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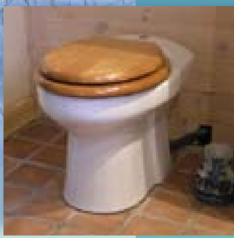
Urine Diverting Toilets in Climates with Cold Winters

Technical considerations and the reuse of nutrients with a focus on legal and hygienic aspects



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More about WECF
Women in Europe for a Common Future is a network of organisations and individuals working for sustainable development, protection of human health and environment and poverty reduction. Our international network consists of members and partners in Western and Eastern Europe, the Caucasus and Central Asia.

WECF supports partners in 12 countries with demonstrations of dry urine diverting toilets for private and public (school) use, in:

- Afghanistan
- Armenia
- Belarus
- Bulgaria
- Georgia
- Kazakhstan
- Kyrgyzstan
- Moldova
- Romania
- Tajikistan
- Ukraine
- Uzbekistan

Contents

1 | Summary

Background and legal aspects

Ecological sanitation, and the most frequent application, dry urine diverting toilets with reuse of urine and faeces in crop production, is growing globally. The millennium development goals have targeted sanitation. There is a need for knowledge on aspects that are related to climates where large temperature differences between summer and winter, and winter temperatures below freezing, are issues. Some of these aspects are the sanitisation of faeces and urine, storage aspects, technical aspects related to freezing of urine, odour, and the reuse of the end products. After the publication of new WHO guideline for the safe use of wastewater, excreta and greywater in agriculture (WHO, 2006), WECF has taken initiative to compile a report on of dry urine diversion in areas with long winters with temperatures below zero.

Dry urine diversion is one way to implement ecological sanitation, or sustainable sanitation. Both terms are used for a sanitation system that is designed for minimal negative consequences on the environment, while being economically and socially viable. According to Bracken & Kvarnström (2005), a sanitation system should consider the users of all parts of the system, along with the collection, transport, and treatment of human excreta, grey water, solid waste, industrial wastewater, storm water, and the management of the resulting end products. This definition recognises sanitation as being multi-facetted, and includes the social aspect of sanitation, the economic and logistical side, as well as resource management.

A urine diverting toilet has two outlets and two collection systems; one for urine and one for the faeces, in order to keep these excreta fractions separate. Other than that, the system has mainly conventional technical construction material/devices, even if they are used in completely or partly new ways.

Urine and faeces are collected in separate containers, stored or treated, and finally used in crop production. Grey water is treated separately, and this is not in the scope of the report.

Ecological sanitation where sanitised human excreta are reused in agriculture is a concept that often falls outside of the existing regulatory framework. Two major aspects related to sanitation in general are public health and environmental protection. However, in the implementation of ecological sanitation there is also a need to focus on agricultural regulation since the objective is agricultural use of human excreta. The often weak legal and institutional framework in many countries makes it difficult to implement and scale up sanitation solutions such as ecological sanitation.

The terminology of ecological sanitation has not yet permeated EU legislation. An example of this is that there is a directive for use of sewage sludge in agriculture, but no regulation on the use of source diverted urine and faeces. A conclusion is that dry urine diversion with agricultural reuse of the urine and faeces does not clash with the EU directives.

WHO has recently published a new set of guidelines for the reuse of excreta in agriculture (WHO 2006) [1]

The guidelines are not legally binding; however, based on the latest scientific knowledge, they represent the most current recommendations on the reuse of excreta. Volume four specifically deals with the reuse of source separated excreta and grey water. The volume gives information on assessment and management of risks associated with microbial hazards. The guidelines set down requirements to promote the reuse of excreta including minimum procedures (see box 2 and tables 1 and 2), and health-based targets.

Aspects of cold winters

Important characteristics for the design of technical systems in areas with cold winters are freezing of urine, ventilation and microbial growth rates. There are also often great differences between winter and summer climate conditions implying that systems should be analysed from a dual perspective. The growth season is short but intense, which is essential knowledge for the design of systems aiming at a recycling of nutrients. In general a long storage period is needed in addition to a period during which nutrients are assimilated by plants. Thus, a chain consisting of collection of urine and faeces – storage and treatment – distribution and application must be established.

During storage the urine should be contained in a sealed tank or container. The urine should preferably not be diluted. The general recommendations for urine are

- Direct use after collection or a short storage time is acceptable on the single household level. For larger systems, storage should be arranged according to storage intervals presented above.
- An interval of at least one month should be observed between fertilisation and harvest,
- Additional stricter recommendations may apply on a local level, in the case of frequent fecal cross-contamination. The recommendations for storage times are directly linked to agricultural use and choice of crop, see box 2 and tables 1 and 2.

Additional practices to minimise the risks include the following:

- When handling the urine precautions related to the handling of potentially infectious material should be taken. These precautions include wearing gloves and thorough hand washing.
- The urine should be applied using close-to-the-ground fertilising techniques avoiding aerosol formation.
- The urine should be incorporated into the soil. This could in practise be done

[1] http://www.who.int/water_sanitation_health/wastewater/gsuweg4/en/index.html

mechanically or by subsequent applying irrigation with water.

There is currently no recommendation of storage intervals for urine that has been frozen. A conclusion regarding temperature aspects on sanitisation of urine is that not enough is known on the fate of pathogens and indicator bacteria in urine solutions that are subject to temperatures below zero. A general opinion is that urine is less risky to handle than faeces, and that the storage treatment of urine according to guidelines generally functions well. A larger concern has been the safe treatment of faeces, see below.

There are research project going on to investigate the environmental effect of pharmaceuticals in urine. Concerning both hormones and pharmaceutical substances, it is better to recycle urine and faeces to arable land than to flush them into recipient waters.

Out of the two fractions it is faeces that pose the greater hygienic risk. Faeces contain large amounts of microorganisms, harmful and unharmful. The sanitisation of faeces has to be designed with care for large scale systems so that disease is not spread as a result of introduction of dry urine diverting toilet systems. The WHO Guidelines on excreta use in agriculture (WHO 2006) give recommendations on treatment of the faecal fraction.

Technical aspects on the urine diversion system are given in the report. Components such as toilet model, piping, storage tanks, ventilation and odour control are covered. Reuse of the urine and faeces is explained, and practical instructions to implement the system are given in the text. Examples from pilot projects in Sweden, Finland, Norway and China are presented, showing different aspects such as urine reuse, ventilation school sanitation, two-storey systems and private home installations.

Knowledge gaps and identified research needs

Well-planned dry urine diversion systems with agricultural reuse of urine and faeces are not mainstream sanitation in the world today. Most people in the world live with dry sanitation, however, the systems are seldom adapted to efficient reuse of the nutrients in excreta. There are some definite areas where there is a need of systematic research and development (R&D). Some of these, especially related to cold winter climate aspects, are specified in the following text. Monitoring and evaluation of existing dry urine diversion projects is a cost-efficient way of generating knowledge. Dissemination of results, regardless of if they are positive or negative, from existing pilots is vital. The establishment of new pilot projects will also contribute to the bank of knowledge.

Conclusions

The major conclusion is that dry urine diversion, including reuse of urine and faeces, is one component of a sustainable sanitation system. Dry urine diversion is a way to fulfil many of the Millennium Development Goals, not only the goal related to sanitation.

- There are functioning examples of dry urine diversion in regions in the world with cold winter climates. The examples presented in the report show that it is possible to arrange agricultural reuse of urine and faeces in large or small scale crop production.
- It is possible to retrofit buildings with dry sanitation, i.e. exchanging a flush toilet for a dry toilet. It is also possible to implement dry urine diversion in many-storey buildings as well as in urban settings provided that collection of the urine and faeces is arranged.
- The fact that there are only short periods during the year when urine can be used as a fertiliser place demands on a storage system for the urine. There are a few alternatives; one of the most economic may be to arrange storage on a farm, in covered storage containers previously used for animal urine.
- The technical solutions for dry urine diversion are not complicated. Most applications can be solved with existing materials and technologies. The concept demands to some extent new thinking, for example regarding ventilation of toilet chambers etc, but no advanced technology is needed, only basic knowledge of ventilation systems.
- There are still development needs and knowledge gaps. Some of these are related to temperate and cold climates, such as the fate of microorganisms in urine at temperatures below freezing. However, this should not be considered a major constraint to the development of dry urine diversion, since the risk is relatively low, and can be handled through combination with other hygienic activities.

2 | Dry Urine Diversion

Background

Ecological sanitation, and the most frequent application, dry urine diverting toilets with reuse of urine and faeces in crop production, is growing globally. The millennium development goals have targeted sanitation, and many programmes are running in developing countries. Most of the programmes are situated in countries with warmer climates in the southern hemisphere, and the knowledge and experiences gathered are generated in these climates. However, recent development is seeing a rise in activities in the northern hemisphere, with projects in Finland, Mongolia, China, Ukraine, Armenia, Uzbekistan, Bulgaria among others. There is a need for knowledge on aspects that are related to climates where large temperature differences between summer and winter, and winter temperatures below freezing, are issues. Some of these aspects are the sanitisation of faeces and urine, storage aspects, technical aspects related to freezing of urine, odour, and the reuse of the end products.

After the publication of new WHO guideline for the safe use of wastewater, excreta and greywater in agriculture, 2006 (WHO, 2006), WECF has taken initiative to compile a report on of dry urine diverting toilets in areas with long winters with temperatures below zero.

Objective

This report contains information on aspects of dry urine diverting toilet systems related to temperate continental climates where large temperature differences between summer and winter are an issue, with focus on the hygienic aspects of reuse of nutrients. Grey water treatment and reuse is not in the scope of the report even if it is intimately related to the urine and faeces system.

Definitions

The scope of this report is dry urine diversion in temperate and cold climates.

Climate regions in the world as used by the FAO, have been defined by Koeppens[2] This report highlights aspects on dry urine diversion related to freezing temperatures, as well as the changing seasons affecting the reuse of urine and faeces.

Dry urine diversion is one way to implement ecological sanitation, or sustainable sanitation. Both terms are used for a sanitation system that is designed for minimal negative consequences on the environment, while being economically and socially viable. Criteria have been set up for sustainable sanitation systems (Bracken & Kvarnström 2005). According to the authors, a sanitation system that is sustainable protects and promotes human health, does not contribute to environmental degradation or depletion of the resource base, is technically and institutionally appropriate, economically viable and socially acceptable. In westernised countries, waterborne sanitation is considered mainstream. However, in many situations this is not a sustainable practice. Some reasons may be costs, lack of water, as well as difficulties in reusing the excreta as fertilisers. In many cases, dry urine diversion rises as a sustainable option and this report seeks to show experiences and strategies for implementation.

It is essential to define a sanitation system, since many have made the mistake of only considering the toilet itself. According to Bracken & Kvarnström (2005), a sanitation system should consider the users of all parts of the system, along with the collection, transport, and treatment of human excreta, grey water, solid waste, industrial wastewater, storm water, and the management of the resulting end products. This definition recognises sanitation as being multi-facetted, and includes the social aspect of sanitation, the economic and logistical side, as well as resource management.

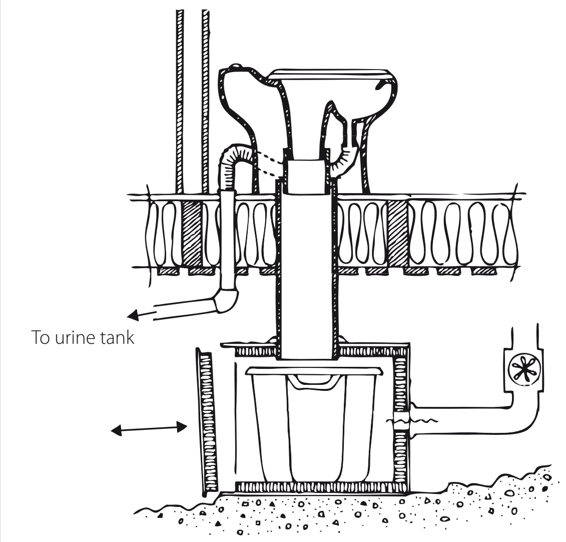
What is a dry urine diverting toilet system?

A urine diverting toilet has two outlets and two collection systems; one for urine and one for the faeces, in order to keep these excreta fractions separate. Other than that, the system has mainly conventional technical construction material/devices, even if they are used in completely or partly new ways.

The urine diverting toilets can be either water-flushed or dry, exists in pedestal/risers as well as squatter models. Research and experience show that the systems function in different settings, provided that the systems are properly installed, operated and maintained.

