SiEUGreen
Sino-European innovative green and smart cities

Sino-European Innovative Green and Smart Cities

Deliverable 2.1

Green Technology (T1) ready

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The project has received funding from the European Union's Horizon 2020 Research and Innovation Programme, under grant Agreement N 774233, and from the Chinese Ministry of Science and Technology.

Throughout SiEUGreen's implementation, the EU and China will share technologies and experiences, thus contributing to the future development of urban agriculture and urban resilience in both.

The project SiEUGreen aspires to enhance EU-China cooperation in promoting urban agriculture for food security, resource efficiency and smart, resilient cities.

The project contributes to the preparation, deployment and evaluation of showcases in five selected European and Chinese urban and peri-urban areas: a previous hospital site in Norway, community gardens in Denmark, previously unused municipal areas with dense refugee populations in Turkey, big urban community farms in Beijing and new green urban development in Changsha in Central China.

A sustainable business model allowing SiEUGreen to live beyond the project period is planned by joining forces of private investors, governmental policy makers, communities of citizens, academia and technology providers.

Technical references

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[1] **PU** = Public
PP = Restricted to other program participants (including the Commission Services)
RE = Restricted to a group specified by the consortium (including the Commission Services)
CO = Confidential, only for members of the consortium (including the Commission Services)

Document history			
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1.0	28/05/2019	NIBIO	Initial Draft
1.1	21/06/2019	NIBIO	Draft version circulated for partners input
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Co-funded by the Horizon 2020 programme of the European Union
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Executive summary

The report presents an evaluation of biogas reactors for possible use in small scale urban settings, as well as use of organic waste to produce alternative growth media by composting and for production of insects or worms as fish feed in aquaponic systems.

Biogas production from toilet waste (blackwater) and organic household waste is a key treatment technology in Fredrikstad showcases in the SiEUGreen project. The anaerobic treatment is a complicated process regulated by several factors. For the showcase in Fredrikstad the project has evaluated four different anaerobic sludge bed reactors with enhanced biomass retention that are currently in use: the Upflow Anaerobic Sludge Bed (UASB) system, the Upflow Sludge Blanket Anaerobic Baffled Reactor (USBABR), the Anaerobic Membrane Bioreactor (AnMBR), and the Antec Biofilm (AB) system.

The UASB system is well tested and has a small footprint, but the high tower feature of the reactor may be a critical issue when the reactor is to be installed indoors.

The USBABR is a new prototype reactor developed in Norway and tested on source-separated blackwater. The performance is comparable with the standard UASB, but with a much smaller footprint. Tests are being performed at pilot scale, but there is no experience with the combination of blackwater and milled food waste.

AnMBR is a combination of anaerobic digestion and membrane bioreactor. It maximizes the effectiveness of the anaerobic process with a minimum space requirement. The integration of the membrane in the anaerobic reactor allows complete physical retention of bacterial flocs and most of the suspended solids, and this reactor therefore offers good disinfection capacity. The main drawbacks of the AnMBRs are the low membrane flux, membrane fouling, and high capital and operational costs..

The Antec Biofilm reactor is a plug flow reactor with biofilm technology. It has a compact design and can be easily installed indoors. The experience with blackwater is limited with this reactor, but results for sewage sludge and cattle manure are promising. The reactor has been tested for SIEUGreen with pig slurry (surrogate for blackwater), toilet paper and food waste. Preliminary data indicate that the reactor capacity is far from optimally utilized, and that additional food waste may be needed to achieve a net positive energy output..

Composting is aerobic decomposition of organic material. It can be done on different scales, from industrially to composting in gardens, and can therefore easily be adapted to urban farming systems. Often the material needs to be cut into smaller pieces prior to composting. The simplest way of composting is in rows (windrows) that are turned regularly. To compost food waste etc. this way, it is usually necessary to mix it with other waste products (e.g. garden waste, wood chips) to get enough air into the mixture and also get a more optimal C:N ratio. There are also several enclosed composting reactors on the market. When composting in urban areas, it is important to place the composting such that any nuisance from smell is avoided. Often reactors or at least enclosed composting will be preferred.

Co-composting of organic household waste /green waste and solar dry toilet residue can produce an alternative growth medium to peat and can be implemented in different showcases.

Using an organic waste product to cultivate insects or worms as fish feed has been evaluated and can be of interest in connection to the aquaponic systems. Insect production from waste resources needs special expertise and can be complicated in small scale urban settings.

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1. Introduction

More than half the world's population currently live in cities or urban areas, and by 2050 an additional 2.5 billion people are expected to live be urban dwellers (FAO, 2019). One of the most pressing challenges of the 21st century will be to feed a projected global population of nine billion people while reducing humanity's agricultural footprint at the same time (Godfray et al. 2010). Sustainable agriculture in urban areas may be one of the solutions to feed this increasing world population. Urban agriculture may have as much as twice the vegetable yield/m^2 as rural farming in Australia, but can be very inefficient with respect to resource and labour inputs (MacDougall et al. 2019). In addition, it is imperative to acknowledge the health and social benefits of producing your own food also when living in urban areas.

Development of green technologies in the SiEUGreen project aims to utilize resources in the city as input to urban agriculture providing citizens with fresh fruits and vegetables. The innovations regarding the green technology lie in generating growth systems based on local resources rather than importing them from the outside. The investigations will focus on developing an integrated solution where waste resources generated from the showcase buildings provide, quality plant nutrients, growth media and water as well as energy. Part of the solution might be to recover energy and nutrients from blackwater and food waste using anaerobic digestion and composting. Due to the characteristics of effluents from toilets and kitchen grinders, only sludge bed reactors with enhanced biomass retention were considered for the showcase in Fredrikstad.

Four different sludge bed reactors that are evaluated, the Upflow Anaerobic Sludge Bed (UASB) system, the Upflow Sludge Blanket Anaerobic Baffled Reactor (USBABR), the Anaerobic Membrane Bioreactor (AnMBR), and the Antec Biofilm (AB) system. Selecting anaerobic reactor technology depends on the performance (recovery of energy and nutrients), environment issues, public health and acceptance as well as economy. The footprint and operation and maintenance are also important evaluation parameters.

Composting or co-composting of waste material to produce growth media that can substitute peat and insect cultivation producing protein fodder based on organic waste are also in green technologies involved in the SiEUGreen project.

Chapter 2 of this deliverable provides a brief overview of the different green technologies recycling different resources. The chapter also describes the readiness level of the technologies selected for implementation.

