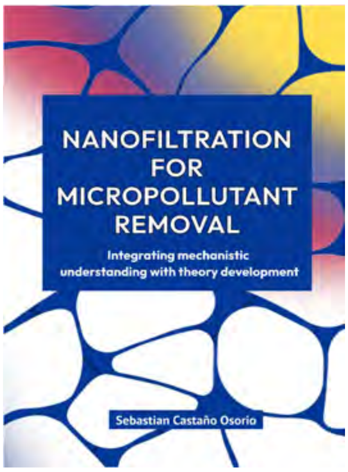
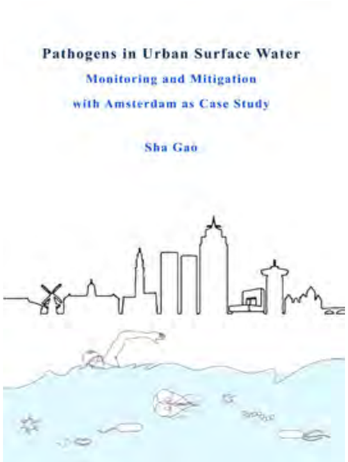
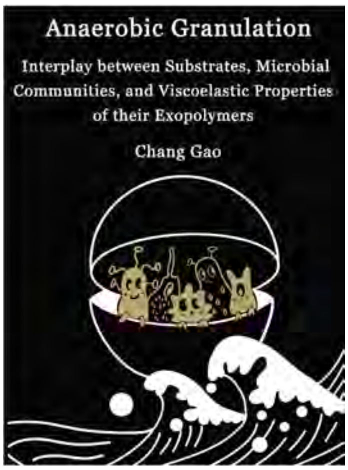
Environmental Technology







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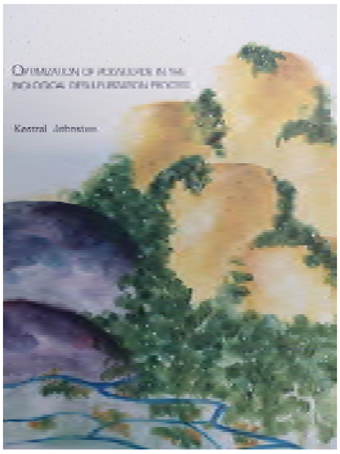
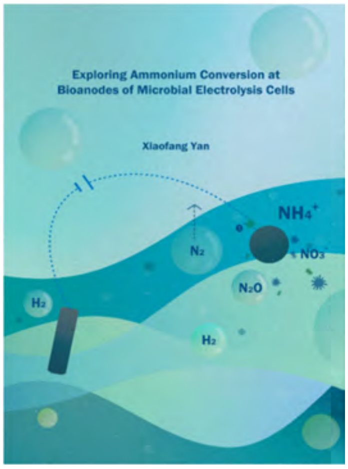
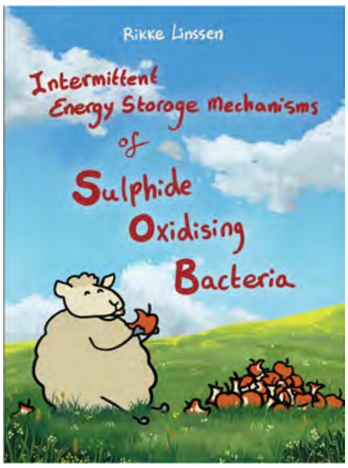
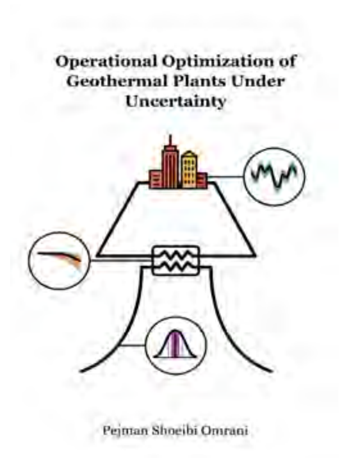
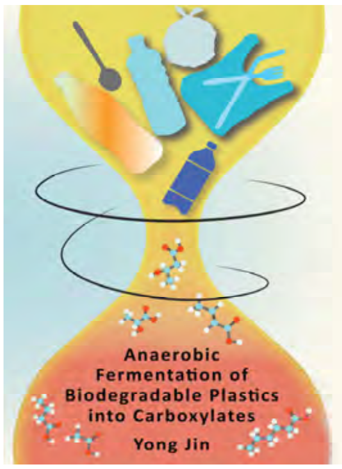