Urine and faeces are collected in separate containers, stored or treated, and finally used in crop production. Grey water is treated separately, and this is not in the

Figure 1: Dry urine diversion components. By Wost Man Ecology



[2] http://www.fao.org/waicent/faoinfo/sustdev/Eldirect/climate/Elsp0054.htm

Figure 2:
A urine diverting toilet seat.
Photo by WECF

Figure 3:
A urine diverting squatting toilet.
Photo by WECF

scope of the report as mentioned above. Urine diversion in itself shall be seen as a complementary technology since the other wastewater flows (faeces, grey water and storm water) also need to be handled and treated.

Development trends

The global sanitation crisis has been recognised by the international community with the setting of a concrete target in the Millennium Development Goals (MDGs) to halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015[3]. However, the Joint Monitoring Programme has found that if the current rate of provision does not improve dramatically, the sanitation target will be missed by over a half billion people, and 2.4 billion people world-wide will still be without access in 2015 (WHO and UNICEF, 2004). In 2006, WHO issued the latest version of guidelines on the safe reuse of source separated human excreta (WHO, 2006).

The UN Task Force 7 on Water and Sanitation has shown that meeting the water and sanitation target will influence, positively, the meeting of all Millennium Development Goals. Water supply and sanitation services were recognised as being critical to sustainable development – contributing to increased food security, supporting and environmental protection, empowering women, and reducing productivity losses due to morbidity and malnutrition.

Even if the challenges are greater in many regions of the world, like Sub-Sahara Africa or East and Southern Asia, there is still a substantial amount of toilets that need to be built in temperate/cold climate regions. A preliminary calculation shows that 1267 toilets need to be built every day in the Eurasian region in order to meet the millennium goal challenge. Thus, countries in areas with cold winters also have an MDG challenge to meet when it comes to water and sanitation.

[3] http://www.who.int/water_sanitation_health/2005advocguide/en/index2.html

3 | EU directives relating to dry urine diversion where urine and faeces are reused in agriculture

The terminology of ecological sanitation has not yet permeated the EU directive texts. An example of this is that there is a directive for use of sewage sludge in agriculture, but no regulation on the use of source diverted urine and faeces. The text below summarises directives relevant to the topic of this report to be implemented by the member states. The source of the information is a website where EU legislation is compiled[4].

A conclusion is that dry urine diversion with agricultural reuse of the urine and faeces does not clash with the EU directives mentioned below. There are aspects to consider, such as timing of fertiliser application, but no direct conflicts. Hopefully, this system may be integrated into EU policy work so that the practice becomes mainstreamed instead of an activity on the side.

Framework Directive in the field of water policy

This directive is also called "The water directive", and the implementation is ongoing in member states. The objective is to establish the protection of inland surface waters, transitional waters, coastal waters and groundwater, in order to prevent and reduce pollution, promote sustainable water use, protect the aquatic environment, improve the status of aquatic ecosystems and mitigate the effects of floods and droughts. The proper name of the directive is ***Directive 2000/60/EC*** of the European Parliament and of the Council of 23 October 2000, establishing a framework for Community action in the field of water policy [Official Journal L 327 of 22.12.2001].

Under this directive, Member States have to identify all the river basins lying within their national territory and assign them to individual river basin districts. Member States must complete an analysis of the characteristics of each river basin district, a review of the impact of human activity on the water, an economic analysis of water use and a register of areas requiring special protection.

The measures provided for in the river basin management plan seek to:

- prevent deterioration, enhance and restore bodies of surface water, achieve good chemical and ecological status of such water and reduce pollution from discharges and emissions of hazardous substances.
- protect, enhance and restore all bodies of groundwater, prevent the pollution and deterioration of groundwater, and ensure a balance between use and recharge of groundwater;
- preserve protected areas.

Pollution caused by nitrates from agricultural sources

The correct term for this directive is ***Council Directive 91/676/EEC*** of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources. [Official Journal L 375 of 31.12.1991]. The objective is to reduce or prevent water pollution caused or induced by nitrates from agricultural sources. The Member States must identify, on their territory:

- surface waters and groundwater affected or which could be affected by pollution, in accordance with the procedure and criteria set out in the Directive;
- vulnerable zones which contribute to pollution.

The Member States must establish codes of good agricultural practice to be implemented by farmers on a voluntary basis. The Member States must establish and implement action programmes in respect of vulnerable zones. Examples are:

- to limit the spreading on land of any fertiliser containing nitrogen;
- to set limits for the spreading of livestock effluent.

The Member States must monitor water quality, applying standardised reference methods to measure the nitrogen compound content

Urban waste water treatment

This directive concerns the collection, treatment and discharge of urban waste water and the treatment and discharge of waste water from certain industrial sectors. Its aim is to protect the environment from any adverse effects due to discharge of such waters. The proper name of the directive is ***Council Directive 91/271/EEC*** of 21 May 1991 concerning urban wastewater treatment.

Key terms used in the act

- urban waste water means waste water from residential settlements and services which originates predominantly from the human metabolism and from household activities (domestic waste water) or a mixture of domestic waste water with waste water which is discharged from premises used for trade or industry (industrial waste water) and/or run-off rain water;
- population equivalent (p.e.) is a measure of pollution representing the average organic biodegradable load per person per day.

The Directive establishes points, which Member States must adhere to, for the provision of collecting and treatment systems for urban waste water in communities which meet the criteria laid down in the Directive. The main points are as follows:

- all communities of more than 10000 „population equivalent" (p.e.) which discharge water into sensitive areas must have a proper collection and treatment system;
- all communities of more than 15000 p.e. must have a collection and treatment system which enables them to satisfy the requirements in Annex I;
- all communities of between 2000 and 10000 p.e. which discharge water into sensitive areas, and all communities of between 2000 and 15000 p.e. which do not discharge into such areas must have a collection and treatment system.

[4] http://europa.eu/scadplus/leg/en/s15000.htm

One important point for the development of dry urine diversion is that it is set down that the use of „alternative" methods must ensure at least the same level of environmental protection as the annual mean technique, usually meaning waste water treatment plants.

Use of sewage sludge in agriculture

The European Union regulates use of sewage sludge in agriculture to prevent harmful effects on soil, vegetation, animals and humans. There is no definition of source separated excreta in this directive.. The proper name of the directive is ***Council Directive 86/278/EEC*** of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture.

In using sewage sludge account must be taken of the nutrient needs of the plants without impairing the quality of the soil and of surface and ground water. Sewage sludge may be used in agriculture provided that the Member State concerned regulates its use.

The use of sewage sludge is prohibited if the concentration of one or more heavy metals in the soil exceeds limit values. Sludge must be treated before being used in agriculture but the Member States may authorise the use of untreated sludge if it is injected or worked into the soil.
The use of sludge is prohibited:

- on grassland or forage crops if the grassland is to be grazed or the forage crops to be harvested before a certain period has elapsed (this period, fixed by the Member States, may not be less than three weeks);
- on fruit and vegetable crops during the growing season, with the exception of fruit trees;
- on ground intended for the cultivation of fruit and vegetable crops which are normally in direct contact with the soil and normally eaten raw, for a period of ten months preceding the harvest and during the harvest itself.

Sludge and soil on which it is used must be sampled and analysed. Member States must keep records registering:•
the quantities of sludge produced and the quantities supplied for use in agriculture;

- the composition and properties of the sludge (Micro biological properties are not included);
- the type of treatment carried out;
- the names and addresses of the recipients of the sludge and the places where the sludge is to be used.

Where conditions so demand, Member States may take more stringent measures than those provided for in this Directive.

Organic agriculture

The European Union regulates organic production in the *Council Regulation (EEC) No 2092/91* of 24 June 1991. Fertilisers used in organic production are specified in a list, and human urine and faeces are not on this list. Attempts have been made to include these fertilisers from Swedish officials, with little success. A pilot study has been initiated in Sweden where an organic farmer, presented in an example in the text below, has been permitted to use the urine collected from houses in a village in production of ley and cereals.

4 | Legal aspects

Ecological sanitation where sanitised human excreta are reused in agriculture is a concept that often falls outside of the existing regulatory framework. One reason could be that the concept is interdisciplinary, making it subject to several different sets of regulations. Two major aspects related to sanitation in general are public health and environmental protection. However, in the implementation of ecological sanitation there is also a need to focus on agricultural regulation since the objective is agricultural use of human excreta. The often weak legal and institutional framework in many countries makes it difficult to implement and scale up sanitation solutions such as ecological sanitation (Stoll & Schönewald, 2003). An enabling legislation and regulatory framework do not alone solve the sanitation problem. It has been shown that without the political will the water policies and legislation may not be implemented at all at the local level (Johansson & Kvarnström, 2005). Creating the political will to solve the sanitation problems at all levels in society is a major challenge.

The specific benefits of the closed loop approach should be communicated and promoted in such a way that the advantages of ecological sanitation, compared to other available sanitation systems and approaches as well as to the "business as usual" alternative, become very clear to decision-makers and politicians.

Figure 4: The reuse of sanitised human excreta in agriculture often falls outside of the existing regulatory legal framework Photo by WECF

Box 1:
Proposed Swedish regulations on sanitizing of digestion residues, faeces and urine.

The Swedish Environmental Protection Agency has proposed new legislation for use of wastewater fractions in agriculture (EPA 2002). Adoption of the proposed legislation is planned for 2007/2008. A key concept in the new legislation is to incorporate the term wastewater fractions instead of sewage sludge, enabling a framework for source separated fractions as well as conventional wastewater and sewage sludge. Other aspects are hygiene and sanitisation of wastewater fractions, limit values for metals in wastewater fractions as well as levels applied to the soil.

Box 2:
Guidelines for the safe reuse of urine and faeces in crop production from the WHO.

WHO has recently published a new set of guidelines for the reuse of excreta in agriculture (WHO 2006). The guidelines are not legally binding; however, based on the latest scientific knowledge, they represent the most current recommendations on the reuse of excreta. Volume four specifically deals with the reuse of source separated excreta and grey water. The volume gives information on assessment and management of risks associated with microbial hazards. The guidelines set down requirements to promote the reuse of excreta including minimum procedures (see table 1 and 3), and health-based targets.

5 | Cold temperature aspects

Important characteristics for the design of technical systems in areas with cold winters are freezing of urine, ventilation and microbial growth and reduction rates. There are also often great differences between winter and summer climate conditions implying that systems should be analysed from a dual perspective. The growth season is short but intense, which is essential knowledge for the design of systems aiming at a recycling of nutrients. In general a long storage period is needed in addition to a period during which nutrients are assimilated by plants. Thus, a chain consisting of collection of urine and faeces – storage and treatment – distribution and application must be established. Read more in the sections below.

Freezing of urine

Sludge treatment by freezing and thawing is a robust and cost saving method in cold climate regions (Hellström, 1998).

For urine, the freezing point depends on the concentration of ions. The last part to freeze will be the most concentrated liquid, and according to experience gathered in lab scale, this can occur at temperatures below – 18 °C (Ganrot, personal communication). If the urine has been totally frozen, the part to thaw first will be the part that froze last, generally on the edges of the container. Urine stored in a tank above ground will start to freeze at temperatures below approximately – 5 °C (Ganrot, personal communication). When the urine freezes, it will expand in volume, which should be considered when planning the system. Tanks should not be filled right to the top, and the design and materials chosen should stand the expansion of the urine or alternatively, give room for the expansion.

During slow formation of ice from liquid salt solutions such as urine, the nutrient ions remain long in the liquid phase as ice crystals are formed. This means that if the ice is removed at a certain stage, the remaining urine solution will be more concentrated with regard to nutrients. More than 80 % of both nitrogen and phosphorus can be concentrated in 25% of the initial volume according to a PhD project in Sweden (Ganrot, 2005). This could be achieved by slowly freezing liquid urine or slowly melting a completely frozen amount of urine. There are not yet any known practical applications of this concentration method.

One question regarding the freezing of urine is the fate of ammonium in the urine solution. Potentially, if a tank containing urine freezes and there is air in the tank, increased concentrations of ammonia could form. This highlights the importance of sealed containers for urine. Observations of urine stored in sealed containers, as well as analyses supports this reasoning since the urine sampled before freezing and after contain generally the same amounts of ammonium (Vinnerås, 1998).

A concentrated urine solution will be a hostile environment to pathogens, which could also shorten the demanded time for storage of urine for hygienisation reasons. This has not been studied.

Hygiene and treatment of urine

Urine is sterile in the bladder of a healthy person and almost so when excreted from the body. Small amounts of faecal matter may however be mixed with the urine in the toilet due to the fact that the diversion can never be perfect; there is always a risk of faecal contamination of the urine solution. This is not a problem as long as the storage times for urine presented in WHO guidelines (WHO, 2006) are respected, table 1. Source diverted urine is sanitised through storage of the urine in sealed containers. The high pH in combination with temperature and the concentration of ammonia will effectively kill harmful pathogens that may be present in the urine.