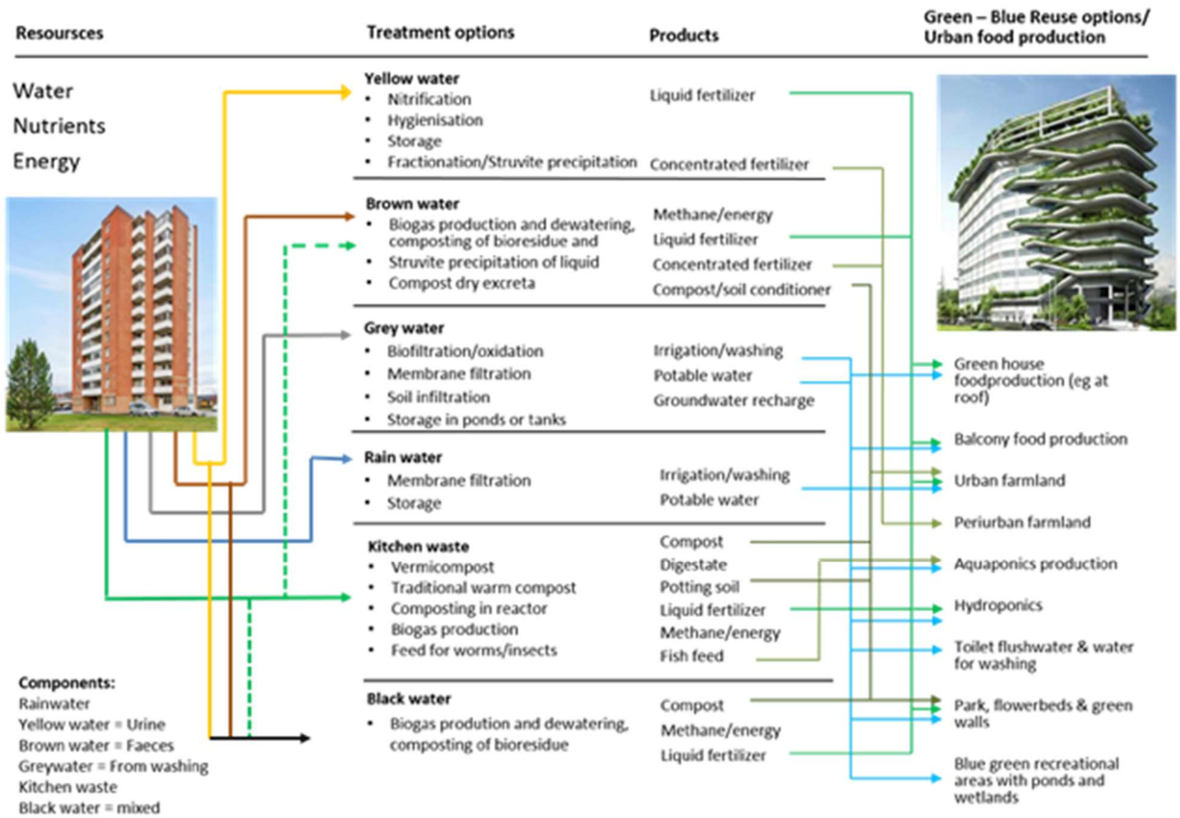
Chapter 3 presents the fact sheets on these green technologies associated with the aim of using the resources provided in a circular system.

The Annex provides the biogas reactor and its site location, and the list of student research carried out in the context of testing the green technologies in controlled growth rooms, greenhouses and on open air roof tops prior to the implementation in the showcases.

2. Showcase technologies for energy and nutrient recovery from blackwater and organic household waste

2.1 Overview of technologies for showcase deployment

The technologies under SiEUGreen that will focus on the reuse of various resources including land, water, waste nutrients, solar energy and biogas have already been established in the SiEUGreen grant agreement. The concept demonstrates a strong focus on agricultural food production with zero or minimum transport, solar energy utilization, water saving and wastewater reuse, waste recycling, residents' involvement and organic green UA for smart city residents. The SiEUGreen model of recyclable resources is presented below.



2.2 Technology readiness level (TRL)

The TRLs of the SiEUGreen technologies are established in the GA. The TRL level of the technologies ranges from 3 to 9. Once the technology is deployed in the showcase it will pass three distinct phases: i) testing of the technology in an open environment, ii) measurable data collection to feed back to research, and iii) adjustment and improvement of the technology to raise the TRL.

3. SiEUGreen green technology fact sheet

Biogas production

Biogas production from toilet waste (blackwater) and organic household waste (OHW) is a key treatment technology. The anaerobic treatment is a complicated process regulated by several factors. The factors such as wastewater characteristics, acclimatization of seed sludge, pH, volatile fatty acids (VFA), temperature, nutrients, presence of toxic compounds, loading rate, hydraulic retention time (HRT), solids retention time (SRT), liquid mixing and reactor design affect the processes of the growth of sludge bed, anaerobic digestion, biogas production, methane yield and effluent quality. Different anaerobic sludge bed reactors with enhanced biomass retention are currently in use: the Upflow Anaerobic Sludge Bed (UASB) system, the Upflow Sludge Blanket Anaerobic Baffled Reactor (USBABR), the Anaerobic Membrane Bioreactor (AnMBR), and the Antec Biofilm (AB) system.

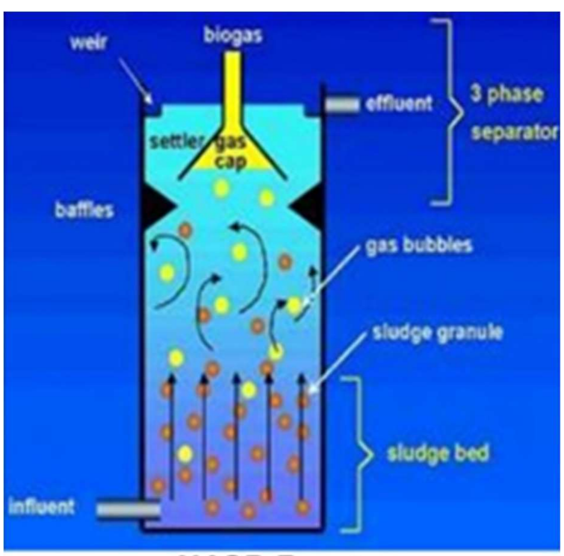
3.1 Biogas production using the UASB bioreactor

Treatment option/process	Biogas production using the upflow anaerobic sludge blanket (UASB) bioreactor
Resources	Blackwater and organic household waste
Expected products	Biogas, growth media and fertilizer
Green-blue reuse options	Electricity and heat, growing vegetables

Short description of technology

The UASB reactor is the most popular and proven technology developed at Wageningen University in The Netherlands (Lettinga et al. 1983, Lettinga and Hulshoff Pol 1991). It is based on the concept of an upflow mode and a three-phase separator, which enables the reactor to separate gas, water, and sludge mixtures under high-turbulence conditions. The feasibility of anaerobic treatment of source-separated blackwater characterized by high-suspended solids using UASB was successfully demonstrated at the lab- and full-scale in The Netherlands with relatively short HRT (de Graaff et al. 2010, Tervahauta et al. 2013, Cunha et al. 2018, Zeeman et al. 2008). The HRT used under these conditions was 8.7 days. If used for the SiEUGreen project with the daily production of 600 L blackwater, the UASB should have a reactor volume of about 5.5 m^{-3}. Advantage: rich experience. Small footprint but the high tower feature of the reactor may be a critical issue when installing the reactor in the basement. Installing outside the building may require good heat installation during the long cold season. Solid particles from food waste may be an issue to test/consider.

