New Sanitation

Bridging Cities and Agriculture

Prof. dr *ir.* Grietje Zeeman

Inaugural lecture upon taking up the post of Personal Professor of New Sanitation at Wageningen University on 13 September 2012

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Mr Rector, ladies and gentlemen.

Sanitation is part of everyone's daily life. In the industrialised world, flushing the toilet with in general too large quantities of water became a routine; 'flush and forget'? In other parts of the world sanitation is not that self-evident. 2.5 billion people have no adequate sanitation at their disposal (UNICEF & The World Health Organization, 2012). Introduction of 'New Sanitation' can bring these people from a lagging to a leading position. Not only health condition will improve but also fertilizers for agricultural production and energy for cooking can be provided.

In the end of the 19th century, the so-called barrel system was introduced in The Netherlands. Faecal matter and urine were collected in barrels, transported and used for making compost or sold for farming purposes without further treatment. The system was designed based on, both hygienic and agricultural criteria. Raw material in faeces and urine, originating from agriculture were recycled for food production. However, the way of application of the system was in many places less attractive than foreseen. Thus the hygienic importance was reduced to a minimum (van Zon, 1986). The introduction of the flush toilet and artificial fertilizers in the beginning of the 20^{e} century reduced the economic efficiency of the barrel system. The connection between food consumption and production definitively disappeared in 1983 with the removal of the last barrel from a household in Alkmaar.

Already early 1900, Franklin Hiram King was severely concerned about the industrialization of agriculture as introduced in the United States and elsewhere. King wrote in 1911 the book 'Farmers of Forty Centuries, permanent agriculture in China, Korea and Japan, which was recently translated and edited by Sietz Leeflang. King describes his travel in 1909 to study the 'cycle' agriculture in China, Korea and Japan; a citation: "on the way from Yokohama to Tokyo, we saw for the first time, both inside the cities and on the country-site, how loads of human manure were transported”. Any loss was seen as a loss of money. Not only the nutrients were valued in the past for agriculture but also the organics, necessary for soil structure. Most organic domestic wastewater sludge is nowadays incinerated.

‘New Sanitation’ can bridge / restore the cycle between food production and food consumption (Figure 1). I do define ’New Sanitation’ as the collection, transport, treatment, recovery and reuse of domestic waste and wastewater. Main objective is maximizing recovery and reuse of raw materials. The necessary high concentration of streams can be achieved with source separation and minimal or no dilution. The main precondition for application is the preservation of public health. Both subjects require environmental-technological research.

More and more people tend to live in cities. Globally, the level of urbanization is expected to rise from 52 per cent in 2011 to 67 per cent in 2050 (United Nations, 2012). So most domestic waste and wastewater are produced in cities. The technology, which is used for converting these wastestreams in ecological and hygienic reliable fertilisers and ‘clean’ water, can be seen as the figurative bridge between cities and agriculture.

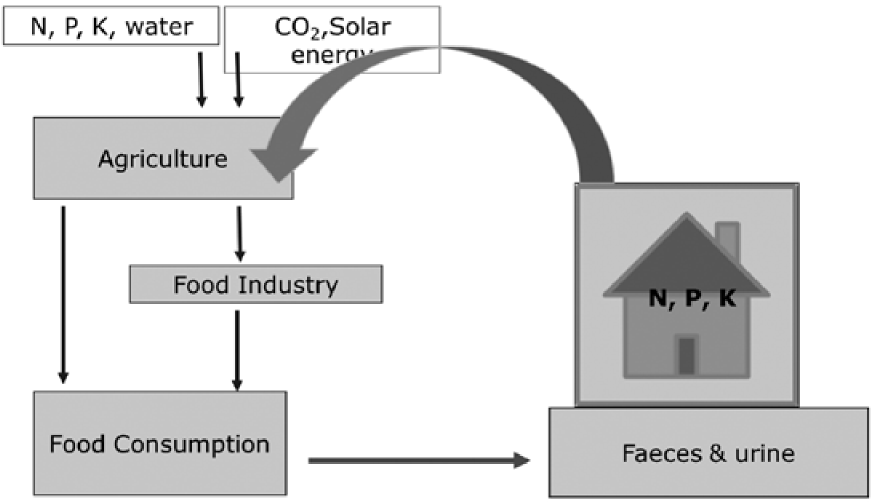

Figure 1 Circular approach for the fertilisers that are used in agriculture for food production and are excreted via the urine and faeces after food consumption

What raw materials are included in domestic waste and wastewater?

