Better use of bioenergy and plant nutrients from human waste

Recycling Closet (**RC**) instead of the Water Closet (**WC**)

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Abstract. We need to protect the water from contamination and therefore human waste (HW), i.e. toilet waste, should be recycled without the use of water as a means of transportation. RC will be used instead of the WC to make better use of bioenergy and chemical elements i.e. plant nutrients that are remaining in HW and thus reduce use of artificial fertilizers, to reduce the transport of drugs into waterways since HW will be treated in biogas plants, to prevent the use of potentially toxic chemicals in sewage treatment plants (WWTP), to improve the working environment for staff who manage renewable organic material (ROM) in household waste (HHW) and HW, and also to reduce the presence of rats in the sewers.
RC can be placed anywhere, but it may be appropriate to start with placement in public places, on trains, buses, planes, boats, campsites and vacation areas or when building new or renovating old city areas. Even food waste (FW) (i.e. food scraps and residue from cooking) can be collected in RC and safely transported to biogas plants. It is an advantage to build effective local biogas plants for co-processing of ROM from HHW with HW collected in RC and with other ROM from municipal solid waste (MSW) as well as residues from cultivation systems and industries. Local biogas plants should use the "optimum solids anaerobic digestion" (OS-AD) to create the best conditions for microorganisms involved in biogas production and should be included in the Sustainable Biological Recycling System (SBRS). This system will increase cost efficiency in the management of all types of ROM, reduce negative impacts on our health, on the environment and improve social conditions.

Key words: Bioenergy, biogas, food waste (FW), household waste (HHW), human waste (HW), municipal solid waste (MSW), plant nutrients, Optimal Solids Anaerobic Digestion (OS-AD), Recycling Closet (RC), renewable organic material (ROM), wastewater treatment plants (WWTP).

1. Introduction

By using today's knowledge as well as new results from research on bioconversion, a large amount of fossil fuels can be replaced with bioenergy which today is lost. Renewable organic material (ROM) in the residues and wastes contains the solar energy, fixed during photosynthesis in plants as bioenergy, which is available in everything derived from plant and animal kingdom. Likewise, all ROM contains chemical elements called plant nutrients. That should be returned back to the cultivated fields.

There are many data on the quantities and types of waste that are based on analyses of various kinds. In 1998 was presented a report on the results from an extensive picking analysis performed on household waste (HHW) in Sweden (**1**) table 1. The report shows that 76% of HHW is suitable for biological treatment. ROM in HHW is a mixture of dry and wet residues, including food waste (FW), which originates from plants and animals. It should be advantageous to mix ROM from HHW with the human waste (HW) collected in Recycling Closet (RC) for bioconversion in local biogas plants.

The world runs on water (**2**). We need to protect the water from contamination and therefore should be recycled human waste (HW) without the use of water as a means of transportation. Grey water from bathing, dishwashing and laundry can be cleaned much easier in small local plants and used locally for irrigation, fountains and water features.

Table 1: Data on solid waste from the Reforsk report compared with data from treatment at that time in Sweden and assumptions on amount of liquid waste as well as suggestions for the treatment in more sustainable ways.

Solid waste	Recommendations in report "Reforsk, FoU 145, 1998" %	Treatment of household waste in 1998 %
Recycling	12	12
Incineration	6	50
Landfilling	6	38
Suitable for biological treatment	76	0
Liquid waste Assumption per person per year	Suitable for biological treatment	Waste water treatment in 1998
Waste water (litre)		73 000 – 100 750*
Human waste (kg)	430	
Grey water (litre)	71 000**	

* Wastewater and human waste

** Water from bathing, dishwashing and laundry. Grey water from bathing, dishwashing and laundry can be cleaned much easier in small local plants and used for irrigation, fountains and water features.

2. Recycling Closet (RC)

The table 1 shows clearly the opportunities available for sustainable ROM management when comparing the report's facts with the current treatment of HHW. The lower part of the table shows the amounts of liquid waste i.e. HW without dilution with water which can be compared to the current practice using WC, sewers and wastewater treatment plants (WWTP).

