# SUSTAINABILITY IN SOLID WASTE AND SLUDGE HANDLING - SOURCE SEPARATION OR END-OF-PIPE SOLUTIONS

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**ABSTRACT**
Towards a sustainable society, a recycling and recovery of products together with handling of scarce resources must be considered. In this article arguments for source separating systems and end-of-pipe solutions for urban wastewater systems are investigated and compared to the close by sector- the handling of solid wastes in households. In Sweden, the handling of solid wastes has come far with recycling of products. The responsibility is on the individual basis to sort out the wastes at the source. The development in urban wastewater systems has not reach the recovery level yet, but the legislations and environmental aspects are implying to go from removal to recovery.
A comparison was made between a source separating system and an end-of-pipe solution. The result showed that the end-of-pipe solution was favoured in most of the criteria, as the criteria were seen as equally important. A strong argument for end-of-pipe solutions is that the future urban environment will be a dense city, which creates strong motives to build further on the central systems already existing. Furthermore, larger organisational resources and dialog between actors are demanded when introducing the source separating systems compared to what is demanded for conventional systems. In addition to that, the local solutions are considerable more expensive than when the city is fully connected to the large scale system. However, it is likely to believe a recovery from WWTP will take place in a dense city and in more scarcely populated areas source separating systems may appear.

**KEYWORDS**
Phosphorus recovery; recycling; sanitation; Sweden; urban wastewater systems

## 1. INTRODUCTION

### *1.1 Material flows in society*

In modern society, great amounts of material are imported to maintain, support, and develop its metabolism and infrastructure. The downside is the vast amounts of residues and waste produced, e.g. wastewater, municipal solid waste, industry wastes and degenerated infrastructure (Palmquist, 2004). The household is a source of many wastes, much of the household waste can be minimized by recycling items such as newspapers, plastic beverage containers, glass, and aluminum (Hedén, 2001). The majority of the household wastewater in Sweden today is collected and led to a central wastewater treatment plant (WWTP) where it is treated mechanically combined with biological and/or chemical treatment. There exist also smaller local scale WWTP and even down to detached households (Vinnerås, 2002).

*1.2 Towards a sustainable society-the future city*

The future city may have different appearance (Berg and Tälleklint, 2005). By an acute resource and environmental crisis the local self-supporting and the close scale recycling are important means to survive a sustainable provision. This will lead to a physical more spread out and maybe less culturally developed city. A strong hypothesis in the planning research in the future urban environment is instead a dense city, which can gather the resource flows and recycling or recovery processes in a central effective facilities with much service demand. In such development it will be reasonable to dense also the surburbs. This creates strong motives to build further on the central systems already existing. However, the American city development seems to be that the city is spread out as sparsely residential districts, similar to the Swedish million programme residential areas, which will promote to install alternative urban wastewater systems (Berg and Tälleklint, 2005).

Sustainable city development demands an integrated handling of the physical, economical, biological, organisational, social and culture-decided resources of the city. The introduction of new or modified technologies and processes must be sustainable and each place unique characteristics must be considered. The success is also dependent on that the citizens can and want support or in each case accept the system introduced (Berg and Tälleklint, 2005).

*1.3 The role of the households*

An improved sustainability of the urban infrastructure may be reached with help of technical arrangements and suitable management systems. The growing chemical society has changed an earlier perception that the technical system can be developed and manage all kind of use included the misbehaviour of the households. The environmental actions of the accommodator have therefore been more important to a good functional infrastructure of water, waste and energy and the accommodators are integrated again in the management system states Drangert (2004).
The role of the households has changed during the last decades and may be described as from anonymous users to a costumer in a municipally or private owned company, and latest as a partner in the recycling work. The change has a decisive influence on the relations between property constructors, the recycling companies and the users.

*Objectives*

This article focuses on finding arguments for end-of-pipe solutions for sludge handling by study the arguments for source separation systems. A parallel comparison is made with the development of solid waste handling in households.

## 2. TODAY SYSTEMS

*2.1 Solid waste handling*

Nowadays, in Sweden, the responsible of the management of waste is not only by the municipalities but also transferred to the people and producers (Hedén, 2001). In Sweden, there has been a change in solid waste treatment from landfilling to more recycling of wastes (Figure 1).

