenient site for the pumper truck to connect.

From the holding tank the blackwater is transported to a treatment facility (liquid composting or anaerobic digester) for hygienization. The processed liquid can then be used as fertilizer in agriculture or silviculture.

Low flush toilets

Vacuum
0.5 - 1.5 liters/flush



Gravity
1 liter/flush



Contemporary Scandinavian bathroom design using vacuum toilets



Comfort and design is not inferior using extremely low flush toilets

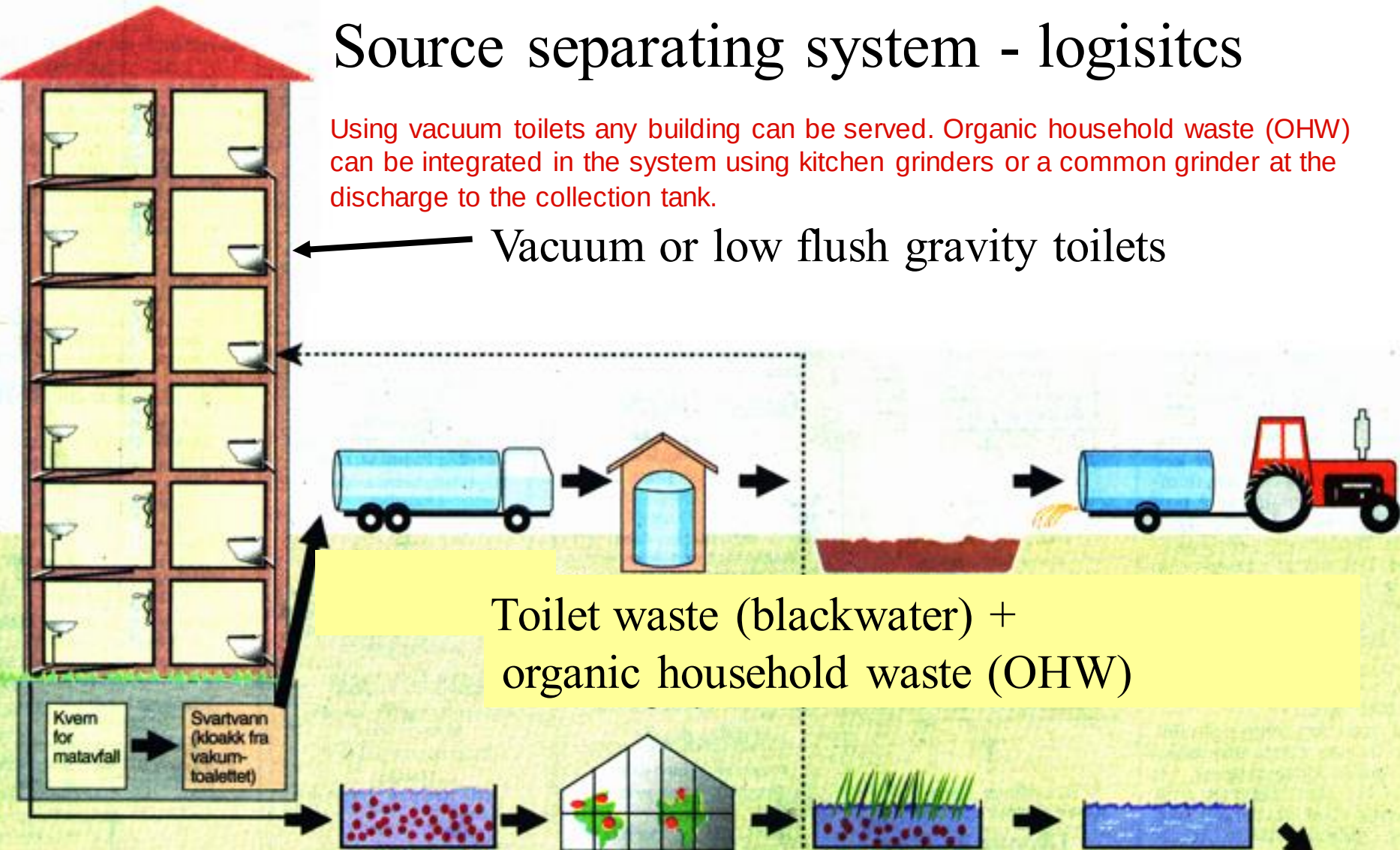
Photos: P.D. Jenssen

Source separating system - logistics

Using vacuum toilets any building can be served. Organic household waste (OHW) can be integrated in the system using kitchen grinders or a common grinder at the discharge to the collection tank.

Vacuum or low flush gravity toilets

Toilet waste (blackwater) +
organic household waste (OHW)



Liquid composting at Norrtälje Municipality, Sweden

Liquid composting is an option that hygienize and deodorize blackwater. Liquid composting systems were developed at UMB and are now commercially available www.biocontrol.no



Biocontrol AS

Four systems in operation in Norway

More information about liquid composting
see: Jenssen and Skjelhaugen (1994)

www.umb.no

Source separating system - logisitcs

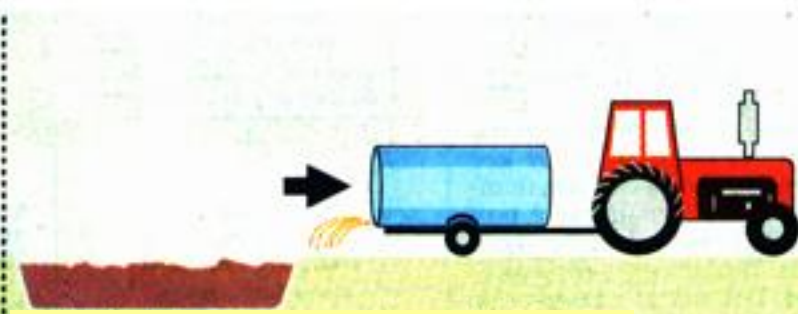
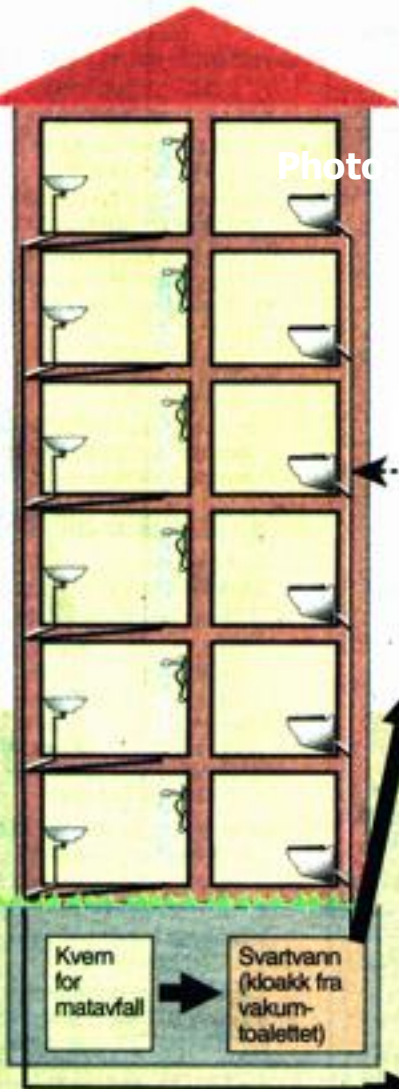
Photo

Anaerobic digestion with (biogas production) is an alternative to liquid composting for treatment of blackwater, especially in warm climate. In a Zero emission building in Havana Cuba blackwater will be used for biogas production see:

<http://www.juventudtecnica.cu/Juventud%20T/2012/ecologia/paginas/edificio%20ahorador.html>

