Environmental Technology 2022

Metropolitan and Environmental Solutions

WAGENINGEN UNIVERSITY & RESEARCH

Introduction

This brochure aims at informing you on the activities of the Environmental Technology (ETE) Group of Wageningen University over the year 2021. Our current activities in education and research are presented in terms of a brief overview of the courses and educational programmes ETE participates in, concise information on each of our running research projects, and our list of 2021 publications. We also present you some output numbers.

The Environmental Technology Group

The ETE group is chaired by Huub Rijnaarts, Professor in Environment and Water Technology since September 2009. Prof. Cees Buisman holds since 2003 the chair in Biological Recovery and Reuse Technology. Cees and Huub form together the strategic leadership of the group. In addition we also have the special chairs of professors Prof. Dr. Ir. Bert van der Wal (Electrochemical Water Treatment), and Prof. Dr. Ir. Bert Hamelers (Electrochemical Resource Recovery) 20 members of scientific staff (from which 5 lecturers and including 1 vacancy), 11 Laboratory and technology supporting co-workers, 9 postdocs (from which 1 vacancy), 3 industrial principle investigators, namely Dr. Ir Arjen van Nieuwenhuijzen from the Amsterdam Institute of Advanced Metropolitan Solutions-AMS, Dr. Ir Adriaan Mels from Vitens-Evides-International (VEI), and Dr. Ir Jan Klok from Paqell. In 2021, 68 PhD students conducted their research in ETE of which 13 graduated, ETE staff is also very proud on 69 graduating MSc thesis students and 26 BSc thesis students. COVID-19 affected the number of completed MSc theses in 2021, several students were delayed, but the numbers of graduating students are increasing again.

Mission

The mission of the ETE group is to create unique breakthrough technologies for establishing new systems for recovery and reuse for both water and resources. A strong nature based and biotechnological component is combined with physics, chemistry and also social sciences. Concepts such as bio-crystallization, micropollutant biodegradation, bio-retention and bio-electrochemistry, combined with redox-chemistry, fluid mechanics and mass transfer processes, generate technologies for producing products such as recyclable organic matters, reusable water and renewable fertilizers. In addition to technology development and engineering, our urban system engineering working group designs urban, industrial and agricultural systems based on circular economy principles, in which we integrate sustainable energy production and use. Here advanced modelling and processing big data becomes an increasingly important component of our work.

Industrial and municipal waste streams are considered as resource streams, from which energy, water and minerals can be recovered, breaking the chain between the increased use of non-renewable sources and growing production and consumption. Thus these technologies and their integration in urban, industrial and agricultural systems help to reduce Human Footprints and safeguard a sustained supply of water, energy, nutrients and other resources for the growing world population. Circular agriculture, as promoted in NL and EU policies is becoming a new and important research line in our program. Furthermore, we believe that water, nutrients and carbon need to be recycled between urban, industrial and agricultural systems, on local and global scales. Technology development and system engineering combined, as done in the Environmental technology group allows us to generate scientific breakthroughs as well as societal innovations, thus creating science with impact. In addition to NL and EU societies, we collaborate with leading global economies (North America, China, India, Middle East) and selected countries in the global south (Uganda, Vietnam, Bangladesh, Brazil, Chili).

In our vision, we believe that new technologies and new system designs come into society through entrepreneurial companies, and therefore we have strong cooperation with industrial technology companies and stimulate technology spin offs, that bring our research outcomes to upscaled implementation in society. The Lettinga Associates Foundation - LeAF - carrying the name of the world wide known icon prof. Lettinga on development and global application of anaerobic water technology, is an important partner for ETE and hosted in our lab. LeAF is recognized by many industrial partners as a powerful independent platform in bringing sustainable technologies for treatment and valorisation of organic residues to global application. The ETE group supports various other spin-off and start-up enterprises such as ChainCraft (producing long chain fatty acids from organic waste) and works with many other companies, consultants, and knowledge institutes like Deltares, Wageningen Research, KWR, to bring science to practice.

Awards/Grants

- Nora Sutton is one of the three scientists from Wageningen University & Research (WUR) who received a Vidi-grant. The 800,000-euro fund allows her to develop her own research trajectory over the next five years. Nora Sutton's research aims to use natural micro-organisms in groundwater to break down micro-pollutants.
- Ricardo Cunha, former ETE and Wetsus PhD scientist, was awarded the KNCV Piet Bennema Prize for Crystal Growth 2021 for his thesis 'Anaerobic calcium phosphate bio granulation'. Every three years, the prize is awarded to a young PhD scientist that has published high-level scientific research in the field of crystal growth.

Research

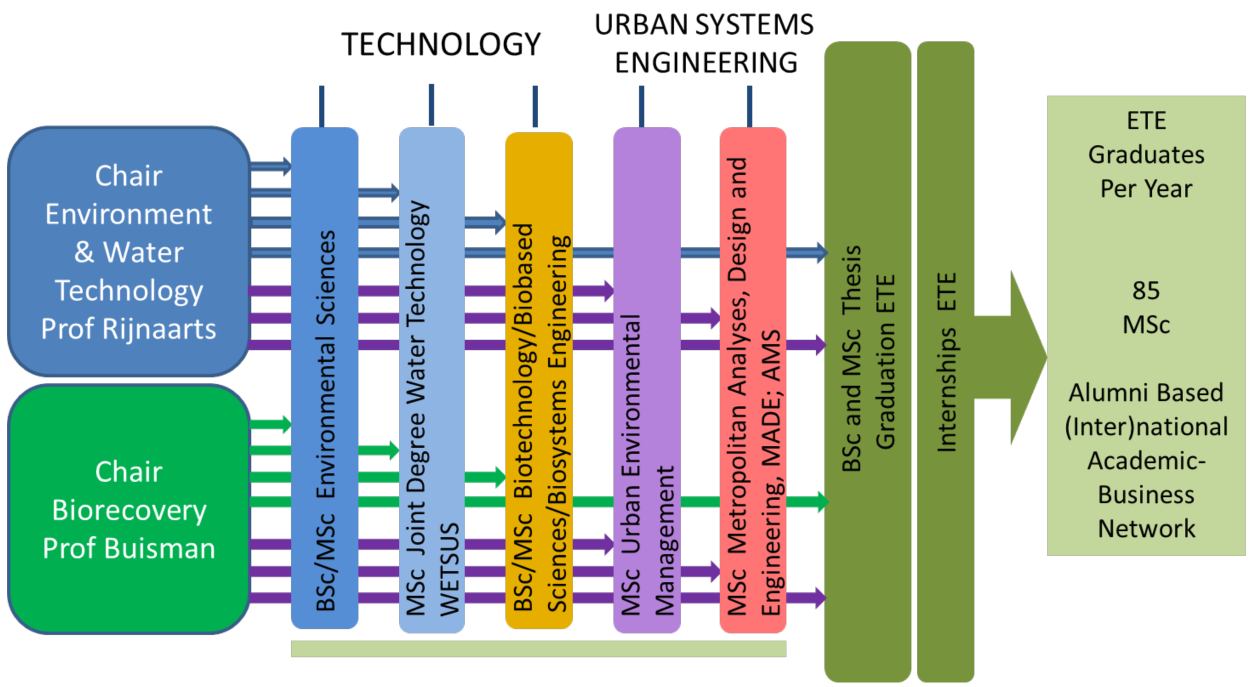
Our research program is characterized as follows:

⇒ **Biorecovery:** The biorecovery group focuses on optimal recovery of minerals and metals from wastewaters and gases and on recovery of renewable energy from waste and wastewater. Attention is being paid to the process bio-crystallisation and of bio-electrochemistry.

⇒ **Reusable Water**: Technology focus is on bio-removal of micro pollutants and pathogens and improve the qualities of water resources for re-use. Our novel electrochemical desalinization techniques focus on reduced energy utilisation, in order to sustainably remove salt from water cycles, and to transform brackish water in delta's into a sustainable fresh water resource.

⇒ **Urban Systems Engineering**: Cities currently hold half of the world's population and it is estimated that three out of every five people will live in an urban environment by 2030. The world's future sustainable development must therefore be largely accomplished by new approaches in urban sanitation, resource management and eco-innovative design of urban and associated agro and industrial systems. Balancing Urban Rural systems is a central theme for research and education.

Education of ETE: Three environmental technology and two urban systems engineering programs delivering around 85 MSc graduates (before the arrival of COVID19).



We hope you will enjoy reading this brochure. Please feel free to contact us in case you want to know more about our education or research or check our website www.wur.nl/ete

Prof.dr.ir. Cees J.N. Buisman Prof.dr.ir. Huub H.M. Rijnaarts
(Chairman ETE group)

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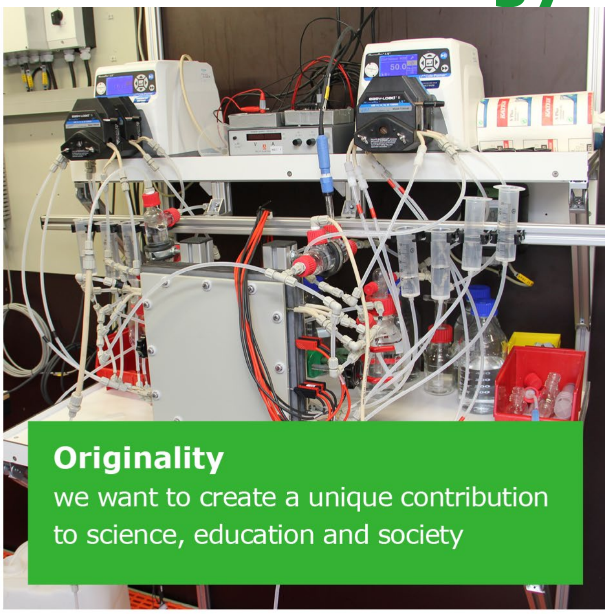
Mission and Vision

We develop and evaluate innovative environmental technologies and concepts based on processes from nature, to recover and reuse essential components and maintain and recreate a viable environment.
Our education inspires students to develop their talents. We impact society by innovation through top science and focus on applicability.

Values of Environmental Technology

Integrity
we stand for our principles and follow our vision and mission



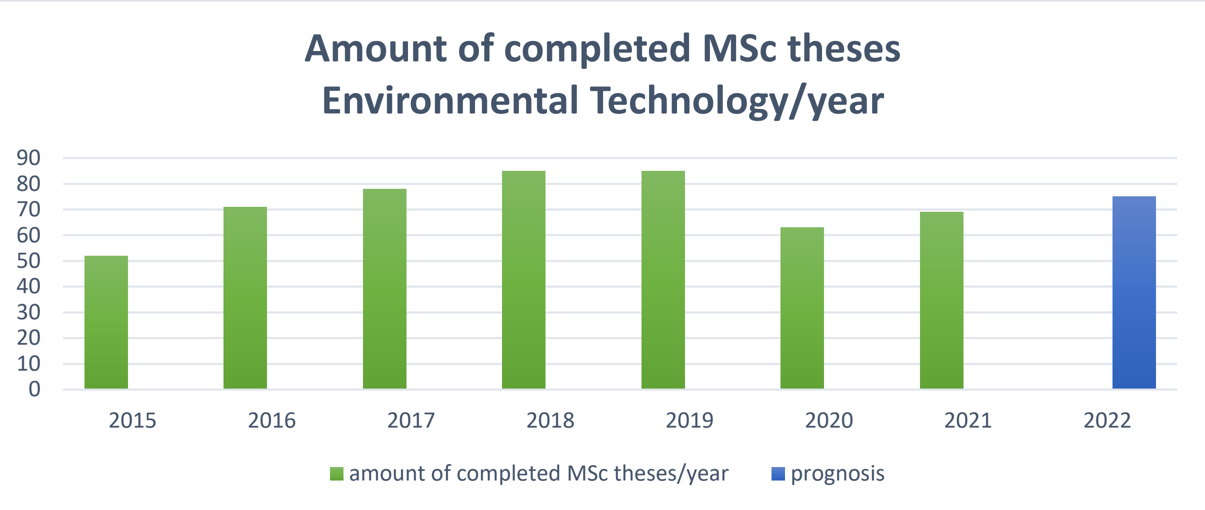
Originality
we want to create a unique contribution to science, education and society

Togetherness
we want everyone in our group to be an active participant

Personal Involvement
we show interest professionally and privately in colleagues and students

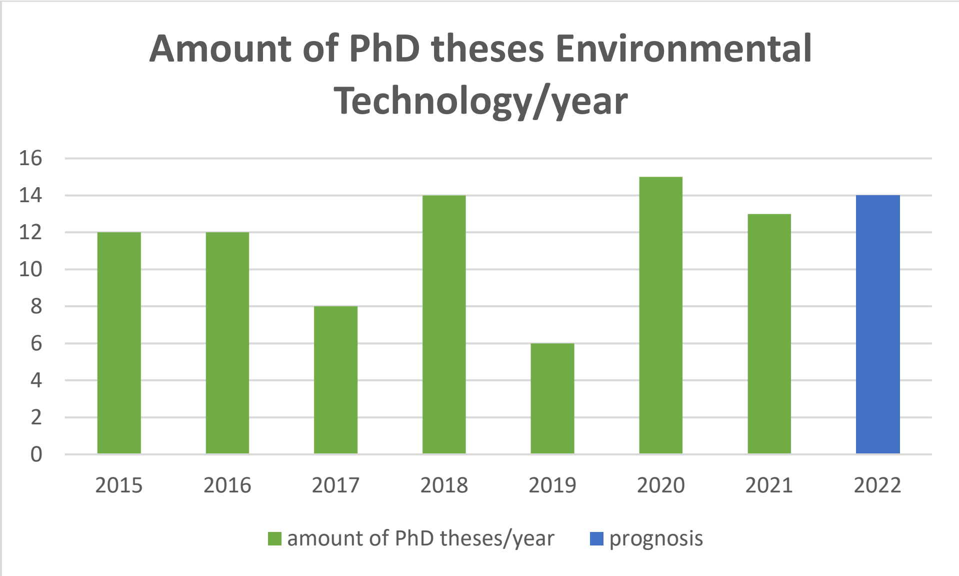
Output ETE 2021

In 2021, 69 MSc student completed a thesis. We still see the effect of the corona crisis. In the coming years we expect to recover, based on the expected total number of students, both in the master water technology in Leeuwarden, as well as at Wageningen University.

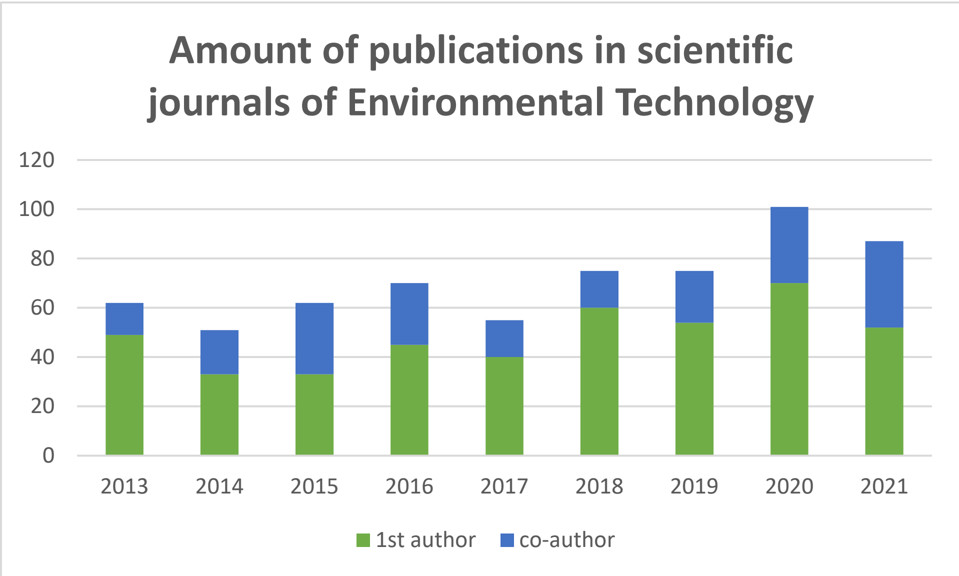


In 2021 we had 13 PhD defences. At the beginning of 2022 68 PhD students were working on their PhD research and did not yet graduate.

PhD Theses Environmental Technology 2021		
Name	**Promotor(s)**	**Title**
Laura Piai	Van der Wal	Micropollutants removal with activated carbon : Adsorption and regeneration by biodegradation
Tania Mubita	Van der Wal	Selective ion removal in electrochemical processes
Casper Borsje	Buisman	Moving bed capacitive bioanodes
Shiyang Fan	Buisman	Heat production from biological wood oxidation
Carlos Contreras Davila	Buisman	Lactate-based chain elongation : Poduction and separation of medium-chain carboxylates from complex organic residues
Daniel Reyes Lastiri	Keesman	Modelling and identification of water and nutrient balances in aquaponics
Rieks de Rink	Buisman	Electron shuttling in haloalkaliphilic sulfide oxidizing bacteria
Thu Hang Duong	Zeeman	Volatile fatty acids and methane production from protein
Indra Firmansyah	Zeeman	Development of a planning approach for resource recovery and reuse on small islands
Andrea Brunsch	Rijnaarts	Managing organic micropollutants in rivers : From monitoring to mitigation
Kamonashish Haldar	Rijnaarts	Urban water reuse in the Bengal delta : Prospects, challenges and socio-technological solutions
Shokouh Rashepar	Rijnaarts	Deep marine oil spills : Oil-particles-dispersants interaction and impact on oil biodegradation
Joeri Willet	Rijnaarts	Alternative water resources for industry : Designing environmentally compatible regional supply networks



The complete Publication List of Environmental Technology 2020 can be found at the end of this brochure.



Education

Environment and Water Technology offers an education and research programme that is focused on sustainable technological solutions for the worldwide environmental problems. Our approach is to combine several disciplines (microbiology, environmental chemistry, physical chemistry, fluid dynamics, mathematical and computational system and grid theory, and system design) in order to achieve innovations for environmental solutions. We consider the social aspects by co-operating with Environmental Policy and Economy, related groups.

Environmental Technology participates with courses and other educational subjects in a number of study programmes of Wageningen University, both on BSc and MSc level:

1. Bachelor of Science (BSc) programme:
   - Environmental Sciences (BMW)

Environmental Technology is one of the three specialisations within this programme.

2. Master of Science (MSc) programmes:
   - Environmental Sciences (MES)
   - Urban Environmental Management (MUE)
   - Biotechnology (MBT)
   - Biosystems Engineering (MAB)
   - Molecular Life Sciences (MML)

In all these Master programmes, students can major in Environmental Technology.

The joint degree programme Water Technology of Wageningen University, Twente University and Groningen University, started in 2008, has now been accredited. The courses are offered in Leeuwarden at the Wetsus academy (*www.wetsusacademy.nl*).

Overview Courses and Planned fieldtrips

Course Number	Course Name	Planned fieldtrips in 2021
ETE10806	Introduction Environmental Technology	• Excursion to soil remediation locations in Wageningen by bike • Excursion to wastewater treatment plant Bennekom by bike
ETE21306	Water Treatment	• Water treatment plant Amersfoort
ETE22806	Principles of Urban Environmental Management	• NIOO Wageningen • AVR Duiven
ETE24804	Fundamentals of Environmental Technology	
ETE 25306	Basic Technologies for Urban Environmental Management	• Wastewater treatment plant • Solid Waste Management company
ETE25812	Environmental Project studies	
ETE26304	Renewable Energy Technologies	
ETE26806	Environmental Process Engineering	
ETE30306	Biological Processes for Resource recovery	
ETE30806	Processes for Water Treatment and Reuse	
ETE32806	Managing Urban Environmental Infrastructure	• Vitens drinking water production site
ETE33806	Planning and Design of Urban Space	• Culemborg – EVA Lanxmeer: • Nieuwegein Centrum West
ETE34306	Urban Energy, Water and Nutrient Cycles	• Digital excursions
ETE34806	Resource Quality in the Circular Economy	• Circular greenhouse facilities at Glastuinbouw in Bleiswijk
ETE35306	Environmental Electrochemical Engineering	
ETE50401/ ETE50406	Capita Selecta Environmental Technology	
ETE50803/ ETE50806	Capita Selecta Urban Environmental Technology and Management	
XWT20805	Water Technologies in Global Context	
XWT30305	Biological Water Treatment and Recovery Technology	
XWT32305	Colloid Chemistry	

Theses and Internships	
ETE80903 BSc Thesis Environmental Technology Part 1: Design Tools	ETE80909 BSc Thesis Environmental Technology Part 2
ETE70424/ ETE70439 Internship Environmental Technology	ETE70824/ETE70839 Internship Urban Sytems Engineering
ETE79324 MSc Research Practice Environmental Technology	ETE79424 MSc Research Practice Urban Systems Engineering
ETE80418/ETE80439 Thesis Environmental Technology	ETE81824/ETE81839 Thesis Urban Sytems Engineering

PhD courses (WIMEK-SENSE)
Masterclass Biobased innovation
Masterclass Modelling Urban Environmental Systems

Facilities

Modutech: a unique technology development facility

Modutech is a fully equipped, state of the art modular technology facility for bio-based and environmental sciences research. It offers a wide variety of support and services. Research institutes, other departments of Wageningen UR and companies have the opportunity to rent individual units to carry out their own research. Within this partnership, we can offer scientific and technical expertise as well as next door laboratory facilities for standard analyses.

Customized to specific research needs

Modutech covers a total of 300 m² including 24 units of 2 m² and 4 units of 12 m². The units can be fully customized and adapted to specific research needs. Each unit has basic supplies, such as electricity (standard 220 V as well as power current 380 V), water and water disposal, nitrogen and compressed air and ventilation. Some units we can control the temperature between 15-35 °C . Extra connections are available for CO_2 and O_2. Additional special safety storage for dangerous gasses is also available for each unit. A Draeger safety system, equipped with gas sensors, can detect different toxic and explosive gasses, for example CH_4, H_2, H_2S and NO_2. In the near future Modutech will have the unique possibility to work under fully anoxic conditions in select units, offering a spacious area to conduct experiments. In 2021 Modutech will be expanded with 6 extra 2 m² units. In 3 of these units temperature, humidity and lighting can be regulated by means of LED lamps to facility research on wetlands.

Scientific and technical expertise

Modutech not only offers fully customizable, state of the art units, but also offers full technical and scientific support. There is substantial in-house expertise on bio-based science, experimental design and laboratory support. Students can be commissioned to carry out either long-term or short-term experiments.

Combination of research facilities

For wastewater treatment and sanitation research, Modutech offers special facilities that go well beyond standard research accommodations. A pipeline from the town of Bennekom directs wastewater (1 m³/hour) to Modutech for research, which can be stored in one of the two cooled 3.5 m³ tanks. Sanitation studies are also possible with 2 Roediger vacuum toilets, 2 Gustavsberg no-mix toilets, 2 Urimat water free urinals and a separate grey water collection facility. September 2013 we installed eight 4x3 m² constructed wetlands (helophyte filtering) for additional wastewater cleaning steps. These offer the possibility to conduct even salt-water experiments. The diversity and quantity of equipment support almost any experimental setup and allow clients to run several experiments simultaneously.

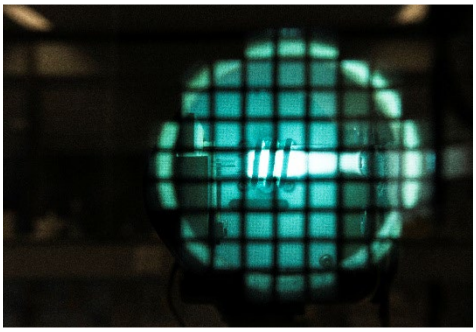
Laboratory facilities @ ETE

MODUTECH is supported by a well-equipped analytical research environment with an analytical staff of 5 persons. They have broad practical knowledge in research and take care of the lab organisation, equipment and support in teaching and guiding the students and researchers in their practical period. Furthermore they take care of the practical input during the practical periods in the ETE educational program. The lab provides the researchers with basic laboratory equipment and a set of route analysis methods (e.g. biogas analysis, VFA & MCFA analysis, PAH analysis, TPH analysis, ICP metal analysis). In addition to the routine setups they can offer some flexibility to switch and set up analytical methods on a number of different GC and LC systems according to the specific analytical research question in a project.

Environmental Technology makes use of concepts and mechanisms from different scientific disciplines also making microbiological facilities important. An anaerobic hood, laminar flow cabinet and microscopes offer us the possibility to make use of these topics in our studies. Of course we also have collaborations with colleague university group which gives us access to more specialised research techniques.

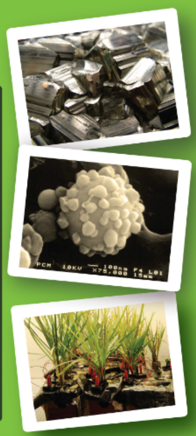
Overview of available measuring techniques in the ETE analytical labs.

Principle	Equipment	Detections method	To analyze
Chromatography	GC	FID	VFA & MCFA
			SC Alcohols
			TPH
		ECD	Chlorinated compounds
		FDP	Mercaptans
		HWD	O_2, N_2, CH_4, CO_2, CO, H_2
	LC	RI	sugars
		UV-Fluorescence	PAHs
		DAD	u-pollutants (medicines, pesticides, hormones)
		Conductivity	NH_4^+
	IC	Conductivity	F^-, Cl^-, Br^-, NO_2^-, NO_3^-, SO_4^{2-}, PO_4^{3-},
Spectroscopy	Plate reader	UV-VIS	Sugar screening
		Fluorescence	Toxicity screening
		Luminescence	
	Cuvette double beam	UV-VIS	NH_4^+, NO_3^-, PO_4^{3-}, Fe^{2+}/Fe^{3+}, Starch, COD, TOC
	ICP	Optical emission	Metal ions, phosphorus & sulphur
X-ray analysis	XRD	X-ray diffraction	Minerals, polymers, nanoparticles
	XRF	X-ray fluorescence	Elemental composition



Environmental Technology

Bio*recovery*



Our research focuses on *bio-based technologies for recovery of valuable components from* residual streams *in the form of fuels,electricity,sulphur, copper, and phosphate.*

Re*usable* **Water**

Water shortage threatens billions of people. Reuse and protection of our water sources are essential. Our research focuses on *removal of nutrients, pathogens nutrients, pathogens from water.*

Urban *System Engineering*

Scale and speed of urbanization leads to new challenges for our urban services. Closed resource cycles are necessary. We focus on *new sustainable biorecovery and cleaning concepts for management of urban and industrial water, sanitation, waste,nutrient and energy. Feedbacks from cities to agriculture are also studied.*

Environmental Technology focuses on resource efficiency and resource recovery to prevent depletion and on quality of water, soil and recycled resources to prevent pollution

Urban Systems Engineering focusses on systematic integration of concepts, techniques and models to improve the Metropolitan Environment.

