

# Food and Energy in a Circular Economy



## Study Tour Report Stockholm October 6, 2017

### Authors

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## 1. Food and Energy in a Circular Economy - background

The wastewater collection and treatment system in Stockholm can be considered one of the best and most efficient in the world in terms of pollution reduction in relation to costs of the processes. It is, and has been for a couple of decades, what is referred to as a “green factory”.

Wastewater contains resources such as *heat, organic matter and nutrients* which to a certain degree can be recovered in conventional wastewater treatment processes. However, the mechanical, biological and chemical unit processes in a conventional wastewater treatment plant are not optimized for such resource recovery; they are optimized for reduction of pollutants in the wastewater with the aim of recipient and public health protection. Given the existing wastewater infrastructure in urban areas in Sweden, attempts to recover resources in conventional wastewater systems can only be made at the end of pipe – at the wastewater treatment plant.



**Figure 1.1:** Energy, heat and nutrient recycling possibilities in a system separating blackwater and organic waste flows.

Stockholm Royal Seaport (SRS) is a new development area with a high sustainability profile. SRS is located within the City boundaries, hence, the area will be serviced with traditional sewer systems. However, the assumption is that by separating flows at the household level, streams can be managed in such a way that biogas, heat and nutrients can be recovered to a higher degree compared to the conventional system.

The CNCA-funded project Food and Energy in a Circular Economy’s purpose was to deliver a feasibility study describing the potential and scenarios of source separating wastewater systems for dense urban areas and a business model for the implementation of such systems. The project was, with the exception of the study tour which is the focus of the report at hand, completed in June 2017. The Executive Summary of the project can be found in Annex 1 of this report.

## 2. Study tour element of the Project

Experiences of separate collection of blackwater and greywater exist in a few places in Europe today, e.g. in Sneek and Hamburg, hence a study tour was planned for participants from Stockholm City and Stockholm Water and Waste Company, to better understand the realities of planning, operation and maintenance of a wastewater collection system where blackwater and greywater are collected and treated separately.

### 3. Report from the study tour

The full program from the study tour can be found in Appendix 2.

#### 3.1 Monday, September 25, 2017

- Study object:** Jenfelder Au, Hamburg
- Host:** Hamburg Wasser
- Participants:** Hamburg Wasser, Hamburg Municipality, Waternet (water utility of Amsterdam), Municipality of Amsterdam, Bauhaus University Weimar, Helsingborg Water Utility, Clean Energy Innovative Project (Ghent), University of Ghent, Stockholm Water and Waste Company, Stockholm City.
- Program:** Networking dinner in Hamburg

An informal dinner was organized by Hamburg Wasser in a restaurant close to the train station, where the participants were given the chance to exchange informally between all participating organizations.

#### 3.2 Tuesday, September 26, 2017

- Study object:** Jenfelder Au, Hamburg
- Host:** Hamburg Wasser
- Participants:** Hamburg Wasser, Hamburg Municipality, Waternet (water utility of Amsterdam), Municipality of Amsterdam, Bauhaus University Weimar, Helsingborg Water Utility, Clean Energy Innovative Project (Ghent), University of Ghent, Stockholm Water and Waste Company, Stockholm City.
- Program:** Visit with Hamburg Wasser, field visit at Jenfelder Au, travel to Sneek in the Netherlands together with Waternet.

##### 3.2.1 Participating organizations and urban development areas

On Tuesday morning all participants gathered at Hamburg Wasser for presentations of each participant's urban development project and team.

- Stockholm:
  - Source separation has been investigated for Stockholm Royal Seaport since 2009;
  - The City and the Utility have had different views on how to proceed with services within the urban development;
  - At the moment it has been proposed that two blocks with 400 apartments will test kitchen grinders in separate system to a tank with grinded kitchen waste. However, an area with 2,000 apartments will also be subject to a pre-feasibility study for a triplicate system, where also blackwater is collected separately.
- Helsingborg
  - H+ is the largest city development project in Helsingborg. It is located next to water, high value property place.
  - The piping out from the house will be separate for food waste, black water and greywater respectively.

- The Ocean Harbor is first out, which is located close to the existing WW treatment plant. The existing WWTP will be covered, and have a section for treatment of separate flowstreams, a test bed for trying out new techs and a show room for the utility and city for meetings.
- The utility will host a site visit to H+ for the IWA Copenhagen 2020 World Water Congress.
- At the moment the sewer networks are getting into the ground and construction of the houses starts in January 2018. People will move in in 2019.



Photo: M. Lennartsson

- Weimar – Bauhaus-Institute for Infrastructure, Bauhaus University – Weimar
  - Research on treatment of blackwater (anaerobic and also removal of pharmaceutical residues).
  - Working with the use of source separation in more rural areas, with co-fermentation with agricultural residues.
  - Most challenging was the organization and the new tasks for small water cooperations.
  - They have also worked on the development of in-line system with two pipes in one, as an alternative to achieve separation of blackwater in existing buildings.
- Ghent
  - Circular economy in a new city district in Ghent.
  - Clean Energy Invest (participant in the study tour from Ghent) is NOT a utility, but are investors into clean energy.
  - The urban development area is a harbor site, previously contaminated with creosote.
  - 400 housing units and a school complex, some shops and offices are planned.
  - First phase will commence with the school.
  - Started in 2012 by a feasibility study, which also looked into law and policy, financing etc.