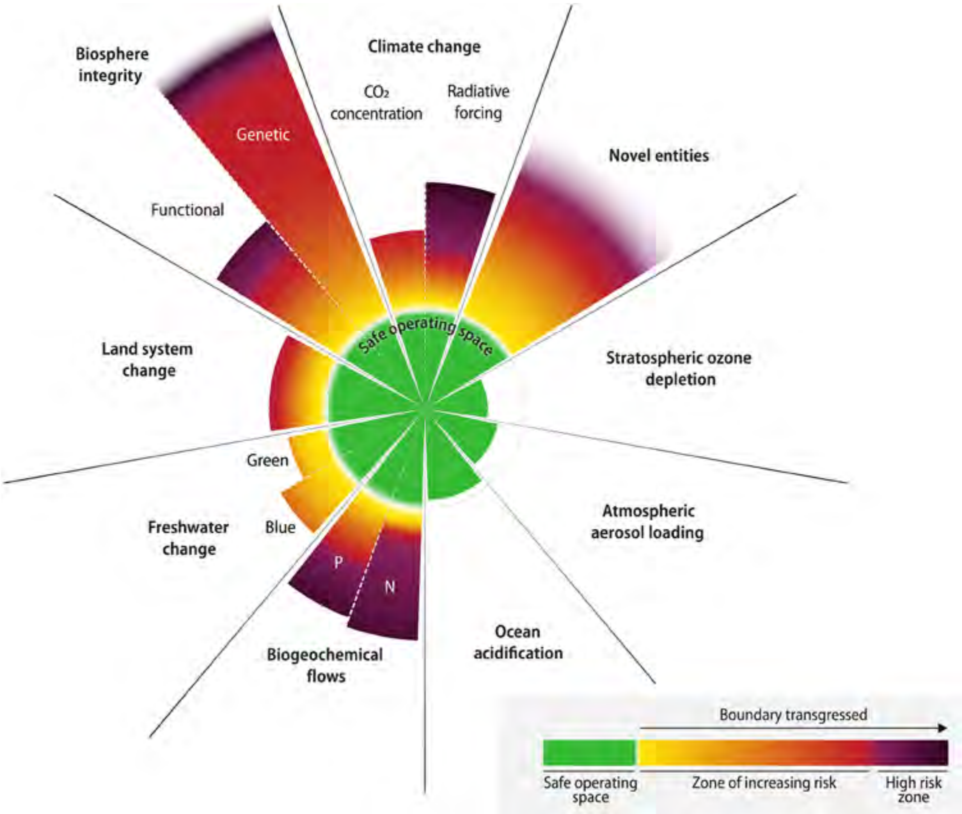
WAGENINGEN
UNIVERSITY & RESEARCH

The Environmental Technology Group (ETE)

At Environmental Technology, 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.

Societal relevance

Anthropogenic depletion and pollution across the globe results in critical challenges for the future health of humans and our planet. Depletion and pollution, as summarized in the Planetary Boundaries Framework (Figure 1; Richardson et al, 2023 in Science Advances), shows that humans have already transgressed the boundaries for many key parameters, like biogeochemical flows and climate change. At ETE, we develop and assess technologies and systems to reduce these impact and to contribute to a more sustainable society.



In our research and education, we contribute to a sustainable and circular world by developing and engineering environmental technologies and urban systems that draw on processes from nature to recover and reuse important resources from residual streams. Novel, innovative technologies are required to achieve sustainable development and circular economy goals. We focus on technologies that recover essential resources from waste streams, such as organics, nutrients, metals, water and energy, and remove contaminants like micropollutants, pathogens, and salts. We also appreciate that novel technologies need to be aligned with existing and/or transitioning resource-waste systems. Thus we also focus on investigating and evaluating these existing systems in order to redesign systems to include our technological innovations.

Through this, we contribute to many of the sustainable development goals:

Research

Our research is organized into three themes: Biorecovery, Reusable Water, and Urban Systems Engineering:

Theme 1: Biorecovery

Biorecovery focuses on the transition to circular resources including nutrients, carbon, metals, and trace elements. The group's research develops key environmental technologies for the biobased and circular economy. Particular focus is placed on biobased chemicals for the biobased economy, renewable energy resources, and circular (micro)nutrient and metals for the circular economy using technologies that can deal with diluted waste streams.

The main focus is on converting solid, liquid, and off-gas waste streams into renewable organic chemicals and recycling reusable minerals such as phosphorous, sulphur and metals from waste. The developed processes aid in the transition towards a circular economy, circular agriculture, and a reduction of carbon emissions. The (bio)recovery group expands the fields of:

1. Advanced fermentations in open systems to generate insights into how to steer microbial conversions, using organic wastes (municipal, agricultural, industrial) and gases (methane,

hydrogen, carbon dioxide) to produce carboxylic acids, polymers and other added-value products.
2. (Bio)electrochemical systems that can recover nutrients and energy, and that can recover commodity chemicals from wastewater and/or CO_2.
3. Bioconversion and biocrystallisation technologies to recover clean fertilizers and to separate and eliminate toxic compounds.

Theme 2: Reusable Water
Water Technology strives to achieve society's goal of water and sanitation for all. The group focuses on the technologies and systems required to achieve fit-for-purpose water reuse, and thus has a very strong focus on water quality. This focus on fit-for-purpose is particularly strategic, as it focuses on selectively removing the most challenging and recalcitrant contaminants that prevent reuse, including chemical and biological contaminants, resulting in water that is tailored to the required quality. Finally, by modelling the system requirements in terms of spatial and temporal quantity and quality requirements, the group contributes to designing sustainable and circular societies of the future.

The technological working groups focus on micropollutants and pathogens and physical-chemical treatment. These groups work together to understand the fate and transformation of water contaminants. Activities focus on:

1. Removal of chemical contaminants, such as organic micropollutants (pharmaceuticals, chemicals in personal care products, pesticides, industrial chemicals, and remnants of historical pollution), salts and other ionic substances.
2. Elimination of pathogens (including faecal and opportunistic pathogens as well as microorganisms with antibiotic resistance) that prevent non-potable water reuse.