Figures presenting the technology or process



UASB Reactor

Figure 1. Upflow anaerobic sludge blanket (UASB) reactor.

Challenges with implementation in the urban setting				
Parameter	Low	Medium	High	NA*
Space requirement			X	
Odour and nuisance		X		
Hygiene		X		
Regulation		X		
Public acceptance			X	
Comments:				

Short description of planned SiEUGreen investigations

Searching for a suitable place to install the reactor, taking special and heating factors into consideration and checking the efficiency dealing with solid waste.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Construction costs	X			
Nitrogen		X			O&M costs		X		
Organic matter, SS	X				Cost efficiency			X	
Pathogens	X				Stability	X			
Resource recovery: Nutrients		X			**Social**				
Energy			X		Social acceptance	X			X
Biodiversity	X	X			**Technical**				
Landscape aesthetics	X	X			TRL levels	>5			

Other comments	
Planned for use in showcase	
Possible use in other showcases	
Last updated	28.06.2019 RL

*NA = data not available or not relevant

3.2 Biogas production using the AnMBR bioreactor

Treatment option/process	Biogas production using the Anaerobic Membrane Bioreactors (AnMBR)
Resources	Black water and organic household waste
Expected products	Biogas, growth media and fertilizer
Green-blue reuse options	Electricity and heat, growing vegetables

Short description of technology

AnMBR is a combination of anaerobic digestion and membrane bioreactor technology (Maaz et al. 2019), intensively studied due to high effluent quality. In this type of anaerobic reactor, a membrane is used as a solid-liquid separator. It maximizes the effectiveness of the anaerobic process with a minimum space requirement. The integration of the membrane in the anaerobic reactor allows the complete physical retention of bacterial flocs and most of the suspended solids, and therefore it can offer good disinfection capacity (Le-Clech 2010). The application of AnMBR for blackwater was tested and reported (van Voorthuizen et al. 2008). The main drawbacks of AnMBRs are the low membrane flux, membrane fouling, and high capital and operational costs, which still hinder AnMBR application (Chernicharo et al. 2015, Maaz et al. 2019).

Figures presenting the technology or process

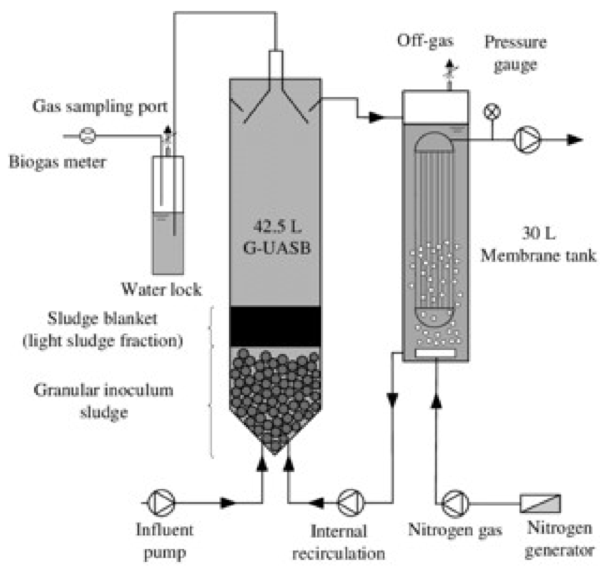


Figure 2. Anaerobic membrane bioreactors.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement			X	
Odour and nuisance		X		
Hygiene		X		
Regulation		X		
Public acceptance			X	

Comments:

Short description of planned SiEUGreen investigations

Searching for the option of increasing membrane flux, membrane fouling while lowering the capital and operational costs

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Construction costs	X			
Nitrogen		X			O&M costs		X		
Organic matter, SS	X				Cost efficiency			X	
Pathogens	X				Stability	X			
Resource recovery: Nutrients		X			**Social**				
Energy			X		Social acceptance	X			X
Biodiversity	X	X			**Technical**				
Landscape aesthetics	X	X			TRL levels	3			

Other comments	
Planned for use in showcase	

Possible use in other showcases	
Last updated	28.06.2019 RL

*NA = data not available or not relevant

3.3 Biogas production using the USBABR

Treatment option/process	Biogas production using the Upflow Sludge Blanket Anaerobic Baffled Reactor
Resources	Blackwater and organic household waste
Expected products	Biogas, growth media and fertilizer
Green-blue reuse options	Electricity and heat, growing vegetables

Short description of technology

The Upflow Sludge Blanket Anaerobic Baffled Reactor (USBABR) is a new prototype reactor developed at the University of Southern Norway (Porsgrunn, Norway) in collaboration with Ecomotive AS and tested at NMBU on source-separated blackwater at HRT of below 3 days (Moges et al. 2018). The technology is based on the principles of UASB and ABR. Its efficient process and the short hydraulic retention time allow the reactor to be small. It requires only about 2 m^3 reactor for the daily production of 600 L blackwater. Comparable performance with the standard UASB but with much smaller footprint. Could be an ideal option. However, Limited experience. Test is being performed at pilot scale. No experience yet at full-scale with source-separated blackwater.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement	X			
Odour and nuisance		X		
Hygiene		X		
Regulation		X		
Public acceptance			X	

Comments:

Short description of planned SiEUGreen investigations

More trials to accumulate experience with specific focus on dilute feedstocks will be carried out.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Construction costs	X			
Nitrogen		X			O&M costs		X		
Organic matter, SS	X				Cost efficiency			X	
Pathogens	X				Stability	X			
Resource recovery: Nutrients		X			**Social**				
Energy			X		Social acceptance	X			X
Biodiversity	X	X			**Technical**				
Landscape aesthetics	X	X			TRL levels	>5			

Other comments	
Planned for use in showcase	Fredrikstad?
Possible use in other showcases	

Last updated	28.06.2019 RL

3.4 Biogas production using the Antec Biofilm Reactor

Treatment option/process	Biogas production using the Antec Biofilm Reactor
Resources	Blackwater and organic household waste
Expected products	Biogas
Green-blue reuse options	Electricity and heat.