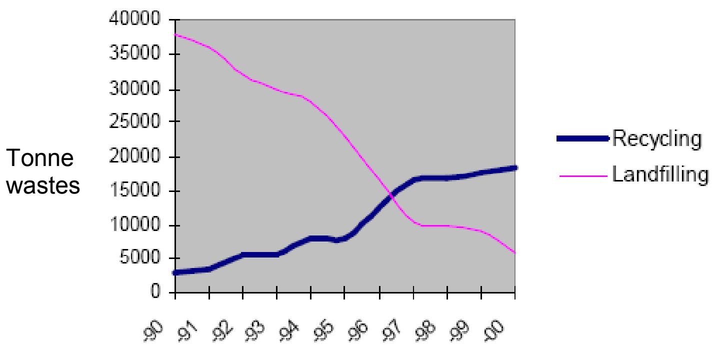


Figure 1: The positive trend between landfilling and recycling in Falun Municipality (Hedén, 2001), which may be seen as representative for whole Sweden.

*2.1.1 Source separating system in Falun*

The Falun Municipality has introduced a management method and system to handle the household waste. The sorting processes start in every household. By sorting, the utility of the household waste content can be increased and the waste can more easily return to the natural resource cycle. Hazardous waste, packaging material, paper and bulky waste, and the remaining household waste are separated. The remaining of household waste is divided into three different colour plastic bags. Left over food and compostable waste is put in black plastic bags. Waste, which can be burned is put in red plastic bags. Other wastes that cannot be composted or combustible are put in green plastic bags (Hedén, 2001).

All refuse, which is collected by the refuse truck, is transported to the waste handling plant. The intention is that the less waste the accommodators through, the less money should they pay. Black plastic bags are transported to Borlänge's and Falun's shared biogas and composting plant. The red bags with combustible waste are transported to the district heating plant in Borlänge. About 25% of the energy production comes from combustible and industrial household waste that has been separated at sources. The other bags with the waste for landfill deposit are transported to the landfill site (Hedén, 2001).

Further, there are approximately 40 recycling collection points in Falun municipality. This is the common method used in the rest of Sweden. The collection points are placed close to shops, parking places, housing areas and other natural meeting places. Everyone can leave the empty packages, coloured and transparent glass, metals, batteries, hard plastic and paper, clothing, shoes as well as newspaper/magazines. The collected packages are recycled, as well as paper are made new packaging and products and used for newspaper and creed paper tissue. Textiles are often used in different aid projects and small batteries are sorted and taken charge of.

*2.2 Sludge handling at WWTP*

The sludge handling in Sweden has so far been focused on as a disposal problem, but there seems to be a change and the sludge is more seen as a resource by the WWTP. The most common method for the sludge was construction soil according to an interview made in the Swedish WWTPs (Gävle Vatten, 2004). The sludge use and cost are summarised in table 1. The handling of sludge has increased in cost the latest years. The cost of sludge treatment in the table is not including transport.

Table 1: Sludge use and cost in Swedish municipalities.

| Sludge use | % of the municipalities | Cost (SEK/tonne) |
|---|---|---|
| Construction soil | 65 | 239 |
| Agriculture | 13 | 226 |
| Landfills | 11.5 | 657 |
| Salix | 8.5 | 221 |
| Incineration | 2 | 559 |

The Swedish farmers organisation, LRF, recommend Salix for sludge use, due to uncertainties about the sludge content. The agricultural use is done within a project called Revaq, which involves 7 municipalities looking how to produce a sludge to agriculture use. Research in the field of reducing sludge volumes and enhancing the sludge quality is tested in Sweden (Manhem and Palmgren, 2004). Also, research in the field of phosphorus recovery from sewage sludge is going on (Stendahl and Jäfverström, 2004; Stark and Hultman, 2003), but still no full-scale plant is tested.