Technologies are developed for contaminant removal using advanced (bio)reactors and nature-based approaches such as constructed wetlands, on-site and in-situ biofilters, and advanced groundwater remediation systems. Biological conversions and physical-chemical techniques are investigated, such as activated carbon sorption, and advanced oxidation and electro-membrane technologies, as well as combinations of biological and physical-chemical techniques. Innovative technologies are developed to generate high quality water for various water reuse purposes. For this, also non-conventional water sources are used, including brackish groundwater and effluents of domestic and industrial wastewater treatment. Performance of developed technologies are monitored using advanced chemical and bio-molecular analyses.

Theme 3: Urban Systems Engineering
Environmental interactions among cities, industries, and agriculture are studied by the working group of Urban Systems Engineering (Wei-Shan Chen) with the vision that cross-sectoral coupling and recycling of resources (such as water and energy) enables a sustainable society. This group develops:

1. System concepts and novel infrastructure where cycles of wastes-resources-demand are redesigned to determine future scenarios for sustainable cities and agriculture.
2. Modelling platforms to match demand and supply, and assessing storage technologies and capacities needed.
3. Approaches to integrate modified urban systems in the urban environment

Treated wastewater effluents, rainwater, brackish water, and other marginal waters are studied with the aim of making these resources available for fresh-water provision for all sectors. A recent new direction following the example used for wastewater, is the development of alternative decentralised networks for the provision of (drinking) water and sustainable energy (electricity and heat).
The cycling of resources, like macro- and micronutrients and carbon between cities, industries, and agriculture are also studied. System concepts to study and achieve recycling of these resources between cities and (agro)industry is essential to enable a sustainable society. An example is novel sanitation as a platform to generate the fertilizers of the future for (urban) agriculture.

Currently, there are 84 PhD candidates working at ETE and they are expected to be graduating in the coming years. In 2025 we had 8 PhD defences and 1 EngD defence, the overview can be found in Appendix b.

The 2025 list of awards and the publication list of Environmental Technology can be found in Appendices c. and d.

Education

Environmental Technology education aims to provide students, at BSc and MSc level, with the expertise, skills and attitudes required to develop technological solutions for environmental challenges, like climate change, the energy transition, resource scarcity, and soil depletion.
In terms of expertise, environmental technologists need basic knowledge in mathematics, chemistry, physics, microbiology, thermodynamics, and informatics is essential. In our ETE courses at BSc level, within the BSc Environmental Sciences (BES), we build on this basic knowledge in courses related to environmental process engineering, environmental technology, renewable energy, and water treatment. In these courses, we teach how to analyze rates and efficiencies (mass balances), to understand microbial conversions, and to study how solution characteristics (pH, buffer capacity) affect process performance. Being able to capture a process in mass/material flows and conversions is of key importance, as well as the use of modeling software, to analyze and design environmental technologies. At MSc level, within MSc Environmental Sciences (MES), we further expand our teaching to environmental electrochemical engineering and processes for water treatment and reuse. In our ETE courses within MSc Urban and Environmental Management (MUE), we focus on basics of environmental technologies and teach aspects of water and energy infrastructure, as well as closing resource cycles and their interaction with the planning of urban space.

In our courses, we give students examples and experiences from practice (e.g. via guest lecturers from industry and excursions), to motivate and clarify why this expertise is required, and to give students a view on possible future job directions.
In terms of skills and attitudes, our environmental technology students need to be pro-active, engaged, can express themselves clearly in speaking, presenting and writing, are good at collecting and summarizing relevant scientific information, can perform lab work safely and independently, and take part actively and efficiently in (interdisciplinary) group assignments. Many of these aspects are well-covered in different courses to which ETE contributes, also in collaboration with other groups.
See for the full list of courses Appendix a. at the end of this brochure.

In addition to these BSc and MSc programs, ETE contributes to MSc Biotechnology (MBT), MSc Biosystems Engineering (MAB), and MSc Molecular Life Sciences (MML). We also teach in the Master of Analyses, Design and Engineering of Metropolitan systems (MADE), at AMS in Amsterdam, including Living Lab, Professional Profile and Thesis completion. Finally, we are part of the MSc Joint degree programme Water Technology at Wetsus, together with Twente University and Groningen University, with the courses offered in Leeuwarden at the Wetsus academy.
In all these Master programmes, students can choose a major and/or thesis in Environmental Technology.

In 2025, 65 MSc student completed their thesis at Environmental Technology. Based on the program insights, we expect a slight decrease in student numbers in the coming years.

Facilities

WaterTechLab

The Wageningen WaterTechLab is a unique facility in the Netherlands for research and education, addressing topics integrating water quantity and quality disciplinary knowledge by combining civil engineering and environmental technology approaches. Environmental challenges that the facility will contribute to are abundant: the nitrogen crisis, the upcoming goals in 2027 of the European Water Framework Directive for water quality, resolving problems of emerging contaminants and micropollutants like PFAS, (micro)plastic distribution in the environment, and resource scarcity, in combination with seasonal droughts and floods. These often very complex challenges show that a combined strategy for studying water quantity and quality is urgently needed in the Dutch water knowledge landscape. The mission of the WaterTechLab is therefore to support research, education and outreach to ensure sufficient and safe water by combining water quantity and water quality knowledge.