- It took a while to find a specific site where to show-case the system in real life.
- In 2014 a cooperative was established for the sustainability services: DuCoop.
- Financing also comes from Horizon 2020 (Run4Life), and other EU programs, also for heating network.
- Zawent, will recover waste heat, nutrients (struvite), UASB, urban eco system, and an industry will reuse the treated greywater for process water. Incineration of anaerobic sludge (legal reasons).
- Kitchen waste and blackwater together.
- Amsterdam
  - Buiksloterham is a former industrial area and new development on the water.
  - Drivers are circular economy, strategic importance for Waternet (Amsterdam's water utility), also to secure New Sanitation within the agenda of Amsterdam.
  - Ambition within Amsterdam: 50,000 new homes will be built in the next 10 years, Buiksloterham is a pilot within that plan for some 550 houses – hopefully leading to more pilots and spreading of the concept within the new developments, as the experience is developed within Waternet and the municipality.
  - Buiksloterham will be a “living lab” for circular economy.
    - Gain insights into the changing role of a water board within an urban area.
    - Cooperation with all parties involved to start circular neighborhood development.
    - Investigate the right scale to close loops for water, energy and resources and to make neighborhoods rain proof.
    - The treatment plant – a bio refinery: black water plus organic waste by vacuum sewer to the bio refinery. UASB, Oland, struvite, energy recovery from biogas (heat, electricity). Will be up and running 2018. The system will be on water, floating.

### 3.2.2 Hamburg

**Jenfelder Au** is an area in which Hamburg Wasser is implementing the concept the Hamburg Water Cycle, under the leadership of the Energy Department and Projects. **The Hamburg Water Cycle** (<http://www.hamburgwatercycle.de/startseite/>) aims at resource conservation and recovery by exploring the connection between the energy and the water cycles. A key feature is the collection and treatment of greywater and blackwater separately. Stormwater is part of the Hamburg Water Cycle, although the management responsibility lies with the city of Hamburg. Kitchen waste is not included in the Hamburg Water Cycle – legally it is not within Hamburg Wasser's jurisdiction.



Illustration: Hamburg Wasser



The project started in 2005-2006 and the zoning took place in 2006-2011; the development started in 2012. The Hamburg Water Cycle concept was developed in 2007. In 2014, the city all of a sudden change their plan, which meant an increase of inhabitants in the area of 46% (from 2,000 to 2,500 inhabitants), and this at a moment when all the vacuum and other pipes were in the ground. This posed challenges to the system but it seems resolved. In 2015 the first houses where finished. In 2016 the pumping stations were finished and by the end of 2016 the black- and greywater systems were up and running. The first inhabitants moved into the area in the beginning of 2017 (54 households). By 2020 the area will have 2,500 inhabitants.

The benefits of the system is 30% water savings, increased biogas potential, heat supplier, climate neutral biogas are some positives from implementing the project. **When finished Jenfelder Au will be the largest source separated system in EU so far.**

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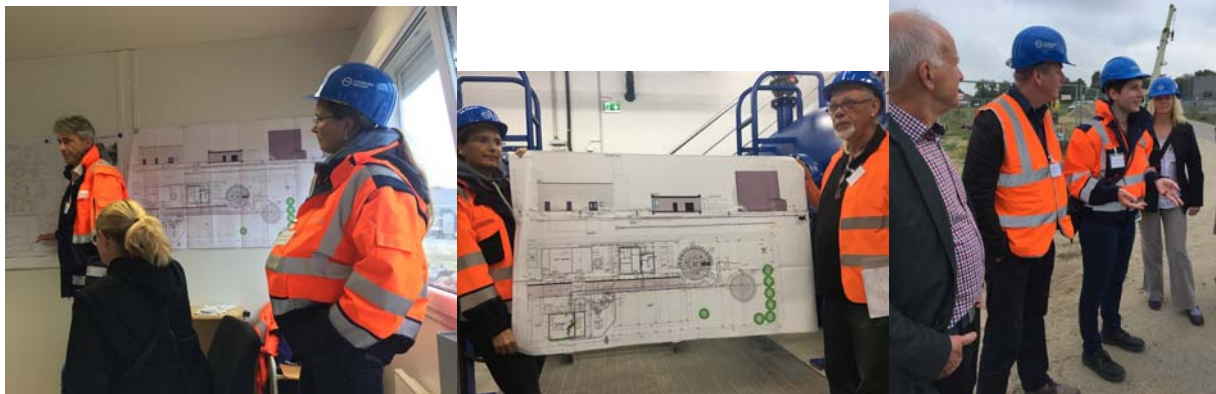
**Legal amendments** have been one of the tricky parts of the implementation of Hamburg Water Cycle; all laws and legislation are formulated for gravity-fed sewers, none of the legal framework is adapted for vacuum systems of separate flowstreams. The legal amendment process started in 2010.

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investors, architects, etc. Each investor and builder can also contact Hamburg Wasser to be hand-held through the process. The aim is not to scare the developers but to clarify the technical details of this new system. Hamburg Wasser further check plans, goes to the sites and makes inspections. Hence, they are really involved during the construction process. They further have a test area where they can show the vacuum toilets etc. They hold a Water Festival on -site for all interested parties, newsletter three times a year and events in the exhibition room on-site. Every Sunday the on-site exhibition room is open for the public. Hamburg Wasser is present at conferences, makes radio and television snippets to bring out the message. The mayor visited Jenfelder Au last year. All of the described is part of a communication plan, which will be shared with the participants in the study tour.

### **Field Trip – Jenfelder Au**

The field trip was organized by Hamburg Wasser.