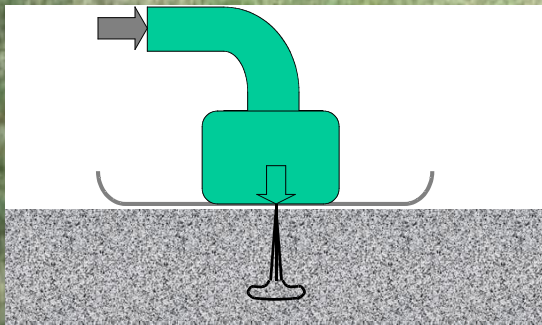
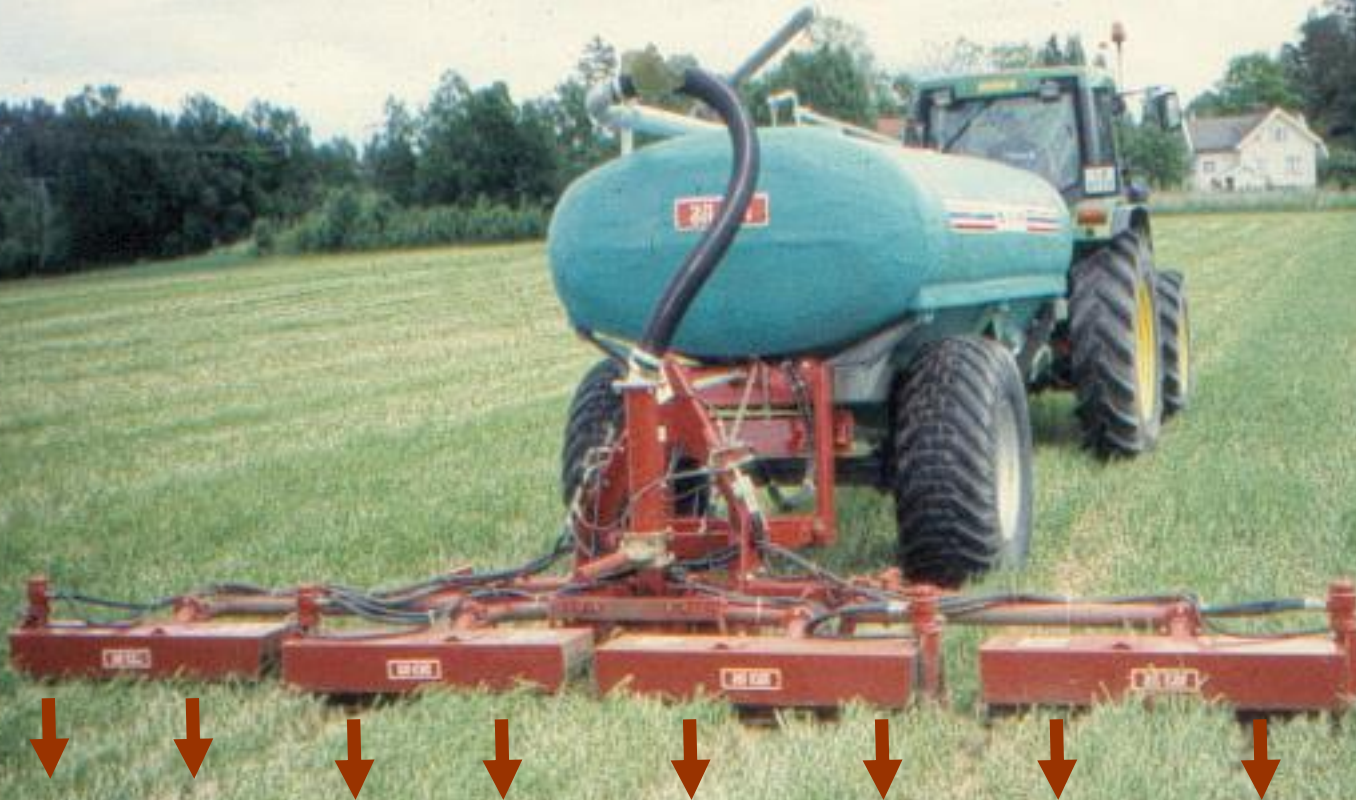
Biogas, CH₄

Blackwater
+OHW



Greywater

Direct Ground Injection (DGI)



DGI (www.moi.no) is a method to inject liquid fertilizer (urine or processed blackwater) without losing too much ammonia. Seeds can be injected with the fertilizer. Yields comparable to mineral fertilizer have been obtained using this technique.