Most nutrients in domestic waste (water) originate from faeces and urine. By diverting black water (BW) from grey water (GW) and adding kitchen waste (KW) to BW, 80–92% of the nutrients N, P and K are separated in a concentrated stream (Table 1) with a small volume (1.5-2 litres p^{-1} d^{-1}). The BW plus KW mixture also contains ca. 70% of organics, expressed in [1]COD, contained in domestic wastewater plus kitchen waste (Zeeman & Kujawa-Roeleveld, 2011). The remaining 30% is in the GW. In conventional sanitation addition of kitchen waste to the domestic wastewater is not recommendable (and not allowed in The Netherlands) as energy consumption during aerobic treatment is increased. Addition of KW however doubles the energy production during anaerobic treatment of high concentration BW (Kujawa *et al.*, 2005) as applied in 'New Sanitation' and can cover ca. 60% of our cooking energy (Zeeman & Kujawa-Roeleveld, 2011).

Table 1 Mean pollution load in urine & faeces (black water) & kitchen waste (adapted from Zeeman & Kujawa-Roeleveld, 2011)

	Urine & Faeces & Kitchen waste (g/p/d)	**% of total domestic Waste-water & Kitchen waste**
N	12.3 g	92
P	1.6 g	80
K	3.9 g	84
COD	111 g	69

Which global issues can be associated with sanitation?

I will mention a few. The world is increasingly facing resource shortages, including water, fossil fuel and nutrients. In the 20th century, water use increased six fold, more than double the population growth. According to the report, 'Coping with water scarcity - Challenge of the twenty-first century' (UN, 2007), in 2025 1.8 billion people will live in countries or regions with an absolute water shortage.

Water

Treated grey water represents a potential water source. Dr. Lucia Hernandez (2010) introduces a total concept for household wastewater management at community level with different treatment levels for different reuse applications. In counties

[1] COD = Chemical Oxygen Demand

where irrigation is required around the year, grey water reuse is feasible (Hernandez, 2010). In other regions, in my opinion, infiltration of treated grey water is the minimum required.

Fertilizers, such as nitrogen, phosphorus and potassium are essential for food production, we know that.

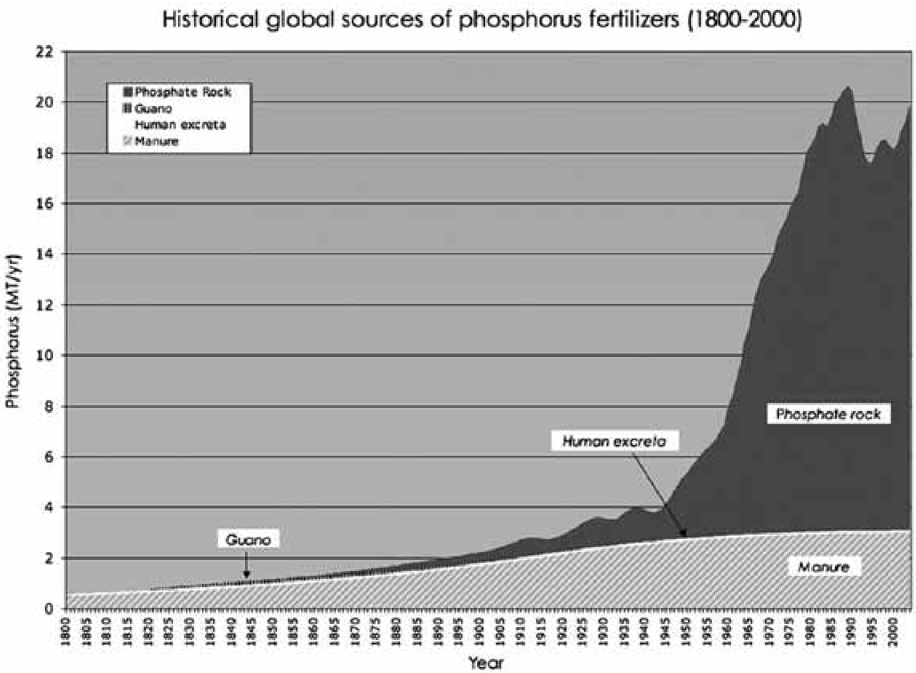

Figure 2 Historical global sources of phosphorus fertilizers (Cordell et al, 2009)

Nitrogen

Nitrogen is abundantly present in the atmosphere and is not a finite resource. Is recovery and reuse of nitrogen then needed? Large scale production of nitrogen fertilizers from the air takes place via the Haber-Bosch process. The Haber-Bosch process consumes a considerable amount of energy (37-45 kJ/g N; Maurer *et al*., 2003). Smith reports in Science in 2002 that about 1% of the world's total annual energy supply is used for artificial nitrogen production (Smith, 2002). Therefore, recovery of nitrogen from domestic waste (water) stands for reduction of energy consumption.