*The Hamburg Wasser personell. Photo: E Kvarnström and M.Lennartsson*

### **Stormwater management**

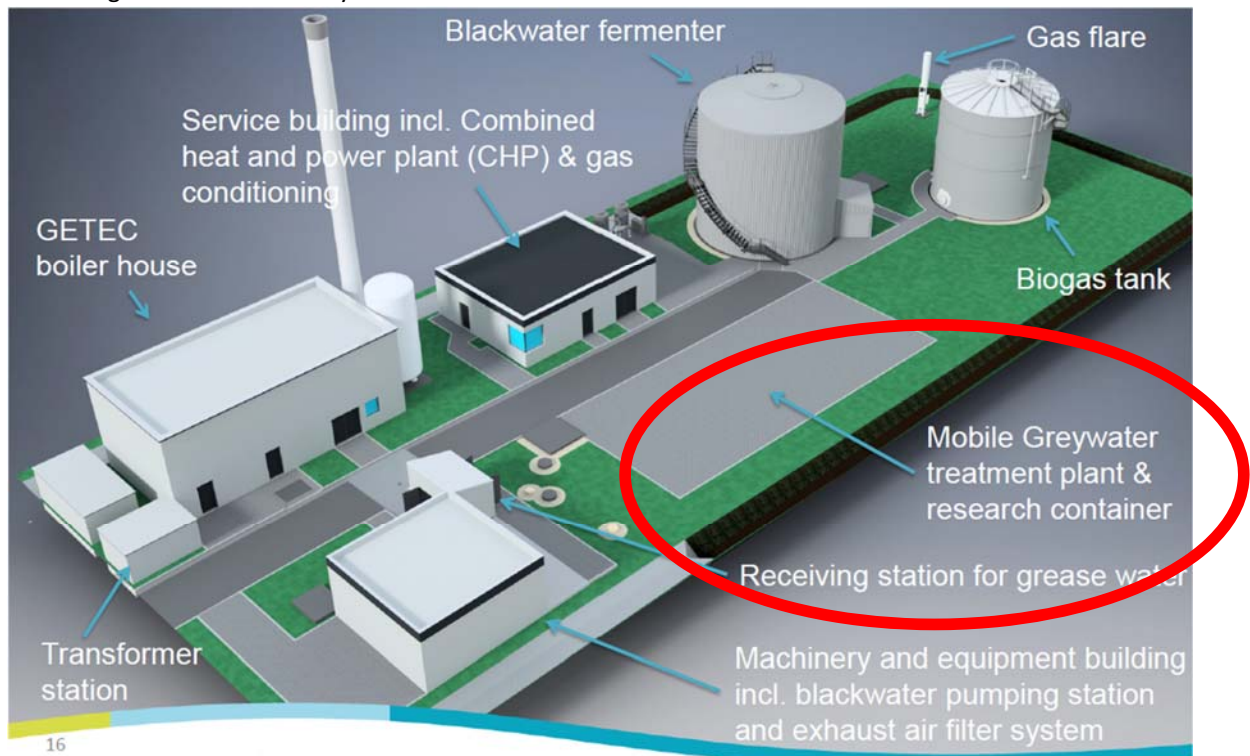
Stormwater management is under the jurisdiction of the city, but is part of the Hamburg Water Cycle concept. The stormwater cycle in Jenferlder Au aims at harnessing natural processes. 30% of the area is unpaved. Landscape architects have used stormwater as a design element in their design to make it more attractive. There will be a cascade with stormwater in a park which is still not constructed.



*Stormwater retention in parks. Photo: E Kvarnström*

## **Greywater treatment**

The greywater production is 75 L/cap/day, which will be conveyed by gravity sewers to the treatment plant in the “work yard”. Hamburg Wasser has a permit to discharge the treated greywater into a nearby stream. However, the discharge permit stipulates stringent quality standards on the effluent and at this point it is unclear how Hamburg Wasser will meet these discharge standards. They will experiment with treatment methods at a smaller scale (container plant to which processes can be added if needed), together with University of Weimar, before going full-scale on the greywater treatment. At the moment they are considering a trickle bed filter system or a membrane reactor.



*The “work yard” with space for research containers for greywater treatment. Illustration Hambrug Wasser*

## **Blackwater management**

### The vacuum system for blackwater collection

In the blackwater network the ambition is to construct a high level of flexibility in daily operations. The vacuum needs to be there all the time. Therefore, the collection system has been designed according to the following criteria

- Redundancy is created in the system by three separate networks.
- Pressure switches are located in provision chambers at every seven house in the system to monitor the pressure - thus problems can be located very quickly.
- Shut-off valves are used, so that small parts of the sewer system can be taken out of service if problems occur.
- Meshing points allow for combining systems.
- All house connections have gates that can be closed off. Additionally, there are pipe junctions for maintenance reasons.



- The vacuum system has to separate vacuum tanks, and if one tank needs to be cleaned, the whole system can be served by the second tank.
- Effort was spent on the development of the system including in-house innovation with companies – special type of valves (ball valves).
- With the three separate systems, vacuum can be kept lower in one area, because of lower height differences.
- There is one central vacuum pumping station – 100% redundancy within the station to increase reliability.
- The vacuum pipes have a saw-tooth profile. Every 100 m a leap but depends on geodetic level.

**Q/A:** Have there been any problems yet with the system?

Only 54 dwellings connected yet, no problems so far so yet no need for using the redundancy and security built into the systems.



*The Jenfelder Au area and one of the newly completed buildings. Photo: E. Kvarnström*

### Blackwater pumping station

The blackwater pumping station is located in the “work yard” of the area and is up and running at a low capacity. Connected to this there is an exhaust air filter system. There is also a boiler house ready to which the Hamburg Water Cycle will produce heat for. Active carbon filter is used for exhaust air from the vacuum pumping station - 1,000 m<sup>3</sup>/hr. Volatile organic compounds will be monitored here.