Table 1: Recommended guideline storage times for urine[a] based on estimated pathogen content[b] and recommended crop for larger systems[c] (WHO, 2006).

Storage temperature	Storage time	Possible pathogens in the urine mixture after storage	Recommended crops
4 °C	≥1 month	Viruses, protozoa	Food and fodder crops that are to be processed
4 °C	≥6 months	Viruses	Food crops that are to be processed, fodder crops[d]
20 °C	≥1 month	Viruses	Food crops that are to be processed, fodder crops[d]
20 °C	≥6 months	Probably none	All crops[e]

[a] Urine or urine and water. When diluted it is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1 g/l.
[b] Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognised for causing any of the infections of concern.
[c] A larger system in this case is a system where the urine mixture is used to fertilise crops that will be consumed by individuals other than members of the household from which the urine was collected.
[d] Not grasslands for production of fodder.
[e] For food crops that are consumed raw it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

During storage the urine should be contained in a sealed tank or container. This prevents humans and animals to come in contact with the urine and hinders evaporation of ammonia decreasing the risk of odour and loss of nitrogen. The urine should preferably not be diluted. The general recommendations for urine are

- Direct use after collection or a short storage time is acceptable on the single household level. For larger systems, storage should be arranged according to storage times presented above.
- An interval of at least one month should be observed between fertilisation and harvest for crops eaten raw. If the edible parts eaten raw grow above soil the urine should be incorporated into the ground.
- Additional stricter recommendations may apply on a local level, in the case of frequent fecal cross-contamination. The recommendations for storage times are directly linked to agricultural use and choice of crop see above.

Additional practices to minimise the risks include the following:

- When handling the urine precautions related to the handling of potentially infectious material should be taken. These precautions include wearing gloves and thorough hand washing.
- The urine should be applied using close-to-the-ground fertilising techniques avoiding aerosol formation.
- The urine should be incorporated into the soil. This could in practise be done mechanically or by subsequent applying irrigation with water.

> There is currently no recommendation of storage intervals for urine that is stored at ambient temperatures below four degrees

Proposed Swedish legislation regarding the agricultural use of urine collected from multiple households has been presented; see box 1 and table 2 (Swedish EPA, 2002). In this legislation, a storage time of one year is proposed for urine where there is no defined temperature for the storage conditions. The requirements presume a pH of at least 8.8 and a nitrogen content of at least 1 g/l. Temperatures and storages times are given as minimum values This is added as a precautionary measure, it is not based on knowledge on bacteria behaviour in urine subjected to freezing conditions.

Table 2: Requirements on storage and allowed crops for diverted human urine that is collected from larger systems. (Swedish EPA, 2002).

Storage temperature	Storage time	Allowed crops
4 °C	1 month	Food crops that are to be processed
4 ºC	6 months	Food crops that are to be processed and fodder crops [1]
20 ºC	1 month	Food crops that are to be processed and fodder crops [1]
20 ºC	6 months	All food crops [2] and fodder crops [3], park areas
–	1 year	All food crops [2] and fodder crops [3], park areas

[1] It is not allowed to spread urine on grasslands for fodder production
[2] For food crops consumed raw it is recommended that urine is spread at least one month before harvest and is incorporated into soil.
[3] It is not allowed to spread urine on grasslands for fodder production

The environment in the concentrated urine is very hostile to bacteria. If the urine is frozen solid, some pathogenic bacteria and proteins such as urease may be negatively affected. The pathogenic bacteria thrive in temperatures above zero. Below zero, they may enter stages of rest, and the knowledge of exactly what happens needs to be developed.

A conclusion regarding temperature aspects on sanitisation of urine is that not enough is known on the fate of pathogens and indicator bacteria in urine solutions that are subject to temperatures below zero. The research carried out in Sweden on sanitisation of urine has defined storage times for 4 °C and 20 °C. The inclusion of storage times of one year when the temperature is not known has been added as a precautionary measure. The municipalities that have handled urine all demand a storage time of at least 6 months. The guidelines are only proposed, implementation in the legal system is planned for 2007/2008. Municipalities place no special demand on storage time for urine that has been frozen. A general opinion is that urine is less risky to handle than faeces, and that the storage treatment of urine according to the above mentioned guidelines generally functions well. A larger concern has been the safe treatment of faeces, see below.

Pharmaceuticals and hormones

There are research project going on to investigate pharmaceuticals in urine and environmental effects (Lienert et al, 2007, Schroeder et al, 2007, Escher et al, 2005). Most studies investigate the content of pharmaceuticals in urine, and the fate of pharmaceuticals in wastewater treatment plants. No studies have yet been presented on the fate of pharmaceuticals in soil. By far the majority of all pharmaceutical substances are derived from nature, even if many are synthetically produced, and they are thus found and degraded in natural environments with a diverse microbial activity. Composting has been evaluated as a biological method to degrade pharmaceutical substances (Guerin, 2001). Urine and faecal fertilizers are mixed into the active topsoil, which has a microbial community as diverse and active as that in composts, and the substances are retained for months in the topsoil. This means that there is potential for the microbes in soil to degrade pharmaceutical substances.

Concerning both hormones and pharmaceutical substances, it is better to recycle urine and faeces to arable land than to flush them into recipient waters. Since the aquatic systems have never been exposed to mammal hormones in large quantities, it is not surprising that the sex development of fish and reptiles is disturbed when they are exposed to wastewater effluent containing hormones. Furthermore, the retention time of the wastewater in the treatment plants is too short for many pharmaceutical substances to degrade and recipient waters are also usually connected to water sources.

There are many indications that the possible risk from pharmaceutical substances in the agricultural system is smaller than the risks associated with the present system of centralised wastewater treatment plants with discharge into water bodies. One such indication is that in many countries the human consumption of pharmaceuticals is small compared to that by domestic animals, as in most countries many commercial feeds contain antibiotic substances, added as growth promoters. Furthermore, the human use of pharmaceutical substances is small compared to the amount of pesticides (insecticides, fungicides, bactericides and herbicides) used in agriculture, which are just as biologically active as pharmaceutical substances. Substance flow studies have confirmed that the dose of natural and synthetic hormones and of many pharmaceutical substances is larger when applying manure than when applying human urine (Magid, 2006; Hammer & Clemens, 2007)

Hygiene and treatment of faeces

Out of urine and faeces, it is faeces that pose the greater hygienic risk. Faeces contain large amounts of microorganisms, harmful as well as beneficial. The sanitisation of faeces has to be designed with care for large scale systems to prevent diseases from spreading as a result of handling the collected faecal matter. The WHO Guidelines on excreta use in agriculture (WHO, 2006) give recommendations on treatment of the faecal fraction, Table 3. More information on the different treatment methods is given in the text below.

Table 3: Recommendations for storage treatment of dry excreta and faecal sludge before use at household and large-scale (municipal) levels. The treatments assume no addition of non-sanitised material (WHO, 2006).

Treatment	Criteria	Comment
Household and municipal levels		
Storage, ambient temperature 2 - 20 ° C	1,5 - 2 years	Will eliminate bacterial pathogens, reduce viruses and protozoa below risk levels.
Storage, ambient temperature > 20 - 35 °C	> 1 year	Substantial to total inactivation of viruses, bacteria and protozoa
Alkaline treatment	pH > 9 during > 6 months, temperature > 35 °C and/or moisture < 25%	Lower pH and /or wetter material will prolong the elimination time
Municipal level		
Composting	Temperature > 50 °C for >1 week	Minimum requirement. Longer time needed
Incineration	Fully incinerated (<10% carbon in ash)	

> There is currently no recommendation of storage intervals for faeces that is stored at ambient temperatures below four degrees

Faeces normally need both a primary and a secondary treatment before application, even if the distinction between these treatments is often diffuse. The primary treatment is that which occurs during collection, and in dry systems this normally occurs beneath the toilet during the collection period. The primary treatment has several objectives:

a) to decrease the risk of odours;
b) to decrease the risk of flies; and
c) to decrease the hygiene risk, i.e. to reduce the number of potential pathogens in the faeces.

In a dry system, this primary treatment can consist of the addition of ash or other cover material such as wood chips after each defecation.

The secondary treatment occurs when the collection period is over and it can take place at the toilet (e.g. in a double vault toilet) or somewhere else. The main objective of the secondary treatment is to render the faeces hygienically safe. Another objective is to transform the faeces mixture into a state where it is odourless and visually non-repulsive. This means that it should no longer be possible to recognise pieces of faeces or toilet paper. This is important when the faecal product is handled manually but less important when the handling is mechanized.

There are several options for secondary treatment; composting, digestion, storage, chemical treatment, incineration and heating in solar toilets. The thermophilic treatments (composting, digestion, incineration) for sanitation rely on all material reaching a sufficiently high temperature for a sufficiently long time to ensure pathogen die-off. This time ranges from seconds for incineration to days or even a few weeks for thermophilic composting. To achieve similar sanitation levels, the other treatments need more time and normally the die-off depends not only on temperature but also on a number of other parameters, such as humidity, pH, ammonia content, etc.

It is important to remember that faeces should be seen as the fraction of human excreta with the larger risk. Out of the treatments below, incineration and urea treatment in a closed container will give high levels of security regarding inactivation of pathogens. Composting, especially in non-isolated containers or in piles, will most likely not give the elevated temperature needed throughout the whole pile. Therefore, if dessication, composting or storage is chosen as treatment alternatives, they should be combined with other safety measures or barriers, such as extra careful hand hygiene, extra strict crop restrictions (no addition to food crops the first year, etc). The WHO Guidelines support this lie of reasoning; quote "Sometimes partial treatment to a less demanding standard may be sufficient if combined with other measures." However, proper hand hygiene and waiting periods should always be observed since the relative inconvenience is rather small compared to the lower risk of disease.

Alkaline treatment and desiccation

The most common treatment of faeces is collection in a ventilated chamber, often with some cover material, such as plant ash, lime and/or dried soil. The additive should be dry and is normally far drier than the faeces. This increased dry matter content decreases the risk of odours and flies. The application of lime or plant ash increases the pH, which will increase die-off of pathogens. The risk of flies and odour is most efficiently reduced if the cover material is applied in such a way that the fresh surfaces of the faeces are not exposed, i.e. the additive should be added after each defecation in such a way that it covers all fresh faecal surfaces. The WHO guidelines indicates that in case an alkaline treatment of faeces is implemented a storage time of 6 month is required if the pH and moisture and temperature of 35 °C is kept. A temperature of 35 °C during six month will not be reachable in areas with cold winters. Therefore the storage time of alkaline treated faeces has to be prolonged, but more research on the safe elimination of pathogens is needed.

Incineration

Incineration is an aerobic process with essentially complete degradation of the organic matter. Thus, if the faeces are successfully and completely incinerated, then essentially all N and S are lost with the fume gas, while essentially all P and K remain in the ash. The ash from successful incineration is a concentrated and hygienic fertilizer high in total P and K. To make best use of this concentrated fertilizer it should be carefully applied.

Faeces – composting

Thermophilic composting, like incineration, is an aerobic process which relies on the heat from the degrading organic matter to reach the temperature desired, > 50 °C, for seven days to ensure safe reduction of pathogens (WHO 2006). Most household composts do not reach this level. It takes knowledge of composting to achieve the good mixture between N, C, liquid and air needed for a good thermal compost process.

The main proportion (typically 90-95%) of the N in the finished compost is organic N (Eklind & Kirchmann, 2000). This organic N becomes plant-available only at the rate that it is further degraded in the soil. The remaining N, 5-10% of the total, is ammonium and nitrate, which are directly available to plants.

A substrate based entirely on faeces is normally not enough to achieve high temperatures, especially if the faeces are mixed with inorganic material such as ash, lime or soil. Addition of easily degradable substrates is needed, usually in amounts at least as large as the amount of faeces. This addition can consist of e.g. food market waste, easily degradable industrial waste or source-separated kitchen waste. In addition to this, good operation and maintenance is needed to maintain a thermal process. To ensure that a large fraction of the compost really reaches thermal (>50 °C) conditions, insulation of its surfaces is recommended.

In sub-zero temperatures, the compost may still generate enough heat to keep the temperature above zero. Naturally, insulation of the surfaces is especially important, as the microbial activity slows down markedly when the temperature decreases.

Storage

Storage at ambient temperature is another possible secondary treatment for faeces. The pathogen reduction increases with increasing ambient temperature (Moe & Izurieta, 2004). WHO Guidelines state that storage for 1,5 - 2 years in an ambient temperature of 2 - 20 °C will eliminate bacterial pathogens and reduce viruses. However, E-coli, Salmonella and soil-borne ova may persist, therefore proper hand hygiene is still recommended for handling of products (WHO 2006). Since composting is a difficult process to monitor, the above mentioned recommendations will give a maximum amount of security.