Short description of technology

This is a Plug Flow reactor with biofilm technology. The principle is similar to the ABR technology as the reactor is divided into several compartments as the biomass flows through the reactor at the speed with the corresponding residence time (7-10 days). The active biofilm formed at the surface supports the natural step-by-step process in the production of methane and by partly returning the biomass significantly increases the rate of degradation so that reactor efficiency becomes high. Advantage: Compact design and a 6-9 m^3 reactor can be easily installed indoors. Disadvantage: Limited experience.

However, results for cattle manure and sewage sludge are promising and a pilot scale reactor was readily available at the project implementation and was therefore selected for testing with pig slurry (surrogate for black water without toilet paper), toilet paper and food waste. The reactor has never been tested with dilute feedstocks, so a closer inspection of the operational characteristics was needed before any recommendations can be made.

Figures presenting the technology or process

Figure 3. Antec Biofilm Reactor.

Challenges with implementation in the urban setting

Parameter	Low	Medium	High	NA*
Space requirement	X			
Odour and nuisance		X		
Hygiene		X		
Regulation		X		
Public acceptance			X	

Comments:

Short description of planned SiEUGreen investigations

More trials to accumulate experience with specific focus on dilute feedstocks will be carried out									
Preliminary evaluation of sustainability parameters									
Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Construction costs	X			
Nitrogen		X			O&M costs		X		
Organic matter, SS	X				Cost efficiency			X	
Pathogens	X				Stability	X			
Resource recovery: Nutrients		X			**Social**				
Energy			X		Social acceptance				X
Biodiversity	X	X			**Technical**				
Landscape aesthetics	X	X			TRL levels	7			
Other comments									
Planned for use in showcase	Fredrikstad?								
Possible use in other showcases									

3.5 Solid digestate from biogas pilot scale reactor as fertilizer

Treatment option/process	Solid digestate from biogas pilot scale reactor
Resources	Digestate from anaerobic digestion of e.g. food waste, sewage
Expected products	Fertilizer
Green-blue reuse options	Gardens, field crops, fruits and vegetables, parks and after treatment in greenhouses, balconies

Short description of technology

Digestates are organic residues from biogas production. They have characteristics that set them apart from both mineral fertilizers and most other organic fertilizers. They are rich in mineral nitrogen, almost exclusively as ammonium (NH_4^+), and they also contain some residual organic matter with some organic N (Alburquerque et al. 2012a, b, Grigatti et al. 2011). Digestates also contain other nutrients in a ratio that is quite balanced compared to the plant's need. Digestates may therefore be good fertilizers (Abubaker et al. 2012, Möller and Müller, 2012, Nkoa et al. 2014). Due to the high content of mineral nitrogen, digestates are better than most other organic fertilizers in grain production (Kristoffersen et al. 2013).

High ammonium content in digestates means that losses of nitrogen as ammonia (Möller and Müller 2012) during spreading and improper storage and handling can be high. Ammonium is not lost as easily as nitrate by leaching, but ammonium is usually quickly nitrified into nitrate in aerobic agricultural soil (Alburquerque et al. 2012b, Grigatti et al. 2011, Tambone and Adani 2017). However, some horticultural plants may not grow well with ammonium as the only source of nitrogen (Phipps and Cornforth 1970). Greenhouse gases can be emitted during digestate handling and also after application to soil (Dietrich 2017, Möller and Stinner 2009).

Digestates are sometimes separated into a liquid and a solid fraction, usually to make storage and transport of the solid fraction more economical (Drosg et al. 2015). The liquid fraction contains most of the plant available nutrients, whilst the solid fraction is mostly organic matter.

Digestates can be used directly as a fertilizer for field crops, fruit and berries and in gardens and parks (Alburquerque et al. 2012c, Gunnarsson 2012). However, application to potted plants with little and/or artificial soil or hydroponics systems may be problematic. Nitrification and breakdown of any other harmful compounds from anaerobic conditions will happen quickly in aerobic soil, and the buffer capacity of the soil will dampen pH changes induced by nitrification. Nitrification (see factsheet) is recommended before application to plants grown with little or no soil and/or little natural microflora in the soil. A diluted solution of nitrified liquid fraction of digestate could be used for watering in greenhouses. The solid fraction of digestate may be a suitable constituent in plant growth media after composting (see fact sheet).

Short description of planned SiEUGreen investigations

SiEUGreen is doing tests on nitrification of liquid digestate, and digestate will be tested as fertilizer directly.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Construction costs				X
Nitrogen	X				O&M costs				X
Organic matter, SS	X				Cost efficiency		X		
Pathogens		X			Stability				X
Resource recovery: Nutrients	X				**Social**				
Energy				X	Social acceptance		X		
Biodiversity				X	**Technical**				
Landscape aesthetics				X	TRL levels	6-9			

Other comments	
Planned for use in showcase	Fredrikstad
Possible use in other showcases	Other?
Important references/other showcases in urban context	

*NA = data not available or not relevant

Production of protein rich fodder for aquatic systems

3.6 Production of insects from organic waste

Treatment option/process	Use of organic waste product to produce insects in connection with aquatic systems
Resources	Food waste
Expected products	Protein rich feed
Green-blue reuse options	Aquaponics, chicken farming

Short description of technology

Insects and other cold-blooded animals convert feed into biomass far more efficiently than warm-blooded animals. Many of them are also able to live on a wide variety of food sources, as long as these provide sufficient protein and energy.

Insect larvae can be cultivated for feed or food. There is a large increase in R&D for this technology in the last five years. SLU has some recent research on this (Lalander et al., 2019). They chose black soldier fly (*Hermetia illucens*) because it does not eat as adults and therefore does not spread diseases. It is also already present in most tropical and sub-tropical areas and cannot survive winters in colder climates. The rearing of the larvae is quite simple; they grow in boxes (Fig. 5) and are fed with waste with a suitable combination of protein and energy (Lalander et al., 2019, Lim et al., 2019). Food waste from households is likely to be suitable. The waste still has some biogas potential afterwards, and production of insects first and then biogas may be the best way to valorise food waste (Lalander et al., 2018). Pathogens appear to be suppressed in the waste but feeding it to insects is not sterilisation (Lalander, 2015a, 2016).

The rearing of black soldier fly larvae is simple, and only requires a box in a room with a suitable temperature. However, the mating and production of new eggs is complicated and requires special infrastructure such as special chambers for mating. The conclusion/recommendation was that for small scale production in urban farming, it would be better to buy eggs from a central facility and only grow the larvae locally.

An alternative to black soldier fly is mealworm (*Tenebrio molitor*) (Feon et al., 2019, Thevenot et al., 2018). These seem to need more nutritious feed than black soldier fly and may therefore be more difficult to rear on any kind of waste, but some results suggest that a combination of both mealworm and black soldier fly may give the best utilisation of the feed (Wang et al., 2017).