WaterTechLab: description of facility

The WaterTechLab is a multipurpose laboratory and field instrumentation facility that will be suited to support water technology related research and education at WUR. It will consist of two venues: one venue located at ETE (AFSG) and one venue located at HWM (Hydrology and Environmental Hydraulics) (ESG).
The ETE venue consists of 34 cabinets, containing a diversity of (bio)reactor setups with (online) monitoring, and outdoor basins with wetlands. In these (bio)reactors and wetlands, research topics like removal of emerging contaminants from water and soil, removal of salts from water, as well as recovery of valuable components from wastewater are covered. These cabinets can be equipped to work safely with toxic compounds. Moreover, there is a direct connection to the wastewater of the wastewater treatment plant in Bennekom, so that research can be performed on real wastewater streams. This venue is supported by lab technicians, who provide knowledge and support for designing and operating these complex setups.
The HWM venue consists of four flumes in different dimensions, two of which can recirculate both water (potable and salt) and particles (e,g. sediment or microplastics), and additional education and demonstration facilities. The flumes are equipped with high-end instruments to measure the flow characteristics and particle transport. Some of these instruments can also be used in the field. In addition, the venue has a a rainfall runoff simulator as testing area for field conditions for water and sediment transport. This facility is supported by a technician.

With these facilities, the WaterTechLab addresses many different water quantity and water quality related topics: water flow and sediment transport and river morphology modelling, (high speed) flow visualisation, (bio)reactor control and operation, transport of (macro and micro) plastics and degradation of plastics, biological and physical-chemical conversions and recovery technologies for industrial and household wastewaters, degradation of pollutants and water retention by wetlands, and nature-based water solutions.

<u>Strategic themes to integrate water quantity and water quality aspects</u>
The WaterTechLab is thus uniquely suited to cover new research areas that address water quality and water quantity aspects. We foresee three main strategic themes that will strongly rely on this integration of water quantity and quality creating synergy:

1) Emerging contaminants

HWM and ETE have a joint interest in the fate and transport of (organic) pollutants that are often present at very low concentrations. HWM focuses on natural systems, including river basins, aquifers, and deltas, to support essential water management solutions. ETE focuses on engineered systems for water treatment and (re-)use. In both natural and engineered systems, a fundamental understanding of the transport, adsorption, and (bio)degradation of pollutants is required. Pollutants of particular interest include PFAS, heavy metals, and microplastics. The WaterTechLab offers specialised facilities to study their dynamics in reactors and sediments, such as column filtration setups and flumes and a rainfall simulator, as well as high-end analytical techniques, amongst others for the measurement of

PFAS. In the context of the new WaterTechLab, ETE and HWM join forces to advance expertise in studying transport, adsorption and (bio)degradation of pollutants across the complete water cycle.

2) Fluid mechanics

HWM and ETE have a joint interest in fluid mechanics, which govern the transport of various types of particles in open water as well as closed conduits. The WaterTechLab offers cutting edge facilities for this, including Particle Image Velocimetry (PIV). PIV is an advanced technique to measure the velocity of fluids. It involves the visualization of the flow of particles that are seeded in the fluid, with high-speed cameras capturing images of the particles as they move. Building on collaboration that ensued from the *Sectorplan Techniek* projects, we can develop PIV expertise to analyse various types of transport processes, with the complementary PIV installations already in place. The insights on fluid mechanics can be used for a wide variety of topics: to assess the effects of climate change on water flows, the distribution and transport of particles (e.g. plastics), as well as the behavior of (microbial) granules and particles in water and wastewater treatment systems.

3) Wetlands

Wetlands are a nature-based solution that use plants for (post)treatment of contaminated water, e.g. for removal of emerging contaminants like pesticides and medicines. The potential for wetlands to treat water relies on the combination of plant growth and microbial activity in these basins. Wetlands do not only offer opportunities for treatment, but also for retention, storage and environmental flow of water. This combination of water quality and water quantity aspects for wetlands will dictate whether or not we can actually achieve water reuse to combat seasonal drought. Water authorities like Vallei en Veluwe, would like to use the full potential of wetlands for both water retention/storage and improving water quality, but very little is known about how retention and storage of water in wetlands affects the treatment capacity and thus water quality.

ETE venue

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 350 m^2 including 30 units of 2 m^2 and 4 units of 12 m^2. 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 ^{0}C . Extra connections are available for CO_2, H_2 and O_2. In 3 of these units temperature, humidity and lighting can be regulated by means of LED lamps to facility research on wetlands.
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. Next to the cabins Modutech has the unique possibility to work under fully anoxic conditions in a glovebox, offering a spacious area to conduct experiments.

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 m^3/hour) to Modutech for research, which can be stored in one of the two cooled 3.5 m^3 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 m^2 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.

Unlock facility

The UNLOCK microbial research infrastructure is composed of three complementary experimental platforms for high-throughput discovery and characterization of microbial communities and a FAIR-data platform for large scale data storage, extraction, analysis. UNLOCK is set up and maintained by scientists from TU Delft and Wageningen University & Research.
The Modular Bioreactor platform consists of different systems that can be used in sequence (technology trains) and or parallel configuration. The platform is specifically suitable for investigating sustainable solutions for environmental challenges, such as water reuse and biorecovery.
The Modular Bioreactor Platform is located at Modutech.

Laboratory facilities @ ETE

Modutech is supported by a well-equipped analytical research environment with an analytical staff of 7 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, u-pollutants 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, DNA extraction and microscopes offer us the possibility to make use of these topics in our studies. Of course we also have collaborations with colleague university groups which gives us access to more specialised research techniques.

Overview of available measuring techniques at ETE.