### *2.3 The recycling companies in Hammarby Sjöstad*

In Hammarby Sjöstad, a new residential area in Stockholm, the companies taken care of solid waste and sludge handling are the Refuse collection administrator (Renhållningsförvaltningen, earlier SKAFAB) and Stockholm Water Co. The municipally owned company Stockholm Water has monopoly to produce and deliver water and treat wastewater from the households. The Refuse collection administrator is the order organisation of the city for several refuse collection services and trade entrepreneurs. The collection of white goods, newspapers and wrappings is regulated in regulations about the responsibility of the producers and others deal it. Another difference between the recycling companies is that they are responsible of different parts of the material flow through the households. Stockholm Water Co delivers the water and treats the residue product the wastewater, while the Refuse collection administrator does not have anything to do with the incoming products, except only the ones leaving the households. These differences must be taken into consideration when discussing cooperation between the recycling companies.

The companies decide their own taxes for their services as a combination of a fixed and a mobile part, and the taxes are the same for the inhabitants in Hammarby Sjöstad as in the rest of Stockholm. The companies have demand to cover all their costs inclusive information efforts. However, the environmental goals are not forcing, but aims and visions, which is not connected to any sanctions.

In Hammarby Sjöstad, each inhabitant gives app. 70 kg digested and dewatered sludge each year. The sludge from Stockholm Water Co contains totally 600 tonnes phosphorus, which correspond to 3-4% of the total Swedish consumption of fertiliser. Sludge of good quality can be used to construction soil, but the main part is today used to restore the area with mine waste in north of Sweden. Each inhabitant in Stockholm generates app. 300 kg solid wastes each year. The households in Hammarby Sjöstad are good in sorting food wastes, which goes to Sofielund compost site and becomes soil. The ordinary waste bag goes to incineration in Högdalen power heat works and becomes distant heat and electricity (Drangert, 2004).

## 3. FUTURE SYSTEMS

### *3.1 Sustainability assessment of urban water systems*

The Swedish research programme Urban Water has developed a concept of a multi-criteria basis intended to support decision-making for urban water and wastewater systems. The five criteria groups established for sustainability assessment of urban water systems are:

1) Health and hygiene
2) Environment
3) Economy
4) Socio-culture
5) Technology

Each criterion requires a set of indicators corresponding to quantifiable facts and figures, or qualitative data to comparatively assess the different alternatives in the decision process (Malmqvuist and Palmquist, 2004). Figure 1 shows the framework of an integrated urban water system that has been equally divided into three subsystems.

- *The organisation* owns, plans, finances, and manages the urban water system, and may be public or private, central or local.
- *The users*, uses the water and need to get rid of the waste products

- *The technical system* (pipes, pumps, treatment plants etc) supplies the water and takes care of the wastewater.

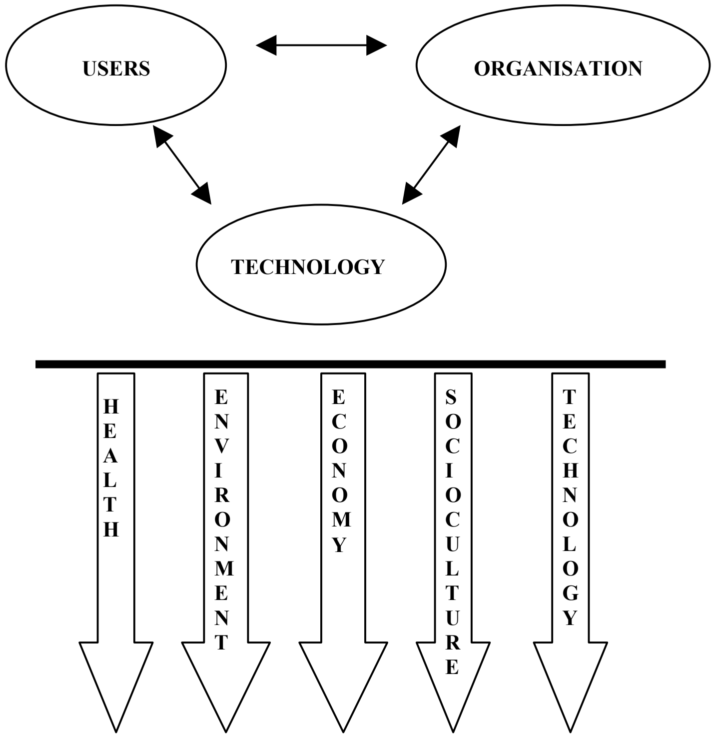


Figure 2: A framework for the integrated sustainability assessment of urban water and wastewater systems as suggested by the Swedish research programme Urban Water (modified from Malmqvist and Palmquist, 2004.)