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Biorecovery and Urban Systems Engineering

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	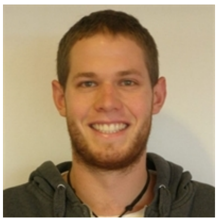 dr. Joeri Willet E-mail: Joeri.Willet@wur.nl Tel: 0317-483339
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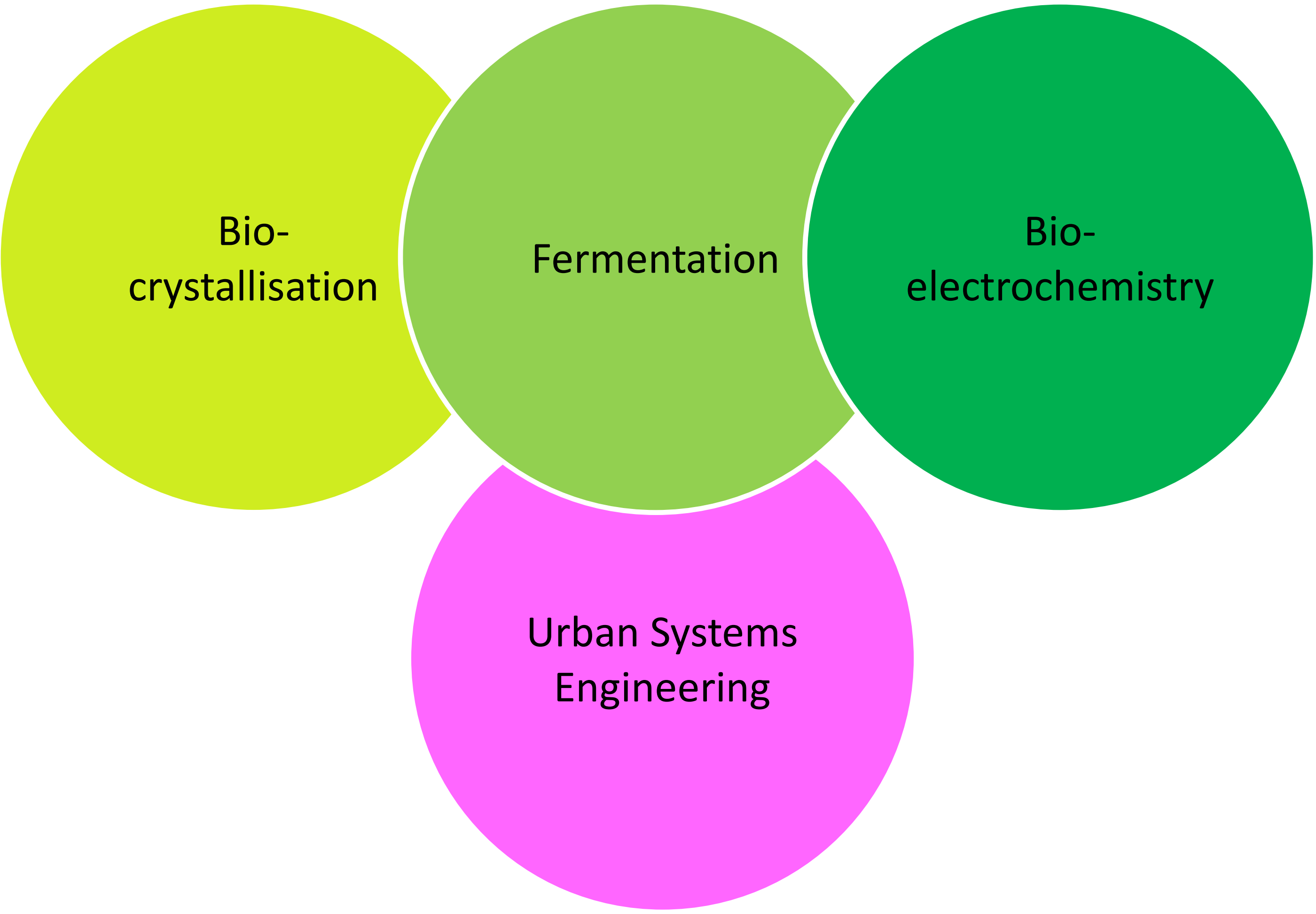
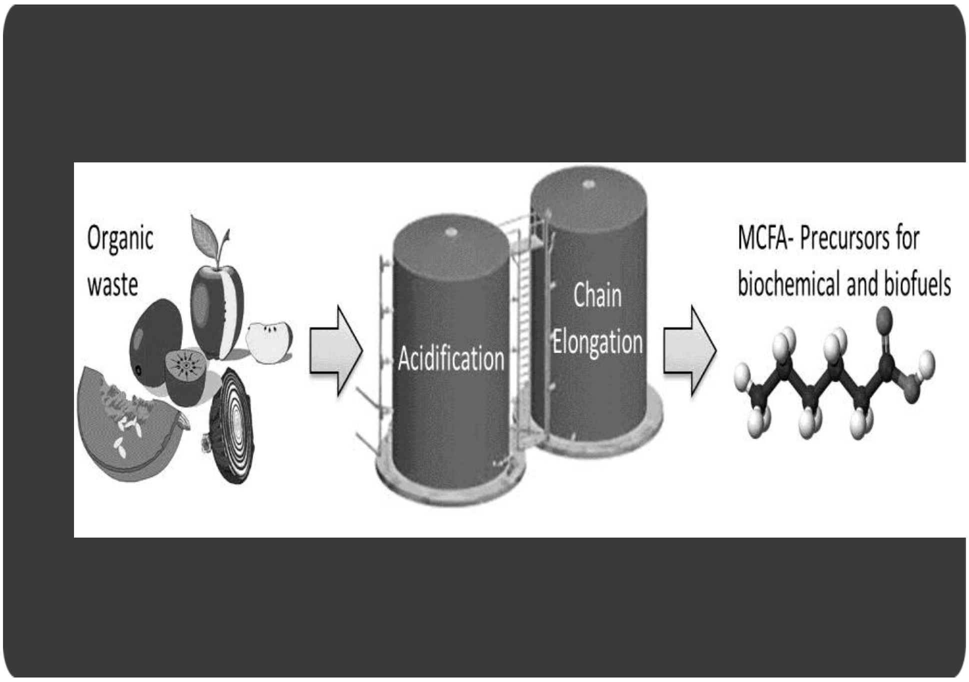
Biorecovery



Biorecovery



Environmental problems

Societies are highly dependent on access to mineral and energy resources. At this moment the world depends on fossil reserves of both minerals and energy. For the transition to a more sustainable world it is necessary to change from fossil sources to renewable sources. For minerals, recovery from many residual streams of industry and cities can be a new source. Energy can be recovered from residual streams from cities and agriculture. Finally, new energy conversion technologies based on the sun (biomass, direct sun conversion, fresh water flows) can be developed.
By developing new technologies to recover energy and minerals from waste, also new methods can be found to clean up the waste streams from existing processes for energy and mineral extraction from fossil sources. These new technologies enable removal of sulphur, metals and nitrogen, or preventing their emissions from water and gas streams. These technologies will have a positive influence on many environmental problems, like acid rain, climate change, and cadmium pollution of soils.

Our solutions

The biorecovery group seeks to solve these environmental problems by using biobased technologies to recover energy and inorganic compounds from residual streams. Innovative research is on-going in the following areas:

1) Production of electrical energy, fuels and sustainable heat from residual biomass. This type of biomass is left over after extraction of valuable (food) ingredients from agricultural products. The use of residual biomass enhances the economic and social potential of our processes. We use natural biotechnology i.e. we employ the processes as they occur in nature.

2) Application of the biological sulphur-cycle in water and gas treatment.

3) Biocrystallisation: biological recovery and removal of metals and minerals from industrial wastewater and/or groundwater.

4) Biological modification of (waste) materials to reduce the environmental impact or improve the efficiency of industrial processing.

Our approach

- Central in our approach is the development and operation of bioreactors that enable the selection of the right organism for the desired conversion. The research is based on lab-scale systems where the selection of natural micro-organisms takes place and can be studied and steered. Next to this practical research models are needed to describe and further develop these processes
- The research has a multidisciplinary character, including microbiology, analytical and colloid chemistry, geology, biophysics, process technology, electrochemistry, and automation.
- Development of innovative processes for the recovery of inorganic minerals, organic fules/chemicals and the production of renewable energy.
- Development of more sustainable industrial production processes, in co-operation with end-users and technology providers.

Development of new biological desulfurization processing schemes

Nov 2020 - 2024

Researcher	Supervisor	Promotor
Kestral Johnston	Dr. ir. Johannes B.M. Klok Dr. Pawel Roman	Prof. dr. ir. Cees Buisman Prof. dr. ir. Karel Keesman

Motivation

Currently, most of the world's sulfur is produced as a by-product of the treatment of gas streams that come from the mining of fossil fuels. These gas streams contain dihydrogen sulfide (H_2S), which is recovered and transformed into sulfur using both energy and chemically intensive processes. As the world transitions to using more sustainable forms of energy, sulfur production will decrease and may no longer be available for use in industries such as agriculture. With this decrease comes the need to enhance current sulfur recovery technologies. The biodesulfurization technology utilizes sulfide oxidizing bacteria (SOB) that convert H_2S gas to elemental sulfur under ambient conditions making it more sustainable than physiochemical processes. However, the current process produces thiosulfate and sulfate as by-products, both of which are unwanted due to their consumption of caustic, bleed stream formation, and reduction in the recovery yield of elemental sulfur.

Technological challenge

Recently, it was discovered that the SOB are able to remove sulfide (HS^-) in anaerobic conditions and reduce oxygen in sulfide-free condition [1]. This ability, known as the shuttling capacity, can be further enhanced when the SOB are grown in alternating "anaerobic-sulfide rich" and "aerobic-sulfide-free" conditions [2]. The underlying mechanisms for the shuttling capacity are not understood; therefore, a multi-scale approach is needed to understand this ability (Fig. 1). The technological challenge is to determine if and how the shuttling capacity can be quantified, stimulated, and optimized for the recovery of sulfur.

The main goal of this research is to understand and explore the mechanisms behind the shuttling capacity of the SOB. By understanding these mechanisms, new biological desulfurization schemes will be developed to produce more robust microbial communities and limit unwanted by-product formation. The following research questions will be addressed:

1. Understand underlying redox processes the SOB use to produce sulfur
2. Develop methods to quantify the shuttling capacity using a continuous-batch flow reactor
3. Develop methods to stimulate the shuttling capacity
4. Propose and test new process schemes

[1] ter Heijne, A., *et. al.*, Environmental science & technology letters, 5(8), (2018). 495-499.
[2] de Rink, R. *et. al.*, Environmental science & technology, 53(8), (2019). 4519-4527.

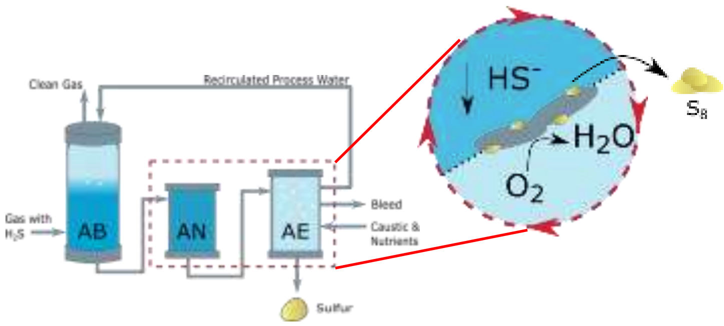


Fig. 1 - Schematic of the current biodesulfurization process and the shuttling capacity the occurs between the anaerobic (AN) and the aerobic (AE) reactors.

CV

Researcher;	Kestral Johnston
Graduated;	Northeastern University, USA, Civil & Environmental Engineering (2019)
Hobbies;	Hiking, traveling, learning new languages
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Recovery of phosphorus from animal manure

Environmental Technology

Sep 2018 - 2022

Researcher	Supervisor	Promotor
Chris Schott	Dr. Ricardo Cunha Dr. Renata v. d. Weijden	Prof. dr. ir. Cees Buisman

Motivation

Phosphorus (P) is essential for life on earth due to its various functions in growth and energy mechanisms of fauna and flora. However, the natural reserves of P are diminishing in quality and quantity. To ensure future food security, P needs to be recovered from waste streams.
In The Netherlands, 71 million kg of P are annually generated mainly as cattle and pig manure. To prevent run off and consequent eutrophication, the agricultural applicability of animal manure is limited. Therefore, its surplus is incinerated or transported at high economic and environmental costs to other countries.
This project aims to design a sustainable biotechnological process which enables the recovery of phosphorus as concentrated calcium phosphate granules (Figure 1) from thin manure. The separation of nutrients allows more nutrient specific and predictable crop fertilization than spreading raw animal manure. This approach increases the value of animal manure and stimulates circular agriculture.

Technological challenge

In animal manure, P is barely abundant as soluble PO43- and the concentration of solids and organic matter is high. Therefore, calcium phosphate granulation is not occurring by simply adding calcium as previously demonstrated for black water treatment.

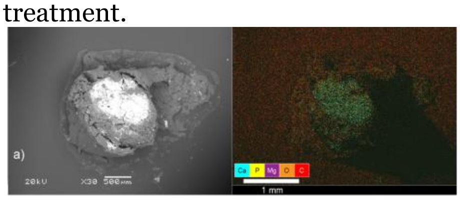
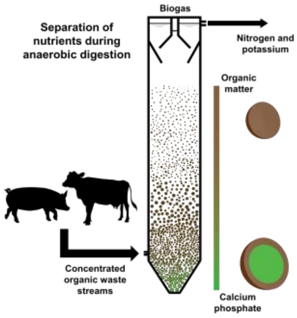


Fig 1. Scanning electron microscope (SEM, left) and electron dispersive x-ray (EDX, right) image of a calcium phosphate granule with an inorganic core consisting of calcium phosphate (EDX green) [4].

Releasing P into solution requires an understanding of how P occurs in animal manure. The phase in which P is present in cow and pig manure as well as various pre treatments to release P into solution will be investigated so that in the main reactor calcium phosphate may granulate.
After enabling calcium phosphate granulation, the collection from the reactor requires optimization. The recovered products need to be suitable for direct use in agriculture or for processing in the fertilizer industry.



Research goals

- Characterizing cow and pig manure and specifically the P speciation
- Stimulating calcium phosphate granulation by increasing the ionic activity of PO_4^{3-}
- Optimizing bioreactor design for recovery of calcium phosphate granules
- Characterizing the products based on their composition, fertilizing performance and applicability

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WAGENINGEN UNIVERSITY & RESEARCH

Organic residues engineering to increase organic matter in agricultural soils

Oct 2018 - 2022

Researcher
Vania Scarlet Chavez Rico

Supervisor
dr. ir. M. van Eekert, dr. P. Bodelier, and dr. V. Sechi

Promotor
Prof. dr. ir. Cees Buisman

Motivation

In the European Union, 970 Tg of soil is lost annually [1]. Despite the policy interventions, such as the "Common Agricultural Policy" and "Soil Thematic Strategy", soil erosion rates are 1.4 higher than soil formation rates [1][2]. One of the most important driving factors of soil erosion is organic matter decline [3]. Ironically, only about one third of the total bio-waste is used to replenish the organic carbon losses [3]. By using organic residues engineering, we could use these residues to produce organic amendments (OA) to improve specific soil functions according the requirements of each specific case.

Technological challenge

New insights on OA engineering are required to increase its efficacy, efficiency and effectivity. For example, different technologies are used to produce OAs. Each technology yields OAs with different chemistry. It is unknown to what extent OA chemistry is modulated by these technologies and what effects these OA have on soil properties. The main technological challenges will be to:

1. Assess the influence of engineered OAs on soil properties.
2. Identify potential improvements for the design of OAs.
3. Modify operational parameters or/and system configurations to produce the designed OAs.
4. Identify strategies that involve engineered OAs to steer specific groups of microorganisms. This will be done by applying ecological stoichiometry principles towards the production of compounds leading to stable organic matter formation.

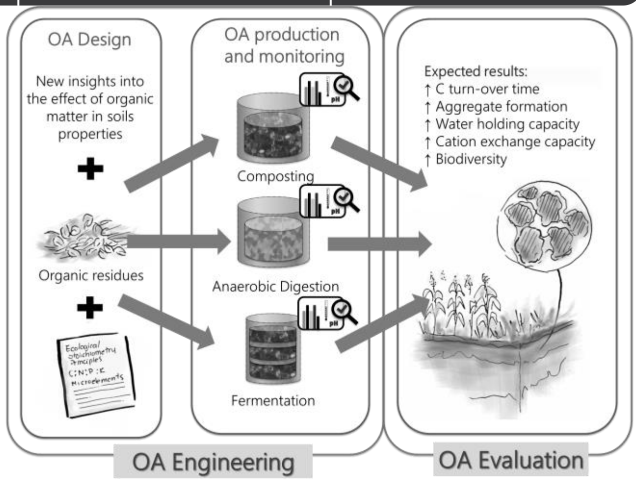

Fig.1 Graphical abstract.
Changes in engineered organic amendments (OAs) will be evaluated by monitoring specific soil properties.

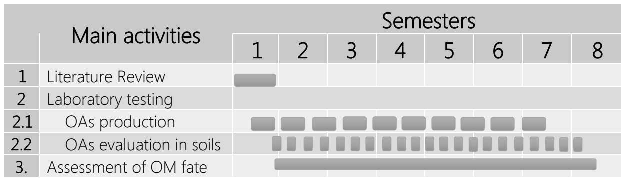

Fig 2. General Schedule

[1] Panagos, P., & Borrelli, P. (2017). Soil erosion in Europe: Current status, challenges and future developments | EU Science Hub. Retrieved January 15, 2019
[2] Verheijen, F. G. A., Jones, R. J. A., Rickson, R. J., & Smith, C. J. (2009). Tolerable versus actual soil erosion rates in Europe. Earth- Science Reviews, (94), 23–38.
[3] Middleton, N., & Thomas, D. S. G. (1997). World Atlas of Desertification. United Nations Environment Programme (UNEP) - University of Sheffield, UK (Vol. 2).

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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Bioconversion of woody biomass into protein by edible fungi and insects (Wood2Food)

Environmental Technology

Sep 2021 - 2025

Researcher	Supervisor	Promotor
Anran Li	Dr. ir. Wei-Shan Chen	Prof. dr. ir. Cees Buisman

Motivation

Conventional protein supply based on intensive farming of livestock and protein-rich crops is inefficient and unsustainable to feed the planet, calling for innovations in both protein sources and production modes. Woody biomass is the most abundant renewable feedstock of cellulosic carbohydrates, which are primary carbon (C) and energy sources for many protein-rich, edible lignocellulolytic (micro)organisms. With proper additions of nitrogen (N) and other essential nutrients, wood could serve as a potential source for producing alternative proteins. In this project, we propose two wood-to-protein routes using edible fungi and insects as bio-converters, aiming at high protein productivity and quality, high N use efficiency (NUE), low costs, and low environmental impacts.

Technological Challenge

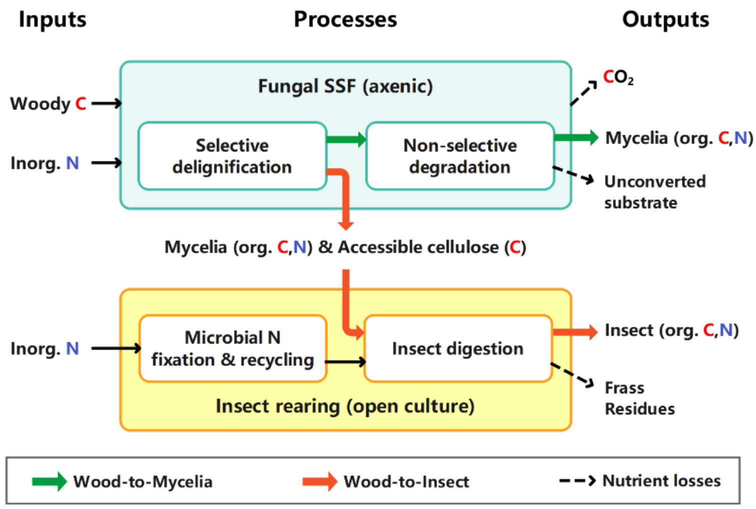
Wood-to-mycelia

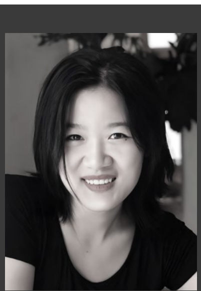
The conversion efficiency of wood is often limited by lignin, an insoluble and amorphous polymer that is recalcitrant towards biological degradation. Fungi are the only major organism that can break down lignin while also good at decomposing cellulose. Besides, some fungi are popular protein sources and can be consumed in the forms of mycelia (e.g. Tempeh and Quorn) and fruiting bodies (mushrooms). In the first research section, we will employ solid-state fermentation (SSF) with ligninolytic fungi to remove the lignin barrier of wood and maximize the production of mycelial protein. The technological challenge is to strategically supply oxygen and nutrients (especially N) for effective and efficient fungal conversion.

Wood-to-insect

When lignin is sufficiently removed, cellulose and hemicellulose become available for cellulolytic edible insects. The second research section focuses on the rearing of one such species, yellow mealworms, on the fungi-delignified woody biomass to generate high-quality insect proteins. Technological challenges are (i) to steer the SSF process towards maximum lignin degradation and cellulose retention, resulting in more digestible feedstuff for insects, and (ii) to integrate the fungal SSF and insect rearing into one artificial ecosystem that allows continuous and efficient transformation from wood and inorganic N to protein products.

The common challenge of both conversions is to minimize nutrient losses and maximize protein production and productivity.





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Integration of direct air capture and biological processes for sustainable production of methane

Environmental Technology

Sep 2021 - 2024

Researcher
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dr. Michele Tedesco (Wetsus)
dr. P (Philipp) Kuntke
dr. Cristina Gagliano (Wetsus)

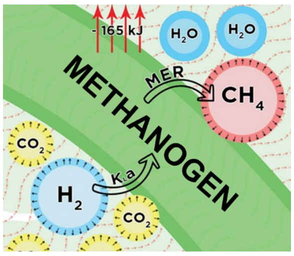
Promotor
prof.dr.ir. HVM (Bert) Hamelers

Motivation

Carbon capture and utilization (CCU) is one of the strategies proposed for mitigating dependency on fossil resources. Direct air capture (DAC) technologies are able to capture CO2 directly from ambient air [1]. The captured CO2 can be used as commodity for multiple purposes or as a carbon feedstock for chemical production. A particularly interesting product is methane. With CO2 and H2 as feedstock, biomethanation reactors are able to produce grid-quality (>95%) methane [2].

Biological CO2 methanation take place in anaerobic, mild conditions [3], with pH range between 6.2-8.5 and temperature between 35-40°C (mesophilic) or 55-65°C (thermophilic), according to the following reaction,

$$4H_2 + CO_2 \rightarrow CH_4 + H_2O$$
$$\Delta G^o = -165 \text{ KJ/mol}$$

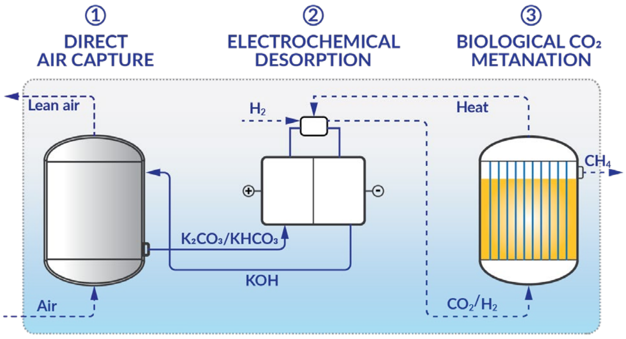


This research seeks to develop an energy-efficient process to produce renewable and biomass-free methane, by integrating a previously described electrochemically-assisted DAC [4] unit and biological CO2 methanation step.

Technological challenge

Typically the electrochemical system can be characterized as fast-responding with extreme conditions, whereas the bioreactor operates best at mild and stable conditions. To integrate the electrochemical unit with the bioreactor unit, the balance between these two systems is crucial.

Mass flows need be explicitly tuned to sustain a stable substrate/product balance for biomethanation. Heat and pH need to be managed



to keep methanogens at optimal metabolic activity. Finally, to reach efficient methane production, individual mass and energy flow need to be optimized in terms of energy requirements (kJ/mol CO2), and product yield (mol CH4/m3 air).

Research goals

The research will be organized into three main objectives:

- Reach stable performance for integrated DAC with electrochemical desorption
- Optimize conditions for CO2 conversion to methane via biological CO2 methanation
- System integration and overall process optimization

[1] Sanz-Pérez, E.S., et al., Direct Capture of CO2 from Ambient Air. Chemical Reviews, 2016. 116(19): p. 11840-11876.
[2] Rusmanis, D., et al., Biological hydrogen methanation systems – an overview of design and efficiency. Bioengineered, 2019. 10(1): p. 604-634.
[3] Lecker, B., et al., Biological hydrogen methanation – A review. Bioresource Technology, 2017. 245: p. 1220-1228.
[4] Shu, Q., et al., Electrochemical Regeneration of Spent Alkaline Absorbent from Direct Air Capture. Environmental Science & Technology, 2020. 54(14): p. 8990-8998.

This research received funding from Dutch Research Council (NWO) in the framework of NWO Wetsus Partnership Programme on Sustainable Water Technology, under project number *ENWWS.2020.004.*

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Pre-defined co-cultures to incorporate microbial electrosynthesis in the syngas fermentation platform

Dec 2019 - 2023

Researcher	Supervisor	Promotor
Marten Gelderloos	Dr ir. D.P.B.T.B. Strik Dr D.Z. Sousa (MIB)	Prof. Dr A.J.M. Stams (MIB)

Motivation

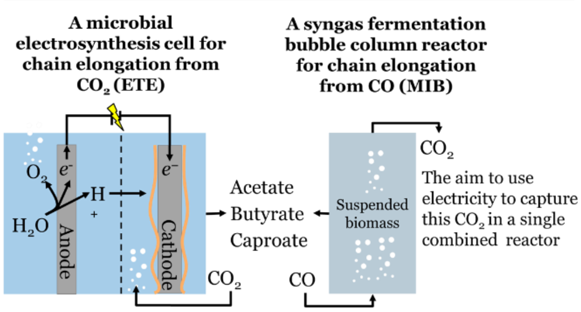
Syngas is a gaseous mixture of CO, H_2 and CO_2, which can be generated by the gasification of biomass. Syngas fermentation (SGF) has received increased attention as a route to use syngas to produce liquid fuels (full-scale stage) or biochemicals (development stage). However, during CO fermentation about two-thirds of the carbon is emitted as CO_2. The complete fixation of CO_2 into products is possible, but requires extra reducing power, e.g. by supplementing H_2 or electricity.

Technological challenge

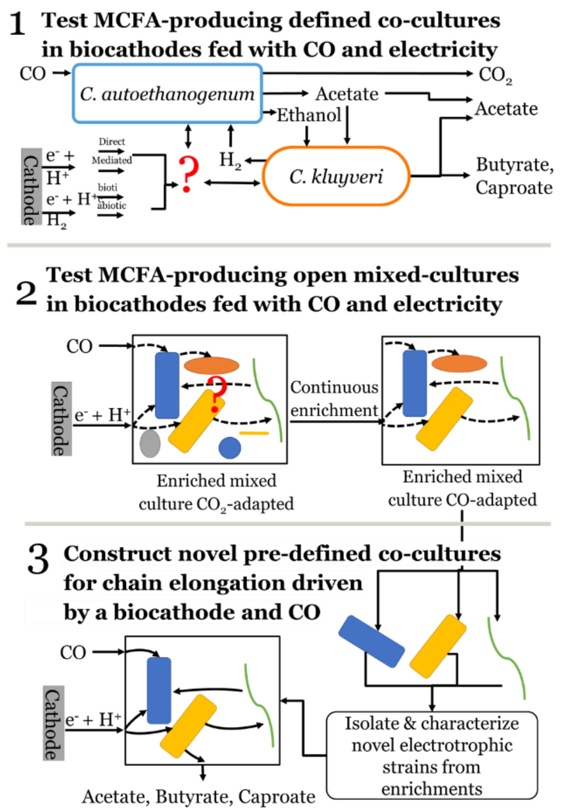
In SGF the main source of energy and carbon is CO, while in microbial electrosynthesis (MES) protons and electrons released with electrical energy from H_2O and CO_2 serve as energy and carbon source respectively.
The aim of this project is to design and characterize pre-defined microbial co-cultures fed with CO and electricity for zero CO2-emission syngas fermentation for the production of medium chain fatty acids (MFCAs).

The technological challenge is to adapt proof-of-principle reactor systems this combined purpose. This will enable us to study the microbial consortia, enrich and isolate usable microbes, and make pre-defined co-cultures to further investigate the important interactions and ultimately develop MCFA producing microbial co-cultures with minimal complexity capable of feeding on syngas and electricity.
To optimally answer these questions this project is a collaboration between ETE and the Microbial Physiology group at the Laboratory of Microbiology

A simplified comparison MES and SGF for MFCA production



Project approaches



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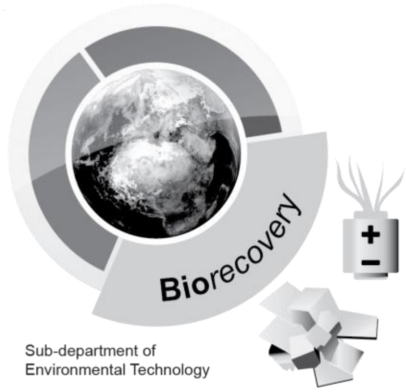
WAGENINGEN UNIVERSITY & RESEARCH

Bioelectrochemical Systems for Ammonia Recovery from Wastewater



Sept 2017 - 2021

Researcher	Supervisors	Promotor
MSc. Steffen Georg	Dr. Philipp Kuntke Dr. ir. Annemiek ter Heijne	Prof. dr. ir. Cees Buisman

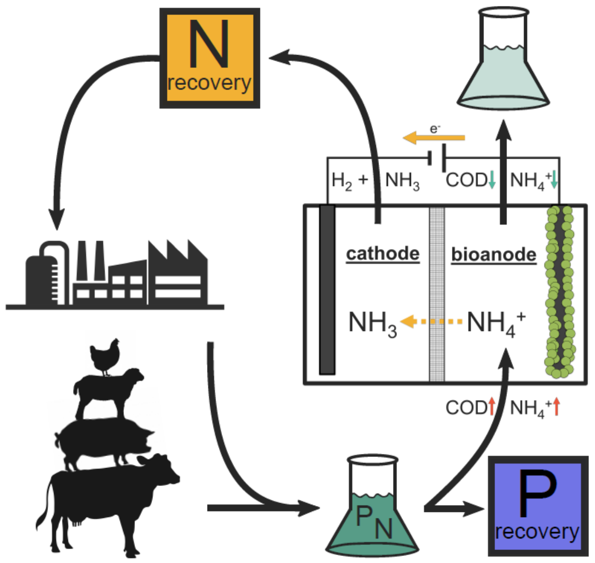


Figure 1: Nutrient removal and recovery cycle.