Changing the management of waste and sewage into local more sustainable systems and transporting HW without dilution with water have been proposed already in 2002 (**3**). To enable a hygienic and easy collection of HW for transport to the biogas plant is now under construction a Recycling Closet (RC).

Why do we need RC?

- To better use of bioenergy from HW where the bioenergy remains after our bodies have utilized only a portion of what is in the food. By the microbial transformation can bioenergy from HW become utilized both as an energy rich methane in the biogas and as biofertilizers containing the bioenergy that is beneficial for soil fertility.

- To efficiently recycle all chemical elements from HW and food waste (FW) by delivering ROM to biogas plants, and thus reduce use of artificial fertilizers. There are 16 essential plant nutrients (**4**). Carbon and oxygen are absorbed from the air, while other nutrients are obtained from the soil solution. In Nutrient Management (2011) are described some more chemical elements as essential (**5**).

- To reduce the transport of drugs into waterways since HW will be treated in biogas plants. Drugs will be processed in completely closed systems for biological transformation and thus the negative impact on the environment is minimized. The current system is lacking control and it negatively affects aquatic life.

- To avoid use of more or less toxic chemicals those are now added to purify wastewater in WWTP, while minimizing the use of mineral fertilizers, especially nitrogen and phosphorus fertilizers.

- To improve the working environment for staff who manage ROM in HHW and HW as everything is performed in closed systems so that all unpleasant smells are avoided

- To prevent the presence of rats in the sewers when ROM is handled in closed systems.

RC can be placed anywhere, but it may be appropriate to start with placement in public places, on trains, buses, airplanes, boats, campsites and holiday resorts or when building new or renovating old city areas.. Since even the FW can be collected in the RC, it is advantageous to build effective local biogas plants for efficient conversion into biogas and biofertilizers not only material from RC but ideally also other ROMs which are in residues and wastes.

3. Bioconversion

Efficiency of bioconversion processes depends on many factors which should be optimal for the microbial consortium that is acting during the process. Bioconversion with high precision is often used in the production of food such as bread, sour milk, yogurt and cheese. Production of wine, beer and sauerkraut are some examples of anaerobic processes where atmospheric oxygen is absent. Increasing yields of biogas and quality of biofertilizers is only possible by better precision in pre-treatment and during anaerobic digestion.

Anaerobic digestion (AD). To obtain maximum benefit, microorganisms need right substrate having all factors at optimum and the right environment that is created with the appropriate equipment. One of the key factors is the substrate total solids (TS), which is used to describe certain types of biogas plants. If TS is between 0.5% and 15% the expression is Anaerobic Digestion (AD). For processes where TS is over 15% is found term Solid-State Anaerobic Digestion (SS-AD). Various European companies such as Valorga use TS between 25% and 35%, Kompogas has range of 23-28% TS and Dranco operate with 30% to 40% TS in bioreactors (**6**).

In 1989 was presented experiments with bioreactors for High Solids Anaerobic Digestion (**7**). The idea was that with increased TS increase the volume of gas produced per volume of bioreactor because the costs of bioreactors for low solids are significant. MSW with TS up to 35% were tested and results showed 6 to 7 times higher yield per volume of bioreactor in comparison with low solids method (**8**).

Optimal Solids Anaerobic Digestion (OS-AD). Development of more sustainable local biogas plants was proposed already in 2012 (9). It is known that optimal TS in the substrate can vary depending on the composition of the ROM. Therefore it is time to use available knowledge and design biogas plants with equipment appropriate to Optimal Solids Anaerobic Digestion and using OS-AD in place of the names SS-AD, HSAD dry-AD or "anaerobic composting" because that all these terms are somewhat misleading.