Principle	Equipment	Detections method	To analyze
Chromatography	GC	FID	VFA & MCFA
			SC Alcohols
			TPH
		ECD	Chlorinated compounds
		FDP	Mercaptans, H2S
		TCD	O_2, N_2, CH_4, CO_2, CO, H_2
	LC	RI	sugars, organic acids
		UV-Fluorescence	PAHs
		DAD	u-pollutants (medicines, pesticides, hormones)
		Conductivity	NH_4^+
	LC-MS	MS targeted	u-pollutants (medicines, pesticides, hormones)
			Pfas
	LC-MS*	MS untargeted	u-pollutants (medicines, pesticides, hormones)
	IC	Conductivity	F^-, Cl^-, NO_2^-, Br^-, NO_3^-, SO_4^{2-}, PO_4^{3-},
			Li^+ , Na^+, NH_4^+, K^+ , Mg^+, Ca^+
Spectroscopy	Plate reader	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
	NMR*	Magnetic resonance	Methanol/Ethanol
	NDIR	Infra red	TOC, TIC
	FT-IR*	Infra red	Plastics
	Raman**	laser light scattering	Methanol/Ethanol
	Laser difraction**	laser light scattering	particale size distribution
	Flow cytometer*	laser light scattering	type and amount of cells
		Fluorescence	
	MS* **	mass spectometry	offgas from reactors
X-ray analysis	XRD**	X-ray diffraction	Minerals, polymers, nanoparticles
	XRF**	X-ray fluorescence	Elemental composition solids
Miscellaneous	High speed Camera**		Track particles in reactor
* within the Unlock facility	** within Modutech facility		

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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

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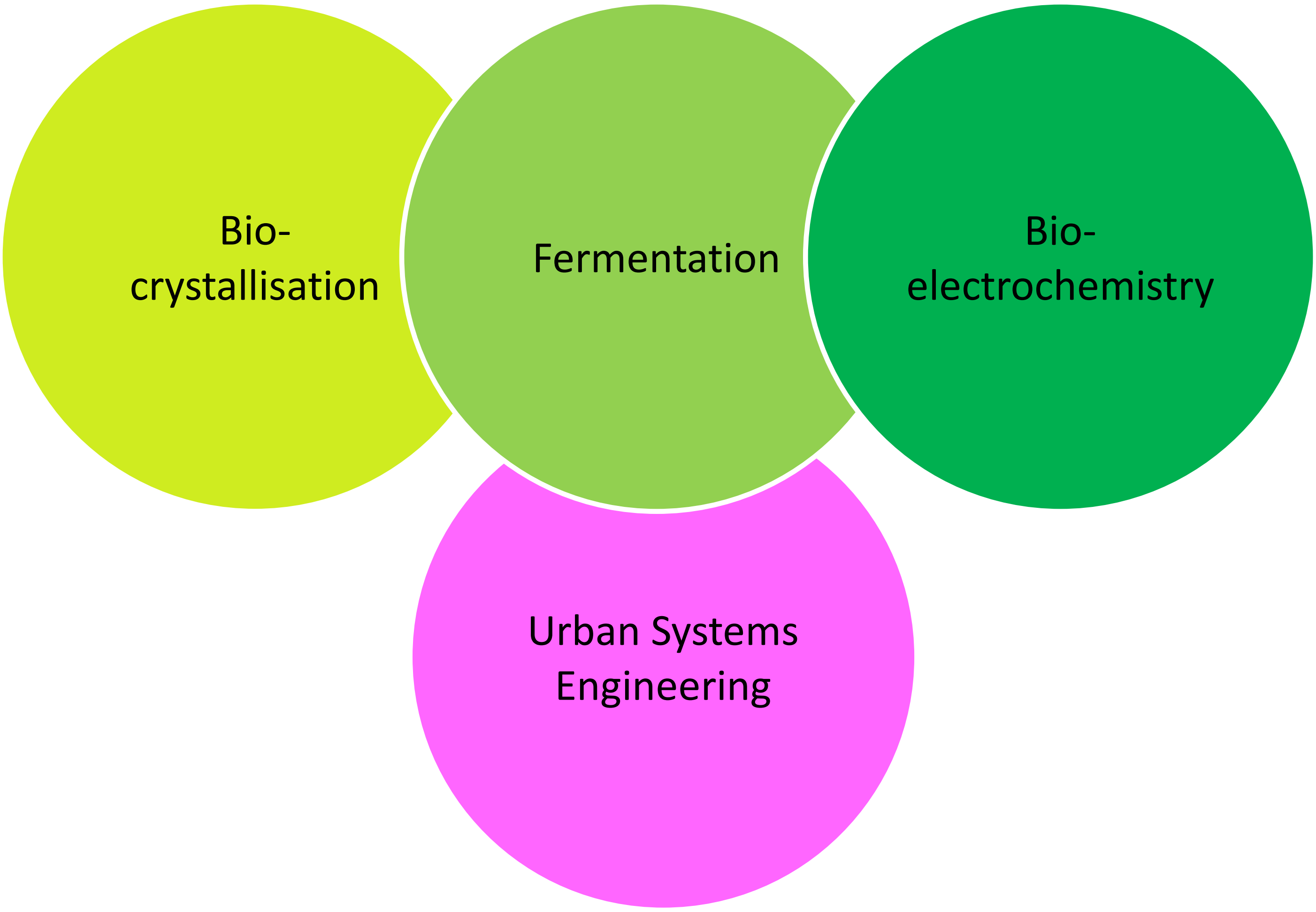
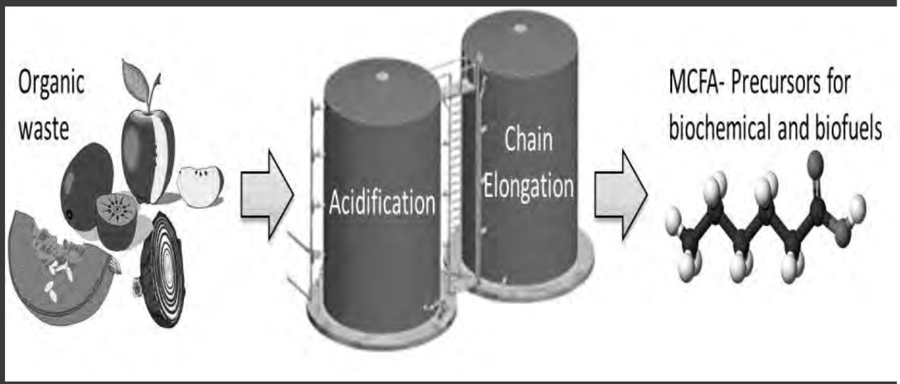
Biorecovery