Motivation

- increasing fertilizer demand for NH_3
- increasing pollution water of NH_3 and organic compounds
- NH_3 and organics can be removed by bio-electrodialysis and subsequent recovery
- Bio-electrochemical Ammonium Recovery (BEAR): elegant combination of removing NH_3 and organics from wastewater and NH_3 recovery for fertilizer (Figure 1)

Technology

- Suitable wastewaters contain high concentrations of biodegradable organic compounds and Total Ammonia Nitrogen (TAN)
- Microbial Electrolysis Cell (MEC) oxidizes organics and removes TAN (Figure 2)
- TAN is recovered by TransMembrane Chemisorption as ammonium salt
- Ammonium salt can be used directly or as precursor of fertilizer

Research

- Investigate bio-degradability of concentrated wastewaters for BEAR
- Understand and improve MEC operational stability to improve process control
- Develop and test new reactor designs for more efficient and effective BEAR

Figure 2: Microbial electrolysis cell removing ammonium from wastewater.

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WAGENINGEN UNIVERSITY & RESEARCH

Plant microbial fuel cell: Mechanistic characterization

Environmental Technology

March 2018-2022

Researcher	Supervisor	Promotor
Pim de Jager	Dr. ir. David Strik	Prof. dr. ir. Cees Buisman

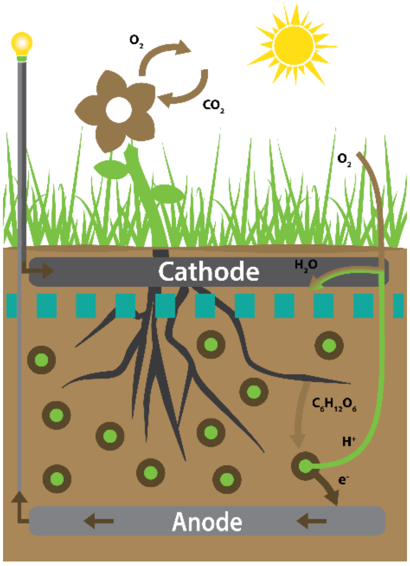
Motivation

The Plant Microbial Fuel Cell is a novel technology in which organic matter is converted into electricity using living plants and bacteria in the soil. Potential applications include desalination of saline and brackish waters, electricity production, methane reduction, and nature conservation. The technology therefore addresses different societal challenges such as the global energy transition, water scarcity, connecting remote communities and sustainable food production. The technology can be applied in all (constructed) wetlands or marine environments without harming the ecosystem or altering the aesthetics of the area. And since no external energy storage or input is necessary, the technology can be applied in remote areas without electrical infrastructure, keeping the costs low.

Plant microbial fuel cells applied in the field

Technological Principle

The plant microbial fuel cell is a fuel cell that utilizes organic matter that is available in wetland systems. This organic matter can become available in the form of exudation (directly excreted by plant-roots) or by other mechanisms such as bacterial conversion, hydrolysis or rhizodeposition in general. Some of this will react with oxygen, also released by plant roots. Micro-organisms in the anaerobic soil of marshes can convert the residual exudates from the roots of plants or dead plant material into CO2, protons and electrons. These electrons can be harvested by placing an anode in proximity of the micro-organisms which is connected through an external circuit to another electrode where a reduction reaction is taking place. By reducing oxygen and protons to water at the cathode, the electrons will flow through the circuit as a result of the potential difference.



Concept of a plant microbial fuel cell.

Research Challenge

In this research project we will aim at understanding some of the underlying mechanisms that are suspected to hinder or be of significant importance to the working of the plant microbial fuel cell. The results from this research can be brought directly into practice through different adjacent projects and companies that are involved

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Fouling and Process Design in reverse electrodialysis: a case study with real waters

Nov 2018 - 2022

Researcher	Supervisors	Promotors
Bárbara Vital	Dr. M. Saakes Dr. ir. T. Sleutels Dr. ir. A. ter Heijne	Prof. dr. ir. Cees Buisman Dr. ir. Bert Hamelers

Motivation

To include renewable energy in the energy matrix can be a challenge for many societies. Blue energy is a promising energy source that uses the controlled mixing of the salinity gradient between river and sea water to produce electrical energy. Reverse Electrodialysis (RED) is a process that allows to harvest this energy. It uses a series of alternating anion (AEM) and cation (CEM) exchange membranes to direct ions and the membrane stack voltage is converted into an electrical current by the means of a redox reaction. This principle is represented in Figure 1. The by-product of the process is only brackish water, so it does not generate any harmful substances to the environment. The estimated salinity gradient power available globally is estimated to be between 1.4 and 2.6 TW [1].

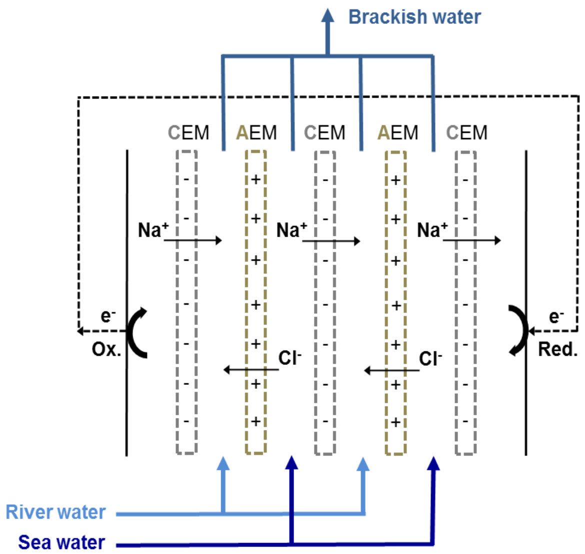

Fig 1. Simplified principle of RED

Technological challenge

Fouling of the ion exchange membranes is known as one of the most severe problems within RED applications, since it decreases the overall power output that can be harvested. Fouling can be present in diverse ways, like organic, inorganic, biofouling and scaling, as seen on Figure 2. It is believed that for a good performance of the process, a feed water pre-treatment is necessary to inhibit fouling.

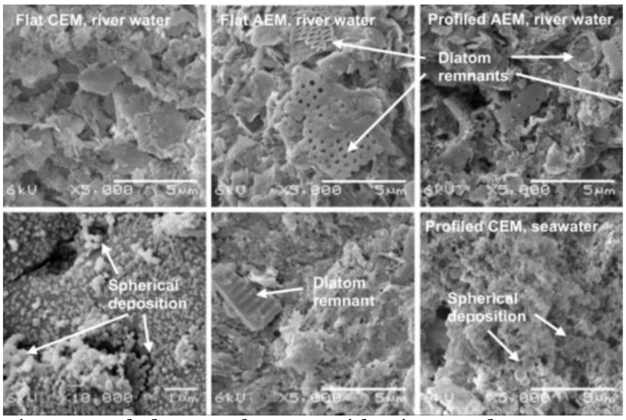

Fig 2. Fouled membranes with river and sea water, different types of AEMs and CEMs. Adapted from [2]

Research goals

- Identify the effect of individual foulants present in natural waters (river and sea) on RED performance,
- Identify how the foulants interact with different membranes (CEM and AEM) and how this impacts the RED process,
- Propose and test pre-treatment combinations and membrane cleaning for fouling control.

[1] Post (2009), Blue Energy: electricity production from salinity gradients by reverse electrodialysis
[2] Vermaas et al, (2013) Water Research 47 (3), 1289-1298

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Novel methods for electrochemical capture and conversion of CO_2

Environmental Technology

Sept. 2018 - 2022

Researcher	Supervisor	Promotor
Qingdian Shu	Dr. ir. Bert Hamelers Dr. Michele Tedesco	Prof. dr. ir. Cees Buisman

Motivation

Climate change is one of the most critical global challenges. Increasing atmospheric CO2 concentration brought by anthropogenic emissions is the primary driver of climate change. Capturing CO2 from emission points and even directly from air provides a potential solution to mitigate the amount of CO2 emissions and reduce the atmospheric CO2 concentration. Anion exchange resin (AER), a polymeric material with amine-functionalized groups usually used in water desalination process, has been proven to be a promising solid amine sorbent for CO2 capture.

Technological challenge

CO2 capture using ion exchange AERs involves adsorption and desorption steps. CO2 from CO2-rich stream can be adsorbed so that the outlet becomes CO2-lean stream, and pure CO2 can be produced during desorption. The adsorption process is due to the reaction between fixed amine groups on the resins and CO2. Since the reaction can be reversed at around 100 °C, conventional desorption process is by heating up the resins. Nevertheless, the regeneration of AERs using a high temperature restricts the application of this material owing to the high energy cost and likely degradation of resins.

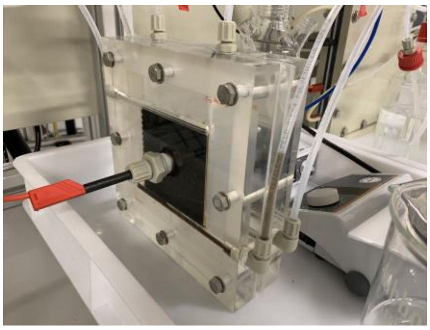
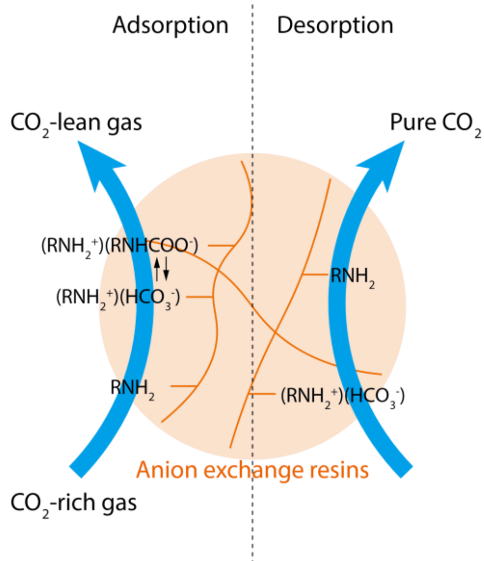


Figure 1. Electrochemical cell used in this study.



In this work, we propose a novel method to combine the conventional adsorption step with a more efficient electrochemical desorption step (Figure 1). The major challenge is to discover operation conditions that give high CO_2 capture performance at low energy consumption.

Research goals

- Developing a novel system for CO_2 capture based on ion exchange resins
- Investigating the CO_2 capture performance and energy consumption of the system under different current density, CO_2 partial pressure, and initial concentration of the regeneration solution
- Studying the performance of the system with different sorbents
- Developing a mathematical model of the system describing the kinetics and transport of various components

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WAGENINGEN UNIVERSITY & RESEARCH

Microbial chain elongation from biowastes to chemicals: polylactic acids (PLA) fermentation

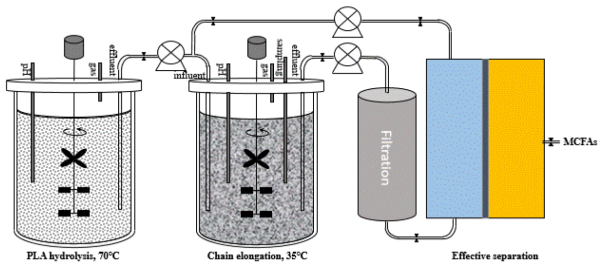
Nov 2021 - 2025

Researcher	Supervisor	Promotor
Yong Jin (John), MSc.	Dr. ir. David Strik	Prof. dr. ir. Cees Buisman

Motivation

Current fossil based plastic production, poor plastic recyclability and invalid waste management take a great threat on the environment and our own health. Biobased plastics are already replacing fossil based plastic in increased amounts. About 50% of the biobased plastics are made of biodegradable polymers like starch or polylactic acid. The biodegradable (bio)plastics end-up in various waste streams and represent a potential feedstock for new biomaterials production. Evidently there is a need to develop sustainable methods to recover the emerging amounts of biodegradable bioplastic wastes.

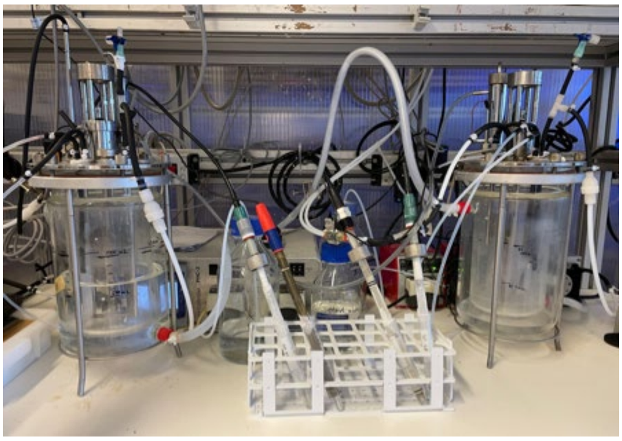
Biodegradable plastic waste is handled in various ways. For example they are biodegraded into CO_2, H_2O and energy by the ways of composting and/or anaerobic digestion. As alternative for this one can develop microbial chain elongation processes to produce medium-chain fatty acids (MCFAs) and prevent methane formation. These MCFAs can be used for various technical applications (like lubricants) but also serve as herbicide or feed additive.



Two stage fermentation-recovery process.

Microbial chain elongation from organic waste to valuable chemicals has been frequently explored in the last decades. A first commercial demonstration factory was launched by ChainCraft B.V. in Amsterdam. Besides the MCFAs also other valuable biochemicals, like alcohols, can potentially be produced from the organic waste as well the biodegradable plastic waste.

Hence, the aim of this project is to identify the feasibility of MCFAs and other valuable biochemicals production from biodegradable plastics (taking PLA as an example) by anaerobic fermentation under parameters promotion and system evaluation.



Continuous operation of bioreactors.

Research challenge

The challenge is to develop a stable and cost-effective fermentation & recovery process via the next steps:

- Study the feasibility of chain elongation from PLA at different temperatures.
- Study the effect of pH and other parameters to form fatty acids and/or alcohols.
- Study effective separation for MCFAs under comparison of different methods: thermal separation vs. alkaline desorption.

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Bio electrochemical degradation of thiols (organo sulphur compounds)

Aug 2018 - 2022

Researcher	Supervisor	Promotor
Margo Elzinga	Dr. ir. Annemiek ter Heijne Dr. ir. Jan Klok	Prof. dr. ir. Cees Buisman

Motivation

The treatment of thiols has been challenging for the petrol industry over the past decades. The combustion of natural gas containing thiols (organo sulphur compounds) forms SO2, resulting in adverse health effects, the formation of acid rain and dry acid deposition. Conventional treatment methods focus on the oxidation of thiols. However, this treatment strategies are not widely applied due to low efficiencies and high installation and operational costs. Bio electrochemical systems (BES) have proven themselves capable of treating complex organic materials at high rates and deep treatment of organic pollutants. BES may potentially be used as new removal strategy for the reduction of thiols.

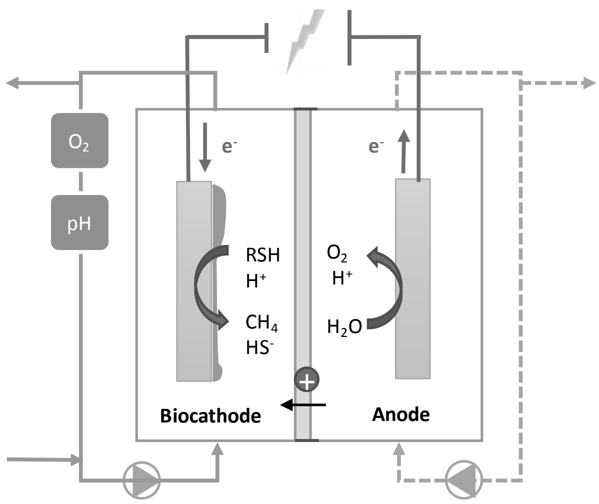
Technological challenge

Bio electrochemical systems are characterized by the separation of oxidation and reduction reactions at the anode and cathode. In these systems at least one of the reactions is bio catalyzed. Electrons flow through an external circuit from the anode to the cathode and reaction rates can be stimulated by changing the electrode potential or current density.

Microorganisms can donate electrons to the anode or utilize electrons from the cathode to perform otherwise thermodynamically unfavorable reactions.

Preliminary studies showed that thiols were successfully reduced to sulfide and methane when a small electric current was supplied. During these tests, arbitrarily operating parameters were chosen. To secure a robust technology various aspects need to be evaluated. Currently the involved reaction mechanisms are unknown. The need for co-substrates, the microorganisms involved, pH and toxicity limits have to be studied. A balance between fast reaction rates and energy efficiency needs to be obtained.

In this study, we will explore the possibility of stimulating anaerobic biodegradation of thiols in BES and its potential to form a safe, low cost and sustainable technology.



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Anaerobic ammonium removal and electricity recovery with bioelectrochemical system

Oct 2020 - 2024

Researcher	Supervisor	Promotor
Xiaofang Yan	Dr. ir. Jan Klok Dr. ir. Dandan Liu	Prof. dr. ir. Cees Buisman Dr. ir. Annemiek ter Heijne

Motivation

Removal of nitrogen compounds from wastewater is essential to prevent pollution of receiving water bodies. In wastewater, nitrogen is mostly present in the form of ammonium. Conventional ammonium removal technologies are biological processes, including nitrification and denitrification. They are energy-intensive due to aeration and carbon resource input. Besides the energy consumption, another downside is the production of NOx. NOx is a greenhouse gas, which emission should be minimized. For these reasons, novel and sustainable ammonium elimination processes should be developed. Bioelectrochemical systems (BESs) have gained attention as an alternative to ammonium treatment. They have been demonstrated to have efficient and energy-efficient ammonium removal performance.

Technological challenge

BESs utilize electrochemically active microorganism to catalyze the reaction in the electrode. Electrons driven by the oxidation of pollutants are transferred into the anode, resulting in pollutants removal. The electrons travel from anode to cathode offer the possibility of converting chemical energy into electrical energy.

In BESs, ammonium oxidation may occur under anaerobic conditions. In this project, we will explore how ammonium-oxidizing bacteria (AOB)/ nitrite-oxidizing bacteria (NOB) are able to directly transfer electrons to anode instead of oxygen and enable the recovery of electricity. Using bacteria to oxidize ammonium at the anode of a BES results in a reduced energy input for aeration, reduction in N2O emissions, and energy recovery from ammonium.

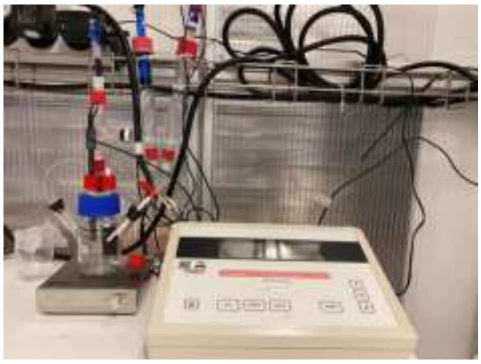

Figure 1 BESs system set-up

The technological challenge is to prove the concept of ammonium oxidation at the bio-anode and understanding the pathway of ammonium oxidation. Subsequently, we will explore the effect of operational conditions on the ammonium removal efficiency and electricity recovery. This study is expected to lay a fundamental basis for developing a more sustainable ammonium removal process using BESs.

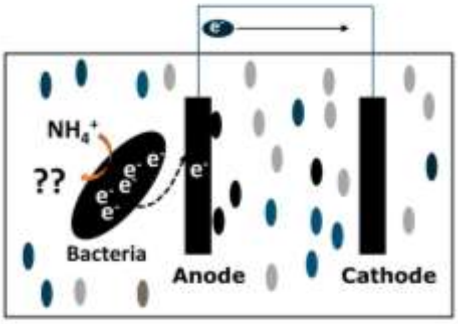

Figure 2 Concept of an anaerobic ammonium oxidation bioelectrochemical system integrating with electricity recovery.

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WAGENINGEN UNIVERSITY & RESEARCH

Optimization of BES by unravelling the storing mechanisms of electro-active bacteria

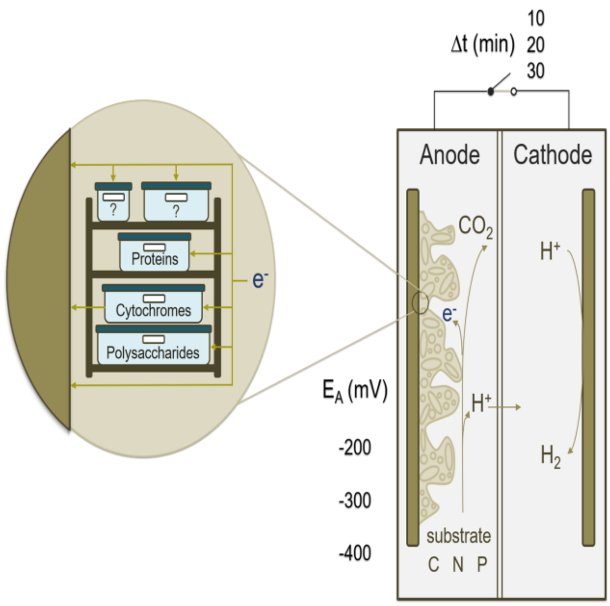
Biorecovery
Environmental Technology

Nov 2019 - 2023

Researcher	Supervisor	Promotor
João Pereira	Dr. ir. Tom Sleutels Dr. ir. Bert Hamelers	Dr. ir. Annemiek ter Heijne

Motivation

Bio-electrochemical systems (BESs) have been referred as a new technology for chemicals productions, bioremediation and power generation. The role of electro-active microorganisms in these systems is crucial. However, their performance in terms of current output is not competitive for practical application. Recently, higher currents have been reported for electro-active bacteria (EAB) controlled under intermittent polarization. Using this regime, biofilm morphology also differed from the structure typically observed under continuous polarization. However, the underlying mechanisms are still to be unraveled. In this project we propose the study of charge storage capabilities of electro-active bacteria by integrating several techniques to understand biofilm growth kinetics and biochemical composition. These results will provide valuable information to control and optimize biofilms performances in BES.



Technological challenge

The main challenge will be the integration of different quantification and characterization methods to assess the biofilm development on the anode. Due to the limited number of in-situ techniques available to track biofilm growth kinetics and chemical composition, the integration of several optical and electrochemical approaches is essential to a better understanding of biofilm behavior and a more detailed biofilm analysis (Figure 1). By studying the effect of operational conditions on the biofilm development, a final inherent challenge will be the creation of knowledge to control biofilm growth kinetics towards better performances in BES.

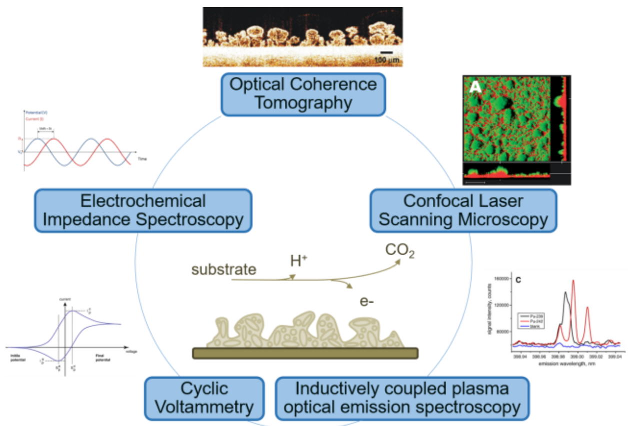


Fig 1. Examples of techniques to evaluate biofilm growth in BES: optical techniques (Optical Coherence Tomography and Confocal Laser Scanning Microscopy), electrochemical analysis (Electrochemical Impedance Spectrosocopy, Cyclic Voltametry) and chemical methods (Inductively Coupled Plasma Optical Emission Spectroscopy).

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WAGENINGEN UNIVERSITY & RESEARCH

Electron shuttling and sulfide storage in sulfide oxidising bacteria

Sub-department of Environmental Technology

May 2020 - 2025

Researcher	Promotor	Co-Promotor
Rikke Linssen	Dr. ir. Annemiek ter Heijne	Prof. dr. ir. Cees Buisman Dr. ir. Jan Klok

Motivation

Hydrogen sulfide gas is a waste product often produced by mining, paper production and petroleum industries. The release of sulfur gas into the atmosphere causes the formation of sour rain, which has detrimental effects on the environment. The removal of H2S from waste streams can be done via biological desulfurisation such as employed in the Thiopaq process. This process uses haloalkaline (high salt – high pH) sulfur oxidising bacteria (SOB), which can convert dissolved hydrogen sulfide into elemental sulfur under microaerobic conditions. Gaining an in depth understanding of the mechanisms behind this process can help optimising the process by lowering caustic consumption and energy use, and thus help making the process more environmental friendly.

Technical Challenges

The addition of an anaerobic sulfide uptake chamber between absorber and reactor already decreases side product formation. However, the mechanism behind anaerobic sulfide removal by SOB is still unknown. It is hypothesized that two mechanisms are the main contributors: oxidation under anaerobic conditions and storage in the form of polysulfides in sulfur globules (Figure 1).

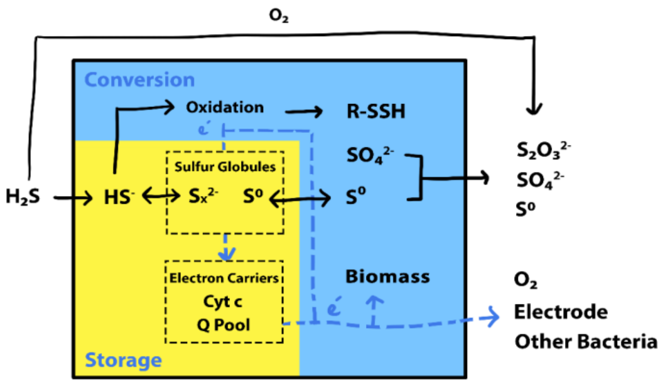
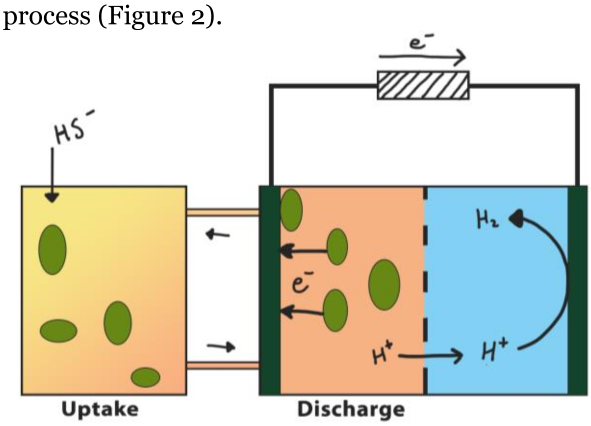


Figure 1 A simplified overview of the postulated mechanics of sulfide conversion and storage yellow field), and electron transfer (blue striped lines).

Additionally, it was found that SOB can use electrodes as electron acceptor instead of oxygen, which suggests the biological process can be performed fully anaerobically. This could reduce side product formation as sulfates and thiosulfates are produced via biological and chemical oxidation, and this opens the possibility of integrating hydrogen production into the desulfurisation process (Figure 2).



$HS^- \rightarrow S0 + H^+ + 2e^-$

Figure 2 A simplified sketch of a sulfide removal SOB fuel cell.

In this project, a measuring method will be developed to study the sulfide uptake and storage and cell discharge. After identifying the storage mechanisms and quantifying uptake and storage, a bioelectrochemical system will be modelled, build, and optimised, with the aim of recovering electrical energy from sulphide oxidation.

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WAGENINGEN UNIVERSITY & RESEARCH

Sub-department of
Environmental Technology

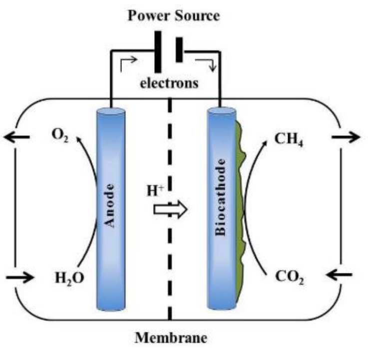
July 2020 - 2024

Power-to-methane in a Bioelectrochemical System

Researcher	Supervisors	Promotors
Ana Micaela Lavender	Dr. ir. Johannes B. M. Klok Ir. Dandan Liu	Dr. ir. Annemiek ter Heijne Dr. ir. Cees Buisman

Motivation

Interest in electricity storage technologies is on the rise with the increasing implementation of renewable energy into the electricity market and consequential fluctuations between electricity supply and demand.
Power-to-methane in a bioelectrochemical system (BES) is a novel electricity storage concept inspired by research on methane producing BES, with the intent of recovering methane from electrical energy. Methane can then be stored or transported through existing natural gas pipeline infrastructure. The energy efficiency of the system quantifies the methane recovery as of electrical power input and is calculated as the product between current-to-methane efficiency and voltage efficiency. With this said, the higher the energy efficiency the less energy is lost between conversions and the more efficiently electricity is stored.