<<

Photo: J. Morken

Source separating system

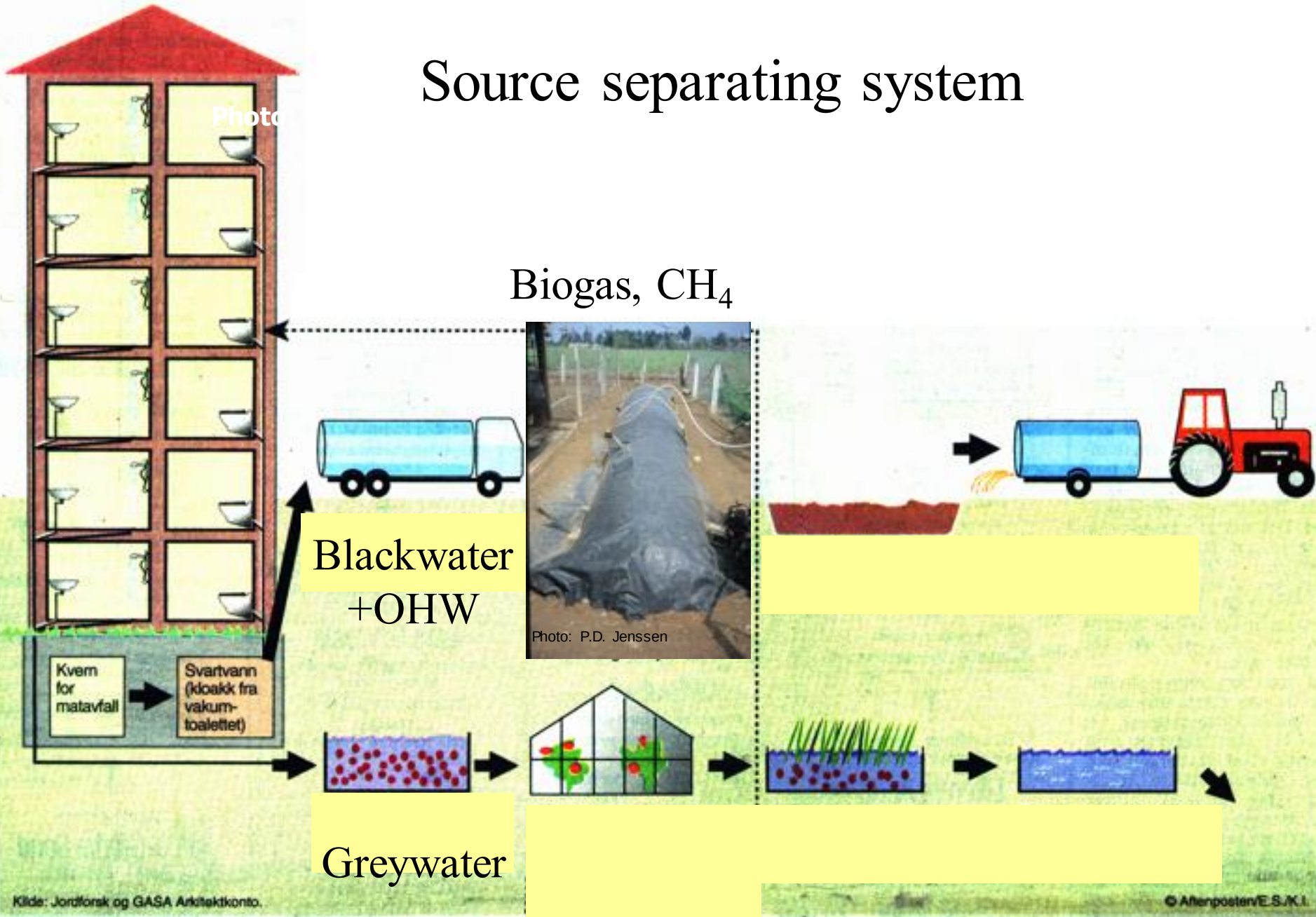
Photo

Biogas, CH₄

Blackwater
+OHW

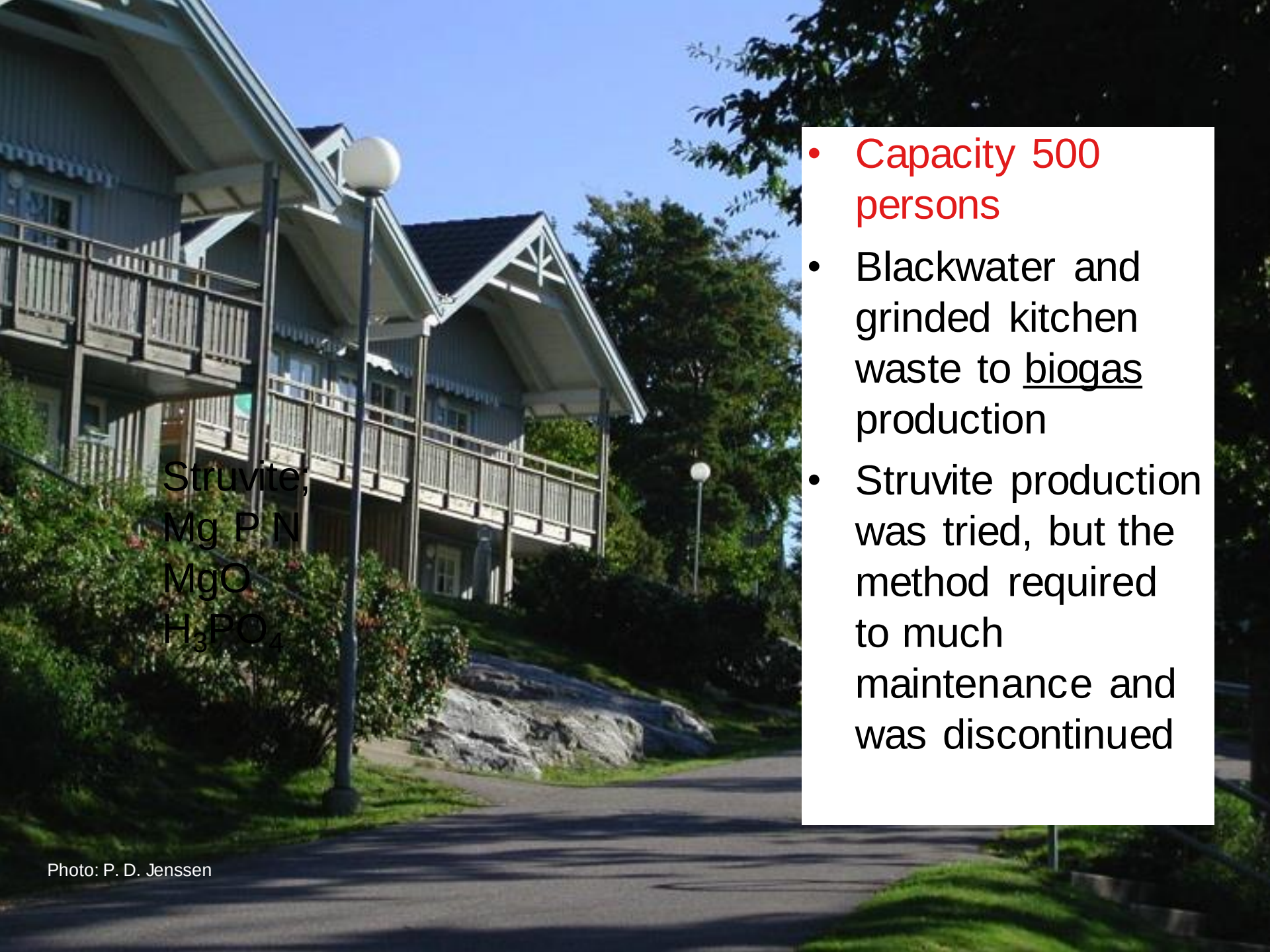
Photo: P.D. Jenssen

Greywater



Volvo's Conference Center - Bokenäs

At Volvo's conference center in Bokenäs they introduced a source separating system using low flush (2/4 liter) toilets as early as in 1991.



Struvite;
Mg P N
MgO
 H_3PO_4

- Capacity 500 persons
- Blackwater and grinded kitchen waste to biogas production
- Struvite production was tried, but the method required too much maintenance and was discontinued

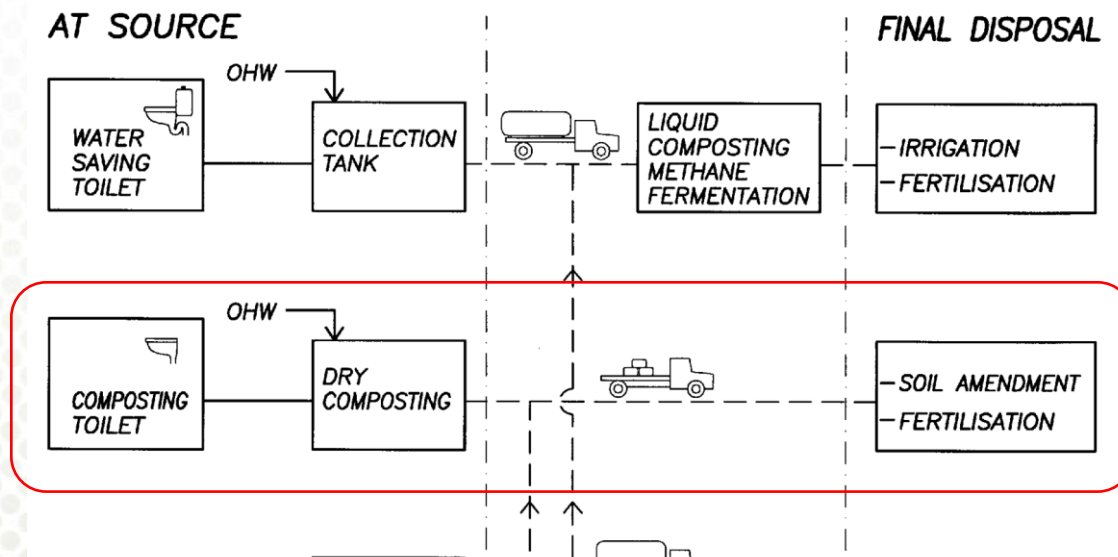


- Capacity 500 persons
- Blackwater and grinded kitchen waste to biogas production
- Natural system for treatment of greywater

Future toilet types (commercially available today)

- Water saving (vacuum&gravity) 0.5 - 1.5 liter/visit
- **Composting /dry sanitation** 0 - 0.1 liter/visit
- Urine diverting 0.1 - 4.0 liter/visit

Toilets and corresponding logistics



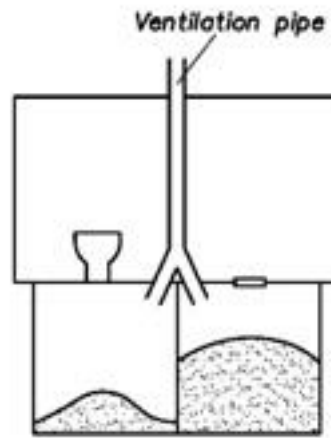
The use of composting toilets in highrise buildings is limited because a straight chute is needed from the toilet to the composting/collection chamber. However, with technical and architectural adaptations composting toilets may be an interesting option in apartment buildings. Since most composting toilets use no or very little water the volumes to be collected is much smaller than for urine diverting or extremely low flush toilets. This simplifies collection and transport, because less capacity is needed.

Handling of faecal matter is something that is not popular among the general public. It may also be connected with increased health risks. It is therefore important to develop systems that are convenient for the user and at the same time reduces the risk of handling. Using removable composting/collection compartments and professional collection may be one option. It is possible to organize collection of compost containers along with collection of other source separated household waste. If the professionals have access to the building or the building is constructed with a separate access for collection of compost toilet waste, handling of toilet waste by the public is eliminated. A secondary composting may be needed to achieve hygienization (Hanssen et al. 2005).

Composting toilets



A



B



C

A: single chamber B. Dual chamber C: Removable compartments

Composting toilets can have many different designs and may also use urine diverting toilet bowls. It is possible and preferable to add carbon rich bulking material to improve the C/N ratio. Organic household waste can be used and some designs (A) have a separate chute where organic household waste can be loaded. The bulking material enhances the structure of the compost and covers up fecal matter so as to avoid flies and odour. It can also absorb liquid that is especially important if the urine is not diverted. Many different organic substances may be used as bulking material; ground up bark, sawdust, leaves etc.