If vermicomposting is used, some worms can be harvested as feed (Lalander et al., 2015b). This is a very simple technology which only needs some equipment for harvesting of worms. A potential problem is that heavy metals accumulate in the worms (Suthar, 2008, Suthar and Singh, 2008), but with clean waste (e.g. food waste), this should not pose any problem.

Figure

Figure 5. Black soldier fly larvae eating newly applied food waste slurry (left) and fish waste (right). Both from the SLU lab in Uppsala (photo: B. Føreid).

Short description of planned SiEUGreen investigations

SiEUGreen does not plan its own investigations in this area, but we are keeping ourselves updated on work elsewhere, and how it could be adapted to a small scale in urban farming.

Preliminary evaluation of sustainability parameters

Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Construction costs		X		
Nitrogen		X			O&M costs				X
Organic matter, SS	X				Cost efficiency				X
Pathogens		X			Stability				X
Resource recovery:	X				**Social**				

Nutrients									
Energy			X		Social acceptance		X		
Biodiversity				X	**Technical**				
Landscape aesthetics				X	TRL levels	4-7			
Planned for use in showcase									
Possible use in other showcases	Fredrikstad, Beijing								
Last updated	27.06.19 BF								

*NA = data not available or not relevant

Co-composting of organic wastes

3.7 Co-composting of organic household waste and solar dry toilet residue

Treatment option/process	Co-composting of organic household waste /green waste and solar dry toilet residue
Treatment option/process	Composting
Resources	Food waste, garden waste, toilet waste, digestate
Expected products	Solid soil improver and/or constituent in growth medium
Green-blue reuse options	Greenhouse, urban farmland, balcony production, parks and flowerbeds

Short description of technology

Processes, general: Composting is aerobic decomposition of organic material (Dominguez et al. 1997, Pommeresche and McKinnon 2011, Sharma et al. 1997, Sørheim et al. 1999, Uhlig et al. 1997). During composting organic compounds are broken down, nutrients made more available and CO_2 released. The result is mass loss and a stabilised product that smells earth-like. Usually the temperature also rises for a period (thermophilic phase), so that most pathogens and weed seeds are killed. Unfortunately, nitrogen (N) is also lost as ammonia gas during composting (Wang et al. 2014, Hao et al. 2004, Boldrin et al. 2009), so the ratio between N and other nutrients in compost is unbalanced compared to the plant's need. Plant nutrients are mineralised during composting so that they become more plant available and some nitrogen is also nitrified to nitrate (Cáceres et al. 2018) that is more immediately available to plants. However, greenhouse gases (GHG) are also emitted during composting (Amlinger et al. 2008, Boldrin et al. 2009).

Types and scales of composting: Many types of feedstocks can be used for composting (Lind 2005, Pommeresche and McKinnon 2011). Composting can also be done on different scales, from industrially to composting in gardens. It can therefore easily be adapted to urban farming systems. Often the material needs to be cut into smaller pieces prior to composting. The simplest way of composting is in rows (windrows) that are turned regularly. To compost food waste etc. this way, it is usually necessary to mix it with other waste products (e.g. garden waste, wood chips) to get enough air into the mixture and also get a more optimal C:N ratio (Diaz and Savage 2007, Uhlig et al. 1997). However, there are also several enclosed composting reactors on the market. Usually larger reactors will have some sort of mechanical aeration and can therefore also treat wet organic waste with little or no structure (Lind 2005). N losses and smell during composting will usually be less the more enclosed the composting is. Composting will usually proceed quicker in reactors but may not be as complete as in windrow composting, where the compost matures after the thermophilic phase.

Vermicomposting: One specific composting option is vermicomposting, composting with earthworms. Earthworms can be added after a thermophilic phase or digestate can be used, or the whole composting can be done at lower temperature, with earthworms. Vermicomposting must be started with a bedding material, and material added in small portions from the top. Earthworms will then move upwards and finalised vermicompost can found in the bottom. During vermicomposting, organic material is "treated" in the gut of earthworms in addition to the microbial breakdown. This will generally make nutrients more plant available, more N nitrified and better structure (Dominguez et al. 1997, Gosh et al. 1999, Kaushik and Garg 2003, Mariani et al. 2007, Mejia et al. 2012, Mupambwa et al. 2018, Padmavathiamma et al. 2008, Solis-Suthar et al. 2015).

Use of compost: The most common use of compost is as soil improver or fertiliser and there are indications that it improves plant growth and soil (Amlinger et al. 2003, Erhart et al. 2005, Evanylo 2008, Føreid et al. 2018, Odlare et al. 2008, 2014). However, as the N content is quite low, other sources of N will usually be required during plant growth. Compost could also be used in plant growth media/potting soil, to replace peat (Nesse et al. 2018). Peat extraction is an environmental problem (Boldrin et al. 2010) and replacing peat with locally available waste will increase the self-sufficiency of urban farming systems. Most growth inhibiting substances that can be present in fresh waste will decompose during composting, but compost will usually have too high content of nutrients/salts and compacted structure. It was possible to develop mixtures with good structure and adequate salt content by using about 70% structure (Nesse et al 2018). In urban farming systems suitable structure material would be e.g. garden waste, dead leaves and chopped prunings. Vermicompost is particularly promising as plant growth medium (Bachman and Metzger 2008, Rivier et al. 2017) due to good structure, physical stability during plant growth, high water holding capacity, no inhibition of germination and plant available nutrients.

Urban composting: When composting in urban areas, it is important to place the composting such that any nuisance from smell is avoided. Often reactors or at least enclosed composting will be preferred. This could also reduce problems with pests (e.g. rats). Furthermore, there may not be access to enough structure material locally to give a good composting process in piles. This can be solved by composting at least some of the material in reactors with aeration or importing structure material. There is a lot of composting being done small scale in private gardens already; usually this works well, but the temperature does not reach the levels necessary to kill pathogens.

Figures presenting the technology or process

Figure 6. Examples of composting at different scales and with different feedstock: In rows (left – photo O. Bergersen) and small reactor for toilet waste (right – photo C. Lind)

Short description of planned SiEUGreen investigations

Composting technology is well developed already, the task will be to choose a technology that is suitable for the type and amount of material to be composted in each showcase, as well as other local factors, such as if composting can be done in a place where some smell is socially acceptable. Good knowledge of amount and type of material to be composted is also necessary before composting option(s) can be decided on.

Investigations will focus on developing plant growth medium from composting locally available waste materials in the showcases.