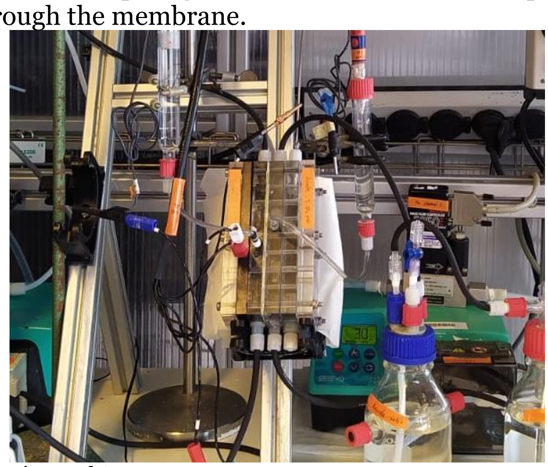


Methane-producing BES: CO_2 is converted to methane by mixed culture microorganisms at the cathode side while at the anode water oxidation provides the protons and electrons necessary for reduction of CO_2.

Technological challenges

So far the energy efficiency of methane-producing BES is below 25%, low in comparison to currently implemented electricity storage technologies.

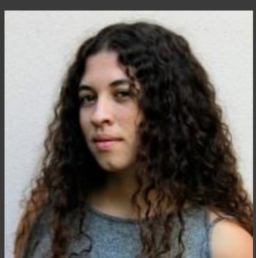
In this context, the main challenge is to increase the energy efficiency while at the same time ensuring a highly productive system. This meaning without compromising methane production rates.
Current-to-methane efficiency is highest when no other reactions occur besides methane production and voltage efficiency is highest the lowest the losses within the BES. These losses can be associated to cathode overpotential, anode overpotential, ion movement, pH gradients and other transports through the membrane.



Experimental Set-up.

With this said the main goals are:

(1) To develop a biocathode at minimum overpotential;
(2) To design a state-of-the-art (highly productive) methane-producing BES;
(3) To study the influence of intermittent electricity supply (characteristic of electricity storage applications) in the state-of-the-art system;
(4) To evaluate the most valuable CO_2 containing waste streams;
(5) To understand the applicability of the state-of-the-art system as an electricity storage technology based on all above.



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Novel nickel-based electrodes for hydrogen production

Feb 2019 - 2023

Researcher	Supervisor	Promotor
Ragne Pärnamäe	Dr. Michele Tedesco Dr. Philipp Kuntke	Prof. dr. ir. Bert Hamelers

Motivation

Hydrogen is considered the most promising fuel for its high energy density, abundance, and no emissions during combustion. Today, however, it is almost entirely produced via steam methane reforming, a process which uses natural gas to produce syngas – H_2 mixed with CO_2. To avoid the use of natural gas, a non-renewable hydrocarbon, and the production of a greenhouse gas CO2, hydrogen can instead be sustainably produced by water electrolysis using renewable electricity.

Technological challenge

The performance of electrolysis depends heavily on the electrodes, which need to be highly catalytic to facilitate the gas' formation. Platinum group metals have outstanding catalytic performance but are expensive. Therefore, new cost-effective alternatives are necessary. Since the development of electrolysers, nickel-based materials have remained state of the art non-noble hydrogen evolution reaction (HER) catalysts for alkaline water electrolysis. While nickel is the most active non-noble metal, it does not outperform platinum group metals. Thus, much effort must be put into optimizing nickel-based catalysts' chemical structure and morphology.

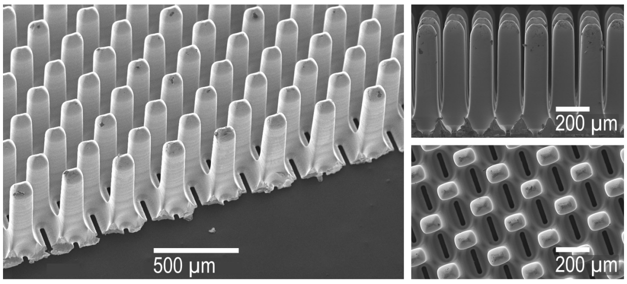


Fig 1. SEM images of the electrodes as provided by the manufacturer (Veco Precision BV).

Research goals

This project investigates pillared nickel electrodes and optimizes their design for H_2 production via alkaline water electrolysis.

Focus is put on three research objectives:

1. Testing the electrodes against state of the art alkaline HER catalyst (Raney nickel) and optimizing the electrode design (pillar spacing and length, electrode porosity) for improved performance.
2. Improving the electrodes' catalytic activity with noble and non-noble dopants.
3. Identifying and demonstrating novel applications for such electrodes.

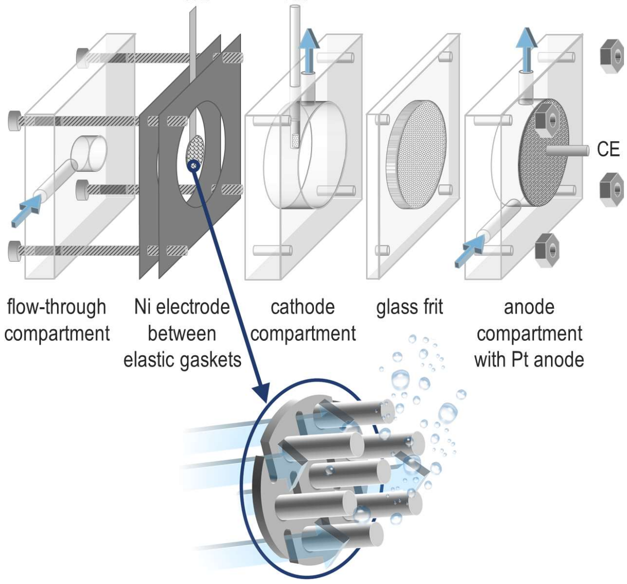
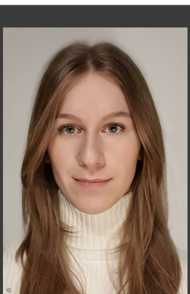


Fig 2. Experimental cell with a flow-through configuration for improved bubble detachment.



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Environmental Technology

Novel electrochemically assisted processes for electricity-driven CO_2 capture

Sept. 2021 - 2025

Researcher	Supervisor	Promotor
Mu Lin	Dr. ir. Annemiek ter Heijne Dr. Philipp Kuntke	Dr. ir. Bert Hamelers

Motivation

Capturing CO_2 from industrial emissions to prevent further increase in atmospheric CO_2 concentration is essential to mitigate climate change and shift towards a climate neutral industry by 2050. Conventionally, CO_2 is absorbed in amine solvents which then are thermally regenerated. However, high energy cost and solvent degradation associated to thermal regeneration raised the interest in developing alternative processes. Here, electrochemical systems offer the clear advantage to conveniently use green (renewable) electricity as energy input for a pH-swing based regeneration. The scope of the study is to demonstrate a novel CO_2 capture process based on pH-swing regeneration (Fig.1) in an electrochemical system (Fig. 2)."

Technological challenge

Previous studies on electrochemical CO_2 capture and regeneration system proves the feasibility of the idea of establishing an acidic trap for the depletion of CO_2 in the basic solvent [1-2].
However, both energy and CO_2 removal efficiency are still below the benchmark of the state-of-the-art CO_2 capture via amine scrubbing [3]. Additionally, a full understanding of such a process from a thermodynamic perspective is still lacking in literature, and it would be fundamental to guide the design and further scale-up of the electrochemical technology. The technological challenge remains to understand and reduce the electrical overpotentials while maintaining a high current density and energy efficiency.
This novel process will be also investigated on pilot-scale, and addressing potential challenges in the scale-up process will be crucial to provide input for follow-up studies towards full-scale implementation.

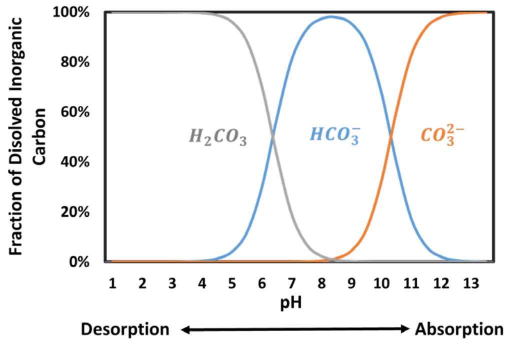

Fig. 1. Fraction of chemical species as function of the solution pH for the H_2O-CO_2 system at 25 °C.

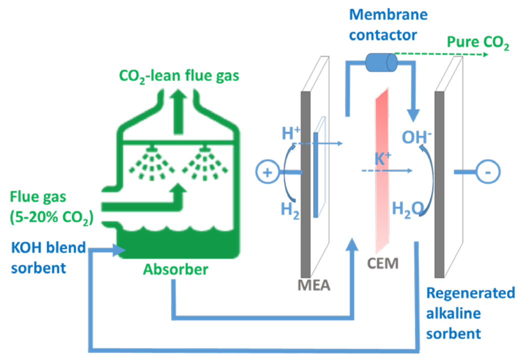

Fig. 2. Schematic illustration of the CO_2 capture process based on absorption in alkaline (KOH) blend and electrochemical regeneration.

References

[1] Legrand et al., Environmental Science & Technology (2018), 52(16), 9478-9485
[2] Shu et al., Environmental Science & Technology (2020), 54(14), 8990-8998
[3] Bui et al., Energy Environ. Sci. (2018), 11 (5), 1062–1176

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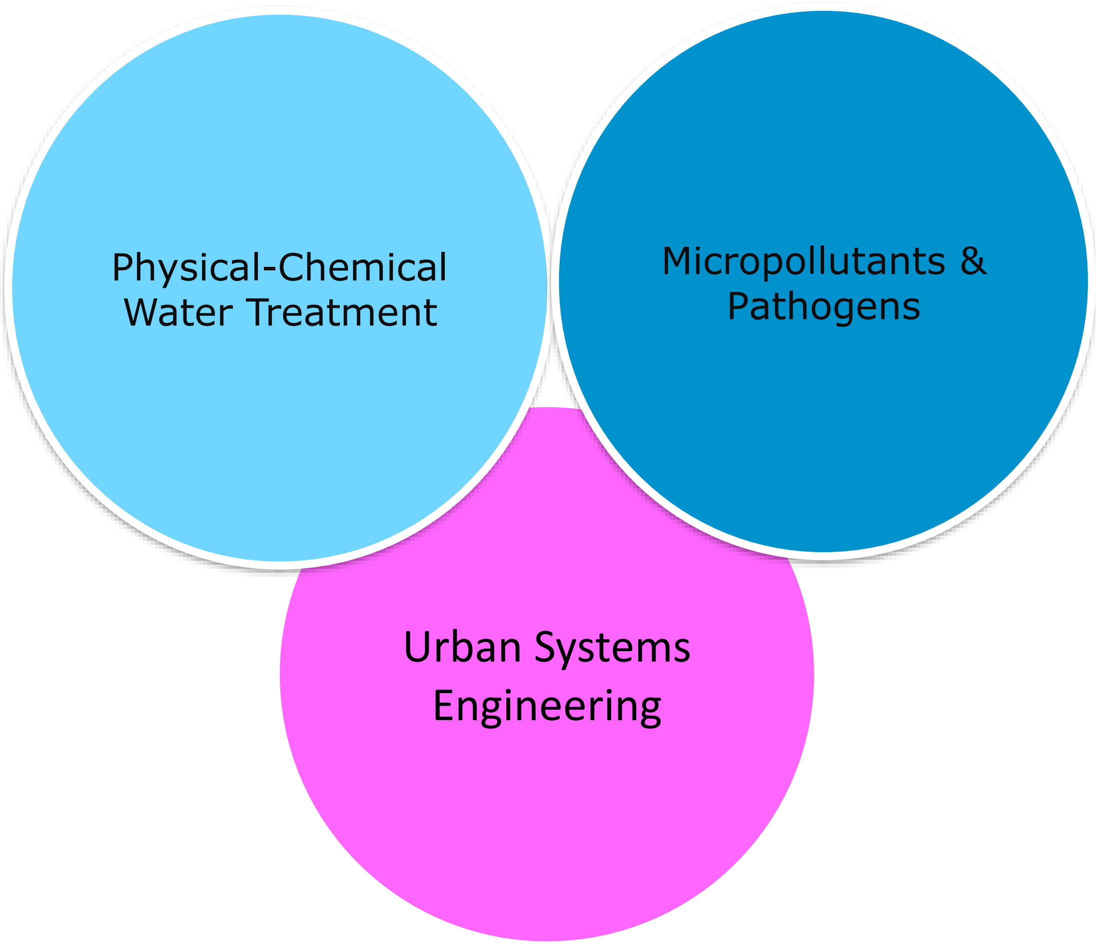
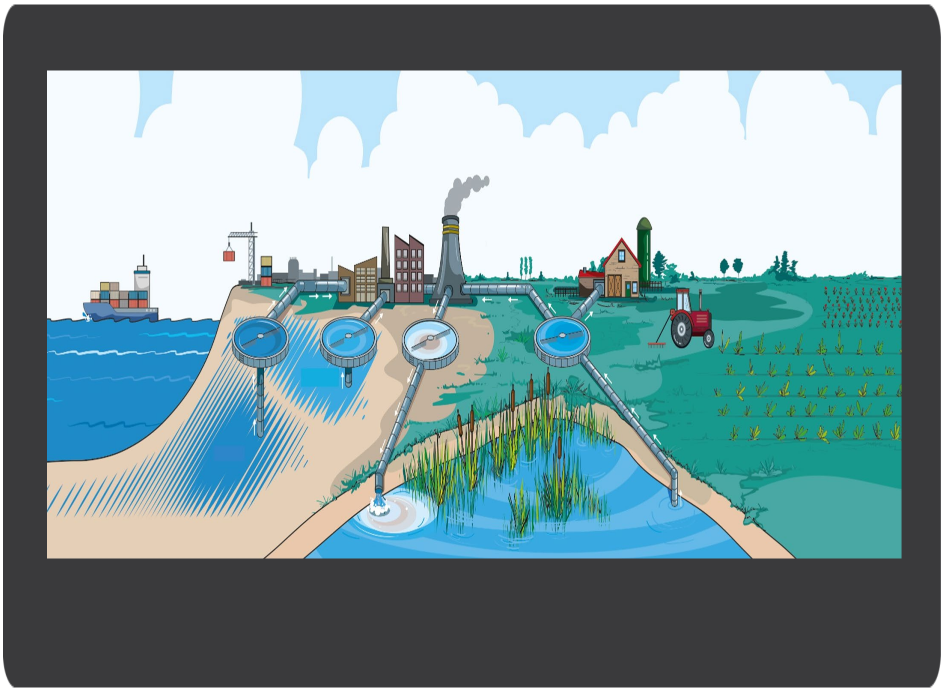
Environmental Technology

Reusable Water



Reusable Water



Water scarcity is just as much a water quality challenge as a water quantity problem. Often, sufficient water may be available, but of the wrong quality. Water reclamation is impeded by the presence of organic contaminants, like micropollutants, or excess salts. Sustainable technologies are required to remove these contaminants to allow for reuse of water.

The Reusable Water group aims at developing technologies to produce water of sufficient quality that it fits the demands for reuse. We research and develop technologies that remove contaminants from a variety of water types, including industrial wastewater, drinking water, domestic wastewater, and groundwater. Our technologies are implemented to close water cycles within and between urban, industrial, and agricultural uses. Our new treatment technologies are piloted together with end-users. And we conceptualize new water reuse cycles together with the USE group.

Micropollutants and pathogens

Organic micropollutants and pathogens are major hurdles to closing water cycles. Reclaimed and repurposed water can contain recalcitrant organic micropollutants, including pharmaceuticals, hormones, pesticides, POPs, chemicals in consumer products, and industrial chemicals, and pathogens, including antibiotic resistance genes (ARGs). These contaminants must be removed from water in order to protect human and environmental health.

Our research focuses on developing effective and sustainable technologies to remove micropollutants and pathogens from water and soil. We focus on biological technologies, relying on natural microorganisms to degrade micropollutants. Biological technologies are, when needed, integrated with physical-chemical technologies such as sorption and advanced oxidation. Our technologies treat many types of water, including wastewater treatment plant effluent, surface water, groundwater, and industrial water. The technologies are thus designed and tailored to be used in different applications, allowing us to produce water of sufficient quality for applications such as irrigation, industrial process water, (secondary) household water, and source for drinking water production.

Physical-chemical water treatment

Saline water provides an immense source for fresh process water and drinking water. Innovative electrochemical and membrane-based techniques including capacitive deionization, nanofiltration and electrodialysis are studied for fresh water production and for selective removal and recovery of ionic species from wastewater and natural water. Polymers and mineral colloidal particles hamper industrial (salt)water treatment and reuse, e.g. of produced water in the oil/gas industry, process water in the food and beverage industry, or in the production of drinking water from surface water. Removal and recovery of organics from wastewater, including methane or bio-flocculants, are studied in bioreactors, which are optimized for fluid and process dynamics, together with the Biorecovery group.

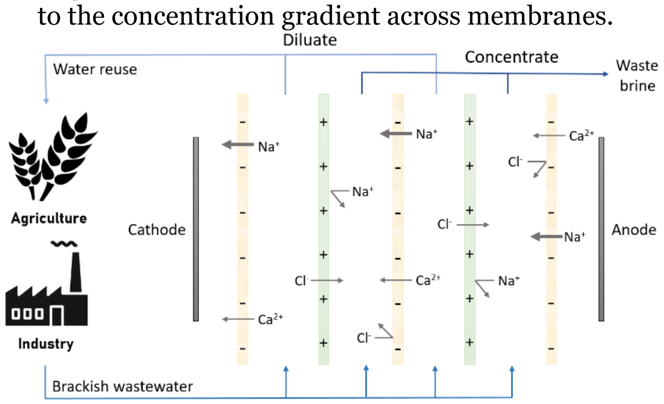
Selective Electrodialysis for Food Industry

Jul 2019 - 2023

Researcher	Supervisors	Promotor
Selin Özkul	Dr. ir. Jouke Dykstra Dr. ir. Harry Bruning Dr. ir. Norbert Kuipers (WFBR) MSc Roel Bisselink (WFBR)	Prof. dr. ir. Huub Rijnaarts

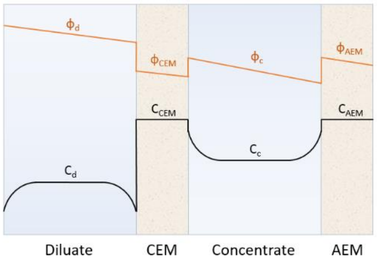
Motivation

In many sectors, there is an increasing interest to desalinate and re-use water due to the rising demand for limited freshwater resources. However, continuous use of water in closed cycle systems can result in accumulation of specific ions in the recirculating water. Especially in agricultural sector, accumulation of sodium ions (Na+) in the irrigation water negatively affects the soil permeability and limits crop growth, thus makes the water unusable in agricultural systems. In order to increase the potential for water re-use, it is important to develop desalination technologies that selectively remove specific ions from the solution.
Electrodialysis (ED) is an electrically driven membrane desalination technology, which has high potential to selectively remove specific ions from the solution. An ED cell consists of two electrodes and alternatingly placed ion exchange membranes between them. When electrodes are electrically charged, the salt concentration increases in each alternate cell due to the arrangement of membranes. Mass transport in an ED cell is the result of electro-migration due to electrical forces, and diffusion due to the concentration gradient across membranes.



Technological challenge

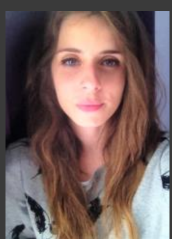
Mass transport determines ion removal rate, quality of the desalinated water and ion selectivity of the ED process. In order to selectively remove undesired ions and recover valuable ones in the solution, ion transport mechanisms should be studied in detail. Several factors can be controlled in the ED system to influence the concentration gradients, thus the ion transport. The technological challenge is to modify these factors in a way to achieve specific ion removal considering membrane characteristics, individual ion properties and system operating conditions.



Methodology

In this project, we aim to study ion-transport controlling parameters to develop ion selective ED technology. For this purpose;

- A theoretical model describing ion transport through ion-selective membranes will be developed for multi-ionic solutions.
- Laboratory experiments will be performed in order to validate and improve the developed model.
- Ion selectivity of the ED process will be enhanced by influencing the concentration gradient between the diluate and concentrate compartments.
- Industrial applications of the developed selective ED process in food industry will be evaluated.



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Enhancing biological stability of drinking water by membrane treatment

Apr 2016 - 2020

Researcher	Supervisor	Promotor
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Motivation

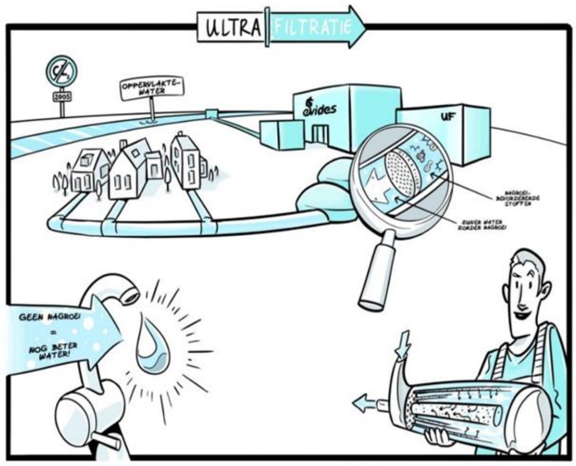
Distribution of potable water without any residual disinfectant eliminates DBP (disinfectant-byproduct formation) and maximizes consumer satisfaction in terms of taste and odor. However, biological stability, i.e. unobjectionable levels of microbial and invertebrate organisms, is to be maintained in the distribution network. Hereto, the drinking water treatment is to achieve production of potable water characterized by a low microbial growth potential (MGP), i.e., low in nutrients (e.g. organic compounds of natural origin) and other growth-promotors (e.g. biomass, particulate matter). Ultrafiltration and capillary nanofiltration membrane treatment have potential in addressing this challenge in surface water treatment. This constitutes a novel application of these existing technologies.

Technological challenge

Ultrafiltration rejects by size-exclusion particulate matter, microbial biomass and, depending on the selected molecular-weight cut-off (MWCO), biopolymeric organic carbon. Therefore, ultrafiltration as posttreatment to existing conventional surface water treatment plants potentially reduces associated MGP. Tighter capillary nanofiltration is to achieve a further reduction in lower Mw organic compounds. However, their impact on biological stability has not been studied extensively yet. Furthermore, although several analytical methods are available to determine waterborne MGP (e.g. Assimilable Organic Carbon, Biomass Production Potential), further extension is desired, whereas it is not yet established with certainty which compounds contribute to MGP.

The behavior of several membrane systems is studied on laboratory, pilot and practice scale. The first results indicate that ultrafiltration posttreatment is capable of significantly enhancing biological stability, and matter of relatively large dimensions is a major factor in MGP. Operational settings and membrane fouling conditions were found to have only marginal impact.

The technological challenge is to (continue to) establish the impact of membrane treatment processes of several MWCO on biological stability, derive in more detail which components govern MGP, and compare and improve analytical methods to quantify MGP predictively in grab samples as well as in practice conditions.



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Environmental Technology

Towards Mechanistic Understanding of the Interactions Between Per- and Polyfluoroalkyl Substances and Adsorption Materials in Drinking Water Treatment

Aug 2021 - 2025

Researcher	Supervisor	Promotor
Marko Pranić	Dr. ir. Jouke Dykstra	Prof. dr. ir. Albert van der Wal

Motivation

Per- and polyfluoroalkyl substances (PFAS) are a family of anthropogenic micropollutants. They have been found in many water bodies, including drinking water sources. This is a problem since even at low concentrations, PFAS pose a risk to human health. Because of that, technologies for their removal during drinking water treatment are developed, and the current benchmark technology is adsorption. However, many physical and chemical interactions between PFAS and the adsorption materials are mechanistically not understood, and a better understanding can contribute to the development of the technology and a reduction of operational costs.

Methodology

In this project a combination of theoretical and experimental methods will be used. Theoretical models will describe the effect of the properties of PFAS and adsorption material on the adsorption. These models will describe conditions of relevance for drinking water treatment, i.e., the impact of the drinking water matrix on the PFAS adsorption. The theoretical models will be validated with batch and column experiments. As a result of the applied methodology, the design requirements for the adsorbents, and for the process conditions will be set. This knowledge will contribute to a more secure drinking water supply, free of PFAS.

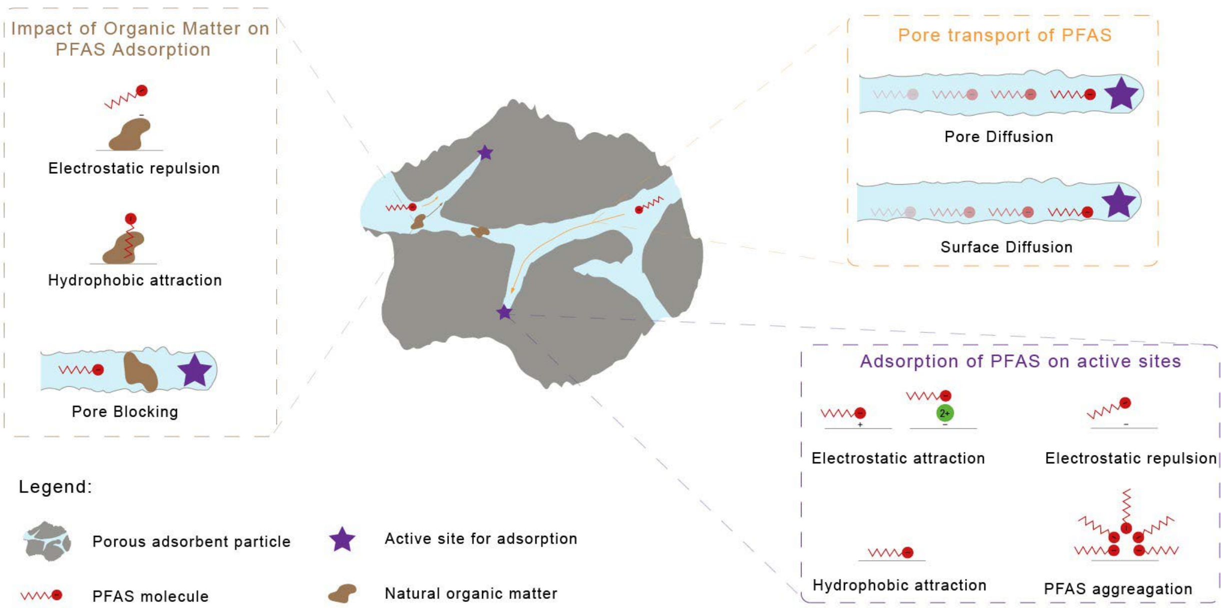

Figure 1. Mechanistic interactions between PFAS and adsorption material that will be studied

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evides waterbedrijf

WAGENINGEN UNIVERSITY & RESEARCH

Chemically modified carbon electrodes for electrochemical separation processes

Oct 2018 - 2022

Researcher	Supervisors	Promotor
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Motivation

Water, being the most essential need for all living creatures, becomes scarce as consumption rapidly increases every year. To overcome the scarcity of potable water, technologies to desalinate and to purify ground water, surface water and sea water can be developed and employed. Electrochemical methods can be used to remove ions and charged molecules from water.

Capacitive Deionization (CDI)
CDI is an electrochemical method for ion removal using porous electrodes. These electrodes adsorb ions from water, resulting in a desalinated stream. Later, the electrodes are regenerated, and the ions are released, resulting in a concentrated stream. Traditionally, CDI uses a cell design with one porous carbon electrode that adsorbs and releases the cations (cathode), and another electrode that adsorbs and releases the anions (anode).

Technological challenge

Since carbons do not have a natural preference for the adsorption of either anions or cations, the ion adsorption is solely based on the potential applied. This results in a reduced ion removal efficiency due to phenomena such as co-ion adsorption.
To overcome this, following strategies can be employed.

- *Selective ion adsorption* by the electrodes can be increased.
- *Selective ion transport* across the electrodes can be achieved through *ion-selective membranes.*
- The effect of faradaic and non-faradaic processes on (selective) ion adsorption, and on potential pH changes during operation, should be understood to increase the performance and stability of the electrodes and membranes.

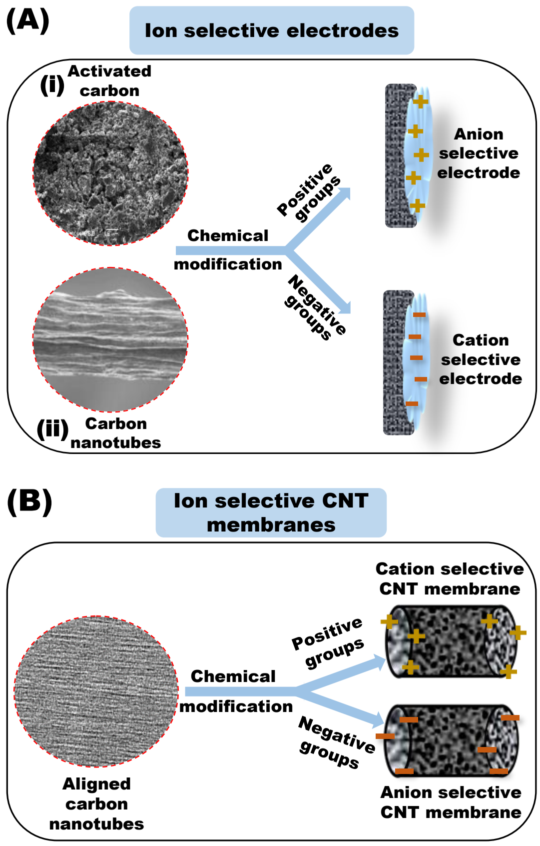

Fig.1: (A) Preparation of ion selective carbon electrodes from (i) activated carbon (AC) and (ii) carbon nanotubes (CNTs). (B) Chemical modification of aligned carbon nanotubes (CNTs) to prepare an ion-selective membrane.