Composting toilets



- Reduces waste to 10 – 30% of original volume
- 50 – 150 liters per person and year

(Del Porto and Steinfeld 2000)

Composting toilet at roadside facility - Sweden

Elected the best roadside facility in Sweden 2003

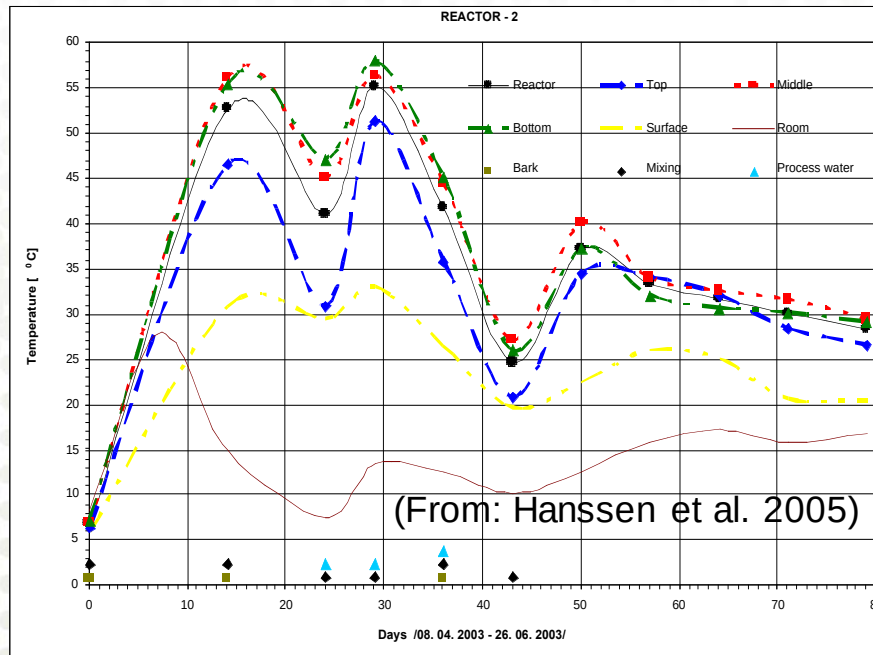


Composting toilet at roadside facility - Sweden



*Clean odourless
toilets*

Dry sanitation - hygiene



- International research show that dry sanitation may give an equal or higher reduction of pathogens and a high reduction in risk of exposure.

(Stenström 2002)

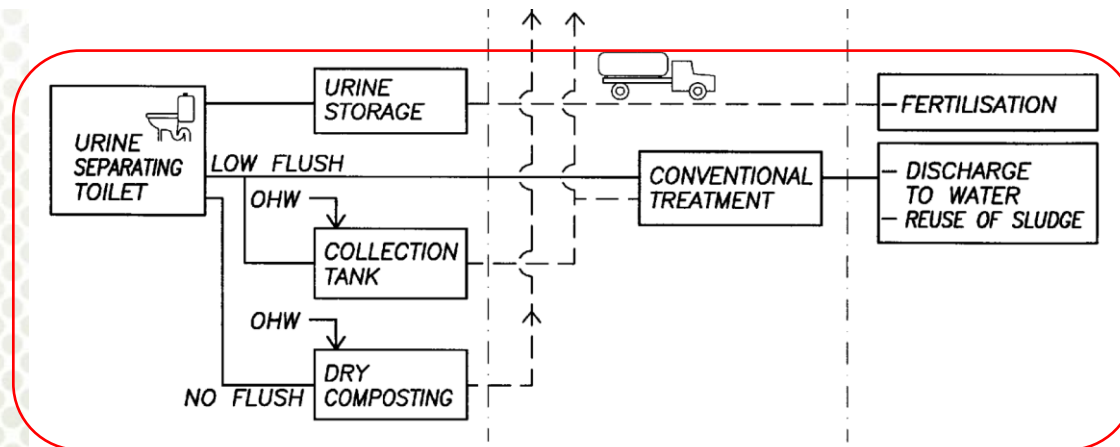


Toilets and corresponding logistics

The use of the «future toilet types» changes the logistics of wastewater handling

Urine diverting toilets come in two editions- single flush or dual flush. If a dual flush urine diverting toilet is used the faecal fraction may either be collected or discharged with the greywater. The combined greywater and faecal matter may either be discharged to a secondary collecting sewer or treated on site. However, if the faecal fraction is added to the greywater the treatment requirements increase due to larger loads of nutrients, organic matter and pathogens especially.

When using a single flush urine diverting toilet the faecal fraction is collected dry. This is normally accommodated by a small removable chamber or bucket or in some models a larger collection chamber. Since the urine is not present the collected faecal matter has much less odour than the combined urine/faecal mixture in e.g. a composting toilet. The experience with the present single flush urine diverting toilet systems is that the faecal fraction is to dry or dessicate when stored under the toilet so that a composting process does not start. In order to achieve composting the faecal matter should be removed from the collection point under the toilet and then composted.



OHW = ORGANIC HOUSEHOLD WASTE

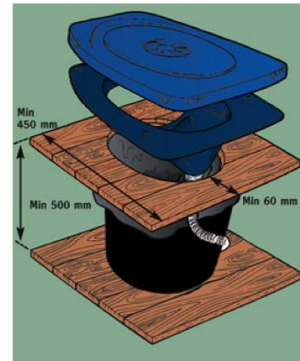
Urine diverting toilets



(a)



(b)



(c)



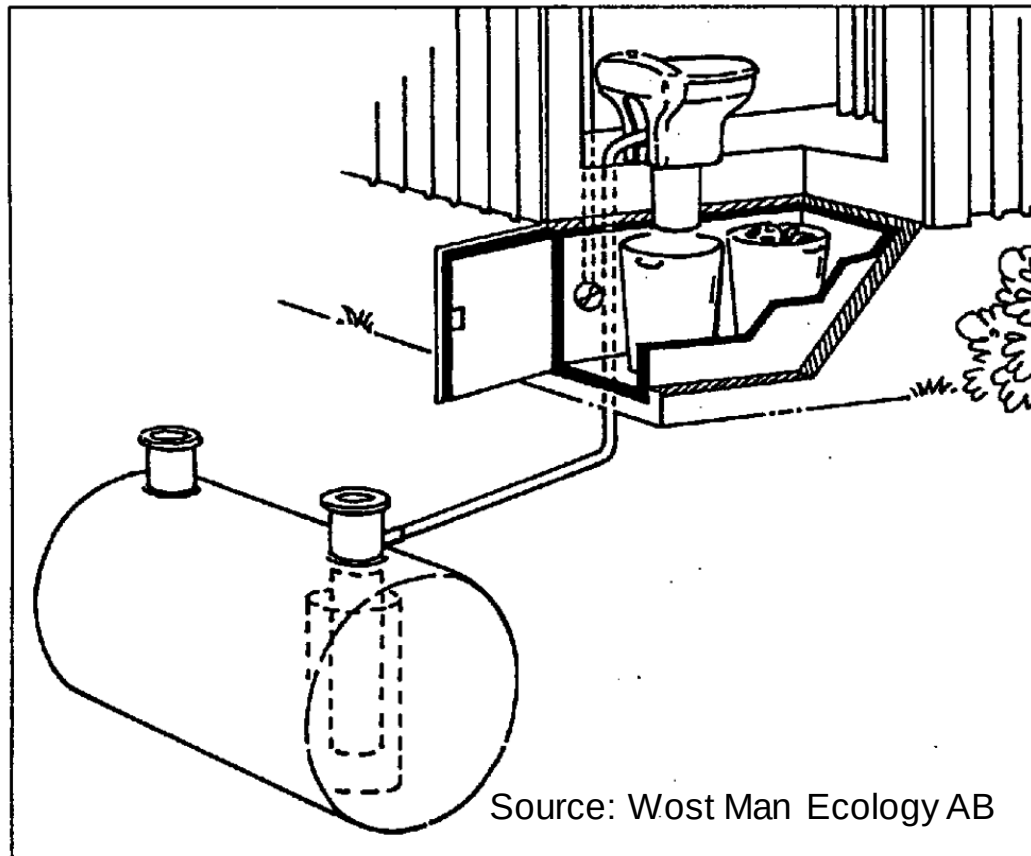
(d)

Dual flush: a and b

Single flush: c and d

Urine diverting toilets

Single flush system



Urine diverting toilets

Single flush and dry composting of fecal matter at Tingvall conference center Sweden



Photo: P.D. Jenssen



Urine diverting toilets

Single flush and dry composting of fecal matter at Tingvall conference center Sweden