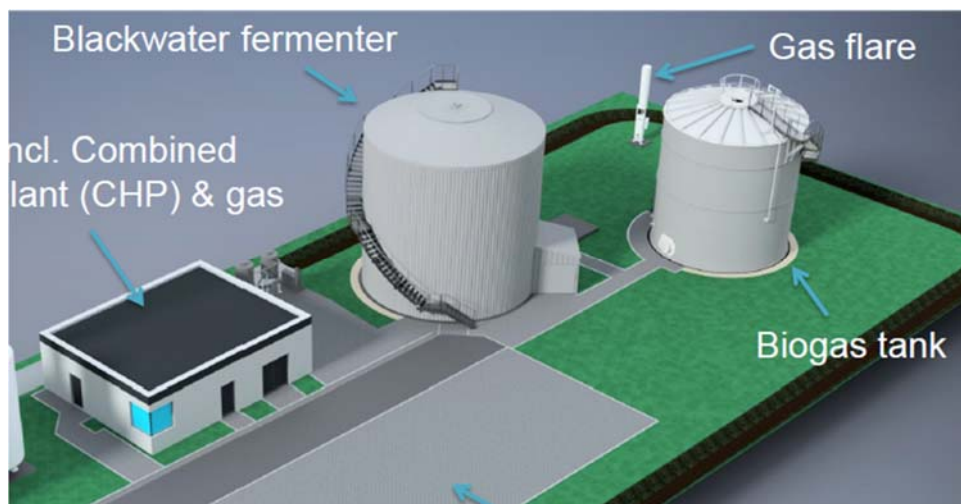
*The pumping station, vacuum tanks and air exhaust. Photo: E. Kvarnström and M. Lennartsson*

### The blackwater treatment plant

The blackwater treatment plant is not yet finished. A CSTR system will be constructed. Hamburg Wasser preferred to go for robustness with a longer retention time rather than an UASB approach (UASB is used in Sneek and will be used in Helsingborg, Amsterdam, Ghent). 700 m<sup>3</sup>, external heat exchanger, stirring unit, continuously monitoring the CO<sub>2</sub> and methane. The plant is designed to mix the blackwater with grease wastewater from gastro industry. 1,380 m<sup>3</sup>/day of gas is the goal and operation will start 2018.

There is a concept for nutrient recovery developed but legally it does not work right now in Germany. They are waiting for legal changes before producing fertilizers from the system. They will also look at the sludge quality when in operation. The alternative solution is at the moment to return the blackwater, after energy recovery, to the conventional system.

Pharmaceuticals – it has been shown that pharmaceuticals degrade better anaerobically than aerobically. If the solids and the liquids are separated, different treatment can be used for the solids and the liquids. Lab scale work is conducted in Weimar as well as in other places.



*The Blackwater treatment plant Illustration: Hamburg Wasser*

### **3.3 Wednesday, September 27, 2017**

**Study object:** Noorderhoek, Sneek

**Host:** DeSaH/Landustrie

**Participants:** DeSaH, Sneek municipality, representative from the housing cooperation in Sneek, Stockholm Water and Waste Company, Stockholm City.

**Program:** Presentation of the Noorderhoek project, field visit, travel back to Stockholm.

Brendo Meulman, CEO of DeSaH, presented their experiences with “New Sanitation”. Representatives from the Sneek municipality and the housing company joined at lunch and for the afternoon on-site visit.

Sneek is located in Friesland – a province in which a considerable part of its surface area is water. People come to Friesland for sailing and boating, among other things. The province therefore has long-standing experience in water management and is known for putting a lot of resources into water technology. Among

other things, there is a center in Leeuwarden, the province's main city, with 60 PhD students working on water-related issues. Sneek's take on the water management is to demonstrate what is researched in Leeuwarden. Some demonstration projects in Sneek are:

- The Landustrie office building has installed toilets to study separation of blackwater, greywater and urine. Urine diversion toilets are installed for women, vacuum toilets and waterless urinals for men. There is a small treatment plant in the office. New Jets toilets will be tested here under a new EU project (Run4Life project).
- Two projects in housing estates –
  - 2007: 32 houses, 80 people (Lemmerweg). Vacuum toilets in the houses. All connected to a small wastewater treatment plant – the objective of the project was to demonstrate that it works technically and that people accept the technology. The idea was to start small, then grow bigger.
  - 2011: start of 200 household project with vacuum for blackwater where kitchen grinders are also connected to the blackwater (Noorderhoek).
- Normally Landustrie/DeSaH builds the system and then operates the treatment plant on contract from the water board (responsible for the treatment). In the Noorderhoek case they also operate the pumping station on behalf of the municipality (responsible for the system up until the treatment plant).

Another interesting project under way is the renovation of a ministry in Den Haag. 1,200 people will be served by a vacuum toilet system and food waste from a canteen serving some 5,000 people will also be connected. The treatment will take place in the building itself. The residence time of the sludge will be up to 200 days so the system will be emptied on sludge a few times a year.



*Toilets and treatment testing plant in Landustrie office building. Photo: E. Kvarnström*

DeSaH as a company focuses on “New Sanitation” for the smaller scale: 200 up to 10,000 to 20,000 households. It is the leading company in the Netherlands within this field and size segment. However, Grontmij did a lot of urine diversion R&D in the late nineties in the really small scale, focusing on different problem areas with different projects.

The cooperating partner of Landustrie/DeSaH in Sweden is R-Con in Norrköping.