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.

Understanding the kinetics, transfers and reactions in the biological gas desulfurization process.

Nov 2022 - 2026

Researcher	Supervisor	Promotor
Joris Bergman	Dr. ir. Annemerel Mol Ir. Margo Elzinga	Prof. dr. ir. Karel Keesman Prof. dr. ir. Cees Buisman

Motivation

H_2S is a toxic and environmentally harmful gas that requires removing from (bio-) gas streams. The biological gas desulfurization process is an environmentally friendly process that converts H_2S into elemental sulfur (S^0) using sulfur-oxidizing bacteria (SOB) under haloalkaline conditions (pH 8-9.5 and ionic strength 1-1.5 M) [1]. Within the process, biological, chemical and mass-transfer reactions take place simultaneously. The process consists of three steps: 1) absorption of H_2S into a (bi) carbonate solution to form dissolved HS^-, 2) anaerobic uptake of HS- by SOB and 3) aerobic conversion of stored HS- into S^0. Aside from S^0 , SO_4^{2-} (sulfate) and $S_2O_3^{2-}$ (thiosulfate) can also be formed through biological or chemical oxidation. Theoretically, 98% of incoming S atoms can end up in S^0, but in practice lower percentages are achieved [2]. Modelling can help understand the interplay between the different processes in order to improve the process design and control. The aim of this research is to model the biological gas desulfurization process using both past data and by generating new experimental data.

Technological challenge

Three challenges must be overcome in the modelling of the biological gas desulfurization process:

- Aspects of the SOB biology, e.g. their ability to take up and store HS- under anaerobic conditions. This most likely requires the development of advanced kinetic models.
- Both sulfur crystals and bacteria are known to enhance mass transfer in the absorber column [3,4]. To date no quantitative information exists on the relative contributions of both forms of enhancement and no model exists in literature that combines both biological and chemical mass transfer enhancement.
- Investigating the hypothesis that most of the chemical conversions in the micro-aerophilic reactor take place within a gradient around the reactor O2 and HS^- injection points. This necessitates the use of computational fluid dynamics (CFD).

The project has the following research goals:

1. Determine the dominant physical, chemical and biological processes and quantify their kinetics;
2. Develop a novel model for the SOB biological rates;
3. Model simultaneous chemical and biological mass transfer enhancement in the absorber column;
4. Model the processes that take place around the HS- and O2 injection points and determine how the mixing pattern around these points affects the process performance;

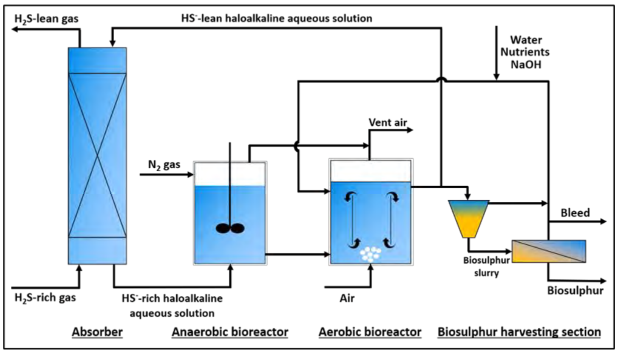


Fig 1. Current process line-up

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High rate biological production of hydrogen sulfide from elemental sulfur for industrial application

Sep 2023 - 2027

Researcher	Supervisor	Promotor
Ding Fang	Dr. ir. Dandan Liu; Dr. ir. Rieks de Rink; Dr. ir. Annemerel Mol	Prof. dr. ir. Cees Buisman

Motivation

Hydrogen sulfide (H_2S) produced from bioreduction of elemental sulfur (S^0) has many valuable industrial applications, such as recovering metals from acid mine drainage and the sulfiding agent in hydro-treatment of (renewable) feedstocks. However, the high operational costs, low sulfide production rates, and its liquid phase nature limit the widespread industrial applications of this technology.

Biosulfur, formed through the partial microbiological oxidation of H_2S in bio-desulfurization reactors, is considered waste. Leveraging biosulfur as both the S^0 and carbon source for sulfide production, along with its role as a pH buffer, enables substantial waste valorization. Moreover, biosulfur (Fig.1) is anticipated to exhibit a higher sulfide production rate compared to chemically produced S^0 due to its high bioavailability.