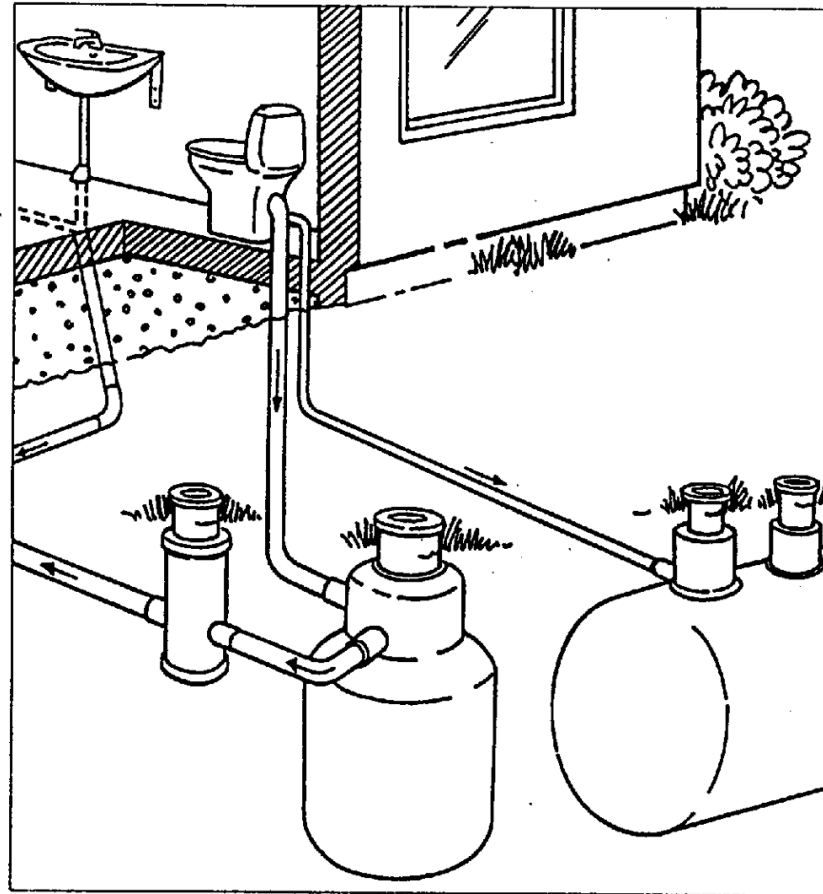


Photo: P.D. Jenssen



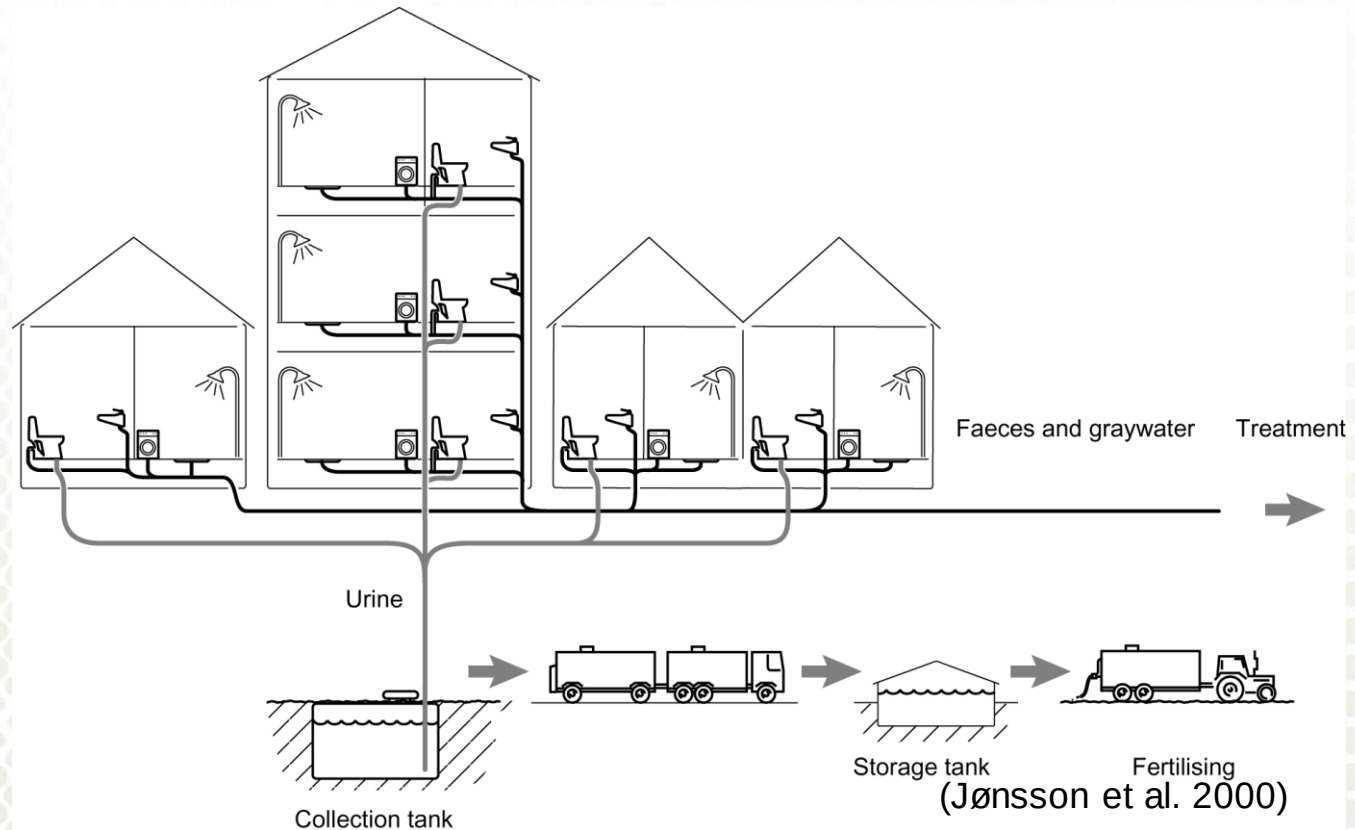
Urine diverting toilets

Dual flush system



Source: Wost Man Ecology AB

Urine diverting toilets – dual flush system



- Urine flushed with 0.1 – 1,6 liters
- Faeces - flushed with 2 - 4 liters

Waterless urinals

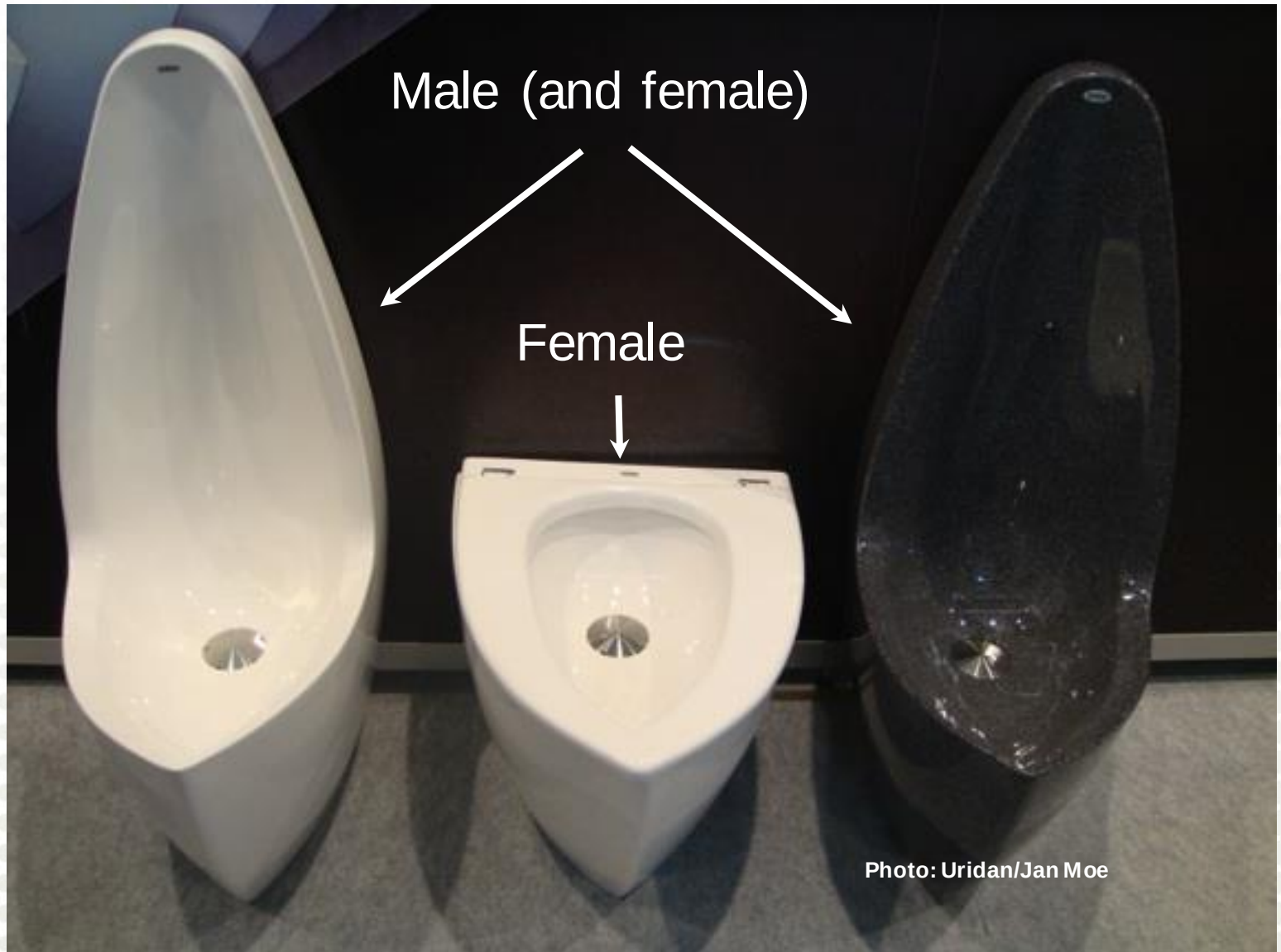
In waterless urinals urine is collected without the use of water. Provided the urinals are cleaned once per day there is no smell from these urinals.