Phosphorus
Unlike nitrogen, phosphorus and potassium are finite resources, derived from minerals. The world has enough potassium for centuries, but phosphate reserves are very limited. Phosphorus use has increased tremendously over the last century, as you can see in this slide (Figure 2).

While debate exists about the exact quantity and quality of available phosphate (Gilbert, 2009), it is now anticipated that if current trends continue, the phosphate stock will be finished at the end of the 21^{st} century (Gilbert, 2009, Driver, 1999, Smil, 2000, Steen 1998, Cordell *et al*, 2009). The potential for P-recovery is significant. Worldwide artificial fertilizer use can be covered for 27%, if all phosphorus is recovered from BW & KW. Similarly a nitrogen recovery potential of 25% can be calculated, which is equivalent to $1.1*10^3$ PJ/y (Table 2).

Table 2 Potential worldwide phosphorus and nitrogen production from black water (BW) & kitchen waste (KW) and artificial fertilizer use

	Worldwide in BW + KW	**Worldwide artificial fertiliser use**	**% coverage**
Phosphorus	3.9*106 (tons per year)	#14.9*106 (tons per year)	27
N	*30.9*106	##121*106	25

World population: 6,911,750,810 people (http://www.census.gov/main/www/popclock.html); #Cordell, et al. (2009).

'New Sanitation' concepts
Various alternative 'New Sanitation' concepts can be developed. Important is to realize that the different elements within the sanitation chain, viz. collection (WC), transport (sewer), treatment & recovery and reuse, will influence one another. Most importantly, preventing dilution during collection (the toilet) and transport will increase efficiency of energy and nutrient recovery technologies. Separation of BW and GW is essential. Modern vacuum collection and transport comply with my predetermined conditions of comfort and minimal water use. Vacuum collection and transport is at large scale applied in airplanes, cruise ships and fast trains. The first application of modern vacuum collection and transport in households was demonstrated by Otterpohl *et al*. (1997) in the so called sewerless city in Flintenbreite in Lubeck, Germany. Vacuum transport of faecal matter and urine for reuse in agriculture was for the first time described in 1867 by Liernur (van Zon, 1986). The Liernur system was applied in several cities in Europe. The system disappeared with the upcoming of flush toilets and artificial fertilizers.

AD as core technology in 'New Sanitation' concepts

As main research line I have chosen for anaerobic treatment of concentrated BW and KW with additional recovery of nutrients and removal of micro-pollutants and pathogens. GW is separately treated. Ultimate goal is the production of safe products for agriculture. The reactor choice for treatment of BW mainly depends on the waste (water) concentration. UASB technology is chosen for BW & KW treatment, based on maximum achievable concentrations, with the use of presently available vacuum toilets. The UASB reactor was developed in the 1970's by prof. dr. Lettinga for the treatment of wastewater (Lettinga, *et al.*, 1980). The wastewater concentration in combination with temperature determines the potential process temperature in the reactor. Low temperature anaerobic treatment leads to low hydrolysis and growth rates of involved anaerobic bacteria, at the expense of large reactor volumes. A rough calculation shows the potential temperature increment of the BW stream, based on maximum achievable methane yield per liter for different dilutions, using different toilets (Table 3). At application of vacuum toilets, with 6 liter water use per person per day, potential temperature increase is 23°C. Anaerobic treatment at a temperature of 25°-30°C can be applied for vacuum collected BW, leaving sufficient biogas for other purposes. I would argue for the development of even more water-efficient toilets (vacuum), because much higher temperatures can be applied (Table 3), which favors pathogens decay. I come back to that later.

Table 3 Volume, temperature, COD concentration of the produced BW using different toilet systems and the maximum temperature increment, based on maximum, achievable methane yield per liter BW

	Flush water (Litres/ flush)	**BW volume (Litres/p/d)**	***Maximum Temperature BW (°C)**	**COD conc. (g/l)**	****Max Temperature increase BW (°C)**
Flush toilet	6	37.5	11.1	3.0	4.7
Vacuum toilet	1	7.5	15.4	14.8	23.4
***Future vacuum toilet	1/0 (F/U)	2.5	26.2	44.5	70.3

*1.5 liter faeces+urine; flush water 10°C; F&U 37°C ; **only energy for warming included, not for heat loss; *** not existing.