Digestion

Anaerobic digestion at thermophilic, mesophilic or ambient temperatures is another option for secondary treatment of faeces. Digesters are closed and all inflowing substances leave them either with the biogas and/or with the digestion residue (including the sedimented sludge that often has to be removed every once in a while). In the digestion process, a large proportion of the organic matter is degraded to biogas (mainly methane and carbon dioxide).

Figure 5: Urine-diverting liner for dry urine diverting toilets in summerhouse settings. By Palmcrantz and Co

Chemical sanitation

Sanitation of faeces can also be achieved by mixing them with urea. This urea is degraded to ammonium by the urease that naturally occurs in the faeces. Thus, this process probably functions best if the faeces are in the form of a sludge, which can be mixed. In the sludge, equilibrium is established between ammonium and ammonia. Ammonia is toxic to microbes and the reduction of pathogens is very good in the process (Vinnerås et al., 2003). Additions such as ash and lime that increase the pH during primary treatment increase the sanitizing effect. This treatment needs to be performed in a closed container. The process resembles storage in that no degradation of the faeces takes place and therefore neither organic matter nor N is lost. They are all left for the microbes in the soil to thrive on after application of the sludge as a fertilizer. The ammonium content of this sludge is higher than that of urine and digestion residue. Thus, it is an excellent fertilizer but, like digestion residues and urine, it needs to be handled and applied with care to avoid ammonia losses.

Technical aspects: construction and maintenance of dry urine diverting toilets in climates with cold winters

Choice of toilet model

In most cases an inexpensive toilet model can fill the needs. Important, however, is that the user in the long run feels comfortable and is satisfied with it. It is therefore recommended that the prospective user, if possible, tries out the toilet before the choice is made. An example of how a municipality can supply the inhabitants with information on toilets systems is Nacka municipality outside Stockholm, where a wastewater exhibition has been set up. Toilets have been installed in a nature school setting, so that people can try the toilets in reality. Other important aspects are that the toilet is easy to clean, that it is robust and easy to maintain. For the cleaning, the surface finish is important and for the maintenance the technology, the availability of spare parts and labour skilled in their replacement etc. are important. Another important aspect is how easy it is to access the urine pipe for cleaning, repair and inspection. Also, when installing urine diversion in a public place special requirements are put on the toilet design. The system must be self-explaining even if information posters should be placed on the walls.

Urine diversion in dry, non-complicated systems

The least complicated, but in many cases well functioning, urine diversion system is built with only one toilet per collecting container, short pipes and reuse of urine and faeces in a small home garden. The easiest way of having a urine diverting toilet is by placing a liner consisting of a funnel in the front of a dry toilet. Figure 4 shows a liner with lid produced in Sweden by Örnplast AB. In wintertime, the toilets are used with an isolating ring to sit on. The urine can be collected in 10-25-litre containers, or a larger 1 m3 tank placed beside the latrine bin. For permanent households the current Swedish recommendation is a collection volume of 2-3m3 for double flushing toilets. In dry systems, a 1 m3 tanks should be enough for a four person family but this needs to be confirmed for the individual setting. At need the container is emptied and the urine used as fertiliser. The effect of fertilizing is best during spring and early summer. It is easily spread by pouring from the container directly, possibly equipped with a hose down to the ground or by use of a plastic watering-can or similar.

Odour seal

To avoid odours it is preferable that toilets installed indoors be equipped with a seal (could be water seal or other type of seal), even though small installations (one toilet or urinal on a short piping system preferably less than 10 metres long and with a good slope, preferably > 4%) can be built without seal. If the inlet pipe goes down to close to the bottom of the collection vessel, the risk of odour from the urine pipe is minimized. If a water seal is not relevant, a latex/silicon membrane can be used. This will allow urine to flow downwards, while no air is emitted out of the tube. The following pictures show a membrane smell trap consisting of a rubber tube that is flat in one end. The urine flows down through the tube, but no smell can pass "upwards" into the flat end of the smell trap. A problem with this system has been clogging and precipitation build-up, and the membrane has needed cleaning every 3-12 months and replacement every 1-3 years, which means that spare parts must be easy to get hold of. Another alternative is a seal with an oil sealant.

Maintenance of urine diverting toilets

In all installations there is a risk of blockages occurring mainly in the odour seal. It is a result of fibres and other particles entering the piping system and of chemical precipitation of struvite (MgNH4PO4) and calcium phosphates (Ca10(PO4)6(OH)2) from the urine caused by the increase in pH which occurs when its urea is degraded. The precipitation also forms a viscous sludge, which will slowly flow towards the tank provided that the slope of the pipes is correct. Another, but more costly way to solve the blockages, is to replace the water seal at regular intervals.

Most blockages that occur in urine diverting toilets are "soft" blockages caused by precipitation on hair and paper fibre. The other type is hard "blockages", caused by precipitation directly on the on the pipe wall. The blockages are removed either mechanically by a drain auger or chemically by use of strong solutions of caustic soda (2 parts of water to 1 part of soda – should be mixed before being poured down the pipe) or acetic acid (>24%). These methods can also be used as preventive measures against blockages.

A suggested initial frequency for preventive cleaning is twice a year and then increasing the frequency if blockages still occur. Irrespective of which method that is used, it is important that the cleaning is followed by pouring 1-2 litres of water down the urine bowl as fast as possible, to flush away any material that might have come loose by the cleaning.

If chemical cleaning is preferred, it is suggested to alternate between caustic soda and acetic acid, as they supplement each other well. The caustic soda is very efficient in dissolving hair and organic residues and frees the mineral precipitates so that they can be flushed away as grains. Care should be taken, however, that the caustic soda is well dissolved in enough water (at least 2 volumes of water per volume of soda), before it is poured into the urine pipe, otherwise there is a risk of the soda itself forming a precipitate in the pipe. It is recommended that enough soda solution is used to also clear the pipe immediately behind the u-bend. A mixture of 5 dl of caustic soda and 1 litre of warm water will often be appropriate, as this will completely fill just over half a meter of a 50 mm pipe. Care should be taken and protective gloves and eyeglasses worn when handling the soda, as it is extremely caustic. The soda solution should be allowed to sit in the u-bend seal and the pipe over night and then it should be flushed away with at least 2 litres of water being poured down the urine bowl as fast as possible (Kvarnström et al, 2006).

When acetic acid is used, it should be as strong as possible. The acetic acid does not dissolve hair or organic matter as

Figure 6: Rubber membrane as odour seal. Photo by WECF

Figure 7: Cleansing tools for urine piping in a urine diverting toilet. Photo by Ebba af Petersens

Figure 9:
One cubic meter tanks suitable for storage of urine.
Photo by WECF

Figure 8:
Hand pumping of urine from household tank for subsequent use in garden.
Photo by Mats Johansson

efficiently as caustic soda, but it is more efficient in dissolving some of the mineral precipitates. Enough acid should be used to completely fill the u-bend and part of the pipe immediately behind it, normally at least 0.5 litres should be used. Also the acid should be allowed to sit over night and the pipe then flushed with at least 2 litres of water.

The caustic soda increases the pH of the urine and thus improves the sanitation of the urine. The acetic acid acts in the opposite direction, with the effect that ammonia losses are minimised. Therefore, it is suggested that acetic acid is alternated with use of caustic soda.

Neither the addition of acetic acid nor of caustic soda will affect the urine solution quality as a fertiliser.

Pipes for urine

Material

Urine is, due to its content of ammonium, very corrosive. Therefore metals, for example copper, should be avoided everywhere in the system. Plastic pipes are preferred to metal ones. To maximize the flow rate of the urine and the sludge, the insides of the pipes should be smooth and flow restrictions, e.g. sharp 90º bends, should be minimized.

Dimensioning of pipes

Piping should be minimized as much as possible. The pipes in small systems without any odour trap can have a small diameter, 25 mm (even down to 12 mm if easily replaced or cleaned), but should have a good slope, a minimum slope of 4% is suggested, and obstacles slowing down the flow, e.g. sharp bends, should be avoided. The piping system should be short, preferably less than 10 metres, to limit the time the urine spends in the piping system and thus the degradation of urea and risk of precipitation in the system.

If the toilet has an odour trap, all pipes should have a slope of at least 1%. The pipe diameter should be at least 75 mm, but where the pipes can be easily cleaned and/or disassembled 50 mm can be accepted, at the expense of regular maintenance e.g. flushing every few years. For underground pipes, a diameter of 110 mm is recommended. Ø110 mm pipes have thicker walls, are more stable and minimize the risk of pipe depressions. Possibility to inspect, flush and clean the pipes in both directions should be provided where there is a sharp bend in the piping, at all transitions, e.g. from vertical to horizontal piping and where the pipes leave the house. To prevent odours, the piping system should be very sparingly ventilated. No ventilation from the tank is needed, however, if the tank is large and a truck for emptying the tank with suction is used, then sufficient inflow of air must be provided so that the tank does not implode. This is achieved by either designing the system with two outlets, where both are opened when the tank is emptied, or to empty the tank with a hose stuck into manhole.

Manholes outside the house shall be equipped with child safe lids that are water tight. To avoid odour, it is usually important that the pipe ends close to the bottom of the collection container to avoid air flow through the pipe into the toilet room.

Care should be taken to prevent ground water leaking into the pipe system. All pipe connections underground must be completely tight (i.e. welded or glued, or if possible, avoided altogether) to minimize the risk for intrusion of ground water. It is essential to avoid sedimentation pockets, negative slope should be avoided in all parts of the pipe system.

The urine pipe is preferably located in the same piping trench as other wastewater pipes. It should be clearly marked, to avoid mix up with the other pipes. There are many examples of misunderstandings from construction personnel who are unaware of urine diversion systems since they are not yet considered mainstream.

Storage

Small scale storage of urine

According to WHO recommendations, urine does not need to be stored for hygiene reasons when it is used in the garden of the home where it is collected. However, as mentioned above, the cropping season is short and urine collected outside that period needs to be stored. In a summer house setting, jerry cans may be sufficient but in an all year round home, larger tank must be provided for. Care should then be taken to cater for simple emptying of the tank, for example by a hand-operated pump, Figure 7.

Choice of tanks for home use is often governed by economy. A cheap way to solve the problem of storage is to reuse containers used in agricultural industry, for example one cubic meter tanks that have been used for silage additives, "sugar cubes", figure 8.

There is no problem with concrete tanks for storage of urine, as long as they are sealed against leakages and covered to avoid ammonia losses and smell.
The tank under the hand driven pump in figure 7 above is a prefabricated concrete tank of 3 m^3. An advantage with concrete tanks is that they seldom have to be anchored to the ground. Plastic or polypropylene tanks need to be anchored if the ground water table is high, see Figure 9.

Large scale storage of urine

When urine is collected from many households, the urine should be stored for a specified time in order to minimise risk of transmission of disease. For small amounts of urine, a number of 1 m3 plastic tanks can be used. This is a flexible solution, since the vessels can easily be moved, and subsequent use in municipal parks, gardens is simplified. In addition, investment costs are low.

For larger amounts of urine, permanent tanks are recommended. Concrete or plastic tanks can be found on the market. Important aspects to consider are

- Suitability of the site where the storage is set up
- Ownership. Proper contracts should be arranged for, regulating storage length, quality control etc. In cases where the farmer provides the storage, the urine can be stored close to the land where it is used. Another alternative is to set up storage on municipal land, for example where the park department is in charge.

Suitable storage for urine can often be found on farms which have had livestock. Empty slurry tanks can constitute a cost efficient storage for the urine. However, air exposure should be minimized and thus covers must be provided as the urine should be stored in covered containers. Existing containers may need modification.

Collection tanks for urine can be fabricated in many different materials and designs. However, urine is very corrosive and if possible metals should be avoided altogether in the system. From an energy point of view tanks made of concrete or just a plastic liner in a dugout in the soil or a wooden frame is advantageous, but of higher importance for proper technical function is to ensure that the tanks used are water and air tight as well as robust. If a large tank is used, it should be suitable for burying in soil. Figure 9 shows the installation of a 10 m3 tank for collection of urine from a neighbourhood in Kullön, Vaxholm. The urine flows by gravity to the tanks which are dimensioned to be emptied twice yearly. Figure 10 shows full rubber tanks above ground for urine collected from households in the Stockholm region.

Most of the urine that is collected in small systems around Sweden is transported to farms where it is poured into the slurry storage. This is a simple way of handling small fractions of urine, however if one wants to make use of the nutrients in an efficient way and there are larger amounts available, designing storage and spreading according to nutrient potential in urine is better.