Kastrup airport
Copenhagen

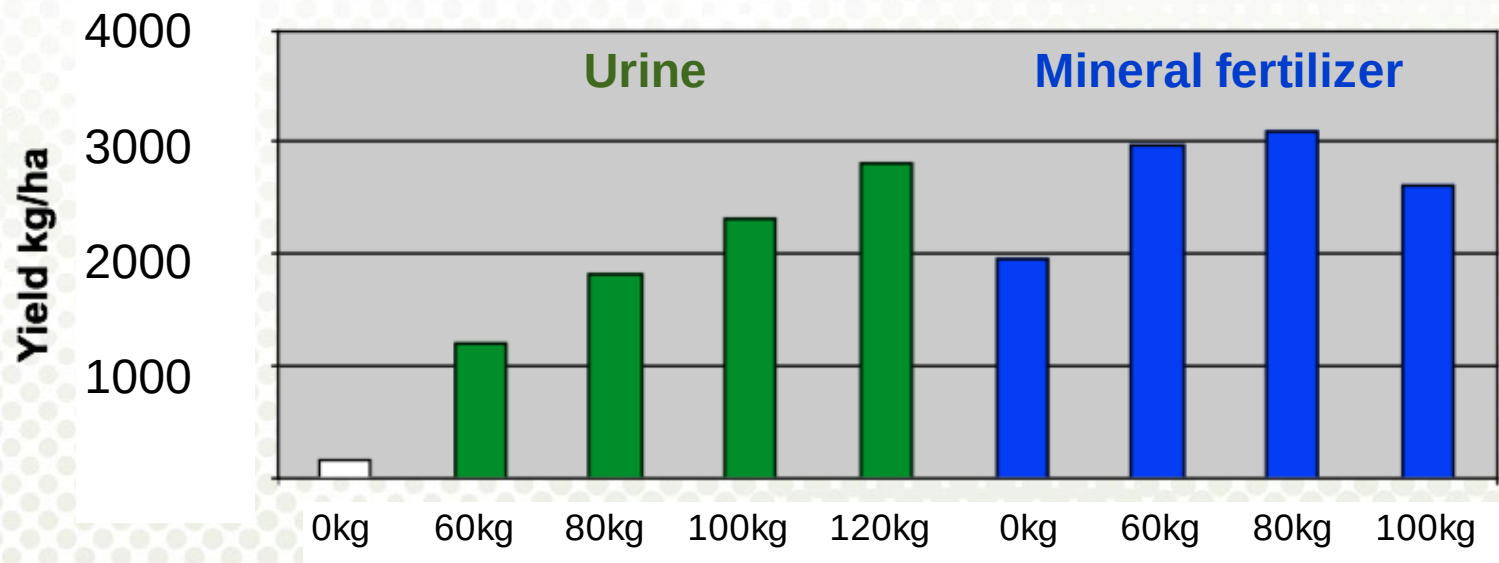
Photo: P.D. Jenssen

Waterless urinals - Female and male



Yield - urine vs. mineral fertilizer

Urine is a good fertilizer and gives yields comparable to mineral fertilizer. The graph below is from an experiment in Norway.



(Cottis 2000)

Features of diverted urine in Sweden

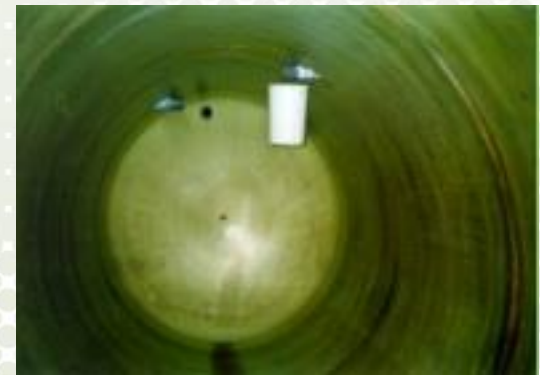


Urine is essentially sterile in healthy persons, but is often contaminated in the toilet or contain pathogens if people are sick. Urine has a self hygienizing effect due to the ammonia content. Ammonia is toxic to many organisms and when the urea in urine is converted to ammonia the pH will increase from about 6 to 9. This high pH also helps to hygienize

Storing of urine

General rule:

6 months to achieve hygienization



Both pillow tanks and tanks of harder material as polyester can be used for storing of urine

Photo: Eco San Res

Sampling and storage of urine



Sampling was performed from different storage tanks in Sweden.