State of the art

Starting 2001, research on anaerobic treatment of vacuum collected black water was oriented towards application of UASB-septic tank technology. Design criteria were developed by dr. Katarzyna Kujawa Roeleveld (Kujawa, 2005). In strong cooperation with the company DESAH BV, the anaerobic treatment and subsequent phosphorus recovery and nitrogen removal, of BW collected by vacuum from 32 houses is demonstrated in Sneek since June 2006 (Zeeman *et al*, 2008). A UASB septic tank is, unlike a UASB, also designed for the storage of sludge. This system can therefore be attractive for use in small communities or house-on-site, where minimal maintenance is required. During pilot and demonstration research 78-87% COD removal and ca. 60% methanisation was achieved at an HRT of ca. 30 days and 25°C (Zeeman *et al*, 2008). The whole project, including PhD, pilot and demonstration research was made possible due to the Dutch government financed EET program and the strong involvement of STOWA, the umbrella organization of the water boards. Programs, like EET enabled the development of innovative interdisciplinary concepts from laboratory to demonstration scale in strong cooperation between academic partners and companies. I strongly recommend any government to reintroducing such programs.

For larger scale applications, dr. Marthe de Graaff extensively studied the UASB for the treatment of BW, within her PhD research at WETSUS. A mass balance over a period of 900 days showed a sludge production of 15% of the influent load at an HRT of 9 days and a temperature of 25°C (Figure 3) (de Graaff *et al*. 2010). Removal efficiencies and methanisation are similar to those achieved in a UASB-septic tank.

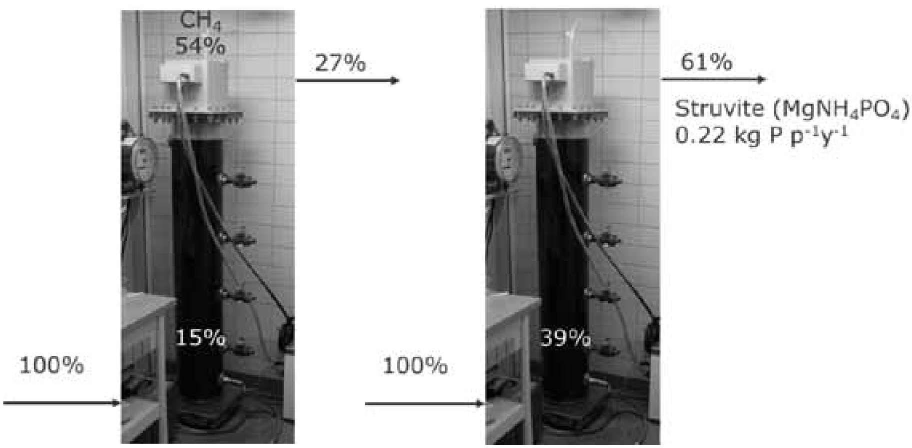

Figure 3 COD (left) and phosphorus (right) mass balance over the total period of UASB operation (951 days). The total amount of COD fed to the reactor during this period was 49 kg COD, of which 0.1% was inoculum sludge (de Graaff et al, 2010, de Graaff et al, 2011)

A phosphorus balance gives insight in the quality of products. de Graaff *et al* (2011) shows that 61% of the influent phosphorus is retained in the effluent, and can be recovered as struvite. Remaining phosphorus is included in the sludge and can be used as P-enriched organic fertilizer (Figure 3). The on-going PhD research of Tainia

Tervahauta at WETSUS is focused on enhanced energy and P-recovery, within the UASB and improved product quality of P-fertiliser and organic-fertiliser. Although ca. 25 times more concentrated than conventional collected domestic wastewater, the concentration of nitrogen in BW is still too low in concentration for an energy efficient recovery using physical-chemical techniques such as ammonia stripping; this is yet another argument for more water-efficient toilets. The best alternative, nitritation-anammox, autotrophic N removal is therefore so far applied (Vlaeminck *et al*. (2009), de Graaff *et al*. (2010b & 2011b).

Grey water

The concentration of organic substances in GW is low compared to BW, but the organic load is considerable due to the large volume. Dr Lucia Hernandez (Hernandez Leal *et al*. (2010b) show how a large fraction of the organics in GW can be concentrated by applying bio-flocculation in a high-loaded MBR (Membrane Bio Reactor). The sludge produced has high biodegradability and adding it to the BW UASB reactor allows energy to be recovered from the GW organics without installing a second UASB reactor.