The Netherlands is basically the shower drain of Western Europe. Hence, almost all water entering the country is already polluted and only a few water bodies have the status “sensitive” in the Netherlands. Discharge standards differ according to size:

- $n > 100,000$  pe: total N:10mg/L, total P: 1 mg/L.
- Into sea, less stringent than above.
- $20,000 < n < 100,000$  pe: total N 10mg/L, total P:2 mg/L
- $n < 20,000$ : total N:15mg/L, total P:2mg/L

Water boards are regulators for surface water quality –they define the rules.

There is a certification process for on-site compact wastewater treatment plants. The certification means that one has to take the plant to an institute where it is tested for a year, after which the institute gives a certification. It was expected that the Netherlands was going to have a boom within the small wastewater treatment plant industry in 2005-2010 but it never happened. Almost all rural areas are instead connected via pressure sewers to closest conventional WWTP.

The Netherlands:

- >99% connected to sewer network, 95% of wastewater is treated. Sewer overflows have been reduced.
- > 99% on clean, running water.

These achievements have demanded large investments over a long time. A total of €80 billion have been invested, of which main investment is in the sewers. From an asset point of view the networks are more valuable than the treatment plants.

So, with all these achievements, why change course from conventional to New Sanitation?

- Otterpohl and Oldenburg were pioneering vacuum in Lübeck some 20 years ago: 450 houses with vacuum for blackwater collection, and greywater.
- In the Netherlands it is not allowed to use sludge in agriculture. The sludge is either burnt or combined with cement. N and P in the sludge are thereby lost.
- Huge debate in Europe what to do with the sludge – what will be the future?
- Our P comes from Africa. 10-20% is entering surface water. Not a sustainable way to deal with nutrients.
- How to change this situation? Look at all the values in the wastewater: water, nutrients, energy.
- When changing course to New Sanitation it is important to use existing infrastructure. In new developments, however, it is possible to for high-tech but decentralized solutions which can be modular, and adaptable to local conditions. For this approach to make sense it is necessary to have a scale of at least 200-300 houses.
- Energy loop, nutrient loop, water loop. Aquifers for potable water are shrinking also in the Netherlands, but for now the water loop is not the main focus here; energy and nutrients are in focus in the Netherlands for New Sanitation concepts.
- Flowstream concentration is key to achieve efficiency in treatment. N and P are difficult to get out from diluted flowstreams. This is the same logic with which organic solid waste is kept separate from other solid waste fractions - to improve the treatment of each fraction. Treatment is simply more efficient when flowstreams with different characteristics are collected and treated separately. The consequence for the wastewater sector is that two separate sewers are needed to keep blackwater and greywater separate.



**Redundancy** – In Sneek for the 200 houses there are double vacuum pumps, double discharge pumps, all sensors inside are double (digital and analogue) and there is a connection for a vacuum truck at the pumping station, should there be a longer power failure. For a shorter power failure, the vacuum tank is sufficient. In settings with frequent power failures redundancy can be organized with a small generator in the pumping station. This is a solution that is used in Crimea. Another possibility to increase redundancy in a setting with infrequent power failures is to provide for a connection for a rental generator set. There are many ways to prevent the complete fallout of the system. It is important, however, to remember that mechanical failures are more frequent than power outages in the Netherlands and Sweden. Brendo did not think that the redundancy considered for the Stockholm pilot, with vacuum pumps on each property feeding to the water company's vacuum station with double pumps was good; firstly it is incredibly costly, and secondly it is not providing redundancy for the full system but only for the part under the jurisdiction of the water company. In Helsingborg they have chosen a similar approach to Sneek and Hamburg, where there are no vacuum units on property level; the pumps are centrally located under the jurisdiction of the water company or other professional entity.

### **Field Trip – Noorderhoek**

The field trip was organized by Brendo Meulman, DeSaH

#### **Blackwater management**

##### Installations in buildings

In the Noorderhoek area where 200 houses are connected to the vacuum system combining blackwater and kitchen waste. All buildings are equipped with vacuum toilets and kitchen waste grinders. Vacuum toilets allow for a 25% reduction of water consumption in the Dutch context through the use of vacuum toilets (1L/flush). The toilets do not look very different from normal toilets. Ø50 pipe is used for the vacuum sewer connection to apartments in the houses with Ø63 standpipes. In the first houses the housing company wanted to have double systems, but in the Noorderhoek area there is no double system – the housing company is confident with the vacuum system now.



*Vacuum toilet and kitchen grinder in the nursing home restaurant. Photo: M. Lennartsson*

The kitchen grinders are mounted in the sink, and one way to reduce the water mixture in the kitchen grinder is to place the faucet off-center between the sinks, so that it makes it more difficult for people to use the kitchen grinder for anything else but organic kitchen waste (automatic nozzles are located in the grinder).

### The vacuum system for blackwater collection

In the streets Ø90 since it is a pipe diameter more frequently used in the Netherlands (Ø75 is used for the main line in Hamburg). Clogging has happened in one place where the vacuum pipe was not installed in the right way (the builders disregarded the installation instructions and installed the pipe with too large spacing, 2.5 m instead of 1 m, between the anchor points on a hanging pipe – a gravity sewer would also clog with such construction errors). Once a year the pipe is de-clogged, but it will be replaced in 2017. Within the houses PVC piping is used and HDPE in outside piping.

In the Netherlands there are manholes every 40-50 meters. The vacuum goes through the manholes of the stormwater, where valves are located.

They have had a leakage once in Sneek. Some heavy equipment used to dig in the soil hit a pipe, something like this is needed to get a leak in a vacuum system. Therefore, it is necessary to lay the pipes in loops (like in Hamburg and Sneek) so that it is possible, by means of closing valves and use loops, to get to the vacuum station in spite of the leak.