Preliminary evaluation of sustainability parameters									
Ecological	High	Med	Low	NA*	**Economic**	High	Med	Low	NA*
Treatment performance: Phosphorus	X				Construction costs			X	
Nitrogen		X			O&M costs				X
Organic matter, SS	X				Cost efficiency				X
Pathogens		X			Stability	X			
Resource recovery: Nutrients	X				**Social**				
Energy				X	Social acceptance		X		
Biodiversity				X	**Technical**				
Landscape aesthetics				X	TRL levels	7-9			
Planned for use in showcase	All								
Last updated	27.06.19 BF								

*NA = data not available or not relevant

4. References

Alburquerque A, De Alicia CF, Cegarra J, Abad M 2012. Assessment of the Fertiliser Potential of Digestates from Farm and Agroindustrial Residues. Biomass and Bioenergy, 40, 181–89.

Alburquerque JA, de la Fuente C, Bernal MP 2012. Chemical properties of anaerobic digestates affecting C and N dynamics in amended soils. Agriculture, Ecosystems and Environment, 160, 15– 22.

Amlinger F, Götz B, Dreher P, Geszti J, Weissteiner C 2003. Nitrogen in biowaste and yard waste compost: dynamics of mobilisation and availability – a review. European Journal of Soil Biology, 39, 107-116.

Amlinger F, Peyr S, Cuhls C 2008. Greenhouse gas emissions from composting and mechanical biological treatment. Waste Management Research, 26, 47.

Bachman GR, Metzger JD 2008. Growth of bedding plants in commercial potting substrate amended with vermicompost. Bioresource Technology, 99, 3155-3161.

Boldrin A, Andersen JK, Møller J, Christensen FE 2009. Compost and compost utilization: accounting of greenhouse gases and global warming contributions. Waste Management & Research, 27, 800-812.

Boldrin A, Hartling KR, Laugen M, Christensen TH 2010. Environmental inventory modelling of the use of compost and peat in growth media preparation. Resources, Conservation and Recycling, 54, 1250-1260.

Cáceres R, Malińska K, Marfà O 2018. Nitrification within composting: A review. Waste Management, 72, 119-137.

Chernicharo, C. A. L., J. B. van Lier, A. Noyola, and T. Bressani Ribeiro. 2015. Anaerobic sewage treatment: state of the art, constraints and challenges. Reviews in Environmental Science and Bio/Technology 14:649-679.

Cunha, J. R., Tervahauta, T., Van Der Weijden, R. D., Leal, L. H., Zeeman, G., & Buisman, C. J. N. (2018). Simultaneous recovery of calcium phosphate granules and methane in anaerobic treatment of black water: Effect of bicarbonate and calcium fluctuations. Journal of environmental management, 216, 399-405.

De Graaff, M. S., Hardy Temmink, Grietje Zeeman, and C. J. N. Buisman. 2010. Anaerobic Treatment of Concentrated Black Water in a UASB Reactor at a Short HRT. Water 2 101-119.

Diaz LF, Savage GM 2007. Factors that affect the process. In: Compost Science and Technology, pp 49-66. Diaz LF, De Bertoldi M, Bindingmaier W, Sentiford E (Eds.), Waste Management Series, V.8 The Netherlands and UK.

Dietrich M 2017. Greenhouse gas emission from digestate in soil. Master Thesis, ETH, Zurich.

Domingues J, Edwards CA, Subler S 1997. A comparison of vermicomposting and composting. BioCycle, April 1997.

Erhart E, Hartl W, Putz B 2005. Biowaste compost affects yield, nitrogen supply during the vegetation period and crop quality of agricultural crops. European Journal of Agronomy, 23, 305-314.

Evanylo G, Sherny C, Spargo J, Starner D, Brosius M, Hearing K 2008. Soil and water environmental effects of fertilizer-, manure-, and compost-based fertility practices in an organic vegetable cropping system. Agriculture, Ecosystem and Environment, 127, 50-58.

Féon SL, Thévenot A, Maillard F, Macombe C, Forteau L, Aubin J 2019. Life Cycle Assessment of fish fed with insect meal: Case study of mealworm inclusion in trout feed, in France. Aquaculture, 500, 82-91.

Foereid B, Bergersen O, Sørheim R 2018. Kompostens virkning i dyrket jord. NIBIO pop, 4, 29.

Gosh M, Chattopadhyay GN, Baral K 1999. Transformation of phosphorous during vermicomposting. Bioresource Technology, 69, 149-154.

Grigatti M, Di Girolamo G, Chincarini R, Ciavatta C, Barbanti L 2011. Potential nitrogen mineralization, plant utilization efficiency and soil CO_2 emissions following the addition of anaerobic digested slurries. Biomass and Bioenergy, 35, 4619-4629.

Gunnarsson A 2012. Plant-Based Biogas Production for Improved Nutrient Management of Beetroot in Stockless Organic Farming. Doctoral thesis, Swedish University of Agricultural Sciences, Alnarp, Sweden.

Hao X, Chang C, Larney FJ 2004. Carbon, nitrogen balances and greenhouse gas emission during cattle feedlot manure composting. Journal of Environmental Quality, 33, 37–44.

Ho, G. 2005. Technology for sustainability: the role of onsite, small and community scale technology. Water Science and Technology 51:15-20.

Kaushik P, Garg VK 2003. Vermicomposting of mixed textile mill sludge and cow dung with epigeic earthworm Eisenia foetida. Bioresource Technology, 90, 311-316.

Lalander C, Diener S, Zurbrügg C, Vinnerås B 2019. Effects of feedstock on larval development and process efficiency in waste treatment with black soldier fly (Hermetia illucens). Journal of Cleaner Production, 208, 211-219.

Lalander CH, Fidjeland J, Diener S, Eriksson S, Vinnerås B 2015a. High waste-to-biomass conversion and efficient Salmonella spp. reduction using black soldier fly for waste recycling. Agronomy for Sustainable Development, 35(1), 261-271.

Lalander CH, Komakech AJ, Vinneras B 2015b. Vermicomposting as manure management strategy for urban small-holder animal farms - Kampala case study. Waste Manag, 39, 96-103.

Lalander C, Nordberg Å, Vinnerås B 2018. A comparison in product-value potential in four treatment strategies for food waste and faeces – assessing composting, fly larvae composting and anaerobic digestion. GCB Bioenergy, 10, 84–91, 84-91.

Lalander C, Senecal J, Gros Calvo M, Ahrens L, Josefsson S, Wiberg K, Vinnerås B 2016. Fate of pharmaceuticals and pesticides in fly larvae composting. Science of The Total Environment, 565, 279-286.

Le-Clech, P. 2010. Membrane bioreactors and their uses in wastewater treatments. Applied microbiology and biotechnology **88**:1253-1260.