Full scale application

Since 2011 the concept UASB treatment of BW collected with vacuum, followed by nitrogen removal and phosphorus recovery is applied at full scale at several locations, *viz*. Villa Flora, an office and exhibition building connected to the Floriade in Venlo, in the Ukraine in a school for 250 students and in a 250 houses estate in Sneek. The concept is also applied in Wageningen, in the new sustainable building of the NIOO, thanks to prof. dr. Louise Vet. Wageningen University and Research further builds on the new campus. Implementation of 'New Sanitation' would, to my opinion, fit very well at the Wageningen UR-campus. Similar concepts, but adjusted to local socio-economic conditions are developed for developing countries. Within the INREF Provide project, coordinated by Prof. dr. Gert Spaargaren and dr. Peter Oosterveer of the WU Environmental Policy group, interdisciplinary research is executed on sustainable waste-water and solid waste infrastructures in East African cities. Within the so called modernised mixtures approach, integration of environmental technological, economic, social and governance dimensions of new environmental infrastructures is researched against the background of specific local contexts. School sanitation applying anaerobic treatment of faeces and separate collection of urine for fertiliser production is part of the research of Thobias Bigambo at Ardhi University in Tanzania.

Sandwich PhD

The so-called sandwich PhD construction is one of the cornerstones of the INREF program. WU has successfully applied the sandwich PhD research approach since 1986. The PhD students are enabled to develop new scientific knowledge that is directly applicable to their home country. The actual research takes place in the home country, while 12 to 18 months of the PhD work is done in Wageningen during the start and at finishing the PhD; the bread of the sandwich. Although I also recognise disadvantages of this construction, the benefits are far greater. The local capacity building is to my opinion the major advantage. The recently introduced measure by the tax office, that prevents WU to provide a scholarship to the PhD students in the period in Wageningen, will result in a reduced number of sandwich PhDs. This measure should be withdrawn.

'New Sanitation' future research

After the ' how and why ', I want to discuss the challenges for the future. To recap: The thus far applied concept includes anaerobic treatment of BW and KW, phosphorus recovery via struvite precipitation and removal of nitrogen with anammox technology. GW is treated via a so called bio-flocculation followed by aerobic post-treatment. The logical final step in closing the cycle of nutrients in food and sanitation, reuse for agricultural production is not yet implemented. A direct link between sanitation practices and agricultural reuse sets specific constraints on the technologies within a sanitation concept. Likewise, the choice of sanitation technology determines the sanitation practices of users and operators as well as the characteristics of sanitation products and therewith the agricultural value for reuse. Moreover, gathering socio-cultural data on perceptions of reusing human excreta in food production is essential for developing a sustainable, integrated concept (van Vliet *et al*. 2010). Developing agricultural knowledge and socio-cultural insights in reusing sanitation products in food production, next to further technological developments, are therefore essential for a full sustainable concept development. As mentioned in the beginning of this inaugural speech, public health is a key condition for application of 'New Sanitation'.

Which technological developments are needed?

Figure 4a visualizes the current state of affairs regarding 'New Sanitation', for BW; phosphorus and sludge are only locally used, nitrogen is removed, MPs (Micro Pollutants) & pathogens are not yet removed. In the desired situation (Figure 4c), the sanitation products are applied in agriculture with low environmental and hygienic risks. This could be achieved within 5 to 10 years.

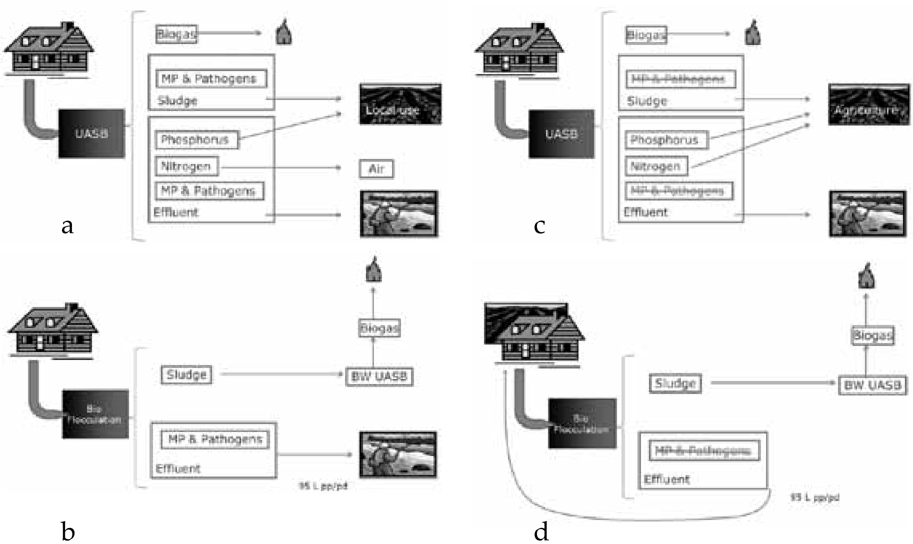

Figure 4 Current state of affairs with respect to BW (a) and GW (b) treatment/recovery and reuse and the preferred situation, to be reached in 5-10 years, where sanitation products are applied in agriculture posing low environmental and hygienic risks (c & d)