Figure 10: Urine tanks for a neighbourhood during construction in Kullön, Vaxholm. Photo by Mats Johansson

Figure 11: Rubber tanks for storage of urine, Photo by Anna Richert Stintzing

Figure 12: Plastic container for collection of faeces, lined with a black plastic bag. Photo by Mats Johansson

Great care should be taken and the regulations issued by the proper authority on occupational safety and health should be followed if it is necessary to go down into the urine tank, and this task should never be undertaken by one person alone.

Faecal collection

The faeces should, at all occasions, be kept dry or moist. If excessive amounts of urine or water from external sources leaks into the system, then smell will be an issue as well as fly breeding and more difficult handling of the faeces. A recommendation is to let faeces drop into a container that can easily be removed, see figure 11. A plastic container will also simplify in case of malfunction, the container can easily be removed, emptied and restarted when the problem has been solved.

The fate of paper used for wiping after toilet visits is a matter of opinion. If the treatment method chosen is composting, then paper can very well be added, since paper is also degraded in the compost. If the treatment method is long time storage, then the user may want to keep the wiping paper separate, so that the final product is less offensive.

If the chamber where faeces are collected is dug down into the ground and a container as mentioned above cannot be used, a proper lining should be arranged. This can be a concrete floor and walls; the only important thing is to insure that water does not enter the chamber even if high floods are a risk.

Odour control with ventilation

Avoiding bad smell is an important aspect for dry sanitation systems, especially when the toilet is installed indoors. Good ventilation as well as successful diversion of urine is the key factor to avoid smell from the toilet system. The following text will give understanding of the principles of ventilation of a urine diverting dry toilet with practical examples. Working aeration guarantees an odourless dry toilet. Great deal of the adjustments made to dry toilets after installation, have to do with the aeration according to experiences from Finland (Hinkkanen, personal communication).

Indoor settings

If the toilet is placed indoors, avoiding smell will be a key issue. The faeces chamber can either be placed directly under the toilet seat, or in a chamber below the floor. If a ventilation pipe is attached to the faecal chamber according to instructions, the warmer air will rise and cause a flow of air through the system, transporting smell out of the house. Care should be taken that the ventilation pipe does not lead down into the chamber, but starts directly near the wall. Warm air rises, and the smell should not be trapped in the collection chamber.

Proper care must be taken so that the air from the faecal chamber does not flow from the faecal chamber into the room where the toilet is places. This can be the case if a fireplace with exhaust chimney draws air from the rest of the house, including the toilet room. If this is the case, the problem may be solved by insuring that the room where the toilet is placed can be closed and that the toilet room is only ventilated through the faecal chamber. The ventilation pipe from the faecal chamber should rise above the house roof with at least 30 cm if fan ventilated and preferably 100 cm if naturally ventilated.

A problem related to ventilation is the condensation of water which happens when warm air is cooled down through ventilation in pipes cooled down by the outside climate. Isolated pipes as well as pipes that run mostly through the house are recommended. The condensation water can even clog the pipe if it freezes. When even a little amount of condensation water starts to melt, it can fall down the aeration pipe on the fan and cause problems. It is best to take the pipe straight up to the roof inside the house. Then the wind will carry the odours away and the pipe is in a warm space.

The use of a small fan to force ventilation is recommended when the toilet is placed indoors. If a small fan is installed, the size of the ventilation pipe may be decreased from 110-150 mm to 75 mm diameter, provided that the function of the fan is stable. There are electrical, wind and solar power operated fans available.

The fan in the dry toilet must not be too powerful, because it might make the toilet uncomfortable due to draft, and in composting devices the compost may dry out. But on the other hand the fan must be powerful enough to work even though there is other source of suction nearby, such as a wooden oven, sauna or another fan. If there is no competing aeration nearby, a small fan will do fine.

Replacement and maintenance of the fan must be easy, because the fan must be replaced or cleaned of extra dust now and then. In some toilet equipment there is already a place for the fan, but if the fan is installed separately, a maintenance hatch for it is recommended. The fan can be either attached to the device or inside a wall.

An electrical fan is vulnerable to power shortages. For short power cuts, closing the lid of the toilet or putting a plastic bag over the seat will be enough to keep the odours inside the toilet. If power cuts are long and frequent, the fan can be connected to a UPS-battery. This will give the fan the required power for the time of the shortage. Another option is to use a fan that operates on solar power when there is access to sun.

Outdoor settings

For a toilet placed in an outdoor setting, the principle that the flow of air runs from the room where the toilet is placed through the faecal chamber and out through a ventilation pipe is still relevant, especially if the toilet is isolated to keep temperatures during winter. This can be insured by assuring that the faecal chamber is air tight, and the ventilation pipe rises over the toilet roof and does not extend too low in the faecal chamber.

Urine

The previous text describes a situation where the faeces generate smell, and how to get rid of it. Another possible source of smell in the dry toilet system is the urine. If there are several toilets attached to one urine tank, it is important that the pipe leading the urine to the tank is submerged in the urine liquid, implying that the pipe must go almost to the bottom of the tank. This will prevent gusts of air flowing from the urine tank into the room where the toilets are placed as the urine is flushed from one toilet into the tank. Another alternative, if smell is a concern, is a rubber membrane or an oil type of odour trap. See section on odour seals.

Finally, the following recommendations are important to insure the absence of smell:

- Successful diversion of urine from faeces. If urine or washing water is led to the faeces container, the risk of bad smell increases.
- Proper ventilation of toilet room including faeces chamber. Use of a fan is recommended.

System for reuse of urine and faeces in crop production.

Reuse of faeces only takes place in the small scale in Sweden today. The reason is that few large scale applications exist with dry urine diversion. One notable exemption is Gebers, mentioned in the examples below. The faeces are composted, and collected by a farmer who spreads the faeces on agricultural land together with

Figure 14: Even for an outdoor setting is a ventilation pipe. relevant Photo by WECF

Figure 13: Maintenance hatch for toilet system fan. Photo by Toni-Petteri Paju, Global Dry Toilet Club of Finland

solid farmyard manure. The amounts of faeces generated from the 35 households are too small to motivate separate handling.

Reuse of urine in Sweden today is carried out both on small scale basis at home and allotment gardens and in agriculture, where it is spread with regular farm equipment for slurry. Both cases are presented below. The practice of fertilising with urine is carried out during the early part of the growing season, which in Sweden lasts from April–May to September–October. This means that in a system with urine diversion, urine collected during winter must be stored until use in April - July. A research project was carried out in 1996-2000 to investigate the use of urine as fertiliser in agriculture. Extensive field trials were carried out and the results are reported in Johansson et al, 2000. Results show that urine can replace mineral nitrogen fertilisers in production of spring sown grain crops. Another finding showed that the ammonia losses when spreading the urine were small, usually around 5% and never higher than 10% of the nitrogen content (Rodhe et al 2004).

It is easy to calculate the value of nutrients in urine and faeces using information of the nutrient content in the products and the cost of mineral fertilisers on the market. The following example based on the figures in box 3 shows that money can be saved by using urine as a fertiliser in the home garden if it used as a substitute for mineral fertilisers:

Box 3:
How much are the nutrients in urine and faeces worth?

A hypothetical household with a dry urine diverting toilet system collects 1500 l of urine per year. The nutrient content in the urine is 7 g N/l, 0,7 g P/l and 3,5 g K/l. There are many other nutrients in the urine, such as sulphur and micronutrients, but the N, P and K are easiest to calculate with. The amount of N and P in the 1500 l is 10.5 kg N, 1 kg P and 5 kg K. The cost of a mineral fertiliser for the garden on the market in Sweden is 149 SEK for a 20 kg bag containing 3,6 kg N, 0,8 kg P and 2 kg K. A rough conclusion of the value of the urine is that it corresponds to two bags of mineral fertiliser or 300 SEK (27 Euro).

Home gardens

Use of urine

There is an awakening awareness among household gardeners, and especially allotment gardeners, of the fertilising advantages of urine. This has had the result that even persons that do not have urine diverting toilets installed are using urine collected in plastic bottles as fertiliser for flowers etc. The Swedish University of Agricultural Sciences has carried out several research projects, one of which was fertilization of leek. The gardening associations have produced fact sheets on the use of urine in home gardens, and the daily papers in Sweden have covered the use of urine as fertiliser. This may result in a demystification of use of urine as fertiliser, which supports the development of urine diversion.

From a legal perspective, the use of urine in the home garden is allowed, but the local environmental authority may pose conditions to the urine use, e.g. on size of the "productive" surface in the garden available for urine spreading. This is to ensure that the urine use does not jeopardize the precautionary principles stated in the Environmental code which could possibly apply if too much urine is spread on too small a surface. However, a too conservative approach has been noted in Swedish municipalities concerning this, when in fact use of urine on cultivated land is a significant environmental improvement compared to any soak-away or infiltration system. See Box 4 for calculation examples showing how the necessary surface, in order to maximize the use of the nutrient in urine.

Urine used as fertiliser does not need to be diluted, but many gardeners do dilute before spreading even though this increases the handling needed. Usually spreading of undiluted urine followed by irrigation is simpler and generates less odour. In the small scale, urine is spread with a watering can. Care should be taken not to use equipment with metal components, and if this is done, the equipment should be carefully washed afterwards since urine is very corrosive.

Urine is best used as fertiliser to nitrogen demanding crops, but most garden crops respond well to urine as a fertiliser. Urine has been used with good results on lawns, roses, berry bushes, vegetables as well as annual and perennial flowers. A one month with-holding period is recommended between last application of urine and harvest of food crops consumed raw, for safety reasons.

Figure 15:
Visitors apply urine in a demonstration garden in Sweden
Photo by WECF

Box 4:
Calculation of necessary productive area in garden to maximize nutrient use in urine.

The necessary productive area (e.g. grass, flower beds, vegetable garden, trees) necessary per person for use on household level depends on three things:

- The nitrogen demand of productive area
- The concentration of nitrogen in the collected urine
- How many "harvests" are made per year (in Sweden we only take one harvest a year, whereas in other climates two or three harvests are taken)

Rules of thumbs are useful, if the exact figures for the above factors are unknown. The nitrogen demand for vegetables, turfs etc. varies between 100 – 200 kg/ha, depending on type of crop and the yield. The concentration of nitrogen in urine depends on the diet. Undiluted urine will usually contain between 3 – 7 g N/l.
A person excretes about 550 l urine per year, depending on liquid intake, climate etc. Thus, the excreted amount of N per person and year will be between 1.65 kg – 3.85 kg, using the figures above. If the nitrogen demand of the crop/turf etc is 100 kg/ha and the N concentration in the urine is 7 g/l the urine from one person can fertilize 385 m^2 (1.5 l of urine per m^2), if one single crop is taken per year. If there is a restriction in plot size, it is usually possible to increase the fertilization up to three - four times (thus using up to 6 l per m^2) without any negative effects on crop or environment.

Calculation example:
A family of five has a plot size of 300 m^2 on which they want to use the urine they collect in their urine diverting toilet. The family lives in a climate allowing for two yearly crops. If we assume that they can apply 4 l per m^2 for the first crop, and 2 l per m^2 for the following crops, how many m^2 do they need to use their urine in their garden?

Answer:
Since they live in an area where two crops can be taken per year and 6 l/m^2 can be can be applied yearly. Each person excretes about 550 l, but assuming that some of the time is spent outside the home, about 300 l per person is collected yearly. The result is 1500 l of urine from a family of five. This will fertilize 250 m^2 since each m^2 will receive 6 l m^2/ on a yearly basis, giving a quite high level of nitrogen fertilisation. Thus, the plot size would be able to productively use the collected urine. In cases where the plot size is too small to use the urine productively, one has to either find other ways of disposing of the urine (could be done as an N supplement to composts for example) or construct a urine collection system.

Box 5:
My 20 litre container for urine is full. How do I use it in the garden?

Twenty litres of urine is sufficient for 4 - 13 m^2 of gardening land, depending on how much nitrogen is needed or can be absorbed, and based on one crop per year.
I would suggest that you apply the urine with a watering can early in the planting season, when the plants are established. Water the plants with the same watering can afterwards, so that the urine is washed off any leaves and into the soil.

Box 6:
I have a flower bed the size of 1 m^2. How much urine do I need to fertilise it?

The flower bed really only needs about 1,5 litres of urine for one season, but this amount can be increased with up to four times at need. Summer flowers demand a good soil structure and quite a good nutrient status in the soil.
A good strategy would be to apply urine on a few occasions during the flower season, for example with 2 - 3 decilitres each time, and to water down the urine afterwards.