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Towards a physical chemical understanding of membrane-based micropollutants removal from contaminated surface water

Sep 2020 - 2024

Researcher	Supervisor	Promotor
Sebastian Castaño Osorio	Dr. ir. Maarten Biesheuvel Dr. ir. Jouke Dykstra Dr. ir. Evan Spruijt	Prof. dr. ir. Bert van der Wal

Motivation

Recently, the number and occurrence of potentially hazardous micropollutants (MPs) in surface water has raised as a result of increased economic activity and the usage of pharmaceuticals and other substances in society. The presence of these organic anthropogenic compounds represents a risk for human health; therefore, achieving efficient removal of MPs from surface water is crucial for the production of safe drinking water.

The aim of this project is to develop a comprehensive physical-chemical model for micropollutant (MP) removal using nanofiltration (NF) and reverse osmosis (RO) systems. The model will provide a better process understanding and aims to contribute to the design of water treatment processes.

Technological challenge

Membrane-based technology for MP removal has already been implemented in the production of drinking water. However, the retention of these compounds and transport through membranes is only poorly understood.

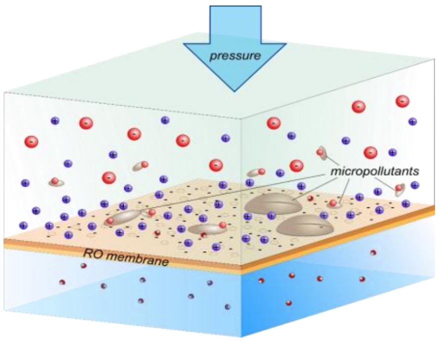

Fig 1 Schematic illustration of the processes at the high-pressure side of a membrane that retains micropollutants from surface water

For instance, because of the general hydrophobic nature of micropollutants, they may condense into nano-droplets on the membrane surface (**Fig 1**) and affect the transport and overall process. In this project, this phenomenon is explicitly considered together with intramolecular and particle-surface interactions.

Besides, this research will study and address the role of ions and charge regulation in MP retention using NF/RO. This integrated approach will provide valuable insights for MP removal using membrane processes. A general description of the methodology proposed is given in Fig 2.

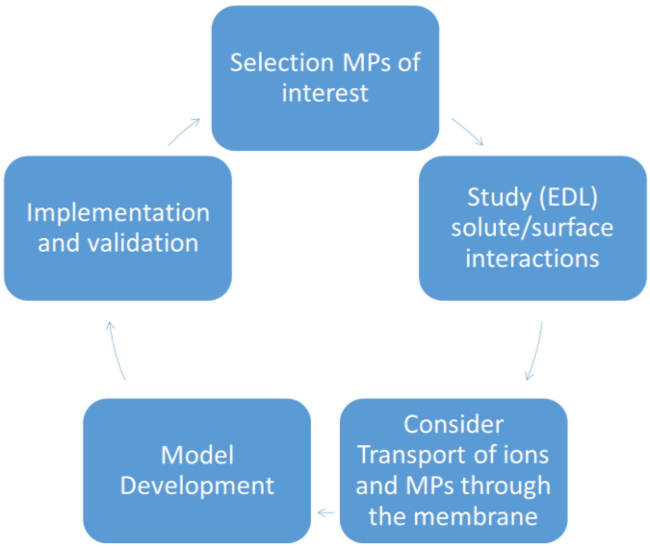

Fig 2 Methodological approached, (EDL) electrical double layer

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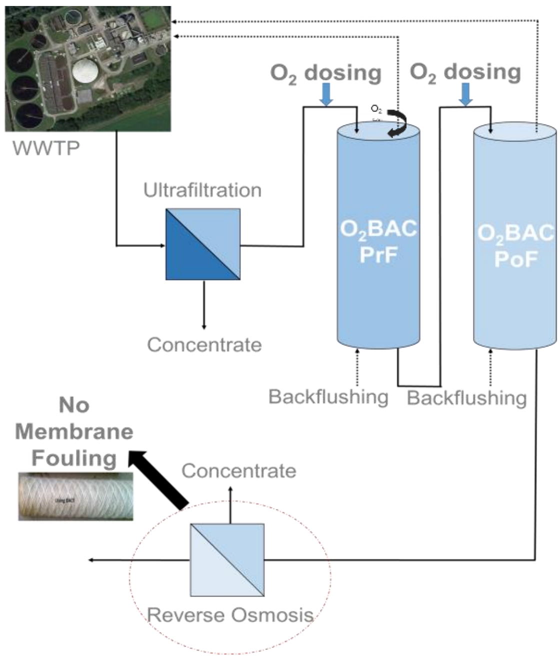
Fouling prevention through biological activated carbon and ultrafiltration

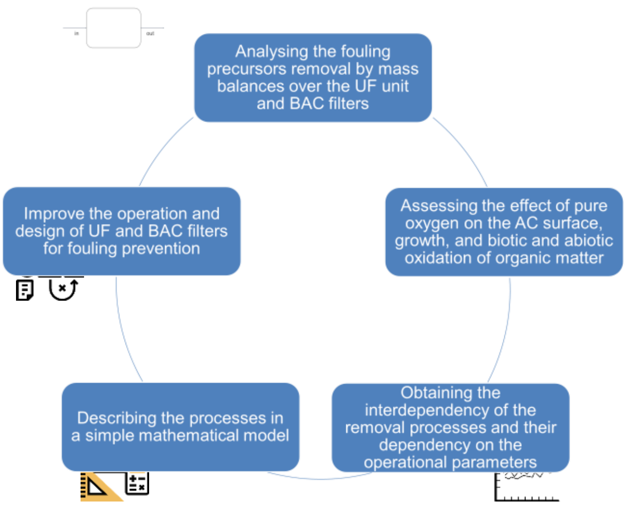
Oct 2019 - 2023

Researcher	Supervisor	(Co-)Promotor
Sara Ribeiro Pinela	Dr. ir. R. J. W. Meulepas Dr. M. C. Gagliano	Dr. R. Kleerebezem Prof. dr. ir. H.H.M. Rijnaarts

Motivation

Biological Activated Carbon (BAC) is a water purification process that combines physical adsorption onto granular activated carbon (AC) and pollutants/organics biodegradation through biofilms. The technology is eco-friendly and cost-effective, since the biodegradation helps to prevent the saturation and replacement of the AC. BAC is an established process in drinking water treatment[1], and also has potential for wastewater reclamation [2,3]. At the Puurwaterfabriek (Emmen, the Netherlands), ultrafiltration (UF), BAC Pre-filter (O2BAC PrF) and BAC Polishing Filter (O2BAC PoF), and ReverseOsmosis (RO) are applied in sequence to produce ultrapure water by treating the effluent of a wastewater treatment plant [5]. The important innovation of this plant, now in operation for over 10 years, is is the absence of fouling of the RO membranes , although in literature BAC treatment is often associated with downstream fouling [4]. This research aims to understand how UF and BAC canprevent downstream fouling of RO units.





Technological challenge

The BAC filters at the Puurwaterfabriek are unique as they are constantly oxygenated and periodically back-flushed. The challenge is to investigate possible synergy between the biotic and abiotic processes contributing to the removal of fouling precursors, and to establish how these processes depend on the BAC operation and design.

[1] Korotta-Gamage, S. M., and Sathasivan, A., *Chemosphere*. 167 (2017) 120-138
[2] Riley, S. M. *et al. Sci. Total Environ*. 640-641 (2018) 419-428.
[3] Tammaro, M., *et al. J. Environ. Chem. Eng*. 2(3) (2014) 1445-1455.
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[5] NWTR, 2016.

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Environmental Technology

Production and Application of Natural Flocculants

Nov 2021-2025

Researcher	Supervisor	Promotor
Berke Kisaoglan	Cristina Gagliano	Prof. Dr. Ir. Huub Rjinaarts

Motivation

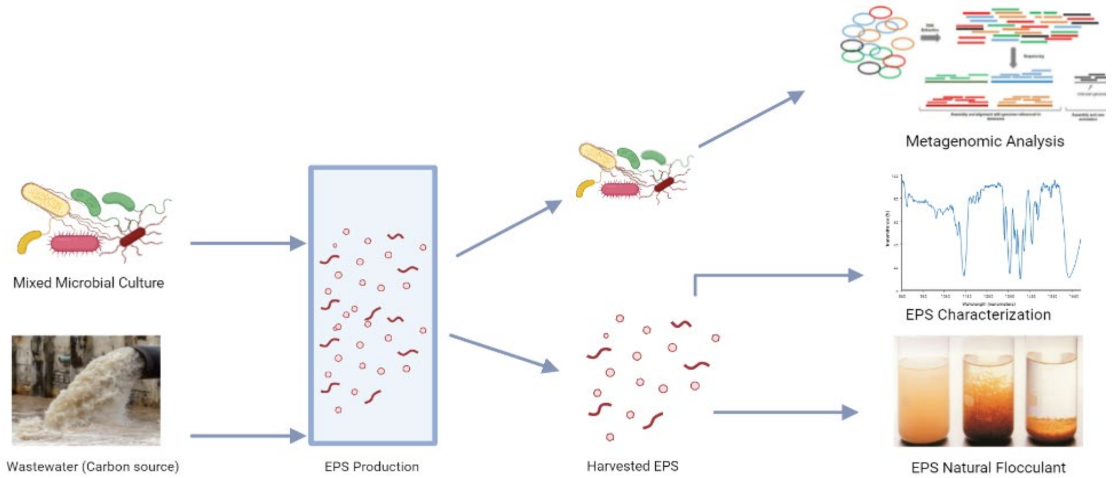
Flocculation has been widely employed in water and wastewater treatment to facilitate water-solids separation. The process requires the use of flocculants that are able to form strong flocs. Currently, the flocculant market is dominated by fossil-based organic flocculants that are poorly biodegradable and potentially toxic. This explains why natural flocculants have emerged as an alternative, environmentally friendly solution since they are non-toxic, biodegradable, and have high flocculation performance.

Technological challenge

Microbial extracellular polymeric substances (EPS) have been explored as promising natural flocculants due to their physicochemical properties. EPS are microbial secretions and may either be produced by pure or mixed cultures. In this context, combination of a non-sterile mixed-culture approach with the use of low-cost feedstocks emerges as cost-effective strategy to produce natural flocculants.

The objective of this research project is to utilize organic waste(water) streams as organic substrate to produce microbial EPS by employing a mixed microbial culture approach, followed by investigating the potential of the produced EPS as natural flocculants. This is accompanied by several challenges and research questions including:

- What is the response of the microbial community to the use of varied organic substrates?
- Can EPS production be maintained when fed with different substrates and what are the effects of it on the EPS composition in terms of protein, carbohydrate, and other biopolymers?
- Which factors determine the competition between production of EPS and internal storage products (e.g PHA)?
- Can the mixed-culture EPS be employed as natural flocculants and if necessary, how can the flocculation efficiency be improved?



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AquaConnect | Key technologies for safeguarding regional water provision in fresh water stressed deltas

Reusable Water

Environmental Technology

2021 - 2026

Program leader
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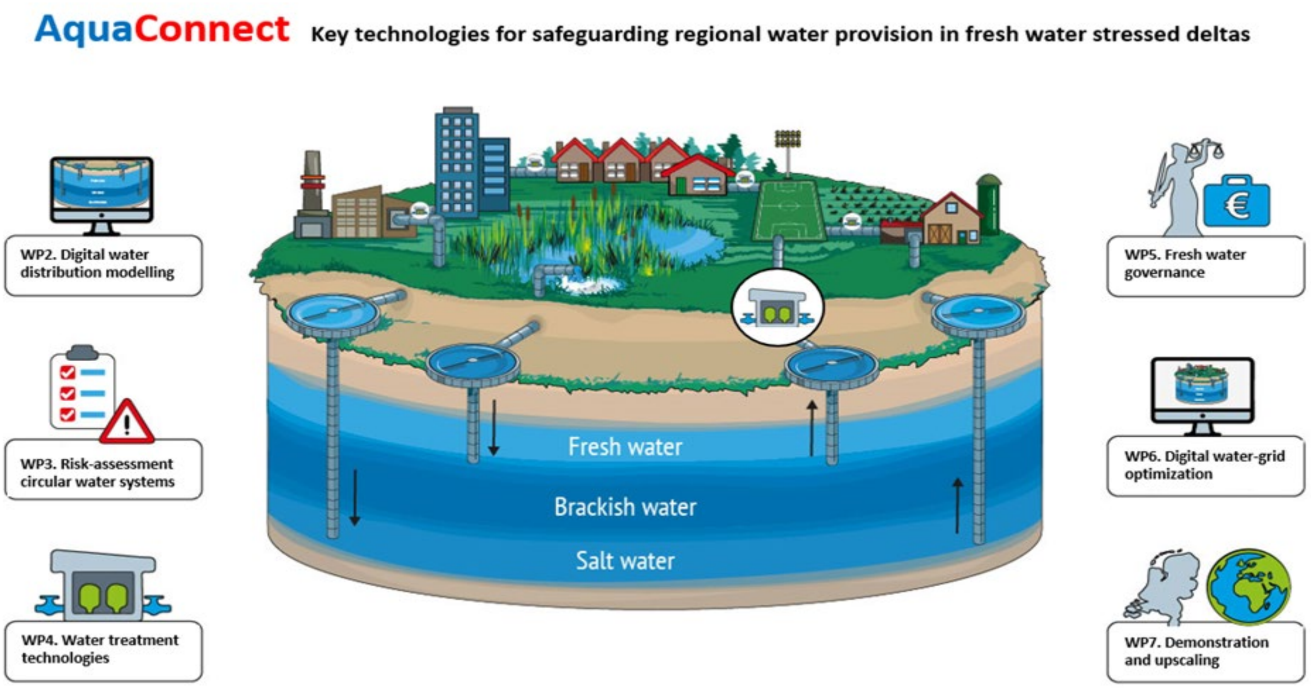
Program coordination
Dr. Thomas Wagner

Technological challenge

The Netherlands experiences increasing threats to fresh water provision essential for ecosystems and societal functioning, including industrial and agricultural production. AquaConnect develops new scientific concepts for solutions that can **ensure future fresh water provision**. New **key digital and chemical technologies, and innovative water governance** approaches are developed that together form the base to design **regional self-sufficient fresh water provision grids. Digital technologies** are local scale modelling and design tools that allow identification and use of unexploited water resources and subsurface water storage. These are needed to design and operate new infrastructural grids to match water demand and supply. **Physical-chemical treatment technologies** will be developed and combined with existing technologies to enable use of brackish groundwater and wastewater treatment plant effluents. Water quality targets will be defined from risk assessments of circular water systems, considering technological and in situ biological removal of emerging pollutants and sustainable management of sludges and brines. Whilst closely working with stakeholders in four utilization cases due attention will be paid to **societal feasibility**, and the value of freshwater for the regional economy. Special focus will be on how to dovetail **policy, legal, cultural change**, **and perception issues** with the new technologies. Demonstration activities aim for **an international outreach program**, exporting technological approaches and sharing know-how on system management, governance and cultural change.



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WAGENINGEN UNIVERSITY & RESEARCH

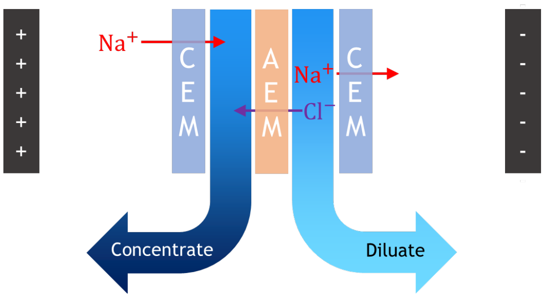
Electrodialysis: towards ion-selective separations

Sep. 2021 - 2025

Researcher	Supervisor / co-promotor	Promotor
Alaaeldin Elozeiri	dr. ir. Jouke E. Dykstra prof. R.G.H. Lammertink	prof. H.H.M. Rijnaarts

Motivation

We aim for a decentralized system that can treat water "fit for purpose". To achieve this, a treatment train with nanofiltration (NF) and electrodialysis (ED, Fig.1) will be developed. NF will effectively remove organic micropollutants, colloidal particles, nano-plastics, viruses, bacteria, and divalent cations, whereas the electrodialysis step can be used to control the effluent salt concentration and ion balance of the treated water (water fit for re-use).



Technological challenge

Currently, several technologies are commercially available to reduce water salinity. These technologies are successfully employed to treat, for example, brackish groundwater. However, salinity is not the only water quality indicator of interest. For effective water re-use, technologies are required to control the ionic composition of water (i.e., removal of specific ions from water, while keeping the others).

In this project, we will focus on electrodialysis (ED), a desalination technology driven by an electrical field. We aim to selectively remove specific ions from water. ED technology controls the exact degree of desalination based on the applied voltage. Still, it is not just the overall salt concentration that matters.

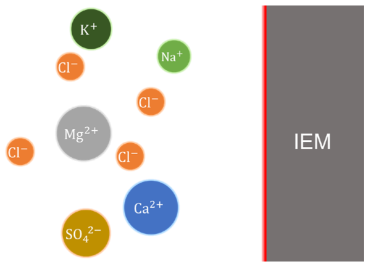
Case study:
Zuid-Holland , greenhouse, wastewater recycling

AquaConnect
https://www.aquaconnect.nu/

For many applications, the exact ionic composition is crucial. Specific separations are considered, e.g., the removal of Na^+ from agricultural wastewater to be reused at greenhouses. We will consider the effluent requirements of the desalinated water as well as the environmental compatibility of the concentrate stream.

Our key objectives are:

- Developing selective ion-exchange membranes (IEM) via surface modifications
- Modeling ion transport through selective IEMs
- Exploring the integration of ED with NF



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Environmental Technology

WAGENINGEN UNIVERSITY & RESEARCH

Assessing the fate of contaminants of emerging concern in effluents during irrigation

Apr 2021 - 2027

Researcher	Supervisor	Promotor
Jill Soedarso	Dr. ir. Nora Sutton	Prof. dr. ir. Huub Rijnaarts

Motivation

During drought periods, treated effluents can be a stable water supply for a more climate-resilient agricultural sector, to protect crop production and groundwater reservoirs. In the Netherlands, the focus is on reuse of the water, to either use it as irrigation water for agriculture and/or horticulture, nature conservation i.e. supplying water to drought endangered brooks and creeks, or for groundwater reservoir preservation by artificial recharge. Internationally, treated effluents are considered to be used as irrigation water in even a wider variety of applications, i.e. for non-food crop production and land greening programs in deserts or even for food-crop related irrigation in fresh water-stressed delta's. In all the situations we miss the knowledge on what is happening on the chemical interaction at the contaminants of emerging concern (CEC) (e.g. pharmaceuticals , PFAS) side and the soil side after irrigation. Therefore, we will focus on the reuse of water (treated effluent) and fate of CEC compounds.

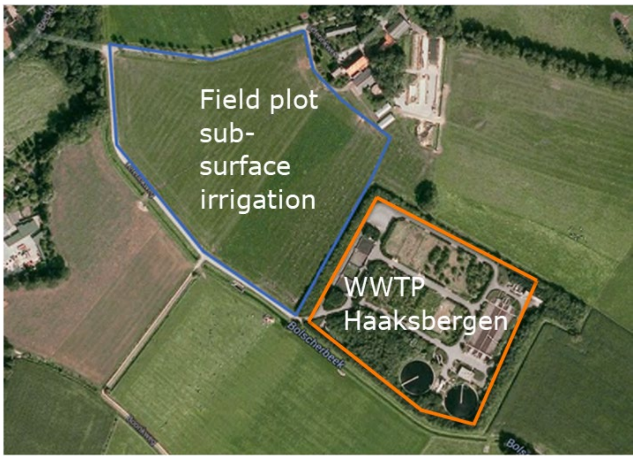

Figure 2 Field-scale pilots (lysimeter Qatar)

By understanding the soil CEC's interaction we can predict the effects on the soil and groundwater quality, in relation to risks associated with water resources and quality of crops. Effluents have the potential to be used as irrigation water during drought periods and other situations described on the left, while the fate of CEC pollutants should be thoroughly understood and the associated risks well managed.

Technological challenge

This research aims to understand the physical and chemical interaction of CEC's with soil and groundwater to understand the fate of CEC's in the environment. A combination of modelling, lab experiments and a field-scale pilot is applied to understand the interactions with CEC's and soils, to assess if treated effluents can be reused in a sustainable way as irrigation water without affecting the soil and ground water quality and surface water flow.

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Investigating the formation and fate of micropollutant transformation products in subsurface water systems

Sep 2021 - 2025

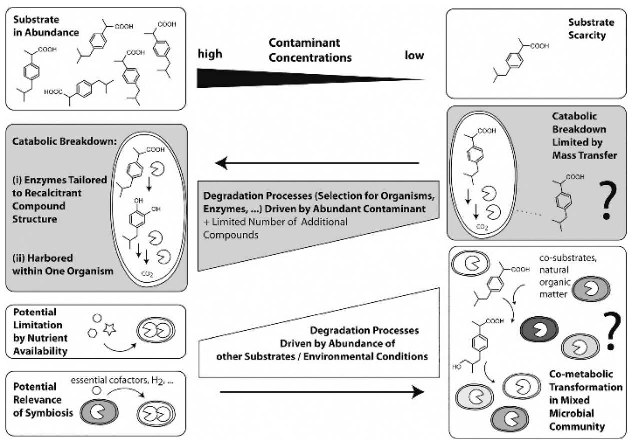
Researcher	Promotor	Supervisor
Alessia Ore	Prof. dr. Annemarie P. van Wezel (UvA)	Dr. Nora B. Sutton

Motivation

Because of climate change, the Netherlands is currently facing seasonal problems with freshwater provision. Alternative water sources, such as surface water and wastewater treatment plant effluents, are being infiltrated to replenish aquifers and store water. However, micropollutants are widespread in the environment, including groundwater and surface water. The infiltration of alternative water sources may introduce more micropollutants into aquifer systems, threatening the quality of the drinking water produced. Furthermore, there is increasing concern on the underground formation, through microbial processes, of micropollutant transformation products (TPs), which can be more harmful than the parent compounds.

Technological challenge

During the travel time in the subsurface and once in groundwater systems, the fate of micropollutants is affected by biotic and abiotic processes. Microorganisms can biodegrade the contaminants changing their structure and forming TPs or mineralizing them into CO_2 and water. TPs can be more recalcitrant and mobile than the parent compounds, but are more difficult to identify, and are thus considered an important blind pot. Under the most favorable conditions, indigenous microbial population may be able to complete the mineralization of contaminants and their TPs. Biodegradation of micropollutants and TP formation is indeed affected by a wide range of parameters, including redox conditions, dissolved organic carbon (DOC) availability and contaminant concentration (Figure 1). In groundwater systems, the conditions (i.e. anaerobic and oligotrophic) are such that do not support biodegradation. However, the presence of micropollutants and TPs in drinking water sources is most unwanted. By providing DOC or more energetically favorable electron acceptors, biodegradation in subsurface water systems may be stimulated. Moreover, by testing different contaminant concentrations, it may be possible to understand if the microbial transformation of contaminants into TPs is due to metabolic or co-metabolic processes. This understanding will be useful to find possible solutions to steer biodegradation towards mineralization.
In the present research, laboratory experiments and field investigation will be closely interconnected and used to assess TPs fate and formation in subsurface water systems. The analysis of data and samples from case studies in the Netherlands will be critical to reach this aim and provide useful insights for a safer production, storage and reuse of water in the future.



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AquaConnect

WAGENINGEN UNIVERSITY & RESEARCH

Dynamics of the microbial community in constructed wetlands treating wastewater treatment plant effluent

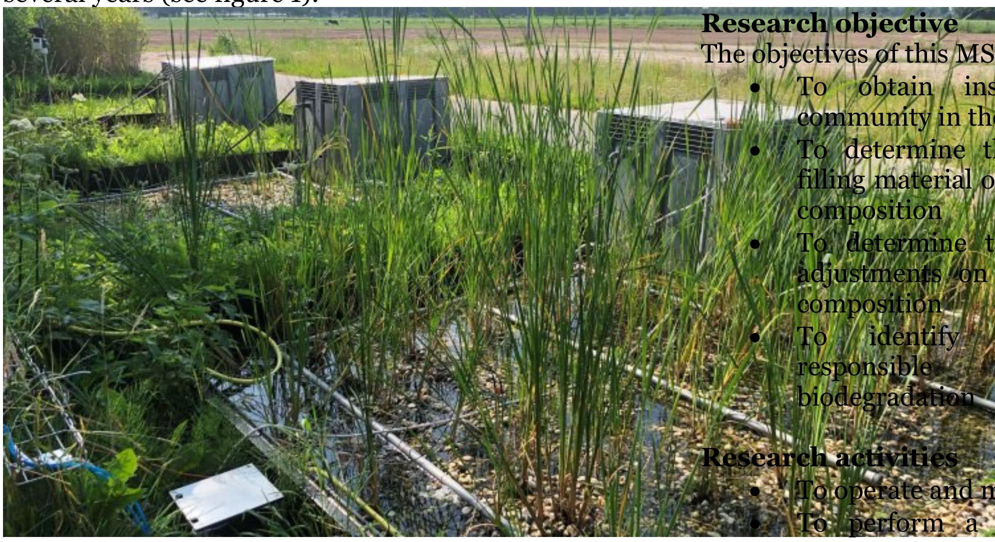
Feb 2022

	Supervisors	Examiner
	Dr. Thomas Wagner Dr. Merve Atasoy	Dr. Alette Langenhoff

Environmental Technology

Motivation

Constructed wetlands (CWs) are man-made wetlands for the treatment of wastewater. In CWs, different processes occur simultaneously that remove pollutants from the wastewater, for instance adsorption, biodegradation and plant uptake. The department of Environmental Technology has extensive facilities for CW research, including outdoor pilot-scale CWs that are up and running for several years (see figure 1).



Technological challenge

The focus of the ongoing research with these CWs is on their removal of micropollutants from wastewater treatment plant effluent. Therefore, these CWs have been upgraded with small technological adjustments to enhance their removal capacity for micropollutants, such as adsorption substrates and active aeration. In 2021, we have shown that these technological adjustments result in an improved micropollutant removal efficiency.

There are strong indications that a substantial part of this removal is due to biological degradation. However, we have limited information about the microorganisms in the CWs that are responsible for this biodegradation. A further understanding of the microbial community would lead to more efficient CW designs for micropollutant removal from wastewater.

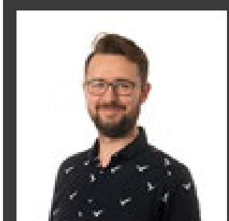
Research objective

The objectives of this MSc. thesis therefore are

- To obtain insights in the microbial community in the experimental CWs
- To determine the effect of different CW filling material on the microbial community composition
- To determine the effect of technological adjustments on the microbial community composition
- To identify specific microorganisms responsible for micropollutant biodegradation

Research activities

- To operate and maintain the CWs
- To perform a short literature study to identify specific genes correlated to micropollutant biodegradation and determine micropollutants of special interest
- To perform chemical analyses and determine the micropollutant removal efficiency of the CWs
- To perform microbial analyses and determine the microbial community composition during the experimental period
- To summarize your findings in a written report



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WAGENINGEN UNIVERSITY & RESEARCH

Environmental Technology

The role of organic substrate and shear forces in anaerobic sludge granulation

Jan 2021 – 2025

Researcher	Supervisor	Promotor
Chang Gao	Dainis Sudmalis	Prof.dr.ir. HHM Rijnaarts

Motivation

Anaerobic wastewater treatment is a well-established technology, which converts organic pollutants contained in wastewater into energy-rich biogas.

Design of compact anaerobic bioreactors requires formation of granular sludge, i.e. spherically shaped biofilm that has excellent settling properties. However, for sometimes unknown reasons granular sludge does not form at all, or only develops at very slow rates. The main goal of this project is to gain more knowledge about the granulation process and use this knowledge to improve it.

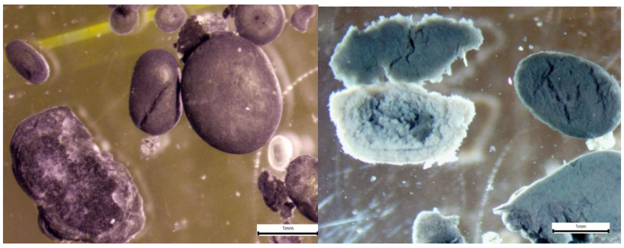
Figure 1 Lab-scale UASB reactors

Technological challenge

Anaerobic granulation is a complex process caused by various physical and chemical interactions between microorganisms and polymers (EPS) they excrete. In addition, these interactions are affected by operational conditions, substrate composition and indirectly by microbial population and activity. This also explains why the scientific literature on this topic often is conflicting. In particular, studies on effect of the type of organic substrate on granulation from dispersed biomass are still lacking.