Similarly treated GW is not yet reused. Depending on the reuse purpose post-treatment for pathogens and micro-pollutants will be applied (Figure b & d). Future research will focus on nitrogen recovery, pathogen removal and removal of micro-pollutants. Two promising N-recovery techniques are developed for nutrient recovery from urine. Philipp Kuntke (Kuntke et al., 2011 & 2012) has disclosed the possibility to use a MFC (Microbial Fuel Cell) for effective ammonia recovery from urine, by migrational ion flux to the cathode chamber, driven by the electron production from anaerobic degradation of organic matter in urine. Latter technology is a breakthrough in energy efficient, even energy producing, recovery of NH_4^+-N. Further development of this technology for 'New Sanitation' will be made in cooperation with the chair group of prof. dr. Cees Buisman of our department and WETSUS.

A second promising technique is the use of photo-bioreactors, using algae for combined recovery of nitrogen and phosphorus. In her PhD research Kanjana Tuantet has shown for the first time that *Chlorella sorokiniana* grow on non-diluted urine with a specific growth rate as high as 0.104 h^{-1} at a light intensity of 105 µmol m^{-2} s^{-1} (Tuantet *et al*. 2012, submitted). In continuous operation phosphorus is completely recovered while ca. 60% nitrogen is recovered as algae biomass.

This research is in our department coordinated by dr. Hardy Temmink in strong cooperation with prof. dr. Renee Wijffels and dr. Marcel Janssen from the department of Bioprocess technology of WU. Both mentioned techniques are certainly also promising technologies for nutrient recovery from anaerobic effluents. Within the INNOWATOR project Algobioloop, cooperation between academic partners, water board and companies, the growth of algae on anaerobic effluent is under research by dr. Tania Fernandes at NIOO.

Pathogen removal by Anaerobic Disinfection
I already indicated that anaerobic treatment of BW was so far only researched and applied at mesophilic conditions. Produced sludge is so far not reused as a fertilizer. Reuse can be enhanced when hygienic safety is guaranteed. When applying high temperature, thermophilic or hyper thermophilic anaerobic treatment (50 - 70°C) in combination with a high 'medium' concentration (i.e. salts, ammonia, high pH) so called multiple stress conditions are created, which can result in increased pathogen decay within short treatment periods, so called 'Anaerobic Disinfection'. (Hyper)-thermophilic anaerobic treatment of BW can be applied energy efficiently only at a high input concentration. The high medium concentrations for BW can be accomplished by very low dilution of faeces and urine. At the same time the low dilution creates the possibility to apply the needed high temperatures for disinfection. Double switch vacuum toilets could be developed, with one liter flush for faeces and no water for urine collection. I challenge the industry to develop such new vacuum toilets. A few references show the possibility of hyper-thermophilic anaerobic treatment. Ahring *et al*, (2001) show the possibility of hyper-thermophilic treatment of animal manure. The combination of hyper-thermophilic anaerobic treatment with disinfection requires a balance between, on the one hand, acceptable environmental conditions for methanogens and other anaerobic biomass and, on the other hand, severe environmental conditions, temperature and medium, for ensuring full pathogen decay. We started cooperation on pathogen removal with prof. dr. Marcel Zwietering within the STOWA project 'Application of Hazard Analysis & Critical Control Points, for identifying critical steps in treatment and application of domestic sewage; I hope to expand this cooperation for further transfer of knowledge developed within Food Microbiology to Environmental Technology and 'New Sanitation'. Also cooperation with prof. dr. Fons Stams from the Microbiology group of WU on hyper-thermophilic anaerobic microorganism would strongly benefit the 'anaerobic disinfection' research.

A promising technique for disinfection of liquid effluents is the Inductively powered fluidised bed developed within the WETSUS PhD research of Johannes Kuiper, within the chair group of prof. dr. Huub Rijnaarts. Powering ultraviolet light emitting diodes (UV-LEDs) might be a possible future application for GW disinfection (Kuipers *et al*., 2012).