Figure 16: Large scale application of urine using a slurry spreader with trailing hoses. Photo by Mats Johansson

Odour when urine is used in the home garden

The smell when using the urine may be an issue in the home garden. Experiences show that if the urine is spread close to and directly onto the soil and watered down there is little smell and urine is currently used in densely inhabited housing areas without complaints from neighbours. However, handling of urine is naturally a smelly activity and thus wise procedures minimizing air exposure, e.g. by using closed containers, application close to soil and immediate incorporation or irrigation, are strongly recommended.

Use of faeces

Most Swedish municipalities demand that the household owner apply for permission to handle the faeces. Some conditions are set up for the approval of local reuse of the faeces. Composting should take place in closed containers with a plastic bottom to avoid leakage. The municipalities usually demand a container size of 500 litres for a household. The compost should not be placed near a water source, open waters or neighbours.

Most municipalities recommend that the faeces are left in the composting container for at least 6 months after last addition of material. This may be adjusted depending on WHO guidelines in the coming years.

There are no restrictions on the use of faeces after they have been sufficiently treated. The faeces can well be used as a soil conditioner. Since the nutrients are bound in organic substances, the release, and the effect will be slow. The nutrient content of the faecal compost will vary quite a lot, and calculating application rates is not as easy as for urine. General guidelines on application rates are 1 - 4 litres of compost per square metre productive land in the garden. The use of faecal compost should be supplemented with quick-acting nitrogen fertilisers, for example urine, during the cropping season.

Large scale agricultural production

Use of faeces

Treated faeces can be used in agriculture in the same manner as solid animal manure, using the same type of spreaders, application strategy and dose per hectare. Frequently, the amount of faeces generated is too small for a large scale farmer to incorporate in a strategic manner in the agricultural production. In these cases, the faeces may be better used in production of plant soils or construction gardening. It is easier to find uses for urine in large scale agriculture.

When treated faeces are used as fertilisers in agriculture, the main value will be the organic content, the phosphorous and to some extent the nitrogen although it is bound in slow releasing forms. Most crops can benefit from the treated faeces, and in regions of the world where there is a lack of phosphorous in the soil, good results on yield have been shown (Morgan, 2004). Normal amounts to apply are 20 - 30 tonnes/ha, corresponding roughly to the amount of treated faeces generated from 2000 - 3 000 persons.

Use of urine

The use of urine as a fertiliser in agriculture has not met practical problems, mainly due to the fact that the use of animal urine in agriculture is common practice. Human urine should be spread in the same ways, i.e. close to the ground and with incorporation as soon as possible in order to minimise risk of ammonia losses, and in periods when the crops need fertilisation. Compared to spreading of mineral fertilizers the agricultural use of urine, same as animal slurry, has a few disadvantages, such as the risk of soil compaction.
This risk can be handled by spreading the urine when the soil contains low amounts of soil moisture, or by using specially designed spreading equipment. There is mechanical equipment for application of the urine and the routines on the farms do not need to be changed substantially. The main aspects that farmers have had to deal with are the storage of urine as well as quality control, certification as well as acceptance by the buyers of the grain, Box 7.

Urine is a suitable fertiliser for agriculture, with levels of N, P and K well matching the needs of grain crops. The nutrients in urine are best utilised when the urine is spread in spring to grain crops, or when the crop is 15 - 30 cm high as a supplementary fertilisation. The farmers using urine in Sweden today spread it either in spring to summer or winter grain, or to leys after first or second harvest.

In large scale agriculture, there is a need to have sufficient volumes of urine for the farmer to even consider using it as a fertiliser. One hectare of grain is normally fertilised with around 100 kg N per year. This means that the urine from at least 25 persons will be needed to supply one hectare with nitrogen fertiliser, if all the urine is collected. Therefore, agricultural use of urine requires introduction of urine diversion on a large scale.

The urine can be spread with conventional spreaders for liquid manures using trailing hoses, figure 13, or a traditional splash plate. If the urine is spread on bare soil, it should be incorporated by harrowing as soon as possible in order to avoid ammonia losses. If the farmer does not have access to the equipment, it can be rented and frequently groups of farmers cooperate using one spreader on many farms. In these cases, it is important to wash the spreader to avoid contamination if fertiliser such as untreated sludge is used.

Odour when using urine in agriculture

Urine does smell, but so do most organic fertilisers. During the application, a strong smell can be felt, but this is not more offensive than slurry, and only a short time after application, no smell can be detected at all. Notably, urine has been applied on fields close to Stockholm, in a recreational area, and no complaints have been received from house owners nearby.

Transportation

Important aspects to consider when planning transportation of urine are choice of entrepreneur, hygiene and documentation. Municipalities usually have one or a few companies that are contracted to transport the waste fractions generated within the municipality. Another interesting alternative is to contract the farmer who will be using the urine for transportation services. This way the farmer can generate some additional income from handling the urine. The hygiene aspect must be considered, and the entrepreneur must have information about measures such as proper hand hygiene after handling of urine. A mouth cover is not necessary, more important is hand hygiene. All transports should be documented as a part of a quality control system.

Box 7:
Quality control and certification

One need for the farmers is to insure that the company buying the crops does not have objections to the choice of human fertilisers. Recent development has seen quality control systems for crop production evolving, and this is applicable for the fertilisers as well. There is currently a Swedish certification system for digested or composted household waste, enabling the use of this waste fraction in agriculture. A similar setup for urine is proposed, which would simplify its use in Swedish agriculture.

6 | Examples from pilot projects and research from the northern hemisphere

Composting toilet with urine diversion in Finland

The family of two adults and two children live in an old country house with an indoor dry toilet. There were several reasons to change from water toilet to dry one. The well for drinking water was running low, the septic tank was too small for the family, and emptying of the tank was expensive. The water toilet caused condensing water when the cold water from the well entered the toilet, and the whole wall behind the toilet was rotting. The family chose a urine separating model which can be installed to replace the water toilet directly. The chosen model has a composting chamber right under the toilet seat. The toilet has been used since august 2005. The grey water is led to a soil filter system.

There are different varieties of urine separating dry toilets with a drum compost inside where faeces and paper are composted, see figure 14. The drum takes the composted waste in to a container, which is emptied regularly. About one litre of carbon rich additives such as peat or wood chips per user is added to the drum compost once a week.

The toilet has been used since august 2005. Total costs for the toilet are about 1600 Euro, as well as a pipe to lead the urine and a 1 m^3 urine container, 50 Euro. The grey water is led to a soil filter system.

Installation

Installing of the toilet seat took only few hours. In the old house the space and door holes were quite small, but they still managed to fit in the equipment. The pipes for urine, 30 mm at the outlet of the toilet, and 75 mm leading to the urine tank, were installed right next to the tap water pipes. As a result, the pipes are easy to access if there are blockages or they need to be replaced. The aeration pipe was lead up straight through the wall, and a wind fan was installed in case of a power shortage. The electrical fan was connected to the light switch so that they turn on at the same time.

The urine tank, a used container from agricultural industry, 1 m^3, is buried outside the house. The family bought several tanks for various uses (rainwater harvesting, etc.) The container was taken in use in august 2005, and emptied for the first time in June 2006. At that time it was not completely full, but it was a good time to fertilize.

Despite the instructions, the aeration pipe was not insulated and some condensation water had flown along the pipe to the toilet seat. The condensation water may have been avoided if the aeration pipe was lead to the roof inside the house or at least insulated. The warm air cools down in the pipe, which causes the water to condense. Mineral wool is an example of an insulation material, other possibilities are prefabricated insulated pipes.

Experiences of maintenance and use

During the first year the use of the toilet has gone well and the residents were satisfied with the toilet. The weekly cleaning is done with a spray bottle and an old dish brush at the same time as all the other cleaning of the house. At the same time the dessication material is added, and the compost rotated.
According to the manufacturer's instructions, only peat was used as bedding in the beginning, but the family thought that it became too compact. The family has used very fine wood chips in their other compost for kitchen waste, and it has worked really well. They decided to mix the peat with the chips to make better bedding for the Naturum. The solid matter from the faecal compost is emptied twice a month during the weekly cleaning and put in the same insulated compost as the kitchen wastes. The compost is used in the garden. The mother of the family commented: "I send the children to their hobbies with their father on Saturdays, and clean all the cages for the pets and the toilet every fortnight. It's more convenient that way than to wait when the bin is full".

The ventilation has worked very well, but some times during autumn or spring there has been a smell of compost in the toilet room. At those times the residents have put the fan on and the odours have been removed immediately.

The urine container was emptied for the first time during the summer 2006. The urine was diluted with grey water and used to fertilize the garden. At the time of the fertilization, there was an odour of urine in the air, but it went away quite quickly and was not half as bad as the smell from the neighbour spreading manure on the field next to the house.

Lessons learned: Finland

The experiences from Finland show that it is possible to exchange a water toilet for a dry toilet with only minor changes in the house. The family has been very satisfied with their toilet although small flies were present in the beginning. After the family adapted to the use and maintenance routines of the toilet, they have enjoyed the toilet. The example highlights the importance of the proper ventilation in cold climates and especially the insulation of the ventilation pipe.

Figure 18: Börje Johansson. Photo by Mats Johansson

Figure 17: Dry urine diverting toilet with faecal collection beneath the toilet seat. Photo by Kati Hinkkanen, Global Dry Toilet Club of Finland

Agricultural reuse of urine and sludge in Hulta, Sweden

Börje Johansson is a farmer in southern Sweden with production of milk, fodder for cows and grain. Börje collects urine from 18 households in the village where he lives, and uses the urine as fertiliser on leys and in grain production. The total amount of urine spread is about 70 m^3 per year, mostly during autumn and spring. The strategy is to spread the urine to leys that will be ploughed, thus fertilising the subsequent grain crop. The system has been running for six years, and Börje is happy with the results. He has full control over timing, which means that he can adapt the collection of urine to needs of fertilising.

The tanks for urine, as well as toilets and piping system were installed as a part of a national investment project to promote sustainable solutions. The villagers received subsidies for part of investments. Today the system runs without external financing, for example from the municipality. Each household pays 200 SEK when Börje comes to empty the tank for urine. The municipality has been engaged and Börje has contributed with experiences from the use of urine to numerous reports and study visits.

The equipment used for spreading of urine is fairly basic, the same equipment used for application of animal urine and slurry. No modern trailing hoses are used. Börje is aware of risks of nutrient loss when spreading nitrogen rich fertilisers, but he plans so that he can spread the urine when rains are coming and the urine will be washed into the soil.

Börjes motive for collecting urine from households was originally to improve the nutrient balance on the farm. The farm is certified organic production, and no artificial fertilisers are imported to the farm. In general, human urine is not allowed in organic production in the EU, but Börje has an exemption from the regulations of the Swedish organisation for certification of organic agriculture as a pilot study.

Most of the households collecting urine have a double flushing toilet, which means that there is no dry fraction of faeces to collect. But Börje has developed a service to the villagers involved, in that he emptied the sludge that is collected in the septic tanks. This sludge is dewatered on site, and the resulting sludge, 30% dry matter, is transported to Börjes farm where it is composted together with straw. The compost is used in agriculture, and spread with an ordinary solid manure spreader. One big advantage with the reuse of the urine and compost from villagers in Hulta is that the loop is closed in a very tangible way. The villagers live close to where the urine and compost is used as fertilisers, and some of them buy food that is produced using their own excreta as fertilisers. "If the people can see for themselves where their byproducts are turned into valuable fertilisers, then we have a very stable and secure system" says Börje.

Local reuse of urine in a demonstration garden, Nyckelviken, Nacka

The municipal gardens and greenhouses in Nacka outside Stockholm demonstrate the use of urine as fertiliser in the garden. The urine is collected from the toilet of the personnel and is stored in two tanks, 1 m^3 each. The tanks are made out of polypropylene, and when one tank is full, it is sealed and set to store for at least 6 months before use in the garden. The tanks are buried outside the greenhouse. No special adaptation to winter climates has been made, the pipes leading to the tanks exit the greenhouse underneath the ground, and in any case, the system is not in use during wintertime.

Figure 19: Tanks, hose and pump for urine. Photo by Ewa Äkerlung

Figure 20: Eva works in the municipal gardens in Nyckelviken, Nacka. Urine is applied several times during the summer season. Photo by Anna Richert Stintzing

The urine is spread with a hose that can be connected to a water stand, enabling subsequent flushing of hose and irrigation of crops. A small trial has been set up, and the experiences after three years of fertilisation are that urine compares well with poultry manure and compost. The garden has numerous visitors from within and outside the municipality, thus the outreach is very good.