H. Ljunggren Professor of Microbiology at the Swedish university of agricultural science suggested that the TS in the bioreactor for optimal microbial conversion should be about 30% since it is optimal TS for most microorganisms (personal communication). Of course, other factors must be as close to optimum as it is realistically possible to achieve the best results.

Among the most important is the ROM free of impurities that can disrupt biological transformation, environment free of atmospheric oxygen, particle size, C / N ratio, pH, temperature and inoculum.

In decentralized biogas plants, where microorganisms receive optimal conditions for efficient biological conversion with the help of modern logistics, mechanization, automation and computerization, we can achieve the maximum use of bioenergy available in methane in the biogas. After the biogas is produced, part of bioenergy and all chemical elements remains in biofertilizer that will be returned to cultivated soils. Biofertilizers are important both for humus formation and as fuel for soil microorganisms that help plants to take up nutrients. Diversity of soil microorganisms also creates balance that reduces the occurrence of plant diseases.

4. Bioenergy and plant nutrient from renewable organic material (ROM)

The amount of HE per capita on average across the EU can be estimated 1.2 kg or 1.2 litres depending on how you want to present it. In 2013 was in Europe 742,500.000 inhabitants. Every resident produces per day also about 0.8 kg ROM in MSW including FW. This means that 2 kg ROM per person per day can be used as raw material in local biogas plants. Totally about 500 million tons ROM can be upgraded to biogas and biofertilizers.

Table 2: The amount of Renewable Organic Material (ROM) that is suitable for biological treatment in some countries round Baltic Sea when human waste (HW) and ROM in household waste (HHW), including food waste (FW), that can be treated in biogas plants, when it is assumed that it is at least 2 kg ROM per person and day; estimated data on the total content of bioenergy, in GWh; how much can be converted into biogas, in GWh; how much will be left in biofertilizers, in GWh; and costs of nitrogen and phosphorus which, with the current system must be replaced with synthetic fertilizer but in biogas plant can be reused, in €.

Inhabitants	ROM (at least) tons per year	GWh Total bioenergy per year	GWh Bioenergy in biogas per year	GWh Bioenergy in biofertilizers per year	€ Value of nitrogen and phosphorus per year
1 000	730	2,2	0.7-0.9	1.0-1.2	5-7
10 000	7 300	22	7-9	10-12	50-70
100 000	73 000	220	70-90	100-120	500-700
1 000 000	730 000	2 200	700-900	1 000-1 200	5 000-7 000
DK 5.5 millions	4 025 000	12 100	3 850-4 950	5 500-6 600	27 500-38 500
SE 9.5 millions	6 935 000	20 900	6 650-8 550	9 500-11 400	47 500-66 500
FI 5.4 millions	3 942 000	11 880	3 780-4 860	5 400-6 480	27 000-37 800
EE 1.3 millions	949 000	2 860	910-1 170	1 300-1 560	6 500-9 100
LT 3.3 millions	2 409 000	7 260	1 540-1 980	3 300-3 960	16 500-23 100
LV 2.2 millions	1 606 000	4 840	2 310-2 970	2 200-2 640	11 000-15 400
PL 38 millions	27 740 000	83 600	26 600-34 200	38 000-45 600	190 000-266 000
EU 742,5 millions	542 025 000	1 633 500	519 750-668 250	742 500-891 000	3 721 500-5 197 500

Table 2 provides estimated amounts of ROM which is included in HW and in the HHW including food scraps and residue from cooking i.e. food waste (FW). The latest can best be collected by RC to prevent contact with air and thereby prevent pollutions that are polluting losses. Regarding only the mentioned countries around the Baltic Sea the amount of ROM is about 44 million tons. When used in biogas plants, working with OS-AD method, value produced biogas will be between 45 TWh and 58 TWh. Potential of biogas production is much higher if all ROM from residues from agriculture and industries and ROM in the waste from parks, gardens, water bodies, etc. are utilized. In biofertilizers would remain about 65 TWh and 78 TWh of bioenergy in organic structures that are important for maintaining and increasing soil organic matter (increase the storage of carbon in soils). The bioenergy in soil organic matter is important for soil organisms and for soil fertility.