What about Micro-pollutants?
Micro-pollutants in domestic wastewater do not only originate from the pharmaceuticals which we use for medical reasons but also from personal care products. Both are used in increasing amounts. Eriksson *et al*. (2003) identified almost 200 micro-pollutants in grey water and 190 different pharmaceutical substances were recorded in literature to be found in sewage effluents, surface waters, groundwater and drinking water (Winker *et al*, 2008). The fate of MPs from personal care products, pharmaceutical residues and oestrogens in anaerobic/aerobic biological systems is studied within three PhD researches of dr. Lucia Hernandez, dr. Marthe de Graaff and dr. Titia de Mes (de Mes, 2007, de Graaff, 2010, Hernandez, 2010). MPs in GW for example, are present in the range of μg/L. Aerobic treatment results in general in better removal than anaerobic treatment. But several MPs are badly removed in every biological treatment system (Hernandez *et al*, 2010). Similar results were found for pharmaceutical residues and oestrogens (de Graaff et al, 2011c; de Mes *et al*., 2008). All three researchers recommend additional physical/chemical treatment. Hernandez *et al*. (2011) show that ozonation and adsorption on activated carbon are suitable techniques for MP removal from GW effluents. Within the PhD research of Andrii Butovskyi at WETSUS the application of a hybrid biological-physical system, for achieving MP free sludge and liquid effluent is under research. So far mainly parent compounds and not potentially formed intermediates are analyzed. Future research, in cooperation with prof. dr. Tinka Murk of toxicology WU and prof. dr. Huub Rijnaarts of our department, towards effect oriented removal of micro-pollutants, is demanded.

Transition

Finally I want to discuss the topic transition with you. 'New Sanitation' requires new infrastructure. The Netherlands and other industrialized countries however are characterized by a high density sewer network connected to municipal wastewater treatment plants. RIONED reports a total sewer network in The Netherlands of 100.000 km representing a monetary value of 62 billion Euros (van der Hoop, 2010). The Netherlands counts 351 municipal wastewater treatment plants, with a total capacity of 24 million person equivalents (CBS, 2011). It becomes clear that a gradual replacement is the only affordable way to introduce 'New Sanitation' at a larger scale; development of a transition strategy is required. As part of such transition, I want to develop technological modules that can be implemented when part of the infrastructure is to be replaced. The faculty of civil engineering of the TUD, prof. dr. Jules van Lier and prof. dr. Francois Clemens recently initiated the development of a project on advancement of new transport (sewer) systems for implementation within 'New Sanitation'. Special attention wills also here be paid to the transition question.

Not only the water sector but certainly also the agricultural sector have an important role here. The Dutch Nutrient Platform, founded in 2011, plays an important role in creating the conditions for the required transition towards more sustainable nutrient management. Dr. Bert Smit of PRI is representing Wageningen UR.
Various academic partners, the Environmental policy group and The Consumer Technology and Product use group, of Wageningen University, the Membrane Technology Group, of the University of Twente and Faculty of Architecture of the Technical University Delft were involved in 'New Sanitation' research from the start, early 2000. ESA of Wageningen University was involved via master thesis research, supervised by prof. dr. Carolien Kroeze. Existing cooperation will be continued and where necessary intensified, while several other disciplines will be involved to develop new interdisciplinary knowledge and a strategy for 'New Sanitation' implementation under various socio-economic conditions. Strategies for industrialized countries will differ from those in developing countries and countries in transition. They can benefit from their backlog in implementation of infrastructure and directly implement 'New Sanitation'. In cooperation with ENP and PRI of Wageningen UR we recently had an INREF seed money project granted entitled 'Sanitation and agriculture: a missed opportunity; Achievement of School-Agro-Sanitation'. This project will focus on the development of hygienically safe sanitation in developing countries, directly linked to improvement of local agricultural production by recycling nutrients.

Mr Rector, I am convinced that WU can play an important role in bridging cities and agriculture, for conservation of our raw materials and establishing more sustainable cities and agriculture, of course in strong cooperation with other academic partners, companies and institutions. An important step to restore the cycle between food production and food consumption is already made, but the 'bridge' is still open.
I feel privileged to work on closing, the 'bridge'.

At the end of this speech I like to acknowledge several people that have contributed to this research.

Gatze Lettinga
I could never have imagined myself a better teacher (leermeester in Dutch) than you have been for me. From the beginning, as a master student looking for a thesis topic, it became clear to me that anaerobic treatment was the way to go. You not only taught me the ins and outs of anaerobic treatment technology, but also how to build on a sustainable future, including 'decentralised sanitation and reuse'. The title of your inaugural speech 'zuiver denken en ecologisch zuiveren' speaks for itself. Gatze thank you for being a great teacher, colleague and friend.

I also want to thank my colleagues of the former anaerobic group, with a changing composition over time. It was always a pleasure to work in this group. I especially want to thank Jules van Lier with whom I worked together for 20 years. I did regret your leave to the TUD but I am very happy to continue our cooperation. Thank you for everything.

Cees Buisman
When you started at ETE you directly recognised 'New Sanitation' as an important research topic for future and encouraged me to continue with that topic. Separation at source became a theme at WETSUS right from the beginning. We supervised several PhD students together and I hope to continue that cooperation. Thanks a lot for the confidence.