In this research, the role of proteinaceous substrate on anaerobic granulation under fresh water conditions will be studied in an up-flow anaerobic sludge blanket (UASB) reactor (Figure 1).

Besides, the relationship between functional groups' abundancy of EPS in the granules and granules' strength will be investigated. This research will be carried out with granules (of different strengths) from full-scale plants of Paques treating various types of wastewater (Figure 2).



(a) Kitchen waste *(b) Rendering*

Figure 2 Macroscope pictures of anaerobic granules grown on different wastewaters.

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Biostimulation of aromatic hydrocarbon mixture degradation in a former gaswork site

April 2019 - 2023

Researcher
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Supervisor
Dr. ir. Tim Grotenhuis
Dr. Ivonne Nijenhuis

Promotor
Prof. Dr. ir Huub Rijnaarts

Motivation

Since the start of the industrial revolution a wide variety of organic chemicals has been released into the environment through anthropogenic activity. One of major concerns affecting the groundwater quality and aquifer ecosystem health is contamination with aromatic hydrocarbons because of their relatively high water solubility, toxicity, and carcinogenicity.

As an efficient and eco-friendly treatment method, in situ bioremediation of contaminated soils and groundwater by naturally occurring microorganisms or by bioaugmentation of adapted microorganisms is possible. Therefore, the aim of this study is to develop a new approach for the biostimulation of aromatic hydrocarbon degradation that could also be applied to many different polluted sites.

Technological challenge

In the presence of oxygen, aromatic hydrocarbons can be rapidly degraded. However, groundwater and soil environments are mostly **anoxic.** Therefore, it is necessary to artificially improve the degradation activity of indigenous microorganisms for an efficient remediation approach.

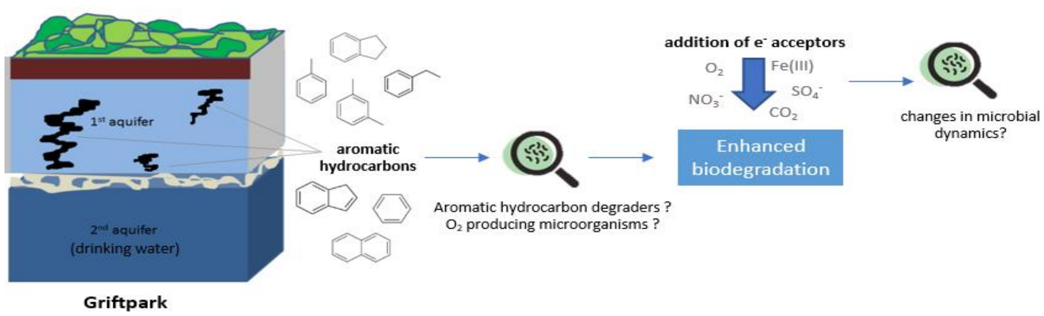
Engineered bioremediation is usually applied to speed up the biodegradation process by addition of nutrients, **electron acceptors**, bioaugmentation or other stimulants. In this project, our target area is Griftpark (Utrecht) which used to be a manufactured gas plant site. The soil and the groundwater is currently contaminated with high concentrations of BTEX, indene, indane and naphthalene.

In this project:

- The effect of different electron acceptors on the biodegradation of a **hydrocarbon mixture** present in Griftpark will be tested.

- Changes in **microbiome dynamics** within different redox conditions will be studied by use of molecular techniques.

- The presence of **O2 producing microorganisms** in Griftpark will be investigated hereby the formed O2 can be used by the microorganism for aerobic catabolic pathways in an anoxic environment, suggesting an ecophysiological niche space of substantial appeal for bioremediation.



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Improving microbiological urban surface water quality with nature-based technologies

Oct 2019 - 2023

Researcher	Supervisor	Promotor
Sha Gao	Dr. Nora B. Sutton (ETE) Dr. Paul van der Wielen (MIB)	Prof. dr. ir. Huub Rijnaarts

Motivation

The microbial quality of urban surface water bodies is important for urban quality of life and citizen health. Exposure to microbiologically contaminated water can result in many severe illnesses like gastroenteritis; fever; skin, ear, and eye complaints and respiratory disease. Currently, expanding uses for urban surface water such as undesignated swimming, intensified recreation, and other unregulated uses require a high water quality, which is not currently covered in existing regulation.

The aim of this project is to develop an understanding of microbiological urban surface water quality and develop mitigation technologies. This research is based in comprehensive screening and mechanistic understanding of microbiological quality of urban surface water.

Technological challenge

• Screening current microbiological water quality
A comprehensive monitoring campaign will be conducted at several vulnerable urban surface water locations in Amsterdam and Toronto. Sampling is performed monthly to investigate pathogens concentration (using qPCR combined with cultural method) and basic physio-chemical water parameters (pH, temperature, salinity, etc.) to look into the factors that influence microbiological urban surface water quality temporally and spatially.

• Mechanistic study of selected pathogens
Several important pathogens will be selected as indicators for research on their behavior in urban surface water bodies. Expriments are performed under highly controlled indoor tanks to understand the growth and/or die-off of selected fecal and opportunistic pathogens effected by environmental factors.

• Mitigation technology development
Nature-based technologies will be developed on laboratory and small-pilot scale that harness photodegradation in wetland or retention pond systems to mitigate point-source releases of pathogens, substrates and particles, and growth of opportunistic pathogens.

• Piloting monitoring strategy
The monitoring scheme and mitigation technology will be piloted in Amsterdam and Toronto to assess the effectiveness on improvement of microbiological water quality.

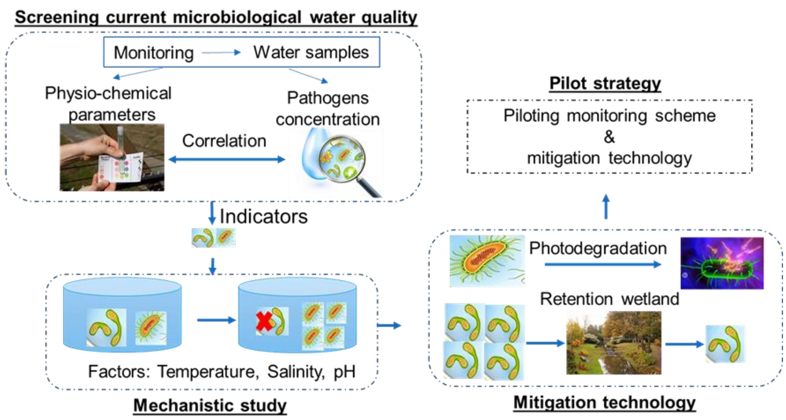

Fig 1 Research approach

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Biological treatment of organic micropollutants present in nanofiltration membrane concentrate

2020-2024

Researchers
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Prof. dr. ir. Huub Rijnaarts

Motivation

There is growing awareness and concern about the presence of so called organic micro-pollutants (OMPs) in our surface water. OMPs originate from consumer products or from medicinal, agricultural or industrial activities. Although in wastewater they are present in very low concentrations (ng-ug/l), they have the potential to cause long-term harm to humans and the environment.

Municipal waste water treatment plants (MWTPs) are considered as hotspots for the release of OMPs into the environment as they were not designed to include the removal of OMPs. We are studying a new process that significantly increases OMP removal by MWTPs, without having to increase their footprint.

Partners in our project are studying the (multi-layered) nanofiltration membranes that can selectively remove OMPs. And the treatment of retentate of these nanofiltration membranes (NF) is the topic of our study.

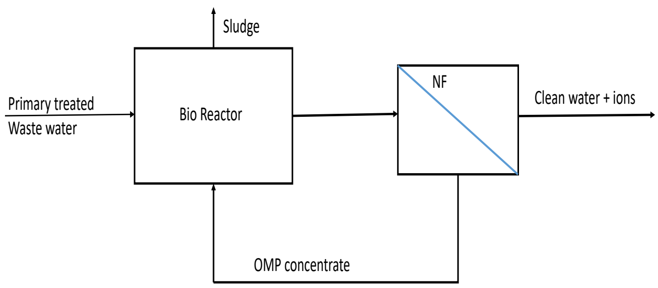

Figure 1 The proposed process, a combination of nanofiltration and biological treatment

Whereas OMP concentrations in MWTP effluents may be too low to initiate their biodegradation, this may be feasible at the elevated concentrations in the membrane concentrate. In addition, recycling of the OMPS to the MWTP's bioreactor increases the contact time between the microorganisms and OMPs further increasing the chances of OMP biodegradation.

This study focusses on biodegradation of the OMPs but also on the effect of recirculation of the OMPS on the primary (biological) functions of the MWTPs, i.e. oxidation of bulk organic pollutants, nitrogen and phosphorus removal and digestion of the waste sludge.

Technological challenge

- Perform several lab-scale experiments in reactors to identify removal mechanisms of OMPs in activated sludge reactors:
  - Biodegradation
  - Sorption
  - Adsorption
- Use different TOC/DOC concentrations in the reactors to identify the effect on the degradation of OMP
- Identify the effect of recirculation of the retentate in the reactors
- Perform bioassays to test the toxicity of parent OMPs and transformation compounds present in the reactor effluent.

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No plastic to waste: Use microplastics to remove micropollutants

Apr 2020 - 2022

Researcher
Dr. Nora B. Sutton

Reusable Water
Environmental Technology

Motivation

Microplastics and micropollutants are two emerging contaminants that threaten environmental and human health. Microplastics are small plastic particles (<5 mm) composed of polymers and additives. They can be unintentionally formed when larger plastic pieces wear. Micropollutants are organic chemicals, such as pesticides and pharmaceuticals, detected in wastewater at low concentration from ng/l to µg/l. Due to their persistency, bioaccumulation and potential toxicity, both microplastics and micropollutants are a rising concern for our modern society.

Technological challenge

Recent studies showed that organic micropollutants can be absorbed by microplastics. This new discovered property might help to reduce the total amount of organic micropollutants reaching the downstream water systems. Treatment of organic micropollutants via adsorption is already widely used in water treatment technologies with activated carbon filters, however, adsorption to another pollutants is a new field that deserves to be developed.
Furthermore, microplastic particles are colonized by microorganisms that can degrade micropollutants. Thus, microplastics act as an adsorbent material for micropollutants and as a biofilm carrier for the microorganisms able to degrade micropollutants. Recent studies show that recalcitrant plastics can be partly metabolized by microbial communities as well. Therefore, we focus on removing micropollutants in wastewater treatment plants (WWTP), which are an important source of discharging micropollutants to the environment, by using microplastics that are present in wastewater.

Research goal

In this project, as represented in fig.1, we aim to use the adsorbent capacity of microplastic to remove micropollutants, such as pesticides and medicines, from water. Adsorbed micropollutants will then be consumed by microbial biofilm growing on the microplastic particles. This project will provide insight on the fate and transformation of microplastics and micropollutants in water. This will be the first step to assess the treatment feasibility of both pollutions.

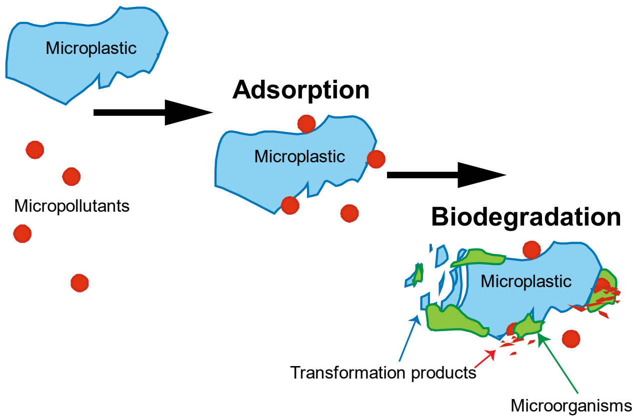

Fig. 1: Experimental approach to investigate the adsorption of organic micropollutants to microplastics and their biodegradation by microbial communities

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WAGENINGEN
UNIVERSITY & RESEARCH

The fate and removal of antibiotics and antibiotic resistance in aerobic granular sludge systems

Environmental Technology

Sept 2021 - 2025

Researcher	Supervisor	Promotor
Zhaolu Feng	Dr. Nora B. Sutton Dr. Heike Schmitt	Prof. Mark van Loosdrecht

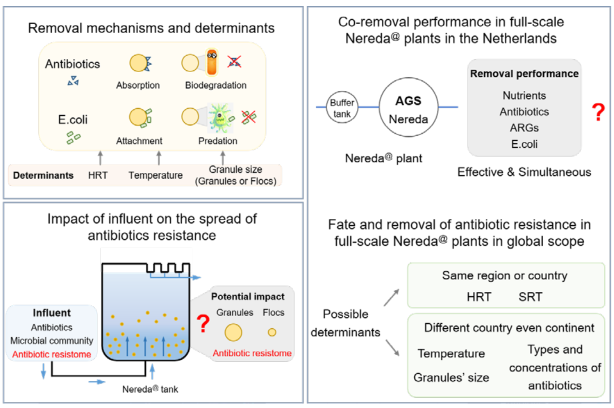
Motivation

Wastewater is an important source of micropollutants (MPs), antibiotics, and antibiotic resistance. However, the main goal of wastewater treatment plants (WWTPs) is to remove organic components and nutrients from wastewater instead of MPs, bacteria, and genes. Thus, the effectiveness of wastewater treatment technologies in removing MPs and antibiotic resistance has received widespread attention.

Aerobic granular sludge (AGS) is becoming a well-established technology for wastewater treatment due to its compactness, energy savings, and good effluent quality. With the development of AGS technology, it has been adapted to the commercial scales (Nereda@ technology). However, the effectiveness of Nereda@ technology in removing MPs and antibiotic resistance remains unclear, and the most important mechanisms controlling the removal of these contaminants and the dissemination of antibiotic resistance genes (ARGs) still need to be studied. Thus, the aim of this study is to investigate the fate and removal of antibiotics and antibiotic resistance, explore their possible determinants, and clarify the potential removal and dissemination mechanisms in full-scale Nereda@ plants.

Technological challenge

- Antibiotics and fecal indicator organisms (E.coli) have multiple removal pathways, such as sorption, biodegradation, attachment, and predation. In this study, the main removal pathway of antibiotics and E.coli and the different dissemination patterns of antibiotic resistance genes in granules and flocs will be clarified. The possible determinants of removal and dissemination, like hydraulic retention time, will be explored.
- Influent, including antibiotic, microbial communities, and antibiotic resistome, is an essential vector for the spread of antibiotic resistance. The potential contribution of antibiotic resistome in the influent to the antibiotic resistome in granules and flocs will be studied.
- To explore the effectiveness of Nereda@ technology in removing antibiotics, E.coli, and ARGs, the co-removal performance of nutrients, antibiotics, ARGs, and E.coli, and their possible determinants will be explored in the full-scale Nereda@ plants in the Netherlands.
- Different types and concentrations/abundances of antibiotics and ARGs exist in wastewater from different regions. To explore key determinants of antibiotics' removal and ARGs' dissemination, the removal and fate of antibiotics and antibiotic resistance in the full-scale Nereda@ plants in the global scope will be investigated.



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Compounds of Emerging Concern removal by microalgae-based technology

Jan 2019 - 2023

Researcher	Supervisor	Promotor
Kaiyi Wu	Dr. ir. Tania V. Fernandes Dr. ir. Alette Langenhoff	Prof. dr. ir. Huub Rijnaarts

Motivation

Compounds of emerging concern (CEC) have become a new challenge for wastewater treatment, as conventional wastewater treatment plants are designed for the removal of macropollutants and not micropollutants, such as CEC. CEC are found at low concentrations (ng/L-µg/L), and negatively affect natural fresh water quality and aquatic ecosystems.

Microalgae-based technology has shown to remove nutrients and CEC from wastewater. The resulting microalgal biomass can be applied as biofuel or fertilizer to achieve a 'zero-waste' treatment system. The aim of this study is to evaluate the removal of CEC and its transformation products from municipal wastewater in a microalgae photo bioreactor (PBR).

Technological challenge

Microalgae-mediated bioremediation of CEC is gaining increasingly scientific interest, yet there are still many unknowns, such as the removal mechanisms due to limited tested compounds, and biotic and abiotic conditions. The research is divided into four work packages:

- Evaluate the removal performance of a selection of CEC and its transformation products in a microalgae PBR. Furthermore, identify which compounds are removed and how they affect algal growth in the PBR.
- Investigate the mechanisms (photolysis, oxidation, adsorption, bioaccumulation, intracellular and extracellular biodegradation, etc.) responsible for CEC removal
- Evaluate the effect of environmental and operational conditions on CEC removal and define the optimal design of a PBR.
- Test the CEC removal in a pilot scale PBR in a greenhouse at Dutch natural light conditions.

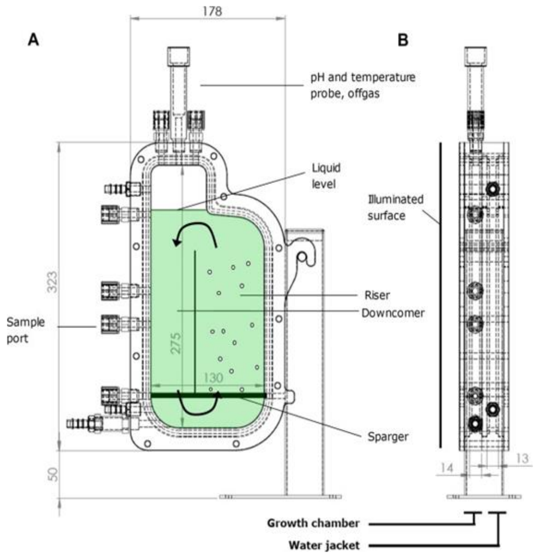

Fig. 1 Design of the lab-scale PBR

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Dissolved Organic Matter Dosing To Enhance *In Situ* Micropollutants Biodegradation In Drinking Water Aquifers

Feb 2019 - 2023

Researcher	Supervisor	Promotor
Rita H. R. Branco	Dr. Nora Sutton Dr. ir. Roel Meulepas	Prof. dr. ir. Huub Rijnaarts

Motivation

Almost two thirds of the drinking water in the Netherlands comes from groundwater. Recent studies have detected micropollutants such as pesticides and pharmaceuticals in Dutch groundwater, sometimes in concentrations close to or above the permitted level (0.1 µg/L for a single micropollutant).
Biodegradation of micropollutants can occur naturally in the environment and it can be influenced by the presence of dissolved organic matter (DOM). In groundwater, DOM is present at low concentrations and is very recalcitrant, which leads to low rates of this natural attenuation. However, previous research indicates that amendment with a labile DOM source can enhance the biodegradation of micropollutants.
Hence, the aim of this research is to study the effect of DOM dosing in order to develop an in situ micropollutants bioremediation technology in groundwater.

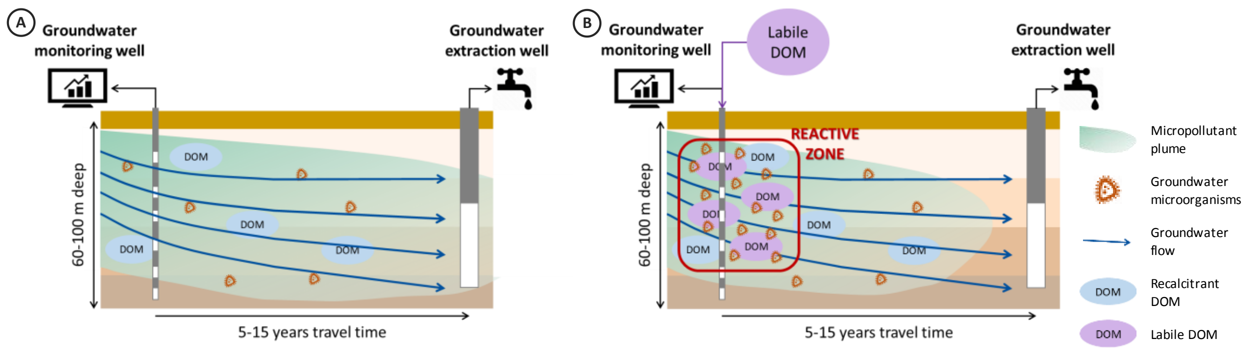
Technological challenge

When developing an *in situ* micropollutants technology some challenges need to be overcome.

The low concentrations of micropollutants (µg/L range or lower) can be hamper to biodegrade and DOM can be preferentially degraded over micropollutants. Furthermore, for micropollutants degradation to occur, favorable environmental conditions are required but groundwater conditions (e.g. low microorganism density, anaerobic environment and low temperature) do not support biological activity. Finally, the *in situ* treatment should not affect the quality of groundwater as it is used for drinking water production.

Research goals

This project is divided in 4 phases:
Phase 1 – Screening for biomass sources capable of degrading micropollutants and assess the effect of different DOM sources on micropollutant biodegradation
Phase 2 – Understand the kinetics and mechanisms of degradation at conditions mimicking the aquifer (column experiments)
Phase 3 – Develop a groundwater transport model that includes the biological degradation processes
Phase 4 – Perform a field demonstration of the developed *in situ* micropollutants bioremediation technology



Micropollutant attenuation in groundwater: A – Natural attenuation; B – DOM amended attenuation

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

Reusable Water
Environmental Technology

Understanding the fate of antibiotic resistance genes from swine manure

Feb 2019 - 2023

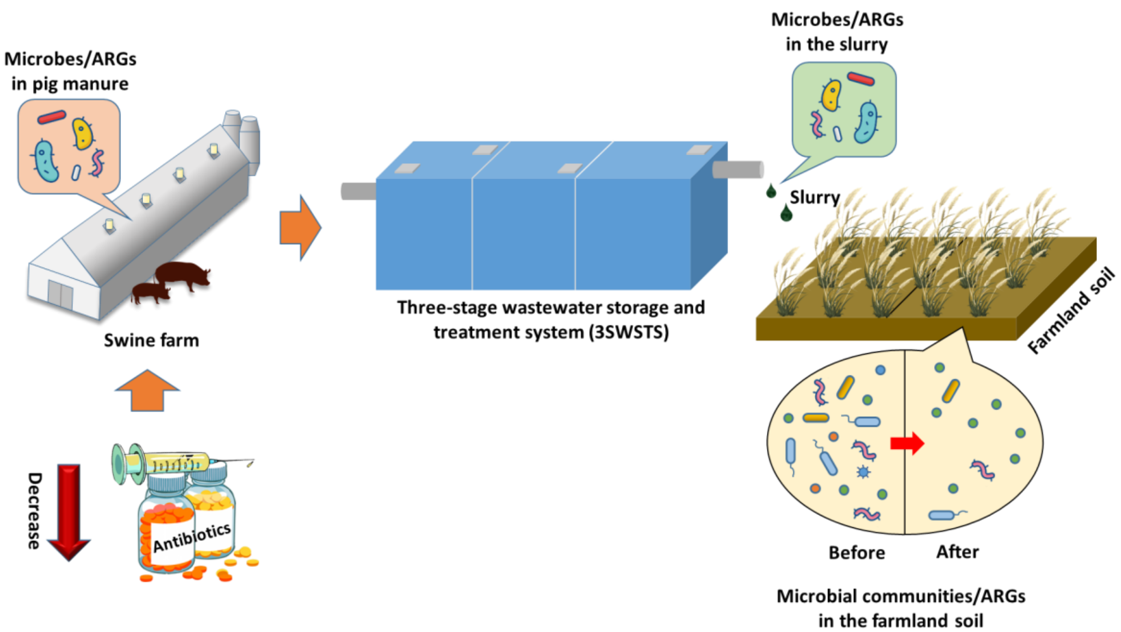
Researcher	Supervisor	Promotor
Yi Wang	Dr. ir. Nora B. Sutton	Prof. dr. ir. Huub Rijnaarts Prof. dr. ir. Hongmin Dong

Motivation

In China, increased use of sub-therapeutic antibiotics on pigs made the microbial populations present in swine manure and wastewaters become reservoirs of antibiotic resistance (AR) genes (ARGs) and posing unknown threats to health of livestock and humans. We aim to measure AR and ARGs in manure and wastewater from Chinese swine farms and in the novel three-stage storage and treatment system which often applied in Northern China. We will investigate the ARGs dissemination mechanism among microbial populations in this system and in soil environments. Finally, the effect of reduced antibiotic use planned in China will be included in this study.

Research Topics

1. The changes of antibiotic resistance (AR) during the antibiotic banning policy execution period.
2. Compare AR between China and the Netherlands
3. The ARGs removal efficiency of the novel 3-stage wastewater storage and treatment systems.
4. The distribution of ARGs and related microbe communities in the 3-stage wastewater storage and treatment system.
5. The dissemination of ARGs from swine farm to the farmland soil environment after apply slurry onto the soil.



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中国农业科学院 CHINESE ACADEMY OF AGRICULTURAL SCIENCES
WAGENINGEN UNIVERSITY & RESEARCH

Three phase flow behaviour of granular upflow anaerobic sludge blanket reactors

Reusable Water
Environmental Technology

April 2021 - 2025

Researcher	Supervisor	Promotor
Hooman Eslami	Dr. ir. Dainis Sudmalis Dr. ir. Harry Bruning	Prof. dr. ir. Huub Rijnaarts

Motivation

Anaerobic granule-based bioreactors, such as up-flow anaerobic sludge blanket (UASB) reactors are attractive technologies for effective biological purification of high-strength wastewaters, and simultaneous energy recovery in the form of methane gas. In these reactors, the biomass retention is promoted by bacterial self-aggregation into dense granules and hence the formation of a strong, active granular sludge bed becomes important for optimal operation of the bioreactors.
Hydrodynamic forces are one of the key factors that affect the physical, chemical, and biological characteristics of granules, and consequently, the performance of the anaerobic process. However, their quantitative effect on granulation and mechanisms by which they affect granulation are yet to be fully understood.

Technological challenge

In UASB reactors, relative motion between liquid, gas bubbles, and granular sludge and particle-particle collisions generate normal and shear forces on anaerobic granules. As there is a continuous three-phase flow in the reactor, the hydrodynamic environment is complex. Complimentary experimental and numerical fluid mechanics methods are required to be applied in such complex bioreactors. Therefore, the ETE lab was equipped with new advanced high-speed cameras (Fig 1) to measure velocities and trajectories of moving particles in order to validate the numerical model.
The main focus of this research is to investigate the effect of mechanical stresses originating from both fluid-granule and granule-granule interactions on the properties of granular sludge utilizing a combination of these new advanced in situ optical tools, computational fluid dynamics (CFD), and bio-chemical characterization of granular sludge. In this way, we can develop operational strategies to provide a hydrodynamic condition favouring the development of dense, strong, and active granules, which is very important for applying these technologies in practice. In this project, we cooperate with companies that market granular sludge technology.

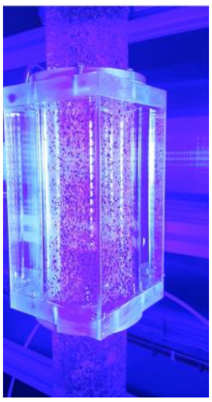

Figure 1 Experimental set-up for fluid flow visualization

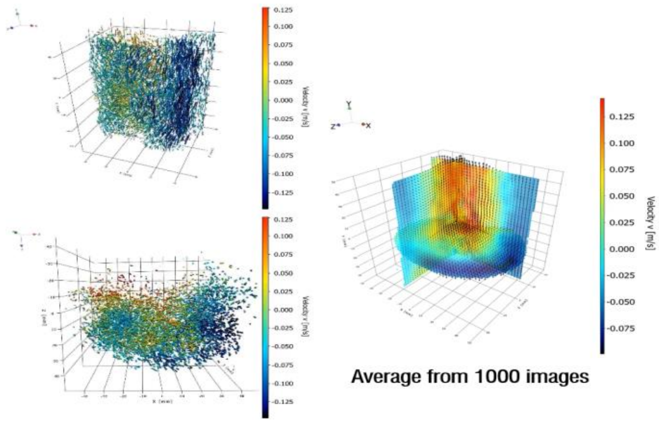

Figure 2 Time-resolved (left) an time-averaged (right) velocity distribution of liquid in the reactor

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WAGENINGEN
UNIVERSITY & RESEARCH

BESTSEWER- Bioelectrochemical system for mitigating sewer gas formation and related sewer pipe corrosion

Feb 2019 - 2023

Researcher	Supervisor	Promotor
Yue Sun	Dr. Wei-Shan Chen Dr. Annemiek ter Heijne	Prof. dr. ir. Huub Rijnaarts

Motivation

As an important part of urban infrastructure, the sewer system plays an important role in collecting and transporting wastewater. However, the generation of harmful gases in sewer aggravates global warming and sewer pipe corrosion. H_2S and CH_4 are the harmful sewer gases of most concern.

Current sewer gas control strategies rely primarily on the addition of chemical reagents (H_2O_2, $KMnO_4$, nitrate, etc.). These strategies not only require capital and energy inputs but also are not sustainable.