Why bother with soil fertility?
We need to protect soil fertility because our children and grandchildren and other future generations will also be able to capture the sun's energy through photosynthesis into new bioenergy in plant biomass that turns into food, feed, fiber and fuel. Biofertilizers also contain all the necessary substances that plants need for growth and development. In Table 2, only the value of nitrogen and phosphorus that runs today lost, in some countries on the Baltic Sea, to between € 300,000 and € 800,000.

Internet search regarding recycling of phosphorus and nitrogen from wastewater led to the web page "Advanced Nutrient Recovery" with the following information:
Wastewater*, municipal* sludge *or the ash after dried* sludge*, which is incinerated or disposed of, can be a very rich source for* nutrients*, in particular* phosphorus *and* nitrogen*.*
Applicability: *Some of these techniques are still not fully developed. Others are already in use in* wastewater treatment *plants around the world. As already mentioned these technologies are expensive and require engineering knowledge to guarantee a* sustainable *and long-term operation of the facility* (**10**). Bioconversion at the source in local biogas plants will be environmentally safer, cheaper and providing green jobs.

Nitrogen. To fail to recycle nitrogen contained in the ROM causes numerous adverse effects. In WWTP during costly denitrification nitrogen is sent up into the atmosphere as N_2, nitrous oxide (N_2O), ammonia and other nitrogen compounds that create unpleasant odours. N_2O is a potent greenhouse gas. About 20% of nitrogen is left in water leaving WWTP polluting waterways.

In Sweden wastewater is purified from one kilogram of nitrogen (by denitrification process) at a cost of between € 5 and € 30. To produce mineral nitrogen fertilizer costs less than 1 euro per kilogram. Inhabitants thus pay twice, for sending nitrogen by energy costly processes to air and then to bind it in mineral nitrogen fertilizer by new energy.

No recovery of nitrogen occurs during combustion and thermal gasification of ROM. When burning ROM produced NOx in the flue gases negatively affect our health by obstructing breathing. These losses of nitrogen are replaced with newly produced mineral nitrogen fertilizer. Some nitrogen is lost during application of mineral fertilizer on soils and some is leaking into groundwater and flows into rivers and oceans.

Reactive nitrogen (Nr) is increasing in our environment. General information about reactive nitrogen is available (11). Pretty scary information about the effects of reactive nitrogen on health, environment and climate change is gathered on Internet (12). More information about nitrogen compounds that negatively affect climate are in Greenhouse gas protocol (13).

Phosphorus will soon become difficult to replace with synthetic fertilizer because the world's reserves are running low. Phosphorus is an essential nutrient and also a finite resource. To recycle phosphorus spreads today sewage sludge (with more or less toxic substances) in the fields. The recycling of phosphorus should occur in a manner so that hazardous substances are not spread. Getting to closing loops by use of RC and OS-AD is both resource-efficient and non-toxic.

"Animals and humans excrete almost 100 percent of the phosphorus they consume in food. In the past, as part of a natural cycle, the phosphorus in manure and waste was returned to the soil to aid in crop production. Today phosphorus is an essential component of commercial fertilizer." (**14**). Reusing of phosphorus from HW and from other ROM in residues and waste should be one of the highest priorities.