With time there will be more leakages – after some years you may have leakage and the valves can be used. However, vacuum sewer systems have been used in the Netherlands already since the 70s. The vacuum valve staying open because of clogging, is one possibility of malfunction. The piping problems would, in essence, be the same with vacuum sewers as with pressure sewers.



*Photo: E. Kvarnström*



### Blackwater pumping station

The toilets are connected to a Roediger vacuum station. The valve is in the basement of the house. In the street one can disconnect every 3-5 houses if there is an issue with the system. There are double pumps for redundancy purposes and also a possibility to connect a vacuum truck to the system, if both pumps would fail simultaneously or if there is a power outage.

The pumping station is located below ground. The station has a 6-fold ventilation of the room, with the exhaust air is going through a biological filter (activated carbon would have been a better design according to Landustrie, but the installed filter works. It was really difficult to sense an odor from the filter even while the pumps were running). Odors are monitored continuously both in the treatment plant and the pumping station. Different sensors are connected to an SMS alarm system, which alerts the operator. So far there has

not been an alarm. The exhaust from the ventilation, as well as the treatment plant and the pumping station, are all located within 15 m of residences.

In the smaller pilot, Lemmerweg, the inhabitants are using wash towels that do not degrade. These do not contribute to blockages in toilet and pipes but they pile up in the vacuum tank. The tank is cleaned once a year. In Noorderhoek this is not a problem, the inhabitants there are not using the same style non-degradable wash towels.



*Blackwater pumping station and air exhaust. Photo: E. Kvarnström and M Lennartsson*

### The blackwater treatment plant

The blackwater treatment plant is located in between the residential housing and the nursing home, with about 15 m to the nursing home and 25 m to the residential housing. The size of the plant is about 12x6m with a height of 7m. One side of the treatment plant has a glass façade, for transparency reasons.



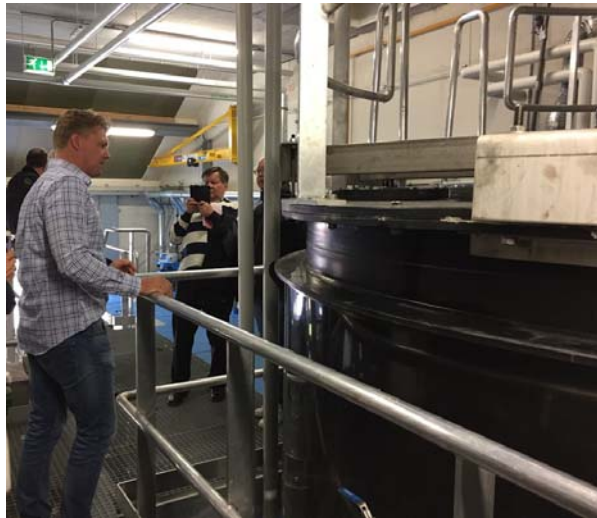
*Treatment plant located in the development. Photo: E. Kvarnström and M Lennartsson*

The treatment processes employed are: UASB+OLAND+struvite, after which the effluent is combined with greywater. The biogas produced is used to run a boiler for water heating to the area. Regulations (ATEX?) surrounding biogas production are dependent on how much gas is produced and how it is stored and under what pressure. DeSaH always keeps below the max storage level for operation in residential areas and similar



(max storage volume is 5m<sup>3</sup>). In that way treatment units can be installed in buildings. As soon as the biogas volume or pressure is close to the limit, the gas is used to heat water. They store hot water, not gas.

Blackwater can be digested separately, it is more complex to digest food waste only, especially on a small scale. Food waste easily hydrolyzes with acid production reducing the pH, which is problematic for digestion. If blackwater is added it will neutralize the acid produced in the food waste.



*Indoor, treatment plant. Photo: M Lennartsson*

### **Greywater treatment**

The greywater is collected and treated in a conventional activated sludge treatment with bio-P removal process. However, as the greywater treatment is located within the neighbourhood and in an indoor facility, the temperature of the water is close to 30° C which is not only beneficial for the process but also allows for a substantial amount of energy to be recovered.



*Bio-rotor for greywater treatment. Photo: E. Kvarnström*



## **Energy recovery**

The energy in the greywater is recovered through a heat-exchanger, and since the water has been treated it is possible to retrieve more energy than without prior treatment. Un-treated greywater normally starts causing problems in a heat-exchanger at temperature of 12-13° C but after treatment it can be brought down to 4-5°C, with a COP of about 6.

The biogas is not stored at high pressure, but after cleaning through a coal filter, it is burned in a conventional gasburner and the energy is stored as hotwater that is used in the local district heating system.



*Heat-exchanger, gasburner and hotwater storage tanks. Photo: M. Lennartsson*

## **Costs**

According to Landustrie/DeSaH a CAPEX comparison has shown that their approach is, when compared to a 100,000 pe conventional plant, cost effective already at 2,400 people. If the savings are included, energy and water, the system is cost effective at 1,200 people.

The water savings are higher than expected for the areas with vacuum toilets only. The kitchen grinder use has lowered the water savings (initially an additional use of 7 L/cap/day but now down to 3L/cap/day).

Flushing the toilets with greywater does not make sense for a vacuum system where the water use for toilet flushing is only 7L/cap/day. Moreover, if the blackwater will be used for agricultural purposes after treatment it is not advisable to mix it with greywater.