Lim J-W, Mohd-Noor S-N, Wong C-Y, Lam M-K, Goh P-S, Beniers JJA, Oh W-D, Jumbri K, Ghani NA 2019. Palatability of black soldier fly larvae in valorizing mixed waste coconut endosperm and soybean curd residue into larval lipid and protein sources. Journal of Environmental Management, 231, 129-136.

Lind C 2005. Kompostering av slam og våtorganisk avfall. Sluttrapport Kolon-prosjektet.

Lettinga, G., and L. Hulshoff Pol. 1991. UASB-process design for various types of wastewaters. Water Science and Technology 24:87-107.

Lettinga, G., R. Roersma, and P. Grin. 1983. Anaerobic treatment of raw domestic sewage at ambient temperatures using a granular bed UASB reactor. Biotechnology and bioengineering 25:1701-1723.

Maaz, M., M. Yasin, M. Aslam, G. Kumar, A. E. Atabani, M. Idrees, F. Anjum, F. Jamil, R. Ahmad, A. L. Khan, G. Lesage, M. Heran, and J. Kim. 2019. Anaerobic membrane bioreactors for wastewater treatment: Novel configurations, fouling control and energy considerations. Bioresource technology 283:358-372.

Mariani L, Jimenez JJ, Asakawa N, Thomas RJ, Decaëns T 2007. What happens to earthworm casts in the soil? A field study of carbon and nitrogen dynamics in Neotropical savannahs. Soil Biology and Biochemistry, 39, 757-767.

Moges, M. E., D. Todt, E. Janka, A. Heistad, and R. Bakke. 2018. Sludge blanket anaerobic baffled reactor for source-separated blackwater treatment. Water Science and Technology.

Mupambwa HA, Nyari P, Mnkeni S 2018. Optimizing the vermicomposting of organic wastes amended with inorganic materials for production of nutrient-rich organic fertilizers: a review. Environmental Science and Pollution Research, 25, 10577–10595.

Möller K, Müller T 2012. Effects of anaerobic digestion on digestate nutrient availability and crop growth: Annual Review in Engineering and Life Science, 12, 242-257.

Möller K, Stinner W. 2009. Effects of Different Manuring Systems with and without Biogas Digestion on Soil Mineral Nitrogen Content and on Gaseous Nitrogen Losses (Ammonia, Nitrous Oxides). European Journal of Agronomy 30, 1–16.

Nesse AS, Sogn T, Børresen T, Foereid B 2018. Peat replacement in horticultural growth media: the adequacy of coir, paper sludge and biogas digestate as growth medium constituents for tomato (Solanum lycopersicum L.) and lettuce (Lactuca sativa L.) Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 69, 287–294.

Nkoa R 2014. Agricultural Benefits and Environmental Risks of Soil Fertilization with Anaerobic Digestates: A Review. Agronomy for Sustainable Development 34, 473–92.

Odlare M, Pell M, Arthurson JV, Abubaker J, Nehrenheim E 2014. Combined mineral N and organic waste fertilization – effects on crop growth and soil properties. Journal of Agricultural Science, 152, 134-145.

Odlare M, Pell M, Svensson K 2008. Changes in soil chemical and microbiological properties during 4 years of application of various organic residues. Waste Management, 28, 1246-1253.

Padmavathiamma PK, Li LY, Kumari UR 2008. An experimental study of vermi-biowaste composting for agricultural soil improvement. Bioresource Technology, 99, 1672–1681.

Pommeresche R, McKinnon K 2011. Kompostering. Bioforsk Tema, 20.

Rivier P-A, Farkas C, Makó A, Foereid B, Dathe A, Vajda Á, Jamniczky D Vermicompost project 2017. FINAL REPORT - Task 7. Investigation of the vermicompost in laboratory experiments

Sharma VK, Canditelli M, Fortuna F, Cornacchia G 1997. Processing of urban and agro-industrial wastes by aerobic composting – a review. Energy Conservation and Management, 38, 453-478.

Solis-Mejia L, Islas-Espinoza M, Esteller MV 2012. Vermicomposting of sewage sludge: Earthworm population and agronomic advantages. Compost Science and Utilization, 20, 11-17.

Suthar S, Kumar K, Mutiyar PK 2015. Nutrient recovery from compostable fractions of municipal solid wastes using vermitechnology. Journal of Material Cycles and Waste Management, 17, 174-184.

Suthar S 2008. Bioconcentrations of Metals (Fe, Cu, Zn, Pb) in Earthworms (Eisenia fetida), Inoculated in Municipal Sewage Sludge: Do Earthworms Pose a Possible Risk of Terrestrial Food Chain Contamination? Environmental Toxicology, DOI 10.1002/tox.

Suthar S, Singh S 2008. Metal remediation from partially composted distillery sludge using composting earthworm Eisenia fetida. Journal of Environmental Monitoring, 10, 1099-1106.

Thevenot A, Rivera JL, Wilfart A, Maillard F, Hassouna M, Senga-Kiesse T, Le Feon S, Aubin J 2018. Mealworm meal for animal feed: Environmental assessment and sensitivity analysis to guide future prospects. Journal of Cleaner Production 170, 1260-1267.

Sørheim R, Lystad H, Molland O 1999. Prosesser ved kompostering av matavfall - Litteraturoversikt. Jordforsk Rapport 60:18 pp

Tervahauta, T., T. Hoang, L. Hernández, G. Zeeman, and C. Buisman. 2013. Prospects of source-separation-based sanitation concepts: a model-based study. Water 5:1006-1035.

Uhlig C, Sveistrup T, Igeland B, Lebesbye R, Olsen S 1997. Kompostering av husholdningsavfall og gårdsavfall. Planteforsk Rapport 45/97 36 pp.

van Voorthuizen, E., A. Zwijnenburg, W. van der Meer, and H. Temmink. 2008. Biological black water treatment combined with membrane separation. Water Research 42:4334-4340.

Wang H, ur Rehman K, Liu X, Yang Q, Zheng L , Li W, Cai M, Li Q, Zhang J, Yu Z 2017. Insect biorefinery: a green approach for conversion of crop residues into biodiesel and protein. Biotechnology and Biofuels, 10, 304 https://doi.org/10.1186/s13068-017-0986-7.

Wang J, Hu Z, Xu X, Jiang X, Zheng B, Liu X, Pan X, Kardol P 2014. Emissions of ammonia and greenhouse gases during combined pre-composting and vermicomposting of duck manure. Waste Management, 34, 1546–1552.

Zeeman, G., K. Kujawa, T. de Mes, L. Hernandez, M. de Graaff, L. Abu-Ghunmi, A. Mels, B. Meulman, H. Temmink, and C. Buisman. 2008. Anaerobic treatment as a core technology for energy, nutrients and water recovery from source-separated domestic waste (water). Water Sci. Technol. 57:1207–1212.