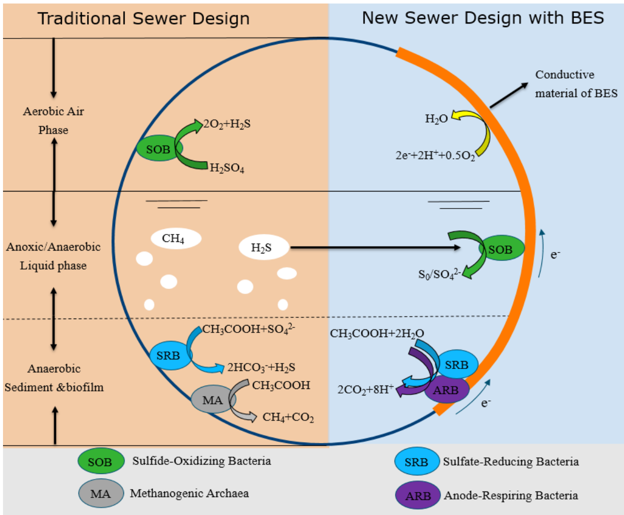


Figure 1. Schematically cross-sectional illustration of bacterial reactions in traditional and BES-based sewer system.

Note: In the traditional sewer system, methanogenic archaea (MA) and sulfate-reducing bacteria (SRB) can utilize degradable organics (acetate, etc.) to form methane and sulfide within anaerobic phases. In the BES-based sewer system, anode respiring bacteria (ARB) can compete electron donors (e.g., acetate) with SRB and MA and possibly inhibit the activity of SRB and MA.

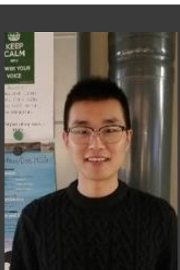
Due to its potential to regulate microbial competition, bioelectrochemical systems (BES) are expected to be an alternative to achieve sewer gas control (Fig 1). Compared with current sewer gas control strategies, the operation of BES requires no addition of chemicals and is more sustainable.

Hence, the aim of this project is to employ BES to continuously steer biological processes within sewers to avoid hazards (explosive and/or toxic gas emissions, greenhouse gas emission) and economic losses (sewer pipe corrosion).

Research challenge

This project focuses on using BES to regulate microbial competition to control sewer gas. The challenge is that this strategy has not yet been proposed or studied to author's best knowledge. Therefore, scientific feasibility of this strategy will be demonstrated first and then proceed with engineering research. This project will be divided into four sections.

- The feasibility of using BES for sewer gas control by regulating the competition between ARB, SRB and MA will be demonstrated.
- The BES sewer performance will be optimized by investigating the effect of hydraulics, and sewer sediment and biofilm.
- Technical solutions for the installation of BES reactors in the sewer system will be developed.
- The long-term performance of BES on inhibiting the formation of sewer gas in real-life sewer system will be studied.



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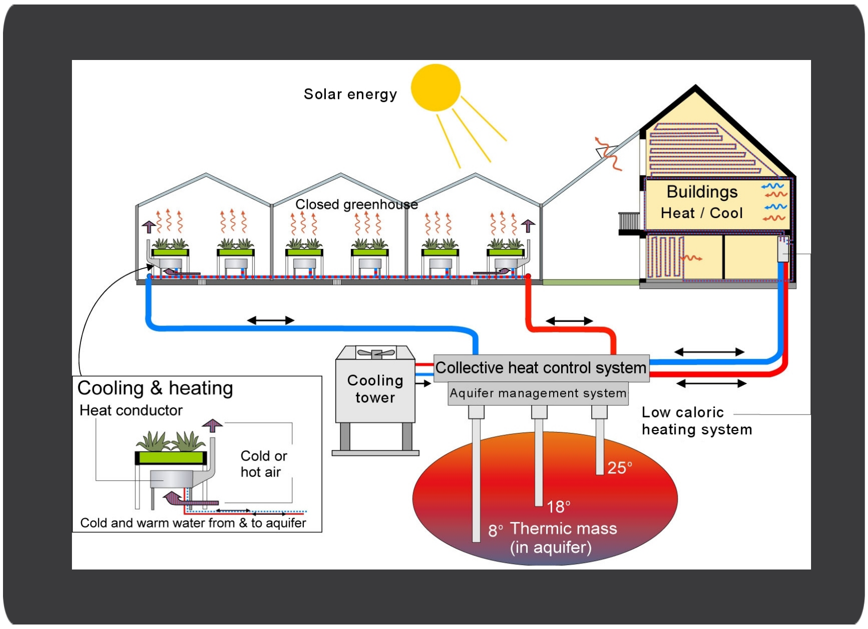
Urban Systems Engineering

Urban Systems Engineering and Biorecovery

Urban Systems Engineering and Reusable Water

Urban Systems Engineering



Environmental Technology

Environmental Issues

The intensity and scale of global urbanization pose major challenges to sustain basic urban services such as food, water and energy supply and sanitation in cities. For example, 780 million people do not have access to safe drinking water at this moment, and 2.5 billion people lack adequate sanitation services[1]. The depletion of resources and the growing demand for renewable energy, clean water, materials and minerals results in an increasing worldwide recognition that new approaches and paradigm shifts are needed, away from the current linear thinking to manage our resources.

Our Research

Our vision is to reduce environmental impact and mitigate resource depletion by closing resource cycles to achieve a circular (urban) metabolism. We focuses on creating new concepts and smart integration of technologies and practices for sustainable urban water, nutrients, materials and energy cycles. These new concepts cover the entire chain of collection, transport, treatment, supply and use of energy, water, nutrients and materials, aiming to preserve these essential resources. We select appropriate technologies for these concepts which are compatible with the local social and economic context and urban typologies. The focus is on (peri-) urban areas and industrial sites, for which we aim at an effective balance between supply and demand of water, energy, nutrients and material resources. We a) apply and further extend own concepts and approaches such as *Urban Harvest*, and b) provide frameworks and tools to evaluate and quantify technological concepts such as *New Sanitation* which is based on separation of wastewater and material streams at source, in order to facilitate recovery and reuse of water and other resources such as energy and nutrients.

Biorecovery

The Urban Systems Engineering (USE) division of the Biorecovery group addresses the recovery of essential resources from domestic, agricultural and industrial residues. As a result of the growing world population there is increased need for food and thus for fertilizers and soil amendments to facilitate crop growth. Furthermore, soils get depleted so resources in organic residues need to be recovered for the restoration of soil quality and ecosystem. The aim is to assess the potential for recovery of organic matter, nutrients and energy for implementation in circular agrofood and other (urban) systems. To this end we develop insights in supply and demand of these different resources and match these within different temporal and spatial scales. We work in the Netherlands but also within the European and African context.

Water Reuse

The USE division of Reusable Water group addresses the analysis, engineering and planning of urban and industrial water systems. We aim to assist the transition to a circular and localized water system. We develop models that trace water quality and quantity dynamics in cities and industrial areas. Using the modelling outcome, we simulate and assess the feasibility of systemic implementation of novel water technologies and infrastructures including, source-diverting sanitation in densely-populated urban area, saline wastewater treatment or reuse for coastal industrial zones and nature-based solutions for securing surface water quality in and around cities.

[1] UNICEF & World Health Organisation (2012). Progress on Drinking water and Sanitation; 2012 update. UNICEF & World Health Organisation, Pg 1-59

Urban circular cities – Optimisation of recovery of organic matter and nutrients

Urban Systems Engineering
Environmental Technology

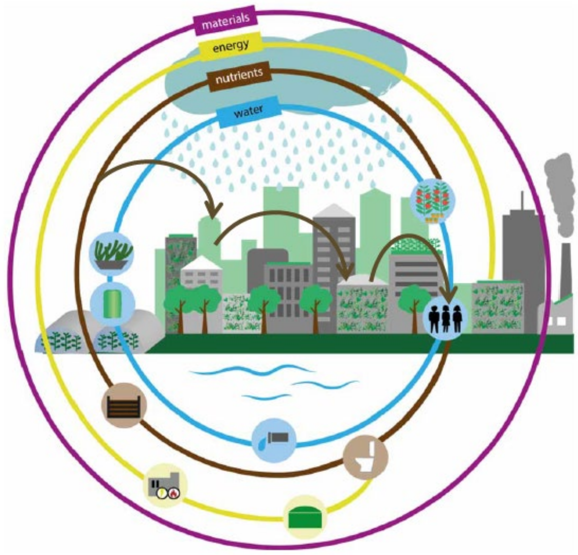
Jan 2022 - 2024

Researcher
Dr. ir. Miriam H.A. van Eekert

Prof. dr. ir. Cees Buisman

Motivation

The world population is growing and this poses an increasing challenge on food security. Besides the depletion of organic carbon in soil there is also an increasing demand for nutrients (NPK) for growing more crops. A pressing problem of our current food system is that it depends on finite resources, like phosphorus rock while at the same time nutrients are lost for agriculture via diffuse emissions. To conserve nutrients for future generations, they must be recycled. There is already a variety of (nature based) technologies in place for the recovery and reuse of nutrients from biomass and waste streams in the urban environment. Nutrients (N, P, K) are recovered in a variety of forms which may be more or less applicable for fertilization purposes.

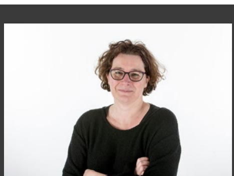


Adapted from doi: 10.2166/bgs.2020.930

Research challenge

The variety of waste streams used as input, recovery technologies and nutrient products (CNPK, others) make a comparative assessment for the optimal recycling strategy in the urban environment very complex. Flows, but also organic matter and nutrient content, purities, additives may vary and as a result some strategies thought feasible from one criterion may not be suitable for other criteria. However, getting a clear overview is essential to design new circular recovery strategies. To enable structural analysis of nutrient recycling strategies we will develop on overview of recycling schemes and quantify the products for each nutrient source. The result will be a database containing a variety of (nature based) technologies, their inputs and nutrient "products" with their specific characteristics: e.g. origin, composition, purity and concentration of the produced nutrient as well as amount of energy used or produced. In addition, the residual stream remaining after production of the nutrient will be taken into account as this is often overlooked. This approach can be used to get a better quantitative understanding of nutrient cycles on an urban scale.

This project will align with the COST action Circular cities (https://youtu.be/eN0Bjt9RTyQ) and the results of the EU H2020 project Run4Life (https://run4life-project.eu/)



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WAGENINGEN UNIVERSITY & RESEARCH

Micronutrients: recycling for a circular agro food chain

Jan 2022-2024

Researcher
Dr. ir. Miriam van Eekert

Prof. dr. ir. Cees Buisman

Urban Systems Engineering
Environmental Technology

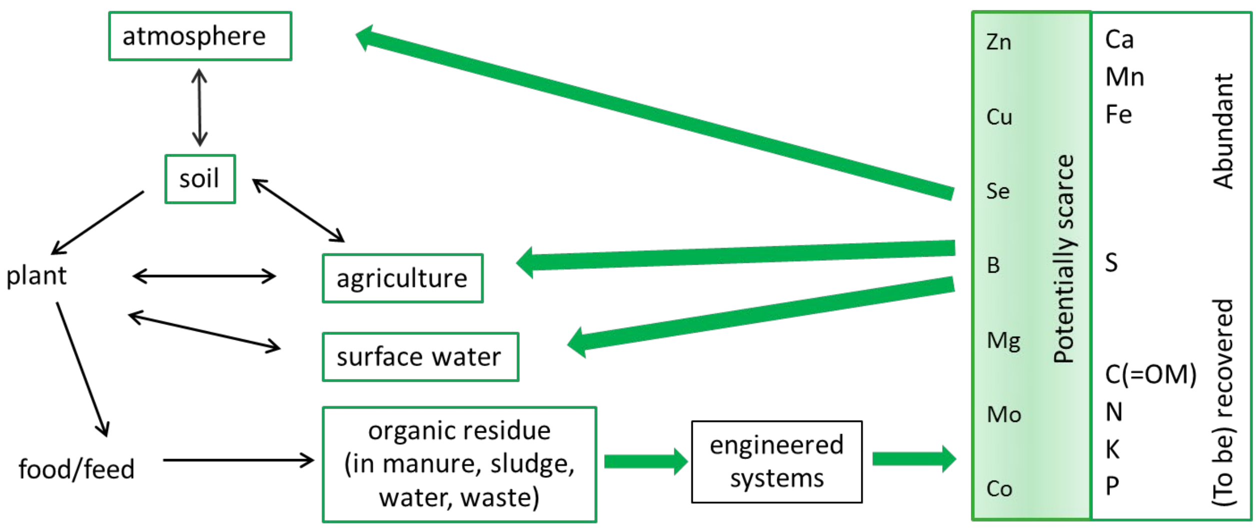
Motivation

Nutrient cycles need to be closed in view of the circular economy, and food security for all humans. For this, management strategies are to be developed.

Several chemical elements are essential for plant growth and human health. Among these are macronutrients like carbon, nitrogen, phosphorous, potassium, calcium and magnesium and micronutrients like zinc, copper, selenium, boron, molybdenum, cobalt and manganese. For some of the macronutrients, recovery technologies and management strategies have been developed, which could be implemented and in some cases are already applied. Methods for micronutrients, that are expected to become scarce on human timescales, often still need to be developed. However, currently there is a lack of knowledge on the flows and speciation of these elements from plants via food/feed and organic residues back to agriculture and losses to (other) environmental compartments. Identification of the sources, sinks and flows will set the stage for development of technologies directed towards the recovery of these specific micronutrients.

Research challenge

The research aims to assess the flows and speciation of micronutrients in the food chain, especially in waste fractions and organic residues like manure, sludge residues, wastewater, (the organic fraction of) municipal of solid waste. The fate and speciation of the micronutrients after treatment (composting, digestion and others) of these organic residues and their application in agriculture will be addressed as well as their fate in surface water and other environmental compartments.



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WAGENINGEN UNIVERSITY
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Restoring circular nutrient cycles in food systems – from a regional perspective

Sept 2017 - 2021

Researcher	Supervisors	Promotors
Bernou Zoë van der Wiel	Prof. dr. Florian Wichern Dr. ir. Jan Weijma	Prof. dr. ir. Cees Buisman Dr. ir. Corina van Middelaar

Motivation

Growing population and changing diets have led to increased food demand, and this trend will continue. The resulting intensification of agriculture has unbalanced nutrient use, in turn this causes environmental, economic and social issues. Future nutrient management has to focus on restoring cycles to overcome inefficient use of available nutrients and dependency on non-renewable resources.

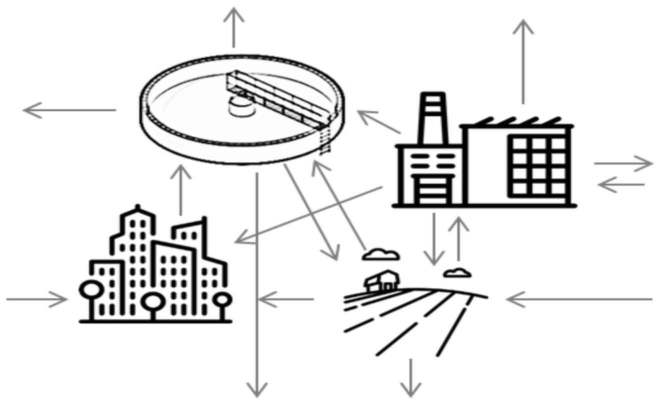
Restoring circularity from a regional perspective

Nutrients, such as nitrogen (N) and phosphorus (P) - which are essential to sustain life for living organisms including bacteria, animals and plants, are also detrimental to the environment when they are in excess. Moreover, intensification of food production can be linked to a decline in organic matter (C) of soils used for agricultural activities. Other nutrients, specifically potassium (K), are also important for efficient production of food.

Approach

The model region in this research project, the district Cleves (depicted in grey, with the Netherlands being the Western border), North Rhine-Westphalia, Germany, is a so-called nutrient saturated area. The district is characterized by intensive livestock production, intensive production of cash crops, vegetables and ornamentals. The high nutrient load in the area has resulted in nutrient load in the groundwater above the European Water Framework Directive. Moreover, a decline in soil organic carbon can be observed.

In order to understand the current regional nutrient flows, a substance flow analysis (SFA) will be performed on the 4 most important substances for efficient food production: P, N, K and C. All biomass flows which are (potentially) important for food production will be quantified, therefore multiple sectors will be considered. Understanding of the flows will facilitate determination of points of inefficiency. Moreover, an inventory of available measures applicable in the region to tackle nutrient losses to the environment and to restore nutrient cycles will be performed in order to identify promising measures. Lastly, consequential life cycle assessment (CLCA) as a tool to determine the effect of measures on restoring nutrient cycles will be explored.



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Upcycling food waste in low income & developing areas- Technological options and economic feasibility

April 2021-2025

Researcher	Supervisor	Promotor
Halimat Abdul-Rahman	Dr. ir. Wei-Shan Chen	Prof. dr. ir. Huub Rijnaarts Dr. Hans- Peter Weikard

Motivation

Continuous urbanization and degradation of our environment can propel humanity into an environment that cannot sustain society. Proper food waste (FW) management will mitigate GHGs emissions and climate change, water footprints, sanitation, ecological and economic impacts. Upcycling is a circular approach of creating sustainable and value added products. It is a promising strategy that can be used to address existing FW challenge in low-income and developing areas. Upcycling food waste offers environmental and social benefits. Economically, value added products can be a market opportunity.

Technological challenge

Possibilities for improving food waste management system remains pronounced in low-income and developing areas, where waste management is characterized by lack of data, lack of collection coverage, lack of treatment technologies, inadequate disposal and finances, and lack of viable business models.

As part of global effort to achieve sustainable development goals, countries are attempting to reduce landfilling and promote environmentally sustainable methods. Different technology options have been used for the treatment of FW. However, some technologies are more limiting in their requirements than others. While this may be true, considering technologies that can treat a wide range of feedstock type and quality is regarded, with consideration of investment and operational cost for low-income and developing areas.

A thorough evaluation of FW quantities and characteristics, in combination with different treatment technologies, upcycled products and how products fit into local market demand is fundamental for informed decision making in low-income and developing areas.

Potential BSc/MSc thesis topics include (but not limited to):

I. Characterize FW generation dynamics (quantity, quality, time) in low-income areas via innovative methods like crowdsourcing.
II. Analyze & compare the economic cost & environmental sustainability of FW treatment technologies in developed v.s. developing context.
III. Analyze the market sizes for potential FW-derived products and their spatial-temporal dynamics in a low income, developing area.
IV. Identify the social-economic opportunities & barriers for implementing circular FW management in developing context.

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Circular Management of Urban Organic Residues to Restore Ecosystem Services of Agricultural Soil (CURESOIL)

Sep 2018 - 2022

Researcher	Supervisor	Promotor
Jiyao Liu	Dr. ir. Miriam van Eekert Dr. ir. Wei-Shan Chen	Prof. dr. ir. Cees Buisman

Motivation

The continuous decrease of soil organic carbon (SOC) results in the soil quality degradation and poses an increasing challenge with respect to food production and environmental protection. Meanwhile, the amount of urban organic residues (UOR) is steadily increasing with the growing world population and urbanization. Matching the SOC demand with the OC from UOR may be a win-win solution for both the soil ecosystem services restoration and the UOR circular management.

It is hypothesized that the nature of urban organic residues determines the way of OC recovery and the most appropriate scale for recovery and reuse.

Practical Challenge

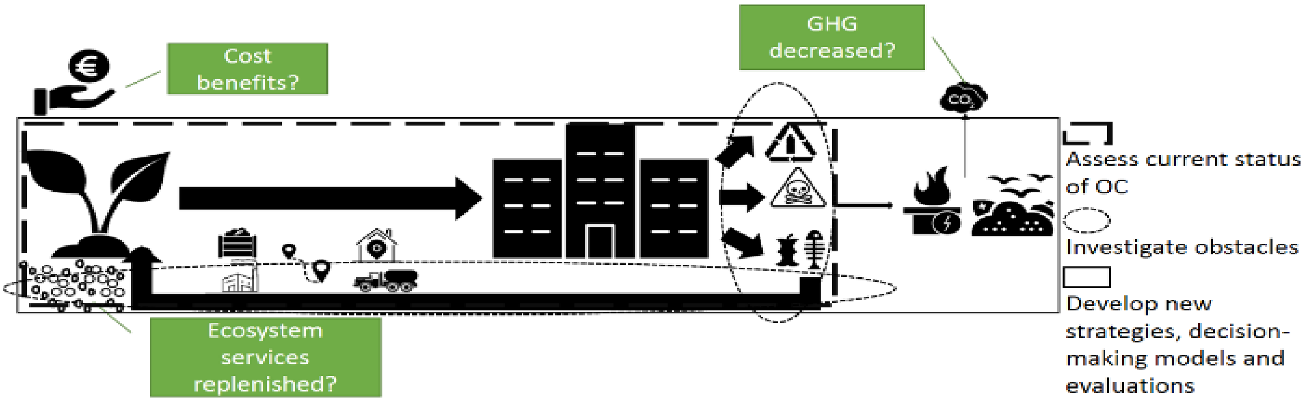
The variety of urban organic residue streams used as input, technologies applied and nutrients (mainly N,P,K) produced make a difficult comparative assessment for the applicability of the products and their effect on the SOC content and the different ecosystem services that agricultural soil could provide.

Objective

To maximize the effectiveness and impact of using urban organic residues for replenishing soil organic carbon to restore multiple ecosystem services provided by agricultural soil.

Approach

- Assess the current status of OC required by agricultural soil and supplied by urban organic residues;
- Investigate obstacles that hinder the carbon recycling. Three aspects are included:
  - The quality of urban organic residues;
  - The rationality of processing strategies;
  - The suitability of applying treated products to particular soil.
- Simulate strategies to match the actual SOC demand with the OC supply. Build a decision-making model;
- Evaluate the proposed strategies and complete the model with judgmental indicators.



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Inorganic solid waste & modeling. Nanoparticles.

Dr. Renata D. van der Weijden

Prof. dr. ir. Cees Buisman
Prof. dr. Ir. Huub Rijnaarts

Environmental Technology

Motivation

The earth's resources are limited. Waste is becoming the new ore. Inorganic solid waste is usually divided in various categories, metal-, construction-,nuclear-, plastic-, and E-waste. In order not to waste the waste, knowledge of its composition, its present (managed) fate, and new knowledge about options to create alternative infrastructures for maximum (re-)use of the waste are desired. Data collection on quantities, character and management (in context) of the waste stream is therefore gathered to design innovative treatment plans that will close the resource cycles most efficiently. In order to estimate the quantity of a waste stream with a focus on a certain chemical element, fluxes from various reservoirs need to be known. These fluxes and reservoir sizes are not static ,but can change as the actors related to the reservoir change behavior. A well-known sink (a dead end flux) are the old cell-phones that disappear in drawers. The latter therefore represents an enormous reservoir for, for instance, precious metals. When consumers (actors) are diligent at handing in these used-materials, then the reservoir will decrease in size, the cycling of precious elements is increased and mining for those elements, with all its environmental repercussions, can be "mine-mized". A waste stream of concern with respect to possible environmental impact are the precious metal nanoparticles (size < 100nm), such as silver. Silver nanoparticles have a wide range of applications, amongst others; in the medical field, in anti-bacterial and anti-fungal treatments of products (like silver nano-particle containing kitchen cloths or as anti-biotic in animal food), in sensing and imaging applications and lasers. At the same time, when released into the environment they can cause great harm by creating toxic conditions.

Research aims and challenges

Silver nanoparticles are valuable, so being able to recover them is also important from an economic point of view. Since there is a rise in the use of nanoparticles, the number of potential reservoirs is increasing as well. The infrastructure for nanoparticle in silver recycling is not yet in place, and losses occur easily when used in household settings. Therefore the aim is:

- Investigate the types of silver nanoparticles, their properties and matrix of occurrence.
- Define silver nanoparticle reservoirs, their fluxes, and losses to create a model for the existing pathway of nanoparticles.
- Analyze the impact on the existing silver resource cycle.
- Analyze the use of other resources required (energy, water, space) to close the resource cycle.

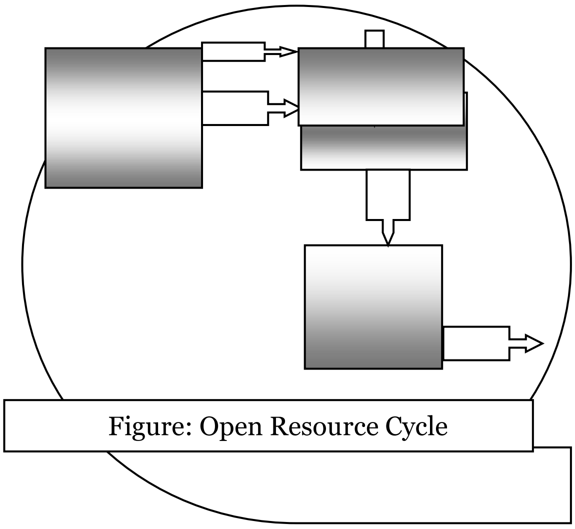

Figure: Open Resource Cycle

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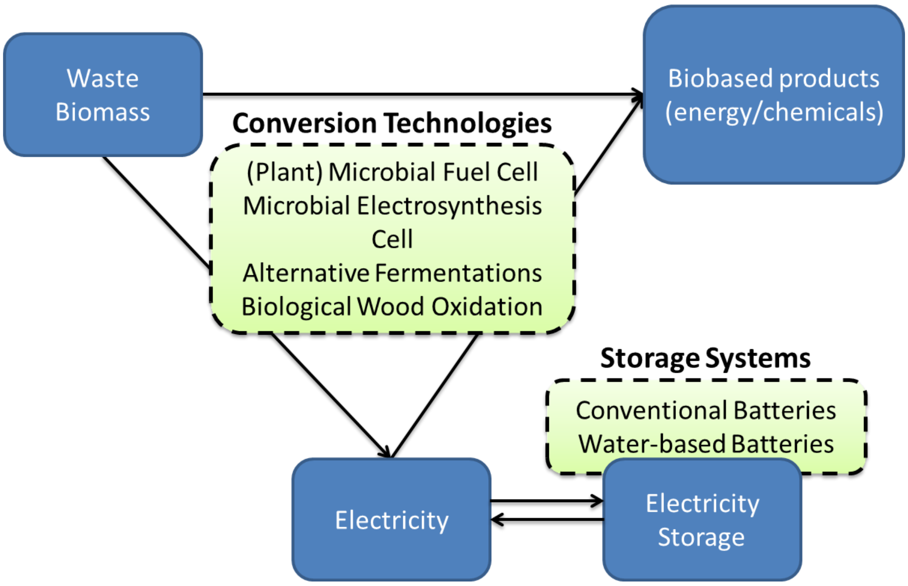
Renewable Energy

Dr. ir. Annemiek ter Heijne
Dr.ir. David Strik

Motivation

In a sustainable future, all our energy and chemicals are produced from renewables. Hereby supply and demand must be matched with the right storage facilities. Waste biomass (e.g. wastewater, household green waste, crop residues) is an attractive renewable source for biobased products, both in the form of energy and chemicals. Also CO2 waste streams are considered as potential feedstock for bioproducts. Due to the intermittent nature of solar and wind power, sustainable storage solutions in the form of batteries are required.



Novel technologies are being developed (e.g. at our own lab at Environmental Technology) to produce biobased products and produce or store electricity. These technologies have the potential to be applied in various ways. To reveal the state of the technology, one should compare the requirements of the actual application (i.e. design criteria) with the state-of-art. This way, the most promising implementations can be identified, as well as alternative technological solutions.

Challenge

Our aim is to assess the potential and performance of new conversion technologies for the production of electricity and biobased products from waste biomass. In addition, the potential for renewable electricity storage systems, using water-based batteries (e.g. conversion of electricity into a salt gradient) will be assessed and compared to conventional batteries.

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Hidden pitfalls of the energy transition: a study on CO_2 dependency.

Mar 2019 – 2023

Researcher	Supervisors	Promotor
Ivonne Servin Balderas	Dr. Annemiek ter Heijne Dr. Koen Wetser	Prof. dr. ir. Cees Buisman

Motivation

The energy transition from fossil fuels to renewable energy is in full progress. This transition is inevitable due to great dependency on fossil fuels and its consequences such as climate change and economic instability. When fossil fuels are burned they emit water, Carbon Dioxide (CO_2), Nitrogen and Sulfur oxides among others. CO_2 is one of the main greenhouses gasses and approximately 80% of its emissions are related to fossil fuels.

CO_2 as a raw material has a great potential. The current potential CO_2 uptake is 70 times lower that the emissions in 2017. However, as society moves away from fossil materials, it might be expected that more carbon based goods be produced from CO_2. In Fig. 1 are mentioned some examples.