## **Housing cooperation feedback**

The housing cooperation's interest in the project was to work with sustainability but without compromising the cost of rent for the tenants. This project, with some external funding, was a way of doing just that. What they have learned is that they, as the housing cooperation, cannot skimp on information about the system and how it works to the tenants. Last year's tenants moved in without any information at all (the cooperation was too busy). In such a situation, people do not know why the system is different, how it works, why the housing cooperation has installed new systems and what they contribute with, as tenants, by using the system properly.

There has been both positive feedback and complaints from the tenants. The complaints are mostly related to the function of the kitchen grinder – the tenants do not know how to reset it if it stops working. Information and communication are solutions to this problem. Others are very happy with the grinder as a less smelly way of dealing with organic kitchen waste.

O&M of all of the environmental services (heat, ventilation, vacuum system within the buildings, kitchen grinders) are outsourced to a service company by the housing cooperation. This service company is doing maintenance on the housing cooperation's full stock of apartments (20,000 units). They find that the new system is generating a few more calls from the tenants compared to from tenants in "normal" apartments. The calls are generally about the kitchen grinder and how to reset it if it has stopped working.

There is no need for behavioural change in terms of product use within the households. One exception is for the nursing home, where all toilets are cleaned at the same time. Hence, in the nursing home they are informed not to use bleach or cleaning agents that use bleach because of the functionality of the activated sludge part of the treatment plant.

## **4. Conclusions**

The two days of touring provided the opportunity to meet professionals involved in, and see installations of, separate collection and treatment of blackwater in two different settings and two different organizational models. In one case the blackwater is mixed with grinded kitchen waste, in the other case blackwater will be mixed at the treatment plant with grease once the process is up and running. The participants were exposed to two different approaches to service delivery, different approaches to redundancy planning and implementation as well as different concerns. Furthermore, the study tour also provided the opportunity to exchange with other municipalities with upcoming urban blackwater projects: Ghent, Helsingborg and Amsterdam as well as with Bauhaus University in Weimar and Ghent University.

The study tour was highly appreciated among both participants from the Stockholm city and Stockholm Water and Waste Company. Comments after the last day included remarks like the tour being an eye opener to vacuum systems and their functionality in urban areas, and on how important it is to see and smell things in real life, especially in our sector where 24/7 reliable services with complete odor control really is paramount to acceptance both from a user and a utility perspective in an urban setting. Introduction of technologies new to a city or water utility really demands in-person experience to create the confidence to start considering different systems than the conventionally applied – it is not enough with "second-hand" references only.

One concrete outcome of the study tour is commitment from Bauhaus University to provide a web platform for continued exchange between Hamburg, Weimar, Ghent, Helsingborg, Amsterdam and Stockholm. It was also decided that the group will meet in a year's time in Amsterdam to learn from their experiences with the implementation of a floating treatment plant for separate black- and greywater treatment.

As for Stockholm and the pilot project under planning in Stockholm Royal Seaport the study tour has provided invaluable insights into vacuum systems and their functionality. The study tour has laid the foundation for a more informed choice when moving forward with the Stockholm Royal Seaport pilot.

## **Annex 1 - Executive summary – Food and Energy in a Circular Economy**

Stockholm Royal Seaport is appointed the next generation sustainable city districts with ambitious environmental goals including resource efficiency and becoming climate positive (according to the Climate Positive Development Program framework). One of the areas subject to investigations has been wastewater management. With funding from the Carbon Neutral Cities Alliance Innovation Fund this study has been possible to carry out.

Wastewater contains resources such as heat, organic matter and nutrients which to a certain degree can be recovered in conventional wastewater treatment processes. However, the mechanical, biological and chemical unit processes in a conventional wastewater treatment plant are not optimized for such resource recovery; they are optimized for reduction of pollutants in the wastewater with the aim of recipient and public health protection. Given the existing wastewater infrastructure in urban areas in Sweden, attempts to recover resources in conventional wastewater systems can only be made at the end of pipe – in the wastewater treatment plant.

It has been shown that a higher level of resource recovery, recycling and reuse could be obtained in the wastewater sector with upstream separation of different wastewater flowstreams. A pre-feasibility study made by the City of Stockholm has shown that source separation provides the best potential for increase in resource recovery from wastewater in Stockholm. This project's purpose is to deliver a feasibility study describing the potential and scenarios of source separating wastewater systems for biogas, heat and nutrients in (i) the Royal Seaport area in Stockholm and (ii) new developments in metropolitan Stockholm the coming 20 years. This report is presenting the results from a scenario assessment, where the potentials for increased recycling of biogas, heat and nutrients are explored for source-separating wastewater systems when compared to a conventional scenario.

It should be noted that this report is presenting potentials for biogas, heat and nutrient recycling. The calculations behind these potentials are based on a number of necessary assumptions, which inherently will afflict the results with insecurity. They should therefore be seen as an assessment of potentials, not as absolute values or absolute results. There is still, however, a value to engage in scenario modeling to inform decision-making processes, since carefully produced scenario modeling with clearly stated assumptions provides a possibility to better understand future possibilities.

### ***Resource Recovery Potential***

#### **Biogas**

A source-separating scenario, where blackwater is separated from the greywater and where the organic waste goes via a garbage disposer to a separate system, is estimated to increase the biogas potential for both organic waste and for wastewater, although the highest potential is estimated to lie with the separation of blackwater from the greywater, around 70%. It can also be concluded that the same potential is considerably lower for the organic waste flow, around

15%, but the losses in this flowstream, both within a conventional system and the source-separating system can be influenced by targeting organic waste behavior at the household level.