5. Annex

5.1 Biogas production from biogas pilot scale reactor

The main objective of this project is to contribute to an overall evaluation of the economic and environmental viability of this technology in an UA context, and more specifically to the Cicignon showcase in Fredrikstad. A Master thesis (Elena Albertovna Fitje) will be submitted on the experimental output from this project by August 15th so a detailed presentation and discussion of the data will not be available until then.

Reactor configuration

The 40 ft container is equipped with a shredder, two buffer tanks, one mixing tank, the reactor tank, several pumps, valves, 5 sampling ports, and a PLS control system.

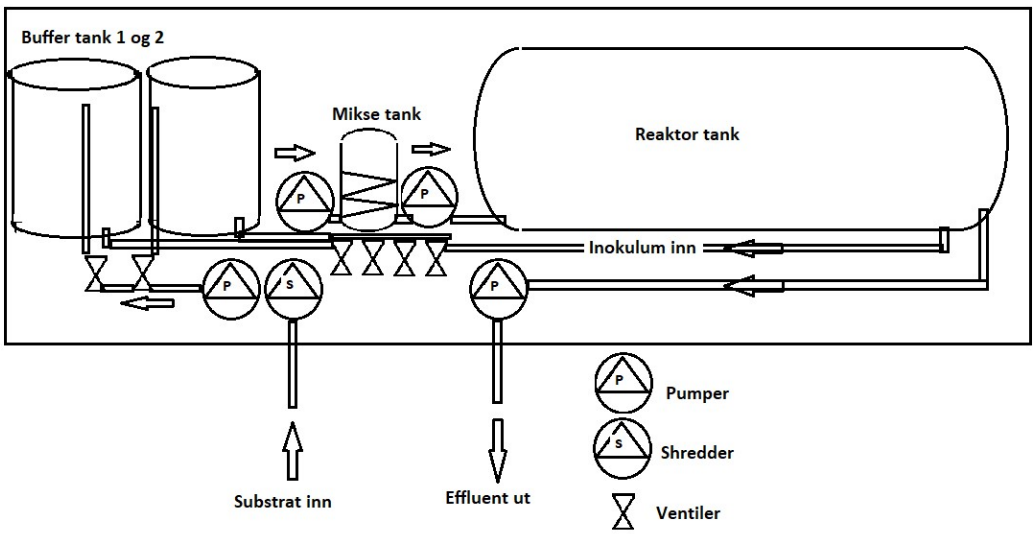


Figure 7. Biogas production reactor.

The five sampling ports make it possible to study the different stages of the process: hydrolysis, monomer conversion/degradation, acidogenesis, acetogenesis and methane production. The total volume of the buffer tanks is sufficient for 6 days' operation at 10 days' HRT. There may be some microbial activity also in the buffer tanks and gas (mainly CO_2) from the headspace is vented off. Thus, the retention time of the buffer tank should be as short as possible. This requirement could not be completely fulfilled because substrate retention time in the buffer tanks was between two to four days for practical reasons. No methane production in the buffer tanks is wanted nor expected.

Reactor start-up

The reactor was installed at the pilot area March 5th and inoculated with starter culture from the Southern Follo Wastewater Treatment plant operating at 55°C and 26 days HRT. The reactor was run for 3 days with wastewater sludge before pig slurry (PS) from NMBU was introduced. After another 3 days hygienized food waste (HFW) was kindly provided from "Norsk Matretur". Daily loading was estimated from Norwegian statistics. Unfortunately, we were inflicted with some technical problems due to cold weather and frozen water. From March 23rd to April 1st the reactor was run with a mixture of 2550 L PS (1-2% DM) and 150 L of HFW (ca. 15% DM). From April 1st the mixture was added toilet paper corresponding to 25 g per person per day. This is a rather dilute slurry, and due to a HRT of 10 days it corresponds to an organic loading rate (OLR) between 2 and 2.5 g/L/day.

Experimental design

When doing experiments on a larger scale outside the laboratory we are faced with several challenges: climate, storage of large volumes of feedstocks, mixing of feedstocks and sampling from inhomogeneous feedstocks and the final digestate. HFW was stored in a cooled container and was well preserved throughout the experimental period. PS was collected in 1000 L plastic tanks once a week and was stored outside since temperature was close to ideal in the critical period, but contained variable amounts of saw dust which complicated sampling and calculation of organic matter degradation. Fortunately, this can be accomplished through several methods and cross checking.

Feedstocks: pig slurry plus toilet paper = blackwater, hygienized/pasteurized food waste.

Process parameters: HRT, OLR, volatile fatty acids (VFAs), nutrient composition, dry matter reduction, organic matter degradation, gas volume, methane yield, energy yield, mass balance and coliform reduction. To produce digestate for composting, dewatering was needed.

Figure 8. The addition of HFW to PS. The blue tube was used for pumping feedstock mix into the buffer tanks inside the container.

Figure 9. How containers were arranged for dewatering of digestate.

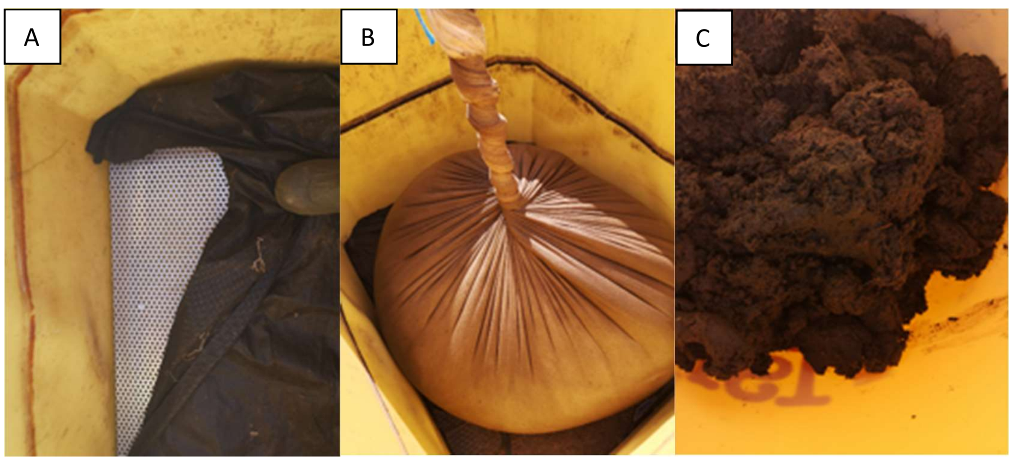


Figure 10. Illustration of the dewatering process and the final digestate ready for composting. The liquid part was collected and used for biofiltration experiments (e.g. nitrification).

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