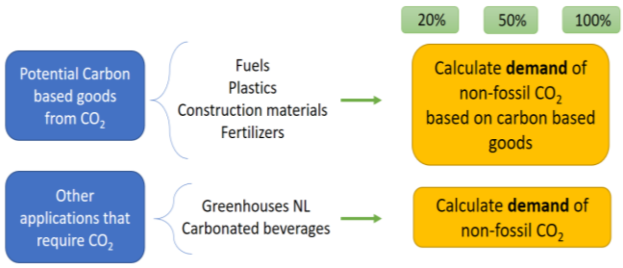

Fig. 1. The potential demand of CO2 and its applications might rise and diversify as society moves away from fossil fuels.

An extreme reduction of CO_2 emissions might be expected. Only a few point sources independent of fossil materials would emit non-fossil CO_2 as a waste stream. Fig. 2 shows the possible change in the sources of CO_2.

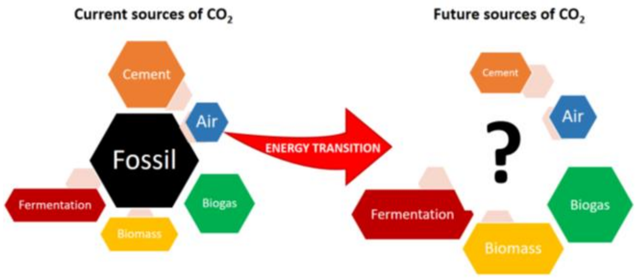

Fig. 2. The sources of CO_2 may diminish through time and the quality and quantities may not be enough for the production of carbon based goods.

Objective

As the energy transition evolves, it is unknown how much CO2 will be needed and if the supply will be enough. The general objective of this research is to study the hidden pitfalls for the role of CO_2 in the energy transition in the years 2019, 2030, and 2050. This study will answer the next question: **What could be the role of CO_2 for the production of carbon based goods as the energy transition becomes stronger?**

To answer this question four steps are required:

- Case study on methanol production based on CO_2 as an overview of the possibilities and opportunities of using non-fossil CO_2.
- Identify the possible applications and demand of CO_2 for carbon based goods production.
- Identify and quantify the possible point sources of non-fossil CO_2.
- Match the potential demand and supply of non-fossil CO_2.

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District heat networks as an alternative for supplying natural gas: *An analysis of technical criteria and policy instruments for Dutch residential areas*

Environmental Technology

Aug 2021 - 2025

Researcher	Supervisor	Promotor
Ir. Anika Steenstra	Dr. ir. Shahab Torbaghan ir. Ieke Kuijpers - van Gaalen MBA (external)	Prof. dr. ir. Huub Rijnaarts

Motivation

The average global temperature has risen in the last decades with far-reaching and potentially catastrophic consequences for humans and nature. In 2015, Countries from all over the world set up the Paris Climate Agreement to fight climate change. One of its goals is to phase out non-renewable sources such as natural gas before 2050. To reach this goal, the Netherlands must urgently transform the energy and heat market, as heating residential housing accounts for up to 78% of the European energy. To create a sustainable energy and heat network, the climate agreement goals are translated to policy instruments on a European level, which are implemented by member states.

Technological challenge

Dutch residential houses are highly dependent on natural gas as an essential source for heating. Since the goal is set to phase out the use of natural gas, new sustainable sources should be put in place. This study focuses on low-temperature heat sources transported to the building through low-temperature district heating (LTDH) networks. To use the low temperature heat from LTDH networks, residential buildings should be adapted to transition towards alternative renewable heat sources. This transition requires action from multiple stakeholders involved in the process. Together they determine the success of the transition.

Especially, the influence of policy instruments from, for example, Dutch governmental institutions are essential to accelerate the energy transition. A key challenge is prioritizing residential housing to adapt an LTDH network. This PhD thesis evaluates the current state of the art in the transition towards LTDH in residential buildings. Furthermore, suggestions for effective policy instruments are generated through the knowledge gained, such as adapting and creating policy instruments compatible with the needs in practice. These suggestions will be based on data analysis and technical criteria. We aim to answer the following question: *What changes are needed to get residential houses and their owners ready for low-temperature district heating before 2050?*

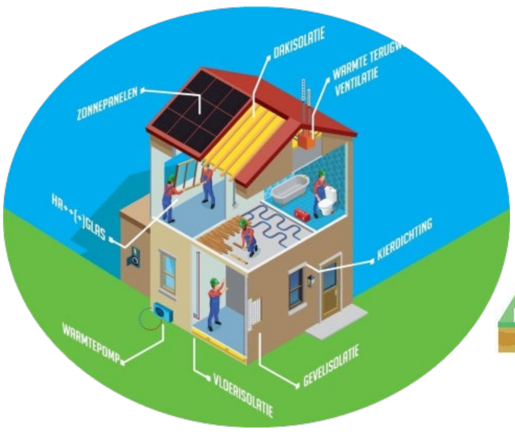

figure 1: Possible changes to become LT-ready

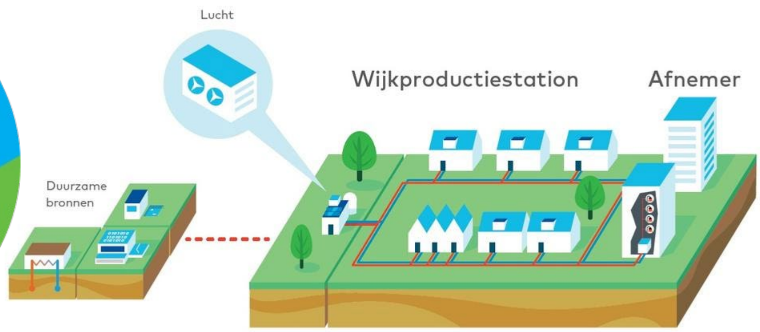

figure 2: Potential set-up of a low temperature district heating network

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RainSolutions: Assessment of Integrated approaches to Nature-based SOLUTIONS

Aug 2019 – Jul 2022

Researcher
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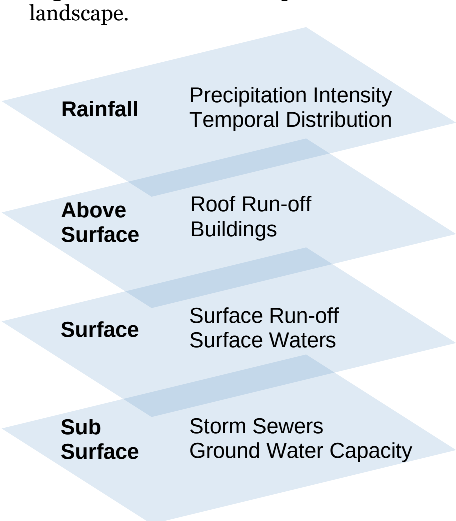
Motivation

Massive urbanization has led to the deterioration of urban water resources, both in terms of quality and quantity. Urban areas with high density of built environment, increase the risk of pluvial flooding and deterioration of surface water quality. Moreover, taking climate variability into consideration, addressing the issues of sustainable urban water management have become crucial. Nature-based solutions (NBS) serve to mitigate the adverse effects of urbanization and climate variability by addressing, among other, the issues of pluvial flooding and poor urban surface water quality. However, the limit to the handling capacity of NBS with respect to the maximum rainfall intensity is still argued. Besides their capacity to improve surface water quality at the city level is unknown. To enhance the application and functionality of NBS in urban spaces, information about the impact of their implementation is necessary.

Figure: The different components of the urban landscape.



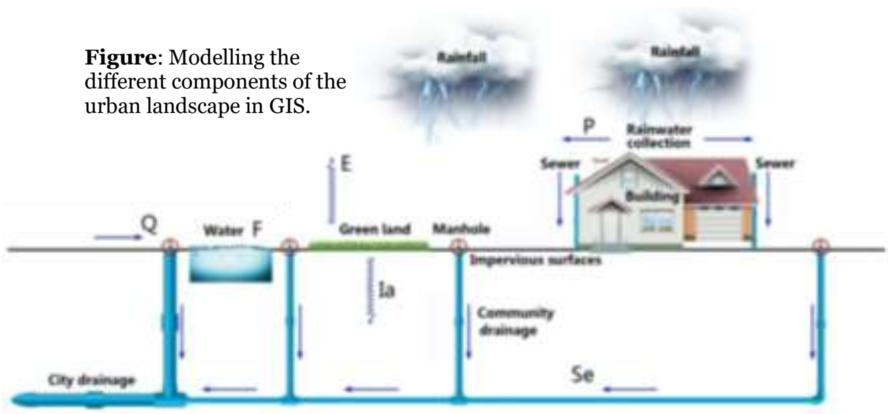
Method

Combining geo-spatial and hydrodynamic models, with the aid of an interface in Python, the changes imparted by NBS to the urban surface water is analyzed. First, suitability of NBS allocation at the neighborhood level is analyzed using a high resolution model. Then, their impacts on water quantity and quality are assessed at the neighborhood and city levels, combining high resolution and low resolution models. This further provides information on the effectiveness of different NBS in terms of the target water quantity and quality. The result will be the development of a tool/framework for spatial planning of NBS. The GIS tool will consist of different modules to handle runoff, surface flow and pipe network flow that will also consider changes in quality of water with time.

Research Objectives

- Understand how to allocate NBS in urban areas and model their impacts on urban surface water.
- Analyse the effectiveness of NBS on water quantity under different rainfall patterns.
- Study the impact of NBS on urban surface water quality at the city level.

Figure: Modelling the different components of the urban landscape in GIS.



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Designing a Framework for an Integrated, Market-based Electricity and Water Coordination Mechanism at Regional and Local Levels.

Nov 2020 - 2024

Researcher	Supervisor	Promotor
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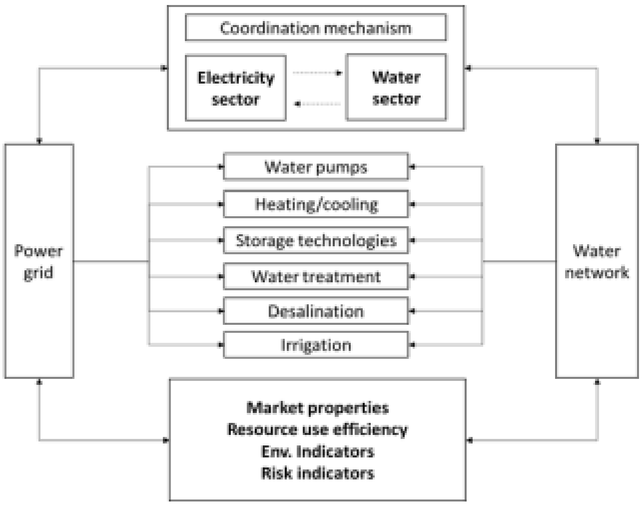
Motivation

Energy and water are two of the world's most critical resources for the sustainable development of human societies. As these resources are intrinsically interconnected, both physically and technologically, there are synergies across the two sectors that could be exploited, to obtain a higher (economic) efficiency. A novel approach to study these synergies is to design/implement integrated, market-based electricity and water coordination mechanisms to evaluate the planning and operation of electricity and water systems at different temporal levels and geographical scales, under centralized and decentralized settings.

Technological challenge

Due to the depletion of fossil fuels and the increased need of reducing energy-related greenhouse gas (GHG) emissions, the energy sector is currently facing the transition from non-renewable to renewable energy sources (RES). The increasing share of RES in the energy mix is posing new challenges in operating the power system (i.e., periods of high renewable energy generation and low price and vice versa). Consequently, system operators (SOs) need to increase their generation and dispatch flexibility. There are different ways to source such flexibility including sector integration, and demand-response (DR) measures. On the supply side, the treatment, transport, and storage of water link the water and the electricity sectors: one could exchange quality water for electricity and vice versa. On the demand side, technologies such as heating/cooling via water (e.g., district heating, heat pumps, etc.) and agricultural irrigation systems could provide additional flexibility. Such flexibility through integrated, market-based coordination of coupling technologies could alleviate the pressure on the energy sector while offering the water sector lower energy costs.

The technological challenge lies in the formulation and algorithmic implementation of appropriate mathematical programming problems to address the planning and operational aspects of the two systems. The coordination mechanism is implemented in the appropriate programming language (i.e., Python and/or Julia) and then used to study the price formation for water and energy. Further, a set of key performance indices (KPIs) is defined, to compare the effect of the proposed coordination mechanism under centralized vs. distributed market settings and for different penetration levels of coupling technologies that link the electricity and water sector, such as pumps, heating/cooling, etc. As an MSc student, you will investigate the modelling and optimization of one or more coupling technologies with regards to the proposed coordination mechanism.



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Gamified Decision Support Systems for Sanitation and Resource Recovery

2018 - 2023

Researcher	Supervisor	Promotor
Darja Kragić Kok	Dr. K. Kujawa -Roeleveld	Prof. Dr. Huub Rijnaarts

Motivation

It is projected that in the near future the majority of the world's population will live in urban areas located in low income countries. Consequently large volumes of urban waste and water will be generated where most of it is likely to end up dumped untreated in the environment, if the current practices continue. Yet, the urban waste and water is rich in nutrients and organic matter that can be recovered for agricultural applications. When properly collected and treated, urban streams can provide hygienically safe fertilizers and soil conditioners, which can reduce farmers' dependence on expensive chemical fertilizers and contribute to sustainable urban waste management in general.

Technological challenge

Making the concept of resource recovery from urban waste work, calls for mobilization of a large number of different actors and applying a combination of approaches to work towards integrated solutions. Technological, economic, institutional, cultural, and social aspects all need to be addressed when aiming at resource recovery. In particular, a range of social factors play a crucial role in acceptance of the use of human waste in agricultural systems.

Serious games can be used to address complex processes and in this research they will be developed to support selection of sustainable urban waste and water management options under given context. The role of gamification for assisting decision makers in low-income countries on sanitation technologies for resource recovery will be further explored. The focus is on designing and validating a gamified decision support system (DSS) for sanitation technologies.

This research will be executed in close collaboration with a group of potential DSS users from several Sub-Saharan countries that will be identified and consulted when designing and testing the gamified DSS platform.
The FAO databases will be used to calculate nutrients present in different waste streams per capita per country.

The main challenge lies in designing a gamified DSS for sanitation technologies that can and will be used in real-life settings – thus making resource recovery and circular economy work.

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Technology and Infrastructure Innovations for Water Supply in Industrial Zones

Aug 2016 - 2020

Researcher
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Supervisor
Dr.ir. Katarzyna Kujawa

Promotor
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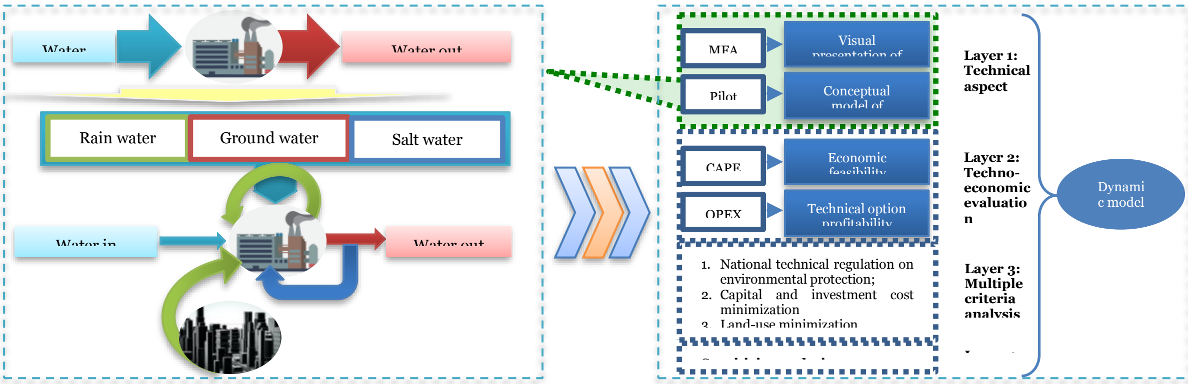
Assoc. Prof. Tran Thi My Dieu

Motivation

Deficiency in industrial and urban water in the future will become a factor limiting the possibilities for further economic development. The workshop which was organized by the ENTIRE - research team in Vietnam with participation of industrial zone companies, industrial zone authorities, environmental policy makers, water supply companies, and environmental companies has put forward three main considerations:

- Continuously increasing water demand has stressed water resources and put pressure on water supply to industries and industrial zones;
- Salt intrusion and competing claims on water services by stakeholders, and restrictions on groundwater exploration are serious challenges;
- Major interest is in innovative research on new sustainable industrial water use.

Technological challenge



Two important knowledge gaps in water supply in the Vietnamese Mekong delta are the following:

1. There is no systematic method to design a circular industrial water supply system;
2. There is no insight in temporal and spatial scales and dynamics of water availability and water needs that is specific to the Vietnamese situation.

Based on material flow analysis (MFA), a set of relevant water quality parameters is determined defining the demand side for industrial water quality, quantities, wastewater quantity, characteristic, time and space. In the next step, Urban Harvest Approach (UHA) strategies which are demand minimization, output minimization and multi-sourcing will be applied to identify technical and operation options to prevent pollution. These strategies will be achieved through pilot experiments with various treatments dealing with the relevant parameters for water quality and quantity. Treatment processes include both natural systems and engineered systems. Lastly, a dynamic model will be developed to design multi-source and circular based water system.

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Evaluating and innovating Green Food system using smart sustainability assessment tools

Sep 2020 - 2024

Researcher	Supervisor	Promotor
Yujun Wei	Dr. ir. Wei-shan Chen	Prof. dr. ir. Huub Rijnaarts

Motivation

Since 1970s, China has made great achievements in reducing resource inputs and pollutants outflow from its food system without compromising the crop yield. This was achieved via more precise fertilizer application, more scientific planting mode (e.g. intercropping), more attention to soil health management, etc. However, the valorization of side-streams and waste from agri-food industry remains inefficient, as the current efforts dedicate to solely better crop cultivation. To solve this problem, China plans to turn its Green Food system into a more circular pattern, meaning more and better use of the agri-food side streams and waste. Currently these side streams are mainly landfilled, incinerated, digested or composted, resulting in low economic value and minimized environmental benefits. A systemic transition towards higher value valorization is required.

Technological challenge

As circular economy has become a popular topic in recent years, more and more valorization methods have been developed for food waste and loss. However, there's no clear criteria to guide the stakeholders in decision-making on the choice of valorization strategies.

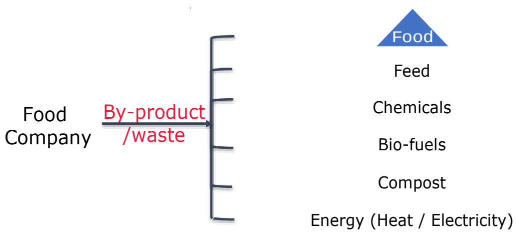

Figure 1. Food valorization hierarchy.

Currently, environmental and economic impacts are the main factors considered by stakeholders. There are typically a lot of trade-offs between the two factors. For example, deep processing can bring higher value to products, while from the perspective of environmental protection, the level of energy consumption and waste generation is not desirable. On the contrary, simple valorization methods often fails to meet the expectations of stakeholders for economic benefits. Some indicators that affect environmental and economic performance are listed in the Table 1. The technological challenge is to determine the valorization strategies that can be both environmentally and economically beneficial.

Possible research topics:

1. Research on the feasibility and potentiality of valorization for food waste and losses on the specific agriproducts such as wheat, citrus, etc.
2. Research on a circular model of materials for the food industry in a specific area under the concept of industrial symbiosis considering environmental and economic impacts.

	Indicators	Energy ——→	Food
Environmental impact	Carbon footprint	☺	☹
	Resource utilization	☹	☺
Economic impact	Cost	☺	☹
	Value	☹	☺

Table 1. Examples of indicators that affect environmental and economic performance.

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Sustainable Technology Integration: How to combine technologies and demand and supply?

Researchers
Dr.ir. Katarzyna Kujawa
Dr. Wei-Shan Chen

Environmental Technology

Motivation

The question how and when to supply resources such as water and energy in a sustainable way to the user is one of the challenges we are working on. Here, we have to deal with a transition towards more decentralized technologies and therefore more decentralized systems as well as an increased complexity. We therefore aim at smart combinations of technologies in order to develop concepts for these systems, which can help to improve the resource efficiency and eventually lead to the closing of resource cycles.
Combined application of technologies, especially on small local and decentralized scale, and the evaluation of their potential based on temporal demand patterns (*How much energy do I need in the morning and how much in the evening?*) and local settings (*How much rainwater can I harvest here?*) offers the opportunity to develop custom-made and highly-efficient concepts for resource management, yet is not free of challenges due to its multi-disciplinary / multi-scalar nature. These concepts would be a milestone in the transition towards more sustainable urban systems.

Objective

The demand and possible supply of a resource depends on the local conditions of a site and the available technologies. We investigate therefore the performance of technologies and the demand of the user in a dynamic way, as the systems have a highly dynamic character. Based on these results, we want to develop concepts that match demand and supply of a resource by smart usage of technologies and combinations thereof. Here, we combine technology know-how, system analysis, user experiences and scenario studies in order to produce guidelines and decision support for planners, engineers, resource suppliers and technologists.

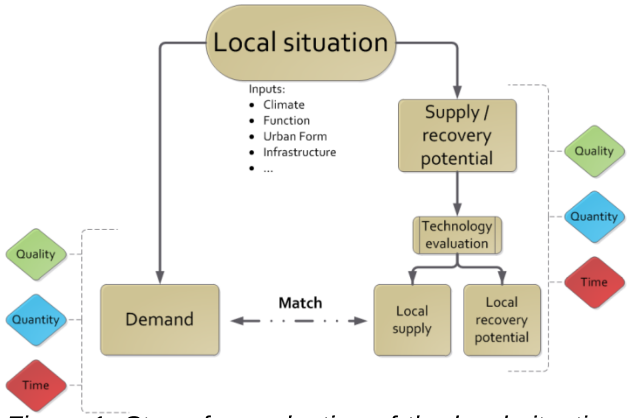

Figure 1: Steps for evaluation of the local situation and technology selection

Points of Interest

In the following, a number of points are mentioned, on which we are working on right now and which represent starting points for possible MSc topics:

- Evaluation of technologies for the supply of electricity and heat (e.g. PV panels and solar collectors) and the storage/supply of heat and cold (e.g. Aquifer Thermal Energy Storage)
- Modeling and analysis of combined resource systems (e.g. parallel energy supply and water treatment)
- Investigation of demand and supply patterns based on user data and / or spatial, demographic or statistical parameters (e.g. How much electricity is used by building YYZ in 2012 and what is the actual usage?)
- Development of methods and tools for the evaluation of systems and technologies (e.g. indicators, which can be used to evaluate a technology and which can be used for comparison)
- Brownfield redevelopment

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WAGENINGEN UNIVERSITY & RESEARCH

Sub-department of Environmental Technology

Transition of urban infrastructure towards circular & resilient cities

Dec 2018 – Sep 2020

Researcher	Supervisor	Promotor
Recruiting (starting April/September 2019)	Dr.ir. Wei-Shan Chen	Prof. dr. ir. Huub Rijnaarts

Motivation & Technological Challenge

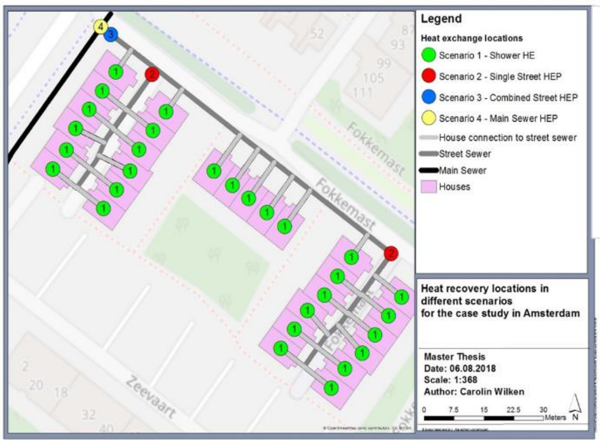
In 2050, there will be likely 10 billion people on the Earth and more than 70% of them will live in urbanised area. At least doubled urban infrastructures are needed to provide the basic services in the coming decades for both new and existing cities, especially for safe ty and sanitary purpose. Existing cities, especially those in the industrialised countries, have established extensive drainage and sanitary infrastructure that are designed based on a centralised and end-of-pipe paradigm, which may require substantial investment and efforts to renovate or even rebuilt in the coming decade.

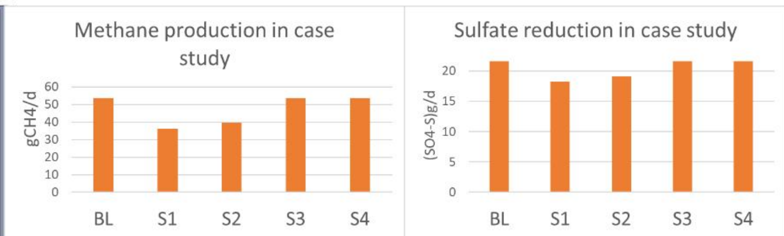
The current paradigm of designing and building urban infrastructures lacks a systematic and interdisciplinary approach. The conventional urban infrastructural engineering approach mostly focuses on optimising a single infrastructure to provide an improved service but ignores the interdependences among the resources or services these infrastructures use or provide.

Research approaches

We integrate LCA, dynamic modelling and geo-spatial modelling to synthesis a decision-support tool for planning and designing urban infrastructural transition. Dynamic modelling is used to describe and simulate the resource dynamics within urban infrastructure. Geo-spatial modelling connects various infrastructural components and reveal the spatial dynamic of the resources within the entire urban infrastructural chain. LCA will be used for characterising and improving the environmental and economic performance.

An example is given in the figure below. A tool is developed to track carbon resources and thermal energy in domestic wastewater. The benefits and impact of decentralised v.s. centralised heat recovery from domestic waste water is assessed using this tool. Both organic carbons and thermal energy start degrading already in the sewer, which may induce environmental and economic challenges like global warming and sewer pipe corrosions.





4 scenarios of heat recovery from domestic wastewater, from household (1) to different locations in sewers (2-4), are simulated in GIS to estimate the thermal energy and temperature dynamics. Together with a simplified sewer bioprocess model, the impact of heat recovery from wastewater on sewer gas formation can be estimated.

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AMSTERDAM INSTITUTE FOR ADVANCED METROPOLITAN SOLUTIONS

WAGENINGEN UNIVERSITY WAGENINGEN UR

Circular Netherlands 2050: Transition towards a circular, safe, inclusive society

Researcher	Supervisor	Timeline
Dr. Kamonashish Haldar	Prof. dr. ir. Huub Rijnaarts	2021 - 2024

Motivation

The demand for resources has increased several folds in the recent past, whereas the availability and supply of resources are shrinking. Transitioning to a circular economy will reduce waste production and enable high-grade raw materials recycling. The Netherlands wants to achieve 100% circularity by 2050 and five transitions agendas: Biomass and Food, Construction, Plastics, Manufacturing and Consumer Goods, have been put forward. However, a successful transition will require collaborative efforts from all actors of society.

Circular Society (CS)

The alliance of TU/e, WUR, UU and UMC Utrecht aims to bring new generations of researchers and students to tackle the challenges with creative solutions. Within the alliance, circular society has two hubs a) **circular, safe hospital**, and b) **circular, inclusive city**. Circular, safe hospital hub focuses on numerous topics, including the shift from disposable to reusables, stakeholder perception and energy transition. The circular, inclusive city hub focuses on the synergy between socio-technological and organizational innovation to foster the circular transition and related topics for WUR students.

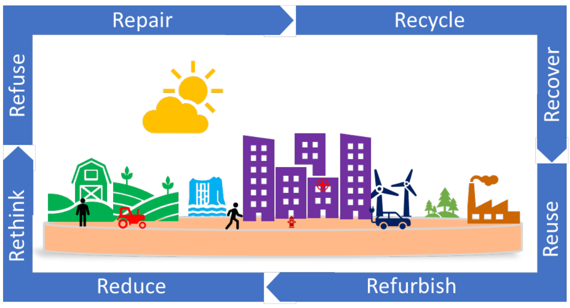

Figure: Graphical impression of a circular society

Anticipated topics on Circular Society:

1. **Defining a circular, inclusive society**
   - *A clear definition is crucial to identify the strengths and limitations of current initiatives in creating a CS. A systematic literature review (SLR) will be used to identify the key performance indicators for a CS and to construct a unified platform for decision making frameworks on CS transitions*
2. **Impact of circular economy paradigms**
   - *Application of circularity frameworks (R-ladder, Urban Harvest Approach) would facilitate the efficient use of resources. Using SLR and expert interviews, we aim to gain insights into the applicability and usability of such frameworks.*
3. **Mapping resource flows in the built environment** (collaboration with TU/e)
   - *Insights on resource consumption are essential to enable circularity. Using MFA, we aim to map the resource flows within a defined system which would also be useful in identifying the recycling/reusing potential.*
4. **Spatial planning for a circular transition**
   - *Under this topic, the role of spatial planning will be investigated in creating a circular city. Especially the issue of scale (local, regional and global) in circularity will be addressed.*
5. **Knowledge and perception towards circular Netherlands** (collaboration with UU)
   - *In addition to the structural measures, it is essential to involve different stakeholders in the discussion. Expert interviews and policy analysis will elucidate the role of perceptions of stakeholders to circularity.*

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