Further, the research programme Urban Water uses five different model cities. They represent a number of habitation types, ranging from a countryside town to a part of a city centre. For each of the model cities, different system structures have been developed, as some are described below.

*3.2 Prerequisites for alternative urban water systems*

*3.2.1 Legal prerequisites*

Olofsson (2004) judged from statements made by the Swedish government in a number of bills on environmental goals and from ongoing investigations that an overall tendency towards legislation aims at making wastewater even cleaner than it is today. More restrictions on the use of sewage sludge in agriculture are also expected. Further, there may be a future opening for alternative wastewater systems, since the need and the will to make use of the nutrients found in wastewater are constantly growing.

As regards EC regulations, the tendencies for a development are in the same direction as in Swedish legislation. For instance, the sewage sludge directive is subject to revision, which will probably lead to more restrictive legislation in that area. Furthermore, the Commission has adopted a policy, which aims at increasing the protection of soil against pollution. Overall, the legal prerequisites for changing system structures into reality are fairly unproblematic. However, the final design must make the systems meet the specific technical requirements that are found in some parts of the legislation. In particular, the treatment processes must be sufficiently effective and the methods chosen must also have the economic capability for adjustment to future demands. In the separating systems, the idea of using untreated human urine in agriculture may be problematic. On the plus side, the blackwater systems and the separating systems divide the wastewater into different fractions, which facilitate access to the desirable nutrients in a more pollution-free form. Sewage sludge is seen as waste in Swedish regulations, which results in demands of the handling and the storing.

*3.2.2 Comparison of different urban water systems in Hammarby Sjöstad*

In Hammarby Sjöstad, different sewage systems have been studied (Hellström, 2005). The systems are:

1) Combined system with sludge handling using supercritical water oxidation (SCWO) and sludge fractionation
2) Blackwater system with urine separation and kitchen waste mills
3) Local treatment plant with nutrient recycling.

All systems are acceptable in the hygiene and environmental load. In the point of view in resource usage, blackwater has with urine separation an essential lower exergy usage than other systems and the system with local treatment plant has the highest exergy usage (as exergy is the qualitative energy). The local solutions are considerable more expensive than when the city is fully connected to the large scale system (1). The total cost is such high that it is not defendable with the potential exergy saving, but must be motivated with demand on recycling/recovery of pure nutrients via a process, which is driven by a decreased adding of process chemicals.

The results indicate that source separating systems qualitative can be seen to have larger technical risks than the combined system. Chemical risks need more data to make a quantative risk judgement of the different systems.

From the users side there are no obvious preferences for any of the systems. Alternative (1), combined system and alternative (3) with local treatment plant mean no deviation from the traditional system from the user and property developer perspective. The blackwater system will however demand another and more intensive dialog with constructor and future property owner. Larger organisational resources and dialog between actors are demanded when introducing the source separating systems compared what is demanded for system (1) and (3). The implementation of all alternatives is depending on Stockholm Water as a central actor.

A hindrance of the development to introduce source separating, local systems is the lack of experience of similar system, no shared values and financing of the increasing costs. The juridical and political acting space is judged as enough to complete any of the alternatives. However, there is no obvious arena for the actors to meet and discuss the aims with the activity (Hellström, 2005).

*3.2.3 Substances flow analysis in Vasastaden, Göteborg*

Substances flow analysis for different sewage systems have been performed in Vasastaden, Göteborg by Ahlman et al., (2004). The study showed that there is no benefit to introduce a source separating system for blackwater, if the sludge cannot be recycled to agriculture or land where the conventional sewage sludge is not accepted. Further, the total cost to build separating sewage systems will be 30 times higher for nitrogen and app. 200 times more expensive for phosphorus. This makes it not reasonable to reconstruct present sewage systems only looking at nitrogen and phosphorus (Ahlman et al., 2004). There would be possible to find other solutions at the source or the treatment plant, which give less cost per kg recovered phosphorus respectively nitrogen. The introduction of source separating systems has not reach satisfaction in the hygiene and the environmental area state Ahlman et al., 2004.