Tanum municipality in Sweden – urine diversion mainstreaming through municipal policy work

There has been a shift in the sanitation discourse in Sweden since 1995. Urine diversion was originally considered an "alternative" sanitation component, mostly eco village-oriented. Today the Swedish EPA is considering urine diversion as a possible option when planning for future investments to meet new legislation and environmental goals. Urine diversion has also been used as one measure to mitigate eutrophication problems along the Swedish coast line.

There are a number of Swedish examples of urine diversion mainstreaming through the establishment of pro-urine diversion policies on municipal level, both within and outside the municipal wastewater jurisdiction. Tanum municipality, with its 12,300 inhabitants, is one example, which is described below. Tanum is located on the West coast of Sweden. In the summer time the number of inhabitants multiplies about 5 times which results in extreme wastewater flow variations over the year. A large part of the inhabitants live in single houses in the countryside in a rocky terrain which makes connections to the centralized wastewater treatment plant difficult and expensive. Thus, sanitation has high priority on the political agenda. This, together with a political will to strive towards a sustainable development, has led to a new municipal sanitation policy that encourages both dry and dual flush urine diversion.

Today there are about 400-500 private households (both dry and dual-flush urine diversion systems), one museum and three camping grounds that have installed urine diverting toilets. Conventional dry sanitation in the form of outhouses is also frequently occurring in the municipality due to its character of summer paradise.

Box 8:
Tanum municipality - Technical System Design

Toilets	Double flushing urines diverting toilets, WM-ekologen and Gustavsberg
Pipes (indoor)	The municipality recommends Ø110-piping after the water seal
Pipes (outdoor)	Likewise
Tanks	At least 3 m^3 per household is recommended by the municipality. The municipality encourages households to arrange for joint tank solutions for several households.
Emptying/use	Urine is collected once a year by entrepreneurs (on contract) or is emptied by the house owner.
Storage – sanitisation	Storage in a separate tank for at least 6 months
Other wastewater fractions	Households with dry sanitation use the faecal fraction in their own garden after composting. Faecal flush water from water flush urine diverting toilets is treated conventionally

Organisation - Local use and cooperation with farmers

To meet up with the increasing number of urine diverting toilets that followed a ban of water toilets in rural settings the municipality started a dialogue with local farmers. Informal recommendations were developed which in 2002 were turned to a municipal sanitation policy. This policy requires urine diversion and/or dry sanitation both for rural settings and within the municipal wastewater jurisdiction. There are a number of newly developed areas in Tanum where conventional, tertiary wastewater treatment will be combined with urine diversion.

Roles and responsibilities

The municipality has declared its responsibility for emptying, storage, and use of urine on arable land and signs agreements with farmers or contractors that are approved for these activities. The sanitation policy states different ways how this agricultural/horticultural urine use can be achieved:

- For houses located within the municipal wastewater jurisdiction, the urine pipes and tanks are owned by the municipality and the municipality arranges for collection of urine and reuse on arable land.
- House-owners outside the municipal wastewater jurisdiction can either arrange for the emptying and use of urine through a municipally contracted farmer or arrange for a private contractor/farmer to empty their tanks. In the latter case the fee is stipulated aside of the municipal contract. The entrepreneurs / farmers reports on their activities back to the municipality once a year.
- House owners, both within and outside the municipal wastewater jurisdiction, can use urine on their property according to given requirements. However, the municipality must give its approval to this for each household.

Economy

Households connecting to the municipal urine diversion system within the municipal wastewater jurisdiction (where the municipality is in charge of tanks etc.) pay the same connection and user fee as households connected to the regular sewer system. Households having their own urine tanks have a reduced connection and user fee. Tanum municipality also works with hardware subsidies for those installing urine diverting toilets, paying half the investment cost for the households.

Information activities and monitoring

Farmers using human urine and representatives from the municipality meet twice a year to exchange experiences and to agree on improvements. In the sanitation policy there are specific requirements for storage and use of urine. There is also general information material available both for household and entrepreneurs / farmers.

Lessons learned: Tanum

One of the most interesting things with Tanum is that the municipality has clarified its role and its responsibilities in the sanitation question and defined itself as a central actor in the system. The municipality of Tanum foresees that different options and strategies may be needed to secure the collection and the use of urine in agriculture. This gives the system flexibility over time and also opens up for individual choices for the households. Of course this is based on a strong political support and that resources are allocated for communication between stakeholders and for good information.

Figure 21: Flemming Arvidsson, Farmer, Grebbestad, in front of the empty urine tanks

„Since we used to have cattle, we already had storage tanks and the machines for spreading urine. There is a summer house area nearby with many urine diverting toilets, which needed collection. It has ended up to around 100 households from which we collect urine, black water or sludge. Today, the urine is diluted with sludge from septic tanks and closed tanks. Therefore the nutrient content is rather low and varies a lot. If there were bigger volumes of urine, we could treat the urine separately and would get a much better fertiliser, with a more exact and stable nutrient content."

Dry urine diversion with reuse of faeces in Norway, private home

Architect Rolf Jacobsen of Gaia Arkitekter has more than 20 years experience in construction of houses with special attention to ecological building methods. In his private home in Tjöme, southern Norway, he has a dry urine diverting toilet system. This toilet system has been in use for 15 years and the owner is very satisfied. The toilet model is a porcelain WM-Ekologen single flush toilet, meaning that the urine is flushed with a small amount of water at need. The flush mechanism is operated by a button, and the user regulates the amount of flush water used.

The faeces are collected in a specially built chamber 1 x 1 x 1,5 m in size. The chamber is built of bricks which have been isolated with 10 cm mineral wool and plastered. Vacation of the chamber takes place from the outside of the building through a hatch. The faeces chamber is emptied manually once a year. This process takes about half an hour, and the secondary treatment consists of composting for one year. After this period the compost is used as fertiliser for bushes and plants in the garden.

The urine is piped to the grey water treatment system, a local treatment plant on the plot, meaning that the urine is not reused in agriculture. The pipe leading out of the toilet is 30 mm in diameter. When the grey water pipes are accessed, the piping is increased to 75 mm in diameter. A ventilation pipe 150 mm in diameter is led through the roof from the chamber. Initially, natural ventilation was tested, but the flow of air out of the system was not enough to avoid smell. A small cable heating the ventilation pipe was installed; it was supposed that this would enable increased flow of air upwards in the system. Since the smell problem persisted, a small fan was installed right at the bottom of the ventilation pipe, forcing ventilation from the chamber. This was successful, and since then smell has never been an issue.

Operation and maintenance includes daily flushing of the urine collection bowl, and washing once a week. Soft blockages in the pipes for grey water occur, 1 - 2 times per year. The blockages are removed with water. A garden hose is attached to the urine pipe and the system is flushed with water at high pressure. Since the urine is not collected, no special care is taken to keep the urine concentrated.

Rolf and his family are very satisfied with the toilet system. "Some of the guests may need a bit of extra explanations, some are curious, but it is seldom a big issue. With the kids sometimes the big stuff falls in the wrong bowl. Not often, really. Emptying of the faeces chamber is a bit rough, but it only takes a half hour every year"

The municipality has no objections to the system of dry urine diversion with local reuse of the faeces.

Dry urine diversion with reuse of urine and faeces in a single-family home, Sweden

Jan and Karin Eksvärd and their two daughters have more than 12 years of experience of dry urine diverting toilet system. The house, situated just north of Stockholm has two such toilets, and when they built the house in 1995-1996, there were very few such alternatives to choose from. There is one toilet on the ground floor, another on the second storey. - We chose the system because it was the best from a sustainability point of view. For us the choice was natural says Jan, Environmental Manager of the Swedish Farmers Organisation.

The toilet model is a porcelain WM-Ekologen single flush toilet, meaning that the urine is flushed with a small amount of water at need. The flush mechanism is operated by a button, and the user regulates the amount of flush water used. Jan and Karin don't use the flushing mechanism since a few years since they noticed that there were hard blockages in the urine pipes due to struvite formation. The blockages have decreased since the family stopped flushing the urine, and one theory is that the magnesium-rich water contributed to the struvite formation. The toilets are cleaned once a week, and indoor smell has not been an issue since initial installation problems were overcome. Both toilets are situated next to a shower, and every second week, Jan takes the shower mouthpiece and flushes a couple of litres of hot water through the system in order to minimise blockages. This is an effective method, and no problems of soft or hard blockages have been noticed.

The house is ventilated, and two of the ventilation outlets are from the toilets. Fans have been installed that draw air from the two bathrooms through the toilet down into the faecal collection chamber and then out through pipes emerging on top of the roof. The fan speed can be regulated, adapting to need of ventilation in the house. At power cuts, smell from the faeces chamber can be noticed in the bottom floor toilet, more seldom on the top floor.

There has been no problem with smell. Once in a while, we have flies, and then it is really important to evacuate the faecal chamber at once, otherwise we have them in the whole house. But if we do that, it is not really a big problem, says Jan.

In the beginning, ash was tested as an additive against flies but it was not effective. Another thing is the diversion of urine for women. It is more difficult for women to direct the urine into the urine bowl, so more urine probably ends up in the faeces bin when women urinate, says Karin.

The pipe leading urine from the toilet has a diameter of 30 mm. The collection pipes in the rest of the system are 75 mm diameter. The urine acts as an odour seal avoiding smell from the urine tanks flowing back into the house.

A three cubic meter polypropylene tank is buried in the garden for collection of urine. The pipes leading from the house, 75 mm diameter, are buried at least 75 cm below ground in order to minimise risk of freezing in pipes. The urine flows to the tank, which is filled from the bottom. There is no pressure equalisation in the tanks. However, the urine flows with such small amounts that there is little risk of back-stopping.

The urine is used in the garden. However, the amounts generated are larger than what is needed and the family would appreciate a system where the urine could be used for example on farmland nearby. As is works today, the urine is spread summertime on grass, using a home made device with hoses dragging on the lawn.

There is much less smell now than when he was spreading it out with the hose, says Karin.

The tank is big enough that the urine could be stored for a couple of years if needed. Initial contacts have been taken with the municipality and a farmer nearby but no interest has been shown.

Faecal matter drops into two separate collection chambers (650 x 650 x 1200 mm), one for the bottom floor toilet and one for the top floor toilet. The collection chambers are situated beneath the house, accessed from the outside, see figure 20. The hatches have been isolated with Styrofoam and the collection chambers are also isolated. This, together with the fact that the ventilation draws heated air from the house into the chambers, means that the faeces do not freeze. No composting takes place in the faecal collection chambers, the faeces are dried and when the chambers are evacuated once every three months, the bins weigh about 15 kg. Twice yearly the dried faeces are taken to a closed faecal compost. The faecal matter is composted for two years and when it is ready, the compost is used on bushes, flower containers and perennials.

In general, Jan and Karin are happy with their toilet system. However, Karin points out the fact that the system is not well known by construction companies. The family has had to make all the plans themselves, and all necessary adaptations such as fitting the pipe for faeces with a plastic flower pot in order to get a better fit.

This system couldn't be built without someone experienced and inventive with this type of practical solutions. As it is now, I could maintain it myself, including emptying the faecal bins and spreading the urine. But when we built it, we couldn't have done it without Jan.

Figure 22: Photographs of WM-Ekologen single flushing toilet. Photos by Rolf Jacobsen

Figure 23: The faecal collection container is accessed from the outside of the house. Photo by Anna Richert Stintzing

Large-scale ecosan services in Dong Sheng, Inner Mongolia, China.

Dong Sheng has a population of 400,000 and is located in Inner Mongolia, in the Yellow River Basin. A new suburb (Hao Zhao Kui, HZK for short) is currently under construction a few km from the city center. In all, the plan is for 2000 households in 1- and 2-storey houses and 4- and 5-storey buildings. The first phase will be completed by 2007.

The efforts in HZK represent an attempt to apply a sustainable approach to water and sanitation systems and services, including

- urine collection, sanitisation and recycling;
- dry fecal collection, sanitisation/composting and recycling;
- kitchen organics collection, composting and recycling;
- grey water collection, advanced treatment and reuse.

The local government is responsible for the operations and maintenance of the ecostations within the area, and the collection service will be included in a monthly fee paid by each household. A training program has been set up for a team to instruct households in the use of the ecosan toilet, the dry urinal, and the source separation of solid waste. The trained ecostation personnel will be carrying out collection of fecal material and kitchen wastes and carry out the composting and eventual packaging for transfer for reuse. Local farmers are trained for reuse of urine and composted materials. The urine storage capacity in the area allows for one month storage. Further storage is organized at the final urine use site. There have been no considerations made for the freezing of urine during cold periods of the year. The storage intervals have rather been geared towards adapting to agricultural needs and organisation. The urine is used in local farms and greenhouses.