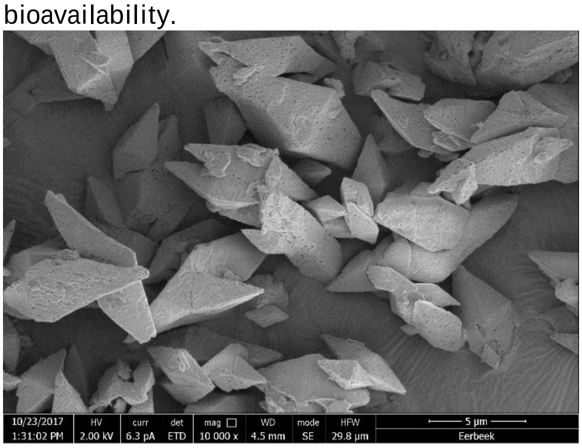


Figure 1. Biosulfur crystals

Utilizing hydrogen (H_2) as both the electron donor (Eq.1) and stripping gas facilitates simultaneous H_2S production and stripping in a single bioreactor.

$$S^0 + H_2 \rightarrow H_2S \qquad (1)$$

This research aims to employ H_2 and biosulfur for the production of gaseous H_2S in a S^0 reducing bioreactor (Fig.2), achieving high sulfide production /stripping rates that can result in cost effective H_2S generation with limited CO_2 concentration at industrial scale.

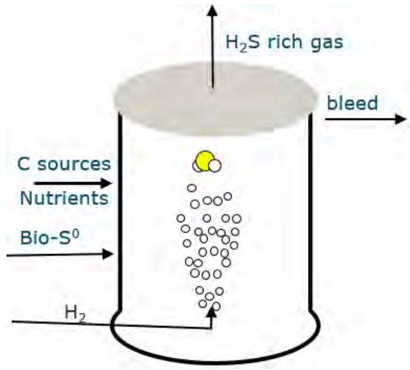
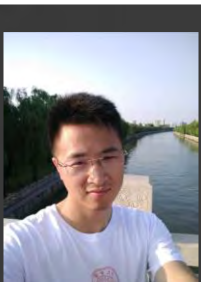


Figure 2. Scheme of S^0 reducing bioreactor

Technological challenge

1. H_2S production and stripping with limited CO2 concentration.
2. Develop methodologies to achieve high rates of sulfide production and stripping.



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Resource circularity in a climate neutral world: supplying biosulfur recovered from wastewater to the agrifood sector

Sep 2025 - 2029

Researcher	Supervisor	Promotor
Qamar Abbas	Dr. ir. Annemerel Mol	Prof. dr. ir. Annemiek ter Heijne

Motivation

Biosulfur recovered from wastewater is a promising sulfur source for crops at a time when many soils are running low in this essential nutrient (Fig. 1). For plants to benefit, biosulfur needs to oxidize well in soil and support healthy growth. This project looks at how the properties of biosulfur influence its conversion to plant-available forms and how different soils respond to it. The work also explores the value of using biosulfur in a circular economy. The findings will help determine when and how biosulfur can be applied to improve crop performance in a safe and effective way.

Technological challenge

The first technological challenge is the agronomic performance of biosulfur. The performance is inconsistent in current literature, and the mechanisms driving this variability, specifically the interaction between its unique physicochemical matrix and different soil environments remain poorly understood. The link between biosulfur oxidation rates and plant sulfur uptake remains poorly characterized making difficult to predict fertilizer effectiveness under field conditions. These uncertainties currently hinder its large-scale adoption as a reliable fertilizer substitute.

Second, the residual salts (Na+, Cl- and S-salts) in the fertilizer product due to the halo alkaline conditions of the desulfurization process pose a challenge. During storage, the biosulfur suspension becomes anaerobic, and in the presence of electron donors, sulfur reducing microorganisms present in the mixed culture can reduce sulfate and thiosulfate (by-products), or biosulfur, causing toxic H_2S gas formation. It is hypothesized that reducing salinity may decrease H_2S production, as the mixed culture is adapted to high salinity conditions. Also, the presence of residual salts presents an agronomic concern by not washing the biosulfur, unnecessary salts are introduced into the soil during fertilizer application, potentially affecting the soil structure and plant performance. Third, in the nutrient circular economy, biosulfur is the missing link that connects wastewater treatment and food production. The economic potential and market adoption barriers for biosulfur as a commercial fertilizer remain unclear.

Research goals

- Investigating the physicochemical properties of biosulfur influence oxidation in soil, leaching, microbial activity and plant growth across contrasting soil types.
- Identifying the maximum salt concentration at which biosulfur remains stable, does not produce H_2S, and still supports active sulfur-oxidizing bacteria such as *Thiobacillus*.
- Evaluating the circular economy potential and market feasibility of biosulfur.

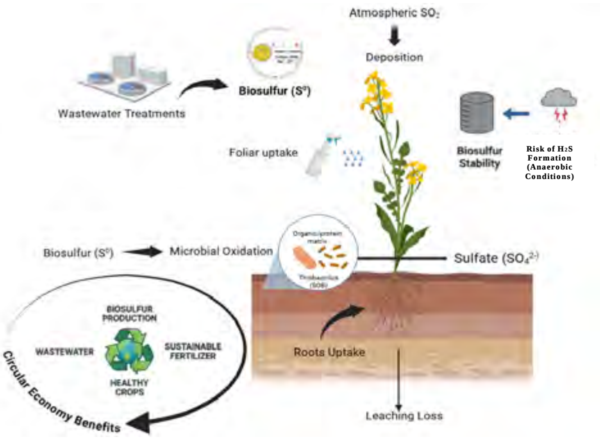

Fig. 1: Conceptual framework of soil sulfur cycle

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Iron recovery and arsenic isolation from drinking water treatment sludge