Huub Rijnaarts
When you came in our department, 3 years ago, you not only build on your own career but also stimulated me to build on my career. You encouraged me to step in the tenure track, which resulted in today's inaugural speech. I am looking forward to the cooperation ahead. Thanks a lot for all your support.

Hardy Temmink
The cooperation with you in supervising students and PhD researchers is always a great pleasure. I appreciate your strong critical attitude and hope for many future projects together.

Harry Bruning
Thanks for the pleasant cooperation within the 'urine research'.

Katarzyna Kujawa-Roeleveld
From 1999 to 2007 we worked together in the DeSaR research. The first vacuum toilets connected to anaerobic reactors; lists with dashes to know how much faeces or urine were produced; unusual work! We worked together, published together and enjoy a very strong friendship. Thank you for always helping out.

I want to thank all my colleagues of ETE and LeaF for the pleasant atmosphere at the department and the strong cooperation. I thank all technicians for cooperation and technical support in the lab.

I especially want to thank Marjo Lexmond, director at LeAF and colleague at ETE for her strong commitment, enthusiasm and leadership. We enjoy a very long cooperation at the department and at LeAF; I hope many years will follow.

I thank Jan Weijma of LeAF for bringing 'New Sanitation' knowledge to practice.

Special thanks also to a group of colleagues and old colleagues, all ladies, always back in the background to help out when projects proposals, reports, presentations or other urgent matters have to be finished; thanks to Liesbeth Kesaulya, Miriam van Eekert, Lucia Hernandez, Darja Kragic, Tania Fernandes, Titia de Mes, Katja Grolle, Claudia Agudelo and Wendy Sanders.

And of course I thank all PhD's and post-docs, with whom I had and have the honour to work. Thanks for your enthusiasm, strong involvement, brilliant ideas, hardworking and patience.

UETM
It is a pleasure to lead the UETM group of ETE since last year. I want to thank all of you for your strong involvement to make this group to a success and bring the education to an even higher quality.

I also want to thank the EET/STOWA DeSaR group; the start of 'New Sanitation' research was with you. It was not always easy, but we achieved a lot. A special group within the DeSaR group is the Sneek group, coordinated by Flip Kwant of Landustrie. Within a very short time we managed to bring the DeSaR concept a step further by its demonstration at the Lemmerweg in 2006. Thanks for the confidence and strong involvement.

Brendo Meulman of DESAH BV
I want to thank you for your enthusiasm and hard working to bring DeSaR to practice.

I want to thank STOWA, and especially the 'koepelgroep' headed by Bert Palsma for taking the lead in implementation of 'New Sanitation' and the involvement of the water boards

Finally I want to thank my family
I deeply regret that my parents did not live to see this important step in my career. They have encouraged me from an early age to explore, stimulated me to study and enabled me to continue with a scientific career by taking care of my kids while I worked. My mother died one day and two years ago, 95 years old; interested in my work till the end. She would have loved to be here.

My dearest brother Pieter
You did not *directly* support to my career, *indirectly* you certainly did and were and are very important for me; to be always there if needed. Pieter and Peter thanks a lot for all.

Ruben and Piet Hein, my dearest sons
I was, for an important part of my life, only focused on two things: (i) be there for you and (ii) my academic career. It is difficult to strike the right balance, but I think I found it, with the help of your grandmother. Now that you are grown-up, I not only enjoy a very good personal relation with you and with your girlfriends, Marije and Sophie, but also our profession connects more than I could imagine. Dear Ruben and Marije, dear Piet Hein and Sophie I am very, very happy with you.

My dearest Paul
From the start, you were also strongly interested in my work; my mission as you call it. Although you consider me a workaholic, you moved from Leiden to Wageningen, increasing your travel distance considerably while I could continue biking to the university. You strongly supported me in the whole trajectory of the tenure track, though it was clear that life would not become less hectic! Thank you for all and I will make sure that we will also continue enjoying other things than work. I also want to thank your children, Robbert, Bernard, Joost and Annemieke and your father Herman Bloem for their interest and support. Unfortunately your mother cannot be here.

Finally I want to thank the Academic Board of Wageningen University for having the confidence to appoint me in the position of personal professor in 'New Sanitation'. Mr. Rector, ladies and gentlemen, I thank you for your attention.

Ik heb gezegd

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'New sanitation' is characterized by recovery and reuse of raw materials from source separated domestic waste (water) streams. Streams are separated according to their concentration and composition. The recovery of raw materials, like organic matter, water, energy, phosphorus and nitrogen, which were originally used for the production of our food, is enabled by the development of new technologies. Most domestic waste (water) is produced in cities as more and more people live in cities. The use of the recovered products brings about the bridging of cities and agriculture.

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