Gebers – urine diverting dry toilets in a 2-storey building

Gebers housing area is situated by the lake Drevviken about 15 kilometres from Stockholm city. In 1998 the house, built in 1936, was reconstructed as ecological condominium housing with 80 inhabitants of 32 apartments in a 2-storey building. Gebers is unique in Sweden due to its sanitation system; the installation of urine diversion with dry collection of faeces in a 2-storey building.

Box 9:
Gebers - Technical System Design

Toilets	Single flushing urine diverting toilets, Wost Man Ecology porcelain model in all apartments. Urine is flushed with a small amount at need.
Pipes	The piping system for urine has a dimension of Ø 50 mm and both pipes and tanks are made of polypropylene. No part of the piping system is insulated.
Tanks for urine	The three collecting tanks are located in the basement. The tanks are not insulated, neither are the pipes but as they are running inside the building, the risk of freezing in pipes is low.
Emptying/use	Tanks for urine are emptied from outside the house by an entrepreneur 2 - 3 times a year and used in agriculture after a storage period of 6 months. Faeces are dropped from the toilet in vertical "Spiro" pipes with a dimension of Ø 200 mm and collected in common plastic bins used for garbage. No dessication materials are added after defecation. Each bin is located in a fire proof metal box. The dry faeces can easily catch fire if someone for example throws a match into the toilet. All pipes are constructed to be completely air- and liquid tight. Each household is responsible for maintenance of their proper faeces bin. If the faeces gets too wet, e.g. by misplaced urine, drying material such as sawdust is added. The plastic bins are emptied by each household, frequency depending on load and user attitudes. Some households empty half full bins every second week, others postpone it until they have to carry out full bins. Intervals vary between every second week and twice a year. The faeces are composted together with carbon rich material in layers in a compost box with a water tight concrete floor and a lid, in order to minimize the possibility of environmental contamination and exposure. The compost is stored for a few years before being removed and used as soil conditioner. The compost has not been tested regarding sanitisation. Since it is stored for a long time in the storage bins, most harmful bacteria will have died by the time the compost is used.
Other wastewater fractions	The grey water is conveyed to the municipal wastewater treatment plant for the area.

Figure 26:
The faeces are composted in a closed bin together with grass and leaves. Photo by Ebba af Petersens

Figure 25:
The sanitation system is unique; a urine diversion system with dry collection of feces in a 2-storey building. Photo by Mats Johansson

Figure 24:
Gebers, once a convalescent home, is today a modern apartment house close to lake Drevviken. Photo by Mats Johansson

User aspects

The user aspects at Gebers have been thoroughly investigated through a research project carried out by Linköping University. The research project revealed both positive and negative attitudes among the users in Gebers towards the sanitation system. The low water use is one positive factor and is mentioned by most respondents as one important factor behind the toilet system selection. One of the users says: *[…] my feeling is that every time I use a conventional toilet I'm wasting something we use as drinking water in this country … it feels completely idiotic to pee a few decilitres and then flush ten litres to get rid of it […].*

As long as the ventilation works there is no smell at all in the bathroom, not even right after defecation, which is perceived as very positive. The ventilation is dependent on a functioning power supply. Thus, if there is a power cut there is consequently a bad smell from the toilet.

The most important negative aspect on the sanitation system in Gebers seems to be occasional fly breeding in the fecal bins, a problem that might be the main reason to why some residents in Gebers are discontented with the sanitation system. However, the fly breeding is less of a problem today than in the beginning due to the establishment of some simple practices. The one practice being the most crucial, both in order to prevent flies from multiplying and for getting rid of the problem once it has occurred is an increased frequency of emptying the bin. One resident says: *[…] so when you spot small, small, small, small flies … then you know that there's a hotbed down there and then it is time to go down and remove the sack and you may have to take it often … […].* Other measures to take are to keep the faeces dry by adding ash or lime/ash mixtures or other drying agents. Insect repellents have also been used.

Another issue is the cleaning of the toilet. Although all toilets need cleaning it seems like the residents in Gebers find the cleaning of their dry toilet more difficult than with a water closet, due to the need to avoid too much water into the fecal bin while still achieving a clean faecal bowl. One resident says: *[…] with an ordinary toilet you can just put the brush down into the water that's there ... but here it's somewhat more complicated as … we have the shower right next to it so you sort of have to shower on the brush and then put it into the toilet and try to clean and after that try to make it (the brush; author's remark) clean and shower it … it's a bit trickier […].*

One respondent underlined that the system is comparatively silent, since there is no flushing involved. *[…] I'm really happy that we don't flush. I've lived in apartment buildings and I've heard it, that is, in a flat where you can hear every sound, where I've not only heard the flushing but even the urinating […].*

Some residents, mostly women, are not satisfied with the toilet design from a user point of view and have expressed concerns about too much urine ending up in the fecal drop hole. One respondent says: *[…] the toilet isn't really designed for girls […] you easily pee into the drop-hole and the urine ends up where it shouldn't be ... […] perhaps the urine-bowl should be more …arched or extended like a triangle maybe […].*

Lessons learned:
The Gebers experience shows that it is possible to have urine diversion dry toilets in high standard, 2-storey residential housing. Retrofitting of buildings from waterborne sewage to dry sanitation has worked, even though it is a challenge. Results also show that when motivation is high among the inhabitants, handling and sanitisation of the fecal fraction can be solved locally, even though there is still potential for improvement of especially the faecal handling in Gebers.

Eklandaskolan in Mölndal – school sanitation with urine diversion

Due to a political initiative, a primary school in Mölndal municipality was in 1999 equipped with urine diverting toilets. The school has 450 students aged 6 – 15 years. Municipal investment money was used to finance the construction. A urine diversion water flushed system combined with a fecal separating system called Aquatron is installed. The urine is collected in tanks for use in agriculture. The faeces are composted and used by the staff in private gardens.

Box 10:
Mölndal - Technical System Design

Toilets	65 Dubletten water double flushed toilets. The urine flows by gravity to tanks with a total size of about 50 m^3.
Emptying/use	The polypropylene tanks for urine are emptied once a year after required storage of 6 months on site. The municipality is responsible for transport of urine to a farmer for use on farmland.
Other waste water fractions	Faeces are separated from the main part of the flush water by the use of a separator and collected in a separate tank in the basement for composting. Collected faeces is stored in the tank for at least 9 months and then used as fertilizer by private persons in the neighbourhood, some of them teachers in the school. Separated flush water from the Aquatron-system is treated locally together with grey water in reed beds. No analyses have been made, but the municipal office for the environment monitors the function and is suitably satisfied.
Maintenance	Daily management of the system is run by a janitor. The janitor uses caustic soda, citric acid, boiling water and pipe cleaners once yearly in all toilets to prevent blockages.

Lessons learned:
Oral information about the system to the users, in this case students and personnel, is very important in order to reduce amounts of misplaced faeces and paper etc. From the beginning of the process it is also very important to inform and motivate the operating personnel, especially janitors and cleaners who will run the system. The need for information and clearly defined roles and responsibilities cannot be over-stressed in a school or other public environment.

The largest factor for success according to municipal officers in Mölndal is the janitor of the school, who has taken a personal responsibility of the operation and maintenance. The students have not been enthusiastic, there were complaints of smell in initial stages, but due to the work of the janitor and teachers, these problems have decreased. The smell problems were due to blockages of urine piping, and the strategy from the school was to immediately take action to clean the piping of a toilet when it was reported to the janitor. Proper maintenance with regular flushing of pipes with caustic soda and citric acid has also been advantageous. The experiences show the importance of committed persons in the school, as well as support from government and municipality officers.

7 | Knowledge gaps and identified research needs

Well–planned dry urine diversion systems with agricultural reuse of urine and faeces is not mainstream sanitation in the world today. Most people in the world live with dry sanitation, however, the systems are seldom adapted to efficient reuse of the nutrients in excreta. There are some definite areas where there is a need of systematic research and development (R&D). Some of these, especially related to winter climate aspects, are specified in the following text.

Research needs

One of the most discussed questions regarding urine diversion is the fate of pharmaceutical residues after excretion, and how this affects choice of collection and treatment of human excreta. Research on fate of pharmaceuticals in waste water treatment plants is being undertaken in Germany and Sweden. No known field studies are taking place on fate of pharmaceutical residues when urine or sewage sludge is applied to the soil. The current recommendation to use urine as a fertiliser in agriculture rests on the analysis that the soil system is well suited to digest harmful organic substances due to microbial life in the surface layers of soil. This would be an interesting field of study that can give valuable information on design of reuse systems.

Sanitisation of faeces is another aspect that needs attention. The WHO guidelines on the reuse of human excreta in agriculture mention the alkaline treatment by adding ashes or alkaline substances with a storage time of 6 month (> 35 °C) as a possible way to sanitise faeces, or 1,5 - 2 years storage time. The temperature intervals given do not cater for needs in temperate or cold climates, which means that knowledge on treatment of faeces in this region should be developed. Research on more simple and robust treatment methods is needed.

Suggested applied R&D projects

- Establishment of new pilot projects and evaluation of existing projects. Monitoring and evaluation of existing dry urine diversion projects is a cost-efficient way of generating knowledge. Dissemination of results, regardless of if they are positive or negative, from existing pilots is vital. The establishment of new pilot projects will also contribute to the bank of knowledge.
- Sanitisation of faecal fraction: research on requested storage in ambient or alkaline environment in temperate and cold climates (winters with temperatures far below zero).
- Sanitisation of faecal fraction: research on the implementation of chemical sanitisation of faeces with urea. This is an interesting method, but the practical implications need to be studied and developed.
- Sanitisation of urine: what happens in the urine when it is frozen and what are the implications for storage intervals?
- Pharmaceutical residues: studies of soil system when urine is used as a fertiliser. Effect on microbial community, speed of decomposition. Comparisons with sewage sludge, farmyard manure.
- Toilet design: development of risers and squat-plates for local production. Care given to needs of different users: children, disabled, elderly, men, women. Toilets of today need development since many do not divert as much urine as possible, and are unnecessarily difficult to clean.
- Systems analysis from an economic point of view. Comparison of investment and maintenance costs of urine diversion systems and conventional sanitation.
- Systems analysis from an environmental point of view. How do different activities affect the sustainability of the system, for example fertilisation strategies, choice of tank, joint measures or single toilets?
- What are the economical incentives for implementation of urine diversion? How to design the economical system with the regard to municipal responsibility and financial support/interactions. How should the systems be organized and which are the most important drivers for the different stake holders.

8 | Annex

Read more

There are a few websites where information on sustainable sanitation is presented. Try the following:

- EcoSanRes, a programmed financed by Swedish International Development Agency, SIDA, hosted by Stockholm Environment
  Institute, www.ecosanres.org
- GTZ, the German International Development Cooperation, www.gtz.de/ecosan
- Report from a comprehensive research programme carried out at EAWAG, the Swiss Federal Institute of Aquatic Science and
  Technology: http://www.eawag.ch/services/publikationen/eanews/news_63/index_EN
- WASTE, Dutch NGO/consultancy group with international ecosan activities. www.ecosan.nl
- EcoSan Club Austrian NGO with many international ecosan activities. Project information and publications. www.ecosan.at
- EcoSanRes discussion group http://groups.yahoo.com/group/ecosanr
- WSSCC Water Supply and Sanitation Collaborative Council. Guidance on household-centred environmental sanitation.
  www.wsscc.org
- IWA International Water Association. Specialist group on ecological sanitation.
  www.iawq.org.uk
- WTO World Toilet Organisation. www.worldtoilet.org
- Global Dry Toilet Club of Finland is a registered Finnish association founded in 2002 to promote the use of dry toilets.
  http://www.drytoilet.org

Ecological sanitation related WECF publications:

http://www.wecf.eu

- http://www.wecf.eu/cms/publications/2004/eco_san_pub.php
  Ecological Sanitation and Associated Hygienic Risk, 2004
  An overview of existing policymaking guidelines and research

- http://www.wecf.eu/cms/publications/2006/sustain_all.php
  Case study „Sustainable Development for All";
  Reducing effects of polluted drinking water and inadequate sanitation on children´s health in rural Romania (2006)

- http://www.wecf.eu/cms/publications/2006/menstruation.php
  Ecological sanitation and hygienic considerations for women

- http://www.wecf.eu/cms/publications/2006/ecosan_pitlatrines.php
  From pit latrine to ecological sanitation
  Results of a survey on dry urine diverting school toilets and pit latrines in Garla Mare, Romania; Experiences and Acceptances

- http://www.wecf.eu/cms/publications/2006/ecosan_reps.php
  Dry Urine Diverting Toilets;
  Principles, Operation and Construction

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