Collection tank for urine at an housing area

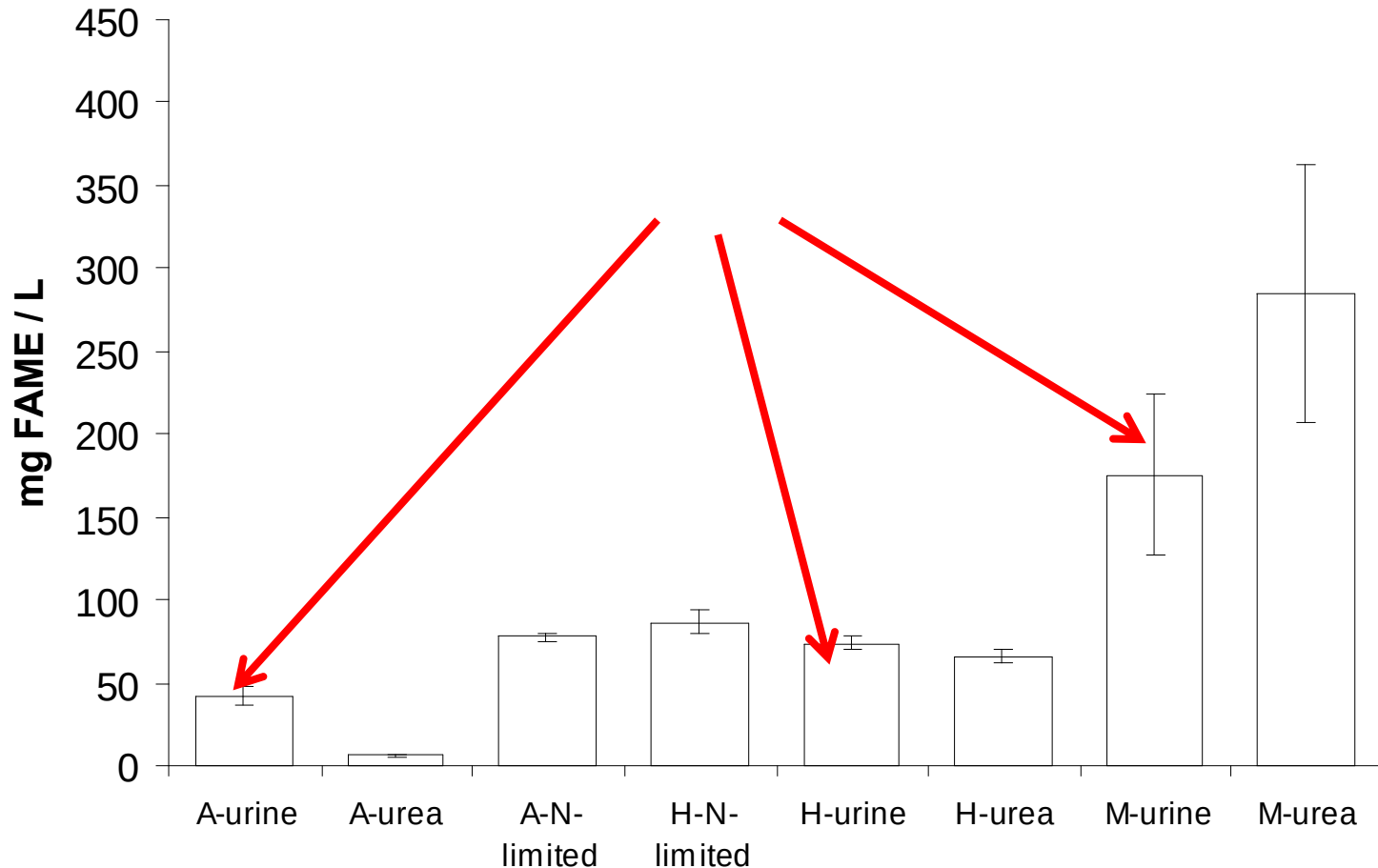


Storage tank for urine at an agricultural area

Biodiesel from algae grown in urine



Urine feeding algae for biodiesel production



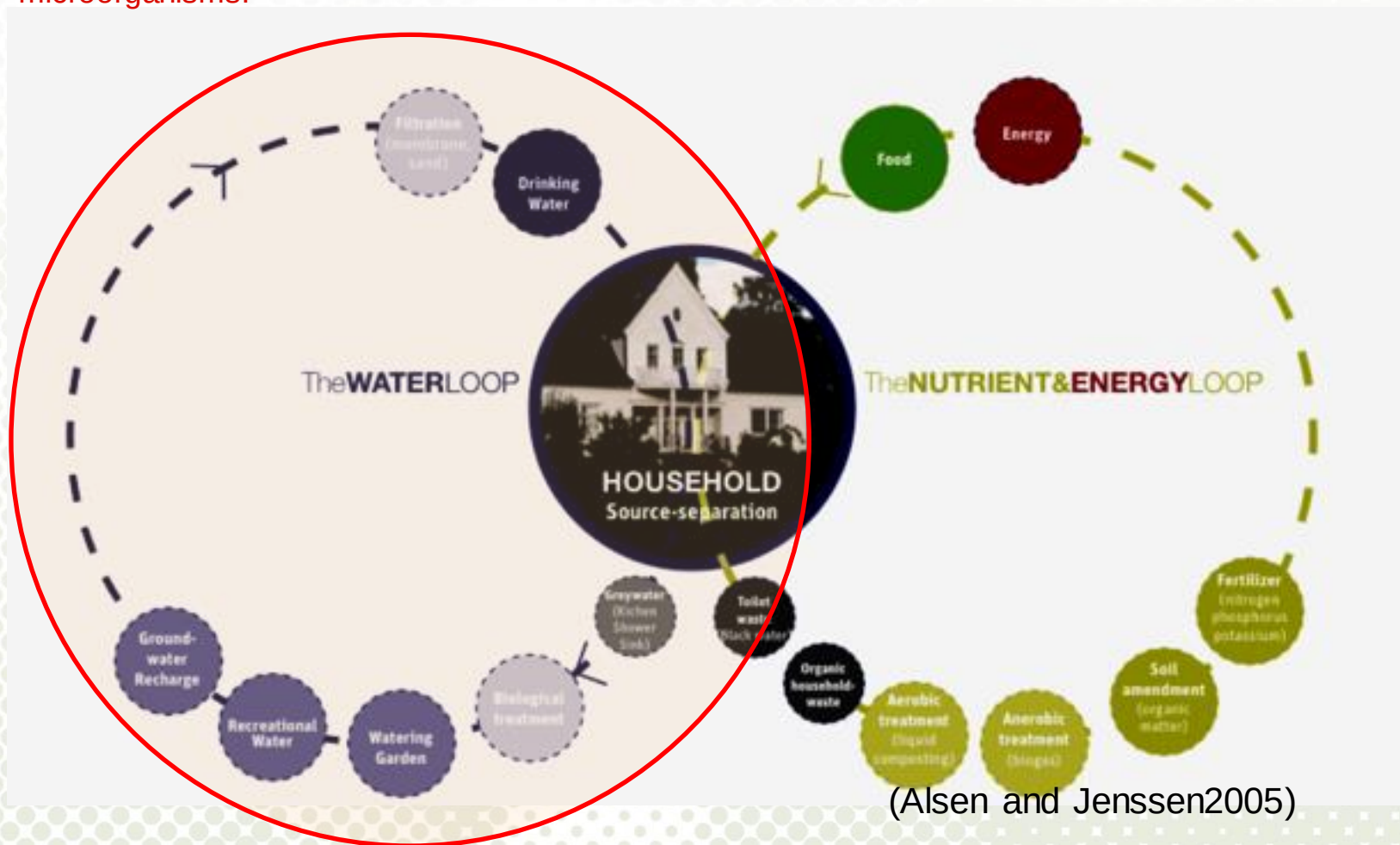
The production of biodiesel from algae was tried with success in the MSc thesis of Sondre Eikås (Eikås 2007).

Sustainable sanitation with recycling of nutrients



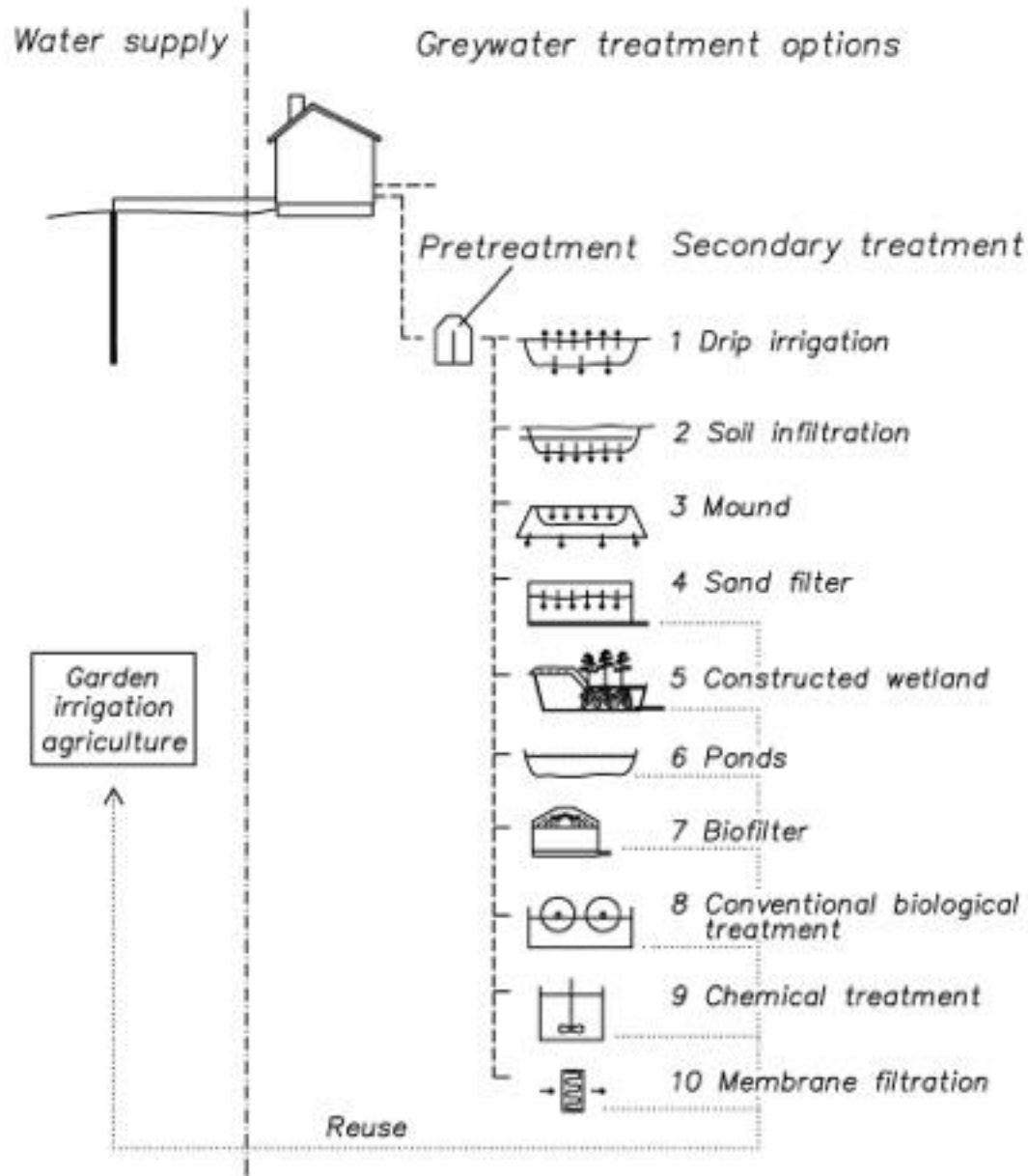
Source separation of wastewater - greywater treatment

Due to the high amount of nutrients (80 - 90%) and organic matter in the excreta fraction treatment of greywater need not focus much on nutrient removal. However, greywater do contain bacteria and depending on final discharge or use may need treatment that reduces potentially harmful microorganisms.