Furthermore, the investigation showed that the sewage sludge from Rya WWTP, Göteborg will pass the heavy metal limits, but has to little phosphorus and need hygienic treat according to the proposed future demands for sludge use in agriculture according to the Swedish EPA action plan year 2020. There are no proposed limits for organics and other risk substances as hormones and medical residues today, which may stop the confidence for sludge use. Efforts to decrease heavy metals in recipient and sludge should start at the source. If the legislation does not forbid the use in larger extent than today, the behaviour of the user must be changed (Ahlman et al., 2004).

*3.2.4 Attitudes to alternative urban water systems in Gottsunda and Hammarby Sjöstad*

The prerequisite to implement new sewage systems has been studied in Gottsunda, a residential area with 7000 persons in Uppsala, north of Stockholm with focus on economical, social and ecological view (Berg and Tälleklint, 2005). The study of attitudes to urine separation shows that the technology must work invisible, the maintenance of the local treatment plant and urine separation is not a work for the people living in the area and that the costs must be close to the normal tax for water and wastewater. Further, the toilets shall also have an esthetical, functional and hygienic standard at least as good as the conventional system. Robustness in reality and a durable technique is necessary. The report states that the area needs a training period to be smoothly introduced, and it demands a strong recommendation by the municipality, by the residence administrator, the residence union, the ethnical organisation and by the school to create a social acceptance.

Drangert (2004) presents views among residents and professionals concerning environmental measures and daily routines to improve sustainability in Hammarby Sjöstad. The interviews show that the visibility of rest products of used water, energy, and goods impacts on residents´ view on who should be responsible for the environment. Most residents are prepared to make the extra effort to sort solid waste, despite rumours that the sorted fractions are being mixed at a later stage. However, they ask for better space in the kitchen and waste-collection room to facilitate the sorting. As for water use, the answers may be summarised; residents neither want to save, nor be wasteful. There is a general awareness that the choice of detergents and soaps impacts on the quality of the wastewater. There is an outspoken willingness from the service providers of water, energy and solid waste to support residents with information. They view investments in residents´ environmental knowledge as important as in the technical maintenance of installations. The information should explain causes and effects of different daily routines, and be concrete or hands-on.

## 4. DISCUSSION

Arguments for source separation or end-of-pipe solutions for urban wastewater systems may differ as negative or positive depending on the asked actor. Most likely there are space for both types of systems in the future city. Following are some arguments for choice of systems;

*-Source separting systems may not be introduced in cities due to long transportation for urine collection etc, therefore it is better to use end-of pipe solutions.*

Comparing to the solid waste handling, transportation is not an obstacle, for example all collected glasses in Sweden is driven to two places in Sweden.

*-Must the individual be involved to reach sustainability? The individual takes more responsibility if one can see the residues, as in source separating systems.*

It seems to that the visibility of the residue product after use is affecting or shape the accommodators perception of their own role in the flow and recycling. It would be said according to Drangert, (2004) that the more visible the residue product is, the more responsibility is on the household. The electricity is an exception since the residue product is invisible. The wastes of household are the other extreme to be visible, both at home and when the refuse truck is coming. The accommodators would see their responsibility for wastes essential larger than for the electrical use. Is this practicable for sludge residues as well? Does the individual need to know what happens after used the flush at the toilet? However, the end-of-pipe solutions do not mean that the individual needs not to take responsibility; instead it is still important to source separate at the households to make the processes work in the WWTP.

Other questions to be raised for the source separating systems are:

- *Physical resources –is the environment winning or losing?*
- *Economical resources- are sorting toilet cheaper or more expensive?*
- *Biological resources –is it possible to link city and land/countryside?*
- *Organisational resources-it must be easier to keep it clean!*
- *Social resources –can the neighbour so can I!*
- *Cultural resources- I will ask my believe or my friends!*
- *Esthetical resources- it must not smell or be noisy*!

Product recovery in the WWTP is a method that "in principle" can solve sludge handling and disposal problems. By the end-of-pipe solution sludge fractionation, hygienisation is normally obtained, heavy metals can be released from the sludge and handled separately, and toxic sludge-bound organic materials may be destructed by incineration of a rest fraction during the fractionation. During the sludge fractionation the sludge amount may be reduced significantly by dissolving inorganic materials for use as precipitation agents and the fraction of biodegradable substances can be increased. The sludge normally gets better dewatering properties. Different sludge products are obtained making it possible obtain far-reaching goals for eco-cycling of resources.