### Heat

The separation of greywater from the blackwater improves the heat recovery potential. Theoretically, 33% more energy can be recovered with a heat exchanger on greywater compared to the same heat exchanger on a mixed wastewater (Nykqvist, 2013). To improve the evenness of the flow, which is also important for the functionality of the heat recovery process irrespective of flow, it could be advisable to employ the heat recovery on a larger level than household/property level. In total up to 80% of the heat can be recovered in a source separated system.

### Nutrients

The nutrient recovery potential assessment includes two different scenarios, both a high-tech nutrient recovery alternative which can be combined with the biogas technology explored under the biogas potential, an alternative called UASB high-tech, and a lower-tech scenario without biogas recovery, called urea sanitization.

The increase in potential of N reuse, compared to the conventional system, is over 2600% for the UASB high-tech scenario and over 3200 % for the urea sanitization scenario. The urea sanitization scenario also has the lowest N “discharge” outlet of all three scenarios.

For P the same dramatic shift can be seen for both source-separating scenarios but from “other use” to “agricultural use” compared to the conventional scenario; the increase is over 2200% for both source-separating alternatives.

For the organic solid waste systems it can be seen that the source-separating technology with garbage disposer to pipe provides a slight increase in biogas potential (15%) and a doubling of the nutrient recycling potential even if the total amount of nutrients is considerably lower than for blackwater. However, the garbage disposer to pipe system can relatively easily plug into the existing biogas production and agricultural reuse system for solid organic waste.

### Water

With the proposed system, replacing a low-flush toilet to a vacuum toilet, 15-20% potable water can be saved.

### *Climate effects*

The potential to reduce GHG emissions is significant. A conservative estimate is that about 130 kg CO<sub>2e</sub> can be reduced if the flowstreams are separated and management of the resources is optimized. 80% is related to recovery of heat, substituting district heating. This equals to a reduction of more than 5% of Stockholm’s average GHG emissions of 2,5 tons/capita.



### *Cost estimates*

Increased performance of a technical system in most cases also entails increased costs. The investment cost in a source-separated system is most likely to land on the developer and the utility (Kärrman et.al. 2016). The investments for the developer can be motivated by the saved heating costs. The investments for the utility will have to be weighed against the economic benefits.

The economic benefits of the system are difficult to fully quantify due to lack of knowledge. In an early cost/benefit analysis done for SRS, one conclusion is that even with limited quantifications, the source-separating systems are expected to generate the largest benefits, even if all of them were not quantifiable. There is a need to further develop the knowledge about the different benefits of different sanitation systems, and their quantification.

Another aspect of societal accountability is the necessity to plan for possible future demands on the sanitation system of Stockholm in the decision-making process due to the long lifetime of urban infrastructure. There are reasons to believe that the future may hold (i) stricter legislation regarding discharge levels of heavy metals, chemicals, and pharmaceutical residues, (ii) increased risks of flooding, (iii) water shortages, and (iv) increased demands on nutrient recycling to farmland.

The above highlights that source-separation of blackwater from greywater will increase the potentials for biogas production, heat recovery, nutrient recycling and water saving. However, it requires acceptance among the stakeholders

- Developers need to accept changes in the design of the sanitation system on the property.
- Utilities need to accept that resource optimized systems may go beyond their conventional mandate and jurisdiction, and
- Farmers' requirements of high-quality fertilizers has to be in focus when designing the system

To optimize the system, the system-boundaries have to be extended, mandates have to be revised and each flowstream with its particular resource must be managed in such a way that it's coming to best use

The above highlights that separation of blackwater from greywater will increase the potentials for biogas production, heat recovery, nutrient recycling and water saving. However, there is a need for further development for blackwater recycling technologies, as well as the need to balance trade-offs between optimal biogas production and optimal nutrient recovery. Furthermore, there is a need to better understand the heat recovery potentials on greywater and its effects on wastewater treatment plant processes.

## **Annex 2 Program for study tour to Hamburg and Sneek**

**Dates:** September 25 to 27, 2017.

**Participants from Stockholm:** Lars Lindblom, Maria Arveström, Mats Ohlsson, Henri Mäkelä, Stefan Lindström, Maria Lennartsson, Elisabeth Kvarnström.

### **Monday, September 25, 2017**

16:50-18:25	Flight with SAS to Hamburg.
19:30	Informal networking dinner with, among others, representatives from Hamburg Wasser, Waternet in the Netherlands, Bauhaus University Weimar, and the water utility in Helsingborg.

### **Tuesday, September 26, 2017**

09:00-09:15	Start of study tour. Coffee and bun at the Hamburg Wasser HQ (Rotheburgsort).
09:15-10:00	Short introduction of participants and of development projects*.
10:00-11:30	Presentation by Hamburg Wassers of their system in Jenfelder Au.
11:30-12:30	Lunch in Hamburg Wasser's canteen.
12:30-13:30	Transport to Jenfelder Au by bus.
13:30-15:30	Jenfelder Au site visit.
15:30	Departure in bus, together with Waternet, towards Sneek. Arrival time in Sneek dependent on the traffic situation.

### **Wednesday, September 27, 2017**

08:50	Departure from Van der Valk hotel to DeSaH/Landustrie (5 min walk).
09:00-09:20	Coffee and short introduction of participants.
09:20-10:10	Brendo Meulman from DeSaH presents the project Noorderhoek*.
10:10-10:30	Presentation of Stockholm Royal Seaport.
10:30-11:45	Discussion
11:45-12:45	Lunch to which the municipality and the housing company also are invited.
12:45-12:55	Departure to Noorderhoek (in Sneek)
13:00-13:30	Visit at an elderly home.
13:30-13:45	Vacuum pump installation.
13:45-14:30	Visit at the WWTP
14:30	Taxi to Schiphol.
18:55-21:00	Flight to Arlanda.