(Alsen and Jenssen 2005)

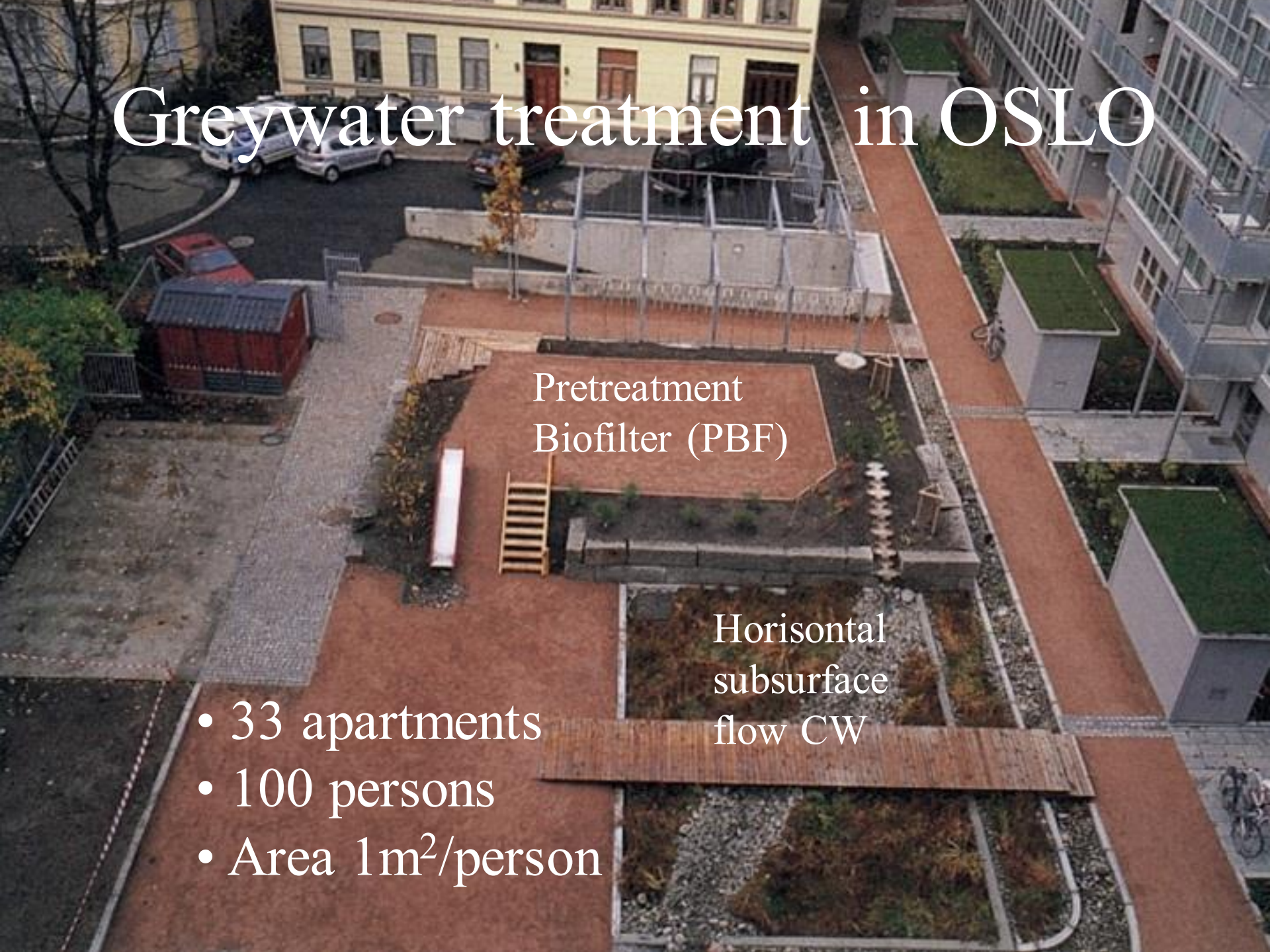
Greywater treatment options



Onsite treatment systems developed for treatment of combined wastewater (including WC) can also be used for greywater treatment. In the figure a number of potential options are shown.

Natural systems as soil infiltration, constructed wetlands and ponds have small energy cost and do not use chemicals. These systems can be integrated as part of a park or natural environment. When recycling of nutrients is not the main issue, as it is with treatment of greywater, natural systems are intuitively sustainable. However, most natural systems require larger areas than the conventional and more technical systems. In an urban setting area may be a limiting factor.

Greywater treatment in OSLO

An aerial photograph of a rooftop greywater treatment system in Oslo. The system is integrated into a green roof with various plants and a red brick path. A yellow building is visible in the background, and a modern glass-fronted building is on the right. The treatment system includes a pretreatment biofilter (PBF) and a horizontal subsurface flow constructed wetland (CW).

Pretreatment
Biofilter (PBF)

Horizontal
subsurface
flow CW

- 33 apartments
- 100 persons
- Area 1m²/person



Greywater treatment at Klosterenga Oslo

Effluent values:

Fecal coliforms:	<10
Total-N:	2,5 mg/l
Total-P:	0,02 mg/l



The effluent quality from the greywater treatment park at Klosterenga allows discharge to open waterways, use in irrigation for groundwater recharge, or could with some additional treatment (e.g. membrane filtration) be suitable as potable water.

Recommendation

If a new sewer system needs to be developed consider to leapfrog the conventional centralized collection and treatment and go straight to modern sanitation based on the source separation



Literature and further reading



Jenssen, P.,D., Grotorex, J. and Warner, W.S., 2004. [Sustainable wastewater management in urban areas](#). In K. Kayser (ed.) "Konzeptionen Dezentralisierter Abwasserreinigung und Stoffstrommanagement" (concepts of de-centralized wastewater treatment and resource management). Universität Hannover Weiterbildendes Studium Bauingenieurwesen "Wasser und Umwelt", 51.p

Rosemarin, A. (2010). [Bridging the Disconnect Between Dwindling Global Phosphorus Reserves, Agricultural and Sanitation Practices and Eutrophication](#). EAWAG Seminar, Dübendorf Switzerland, 28 May.

Refsgaard, K., Halberg, N. & Kristensen, E.S. (1998). [Energy utilization in crop and dairy production in organic and conventional livestock production systems](#). Agricultural Systems 57(4).

JENSSEN, P.D. and A. VATN 1991a. "Ecologically sound wastewater treatment: Concepts and implementation." In: C. Etnier and B. Guterstam (eds.) Ecological engineering for wastewater treatment. Proc., Int. conf. Stensund, Bokskogen, Sweden.

Jenssen, P.D. and O.J. Skjelhaugen. 1994. Local ecological solutions for wastewater and organic waste treatment - a total concept for optimum reclamation and recycling. Proc. Seventh International Symposium on Individual and Small Community Sewage systems, Atlanta, ASAE 18-94, pp. 379-387.

Eikås, S. 2007. Biodiesel from microalgae -Enhanced sustainability of biodiesel production by cultivating microalgae with urine as fertiliser and CO2 addition from power plant emissions. MSc thesis, Department of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences. 36p.

Jenssen, P. D. and L. Vråle. 2004. [Greywater treatment in combined biofilter/constructed wetlands in cold climate](#) In: C. Werner et al. (eds.). Ecosan – closing the loop. Proc. 2nd int. symp. ecological sanitation, Lübeck Apr. 7-11. 2003, GTZ, Germany, pp:875-881.

Jenssen, P.D. 2005. [Decentralized urban greywater treatment at Klosterenga Oslo](#). In: H. v. Bohemen (ed.) Ecological engineering-Bridging between ecology and civil engineering, Aeneas Technical Publishers, The Netherlands, pp 84-86.

Jenssen, P.D. 2002. ["Design and performance of ecological sanitation systems in Norway"](#), Paper at The First International Conference on Ecological Sanitation, Nanning, China.

Stenstrøm T.A., 2002. [Reduction efficiency of index pathobgens in dry sanitation compared with traditional and alternative wastewater treatment systems](#). Proc. The First International Conference on Ecological Sanitation, Nanning, China. EcoSanRes. Stockholm.

Hanssen, J.F., A. Paruch and P.D. Jenssen 2005. [Composting human waste from waterless toilets](#). Presentation at the 3rd. International Conference on Ecological Sanitation, Durban May 24. 2005. ppt presentation.

Jenssen, P.D. 2004. [A complete recycling \(ecosan\) system at student dormitories in Norway](#). In: H. v. Bohemen (ed.) Ecological engineering-Bridging between ecology and civil engineering, Aeneas Technical Publishers, The Netherlands, pp 81-83.