5. Treatment of ROM now and in the future

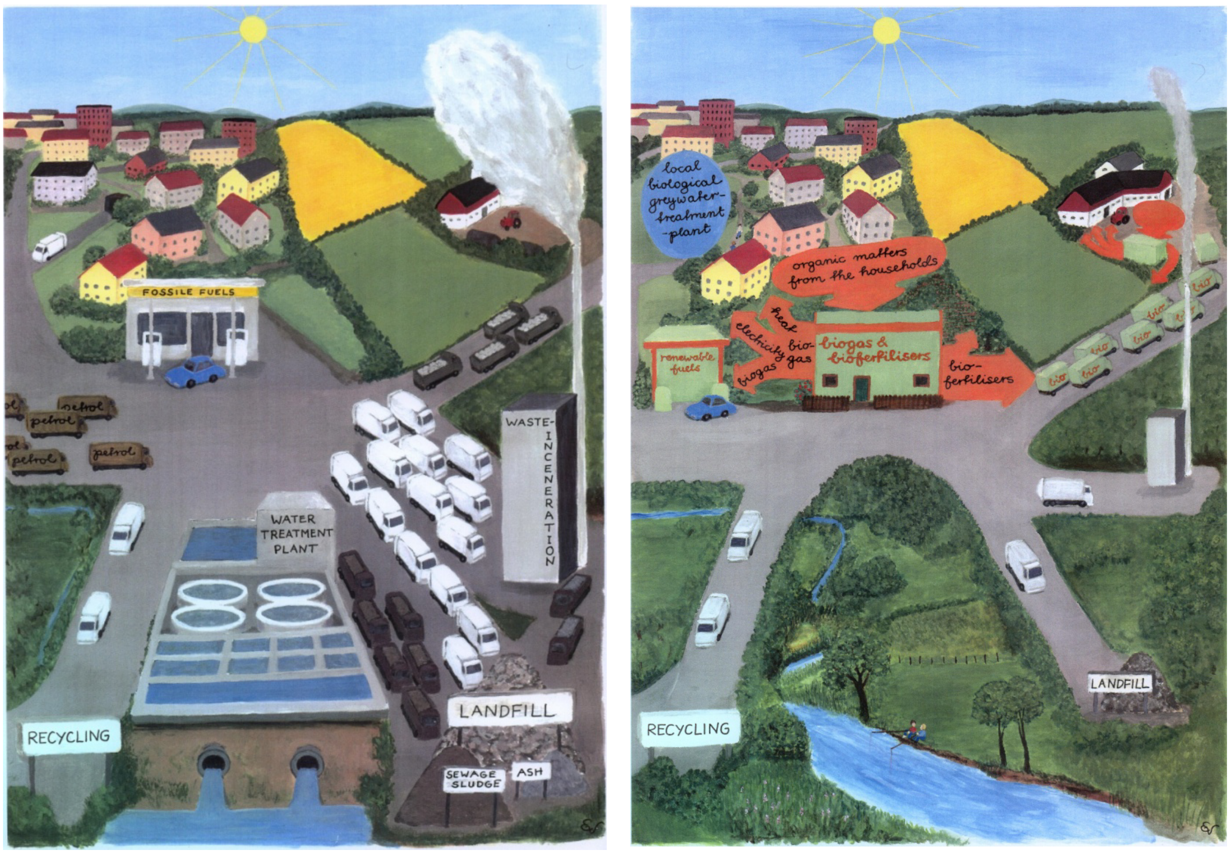

Figure 1: Comparison of current management of solid and liquid wastes from households and the option that is possible in the future presented in REFORSK Report. The artist Ewa Widegren created pictures after data which are presented in Table 1.

At the time when Reforsk presented the report, the amount of MSW was 350 kg per person per year. The amount of wastewater daily purified in WWTP was 200 litres per person and day in a small municipality with separate pipes for storm water and 550 litres in Stockholm where all the water was collected in the sewer system. Thus, the amount of wastewater, undergoing wasteful purification, that can never make water clean again, ranged from 73,000 litres to 100,000 litres per person per year.

The HW consists on average of about one litre of urine and 200 g of faeces per person per day. It is impossible to effectively recycle plant nutrients and utilize bioenergy when HW is dissolved in several hundred litre wastewater that contains heavy metals and many man-made toxic chemicals.

Important questions: Why dilute 1.2 kg HE with a few hundred litres of wastewater that is in WWTP "purified" with more or less toxic chemicals? Why use costly denitrification in biological treatment step where most nitrogen and some carbon are lost to the air? Why use sewage sludge, containing inappropriate substances, for biological treatment in a biogas plant? Can it be a cost-effective production of biogas and efficient recycling of nutrients? Is this knowledge-based sustainable resource management?