A comparison is made between a source separation system and an end-of-pipe solution, both systems are including recovery. The chosen systems are a blackwater system with urine separation and a WWTP plant with Aqua Reci process (using SCWO) as the energy and recovery unit for fertiliser. Selected indicators for each criterion are chosen according to Malmqvist and Palmquist (2004). Since each indicator may be positive or negative, a change of the indicators is made to be in positive manner, which will facilitate the comparison between the systems. Data for the comparison are taken from Ahlman et al., (2004); Balmér et al., (2002); Berg and Tälleklint (2005); Hellström, (2005); Stendahl and Jäfverström (2004); Stark and Hultman (2003); Vinnerås (2002). Table 2 shows the comparison between the source separating system (S) and the end-of pipe solution (E) with selected indicators for each criteria. The system chosen is the one which gives lowest respectiviely highest effect depending on the indicator.

The comparison between the systems show that the end-of-pipe solution gets more positive indicators than the source separating system when each indicator are seen as equal important. Weighted indicators and criteria may change the results. However, larger organisational resources and dialog between actors are demanded when introducing the source separating systems compared what is demanded for changes in the conventional system. Source separation is motivated by easily recover of nutrients to farmland, but need social acceptance and the factor economy is essential for the individual. Source separation systems are preferred to be installed in small-scale units, and in residential areas outside the dense city.

The juridical and political acting space is judged as enough to complete any of the alternatives. The future regulation seems to be stricter in discharge and sludge use, but promote alternative urban wastewater systems.

Table 2: Comparison between a source separating system (S) and an end-of pipe solution (E) with selected indicators for each criterion.

| CRITERIA | | | | |
|---|---|---|---|---|
| **HEALTH AND HYGIENE** | **ENVIRONMENT AND USE OF NATURAL RESOURCES** | **ECONOMY** | **SOCIO-CULTURE** | **TECHNICAL FUNCTION** |
| | *INDICATORS* | *WITH CHOSEN* | *SYSTEM* | |
| Lowest microbial risks: Exposure to pathogens **E** | Lowest flows of heavy metals to water **S** | Lowest annual cost **E** | Best institutional capacity, incl. Split of responsibilities and risks between actors **E** | Highest technical robustness **E** |
| Lowest chemical risks: Exposure to pharmaceutical residues **E** | Lowest flows of heavy metals to farmland **E** | Lowest transition cost **E** | Best possibilities for learning and participation **S** | |
| | Highest reuse of nutrients to farmland **S/E** | Lowest financial cost **E** | Best social robustness **E** | |
| | Lowest use of energy **S** | | Best comfort **E** | |
| | Lowest discharge of nutrients to water **S** | | | |

Solid waste handling in Sweden, has moved from landfill to source separation. Several of the fractions that are sorted are recovered by different material companies, which were founded after the introduction of the law of product responsibility 1994. Today, there are only regulations about removal and not recovery in WWTP, but it will probably appear regulations in the future. This will have a major influence on future sludge handling technologies.

## 5. CONCLUSION

The last decades, the tendency in solid waste handling of households in Sweden is essential more source separating handling. The development in urban wastewater systems has not reach the recovery level yet, but the legislations and environmental aspects are implying to go from removal to recovery.

A comparison was made between a source separating system and an end-of-pipe solution. The result showed that the end-of-pipe solution was favoured in most of the criteria, as the criteria were seen as equally important. The development of source separating wastewater systems may meet disturbance as by public acceptance, high cost for individuals and organisations in dense future cities. Source separating systems are favoured in sparsely residential districts and when individuals want to be involved in the recycling process. However, an end-of-pipe solution does not mean that the individual needs not to take responsibility, instead it is still important to source separate at the households to make the processes work in the WWTP, even though the residues is not seen in the household.

Following arguments for end-of-pipe solutions are found:

- The future urban environment will be a dense city, which creates strong motives to build further on the central systems already existing.
- Less organisational resources and dialog between actors are demanded with conventional systems compared with what is demanded when introducing the source separating systems.
- It is cheaper to have the city fully connected to a large-scale system than have local solutions.
- Less maintenance and less technical risks in households are considered with end-of-pipe solutions.

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