6. Challenges for sustainable management of renewable organic material (ROM)

One of challenges is to utilize more efficiently the bioenergy and to recycle with higher precision plant nutrients that are available in ROM. The most sustainable approach will be obtained only when ROM in residues and waste is treated by biological methods. We must be aware of the values of both bioenergy and plant nutrients in HW and MSW that is now treated with various less sustainable practices such as WWTP, landfilling, composting, incineration and thermal gasification.

Nowadays HW is diluted often with tap water and goes to the sewage where it is mixed with various toxic compounds and then a huge amount of wastewater is treated in WWTP. This system is costly, polluting and working environment for staff in WWTP is unhealthy. The sewer system is about 100 years old. There are alarming reports that wastewater contaminates drinking water and the risk increases with each passing year. Municipalities in Sweden are planning to renovate sewers but unfortunately the budget extends on average over 350 years. The challenge is that in the new housing and renovations focus on RC and local biogas plants instead of patching unsustainable system.

To succeed in replacing fossil fuels while protecting the environment and increase food production in a sustainable way, we must meet the challenge to study thoroughly the ability of microorganisms to efficiently convert ROM into two valuable products, namely biogas and biofertilizers. The challenge for engineers is to adapt modern technologies both to needs of microorganisms and to staff who handle waste and wastewater.

One tough challenge is to create conditions under which all residents can properly handle the ROM of residues and wastes. The ROM, which is a raw material for biogas plants, must be free from impurities which hinders or prevents the microorganisms to produce quickly good products. The conversion process should go as fast as possible but it is equally important to get the right products to promote good economy.

Because some analyses of wastes made in other developed countries show similar data which are presented in Table 1, it can be assumed that there are opportunities for joint challenge to develop more sustainable systems for biological handling of the ROM. For example, the amount of ROM in MSW tends to be approximately 70% in many industrial countries.

It is really big challenge in EU to transform, only from HW and HHW, about 542 million tons ROM per year to biogas - to increase independence with help of bioenergy - and to biofertilizers - to increase the conditions for increased growth of plant biomass on the fields.

Sustainable Biological Recycling System (SBRS) is under development. This system shall include the right collection of ROM, short-distance transport, pre-treatment of various types of ROM for maximizing the yield of methane in biogas in local biogas plants using OS-AD. Various biofertilizers that meet requirements of different cultivated crops will be produced.

7. Conclusion

With help of biotechnology we can get paradise on Earth. We all leave behind - in our homes, at work, on travel, in leisure activities - ROM in residues and waste, that originates from plant and animal kingdom, and that can be used for manufacture of many valuable products.

Here was presented the ROM in HW and HHW because there are facts about amounts and also about chemical content of urine and faeces as well as amounts of various waste fractions in HHW from picking analysis. The MSW contains more ROM than HHW because it includes ROM from restaurants, shops, farmers' markets, etc.. ROM in residues from forestry, agriculture, horticulture and fishery are also suitable for co-processing in biogas plants.

All the ROM in residues and waste can give higher yield of biogas when treated in Optimal Solids anaerobic Digestion (OS-AD) after correct pre-treatment. Microbial conversion is important for utilizing bioenergy when it is transformed to energy rich methane in the biogas. Biogas can be used locally for production of electricity and heat. Biogas can also be used as fuel for vehicles.

After processing some bioenergy is left in organic structures and in microbial biomass in biofertilizers. Almost all plant nutrients - the 16 essential elements - can be reused as biofertilizers in cultivation systems in beneficial way for the environment, economy and peoples health.

Now there is knowledge that appropriate technology will contribute to healthy prosperity for people throughout the globe. You and I can influence decisions that result in resource management to lower costs while reducing the negative impact on health and environment.

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