Biorecovery
Environmental Technology

May 2022 - 2026

Researcher	Supervisors	Promotor
Milan Adriaenssens	Dr. ir. Annemerel Mol Ir. Leon Korving Dr. Renata van der Weijden	Prof. dr. ir. Cees Buisman

Motivation

During the production of drinking water, carcinogenic arsenic is removed from the raw water into an iron sludge. While the iron in the sludge still has value, a high concentration of arsenic in the sludge challenges its reuse. Consequently, drinking water treatment sludge is regularly landfilled, risking arsenic leaching into soil and groundwater and inhibiting circularity in drinking water production. With the development of an iron-sludge treatment technology, both iron recovery and stable arsenic storage are aimed for, eliminating iron landfilling.

Technological challenge

Clean drinking water can be obtained, due to the high affinity of arsenic to iron adsorbents. However, this results in a challenge to separate/mobilize arsenic from the iron compounds, an essential first step in the isolation of arsenic and recovery of iron. By altering reaction conditions, affecting both chemical and biological processes, a separation between iron and arsenic is hypothesized (Fig 1).

Secondly, the obtained arsenic should be immobilized into a stable mineral to avoid environmental contaminations when disposed of. For example as scorodite, which has a low Fe/As molar ratio.

Finally, the recovered iron needs to be obtained in a quality/purity suitable for other application. Potential end-users could be WWTPs for phosphate removal or bio fermenters for sulfide elimination. If reuse in drinking production is possible, lower operational costs can be obtained, making save drinking water more available.

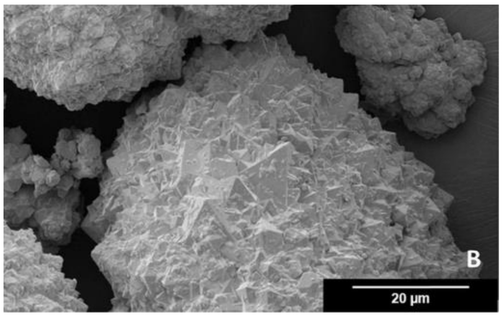

Figure 2. SEM picture of bioscorodite (by Vega-Hernandez et al., 2021)

Research goals

- Understand the mobility of iron and arsenic under different reaction conditions.
- Identify reactions to form a stable As-mineral at low arsenic concentrations.
- Comprehend how different conditions affect the value of the obtained iron product.

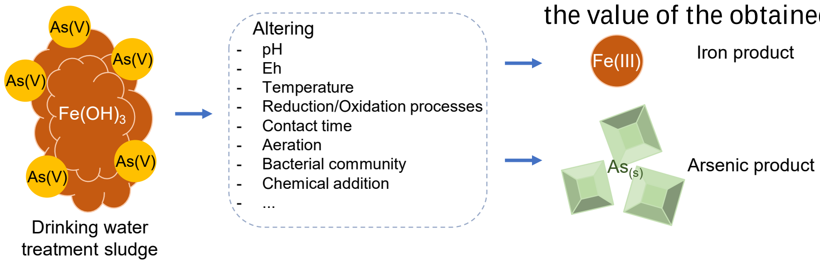

Figure 1. Proposed scheme for iron recovery and arsenic isolation

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wetsus

WAGENINGEN UNIVERSITY & RESEARCH

Experiments in Wageningen

Investigating selenium-sulfur interactions for selenium recovery from wastewater

Feb 2025 - 2029

Researcher	Supervisor	Promotor
Yulian Chang	Dr. ir. Annemerel Mol Dr. Renata van der Weijden	Prof. dr. ir. Annemiek ter Heijne

Motivation

Selenium is a semi-conducting non-metal that is an essential element to humans and other organisms. It is used in glass manufacturing, metallurgy, electric appliances and agriculture. Approximately 90% of selenium is produced as by-product from copper mining[1]. It is present in low concentrations in the soil with an irregular regional distribution. Selenium in waste is often present in low concentrations making recovery cost intensive.

Selenium can be present in elevated concentrations in mining, fossil fuel refinery and agricultural wastewaters. While selenium is an essential micro-nutrient, it is toxic in low concentrations and exceeds the Dutch surface water regulation limits in most water systems[2]. Next to this selenium is predicted to become a more scarce resource. Biological recovery of selenium from wastewater offers a solution to both prevent selenium pollution and provide a new selenium production source.

Knowledge gap

Selenium is present in wastewater as selenate (SeO_4^{2-}) and selenite (SeO_3^{2-}) and can be reduced by bacteria to elemental Se^0. The produced elemental selenium is generally formed as red amorphous nanoparticles up to ~400nm and is encapsulated by proteins and extracellular polymeric substances (EPS)[3]. This organic layer possibly restricts further growth or crystallization of selenium particles. These nanoparticles are difficult to separate from the bacterial biomass, making the recovery of selenium inefficient.

SeO_3^{2-} can react chemically with sulfide (H_2S) to form SeS_2 crystals. The sulfur from these crystals can be reduced by bacteria back to sulfide. This leaves behind black hexagonal selenium crystals whose size can get up to 10µm and are more easily separated from the process solution. This process is still poorly understood and is speculated to be mediated by reactive polyselenosulfide ($Se_xS_y^{2-}$) anions, for which no well established analytical method is developed yet.

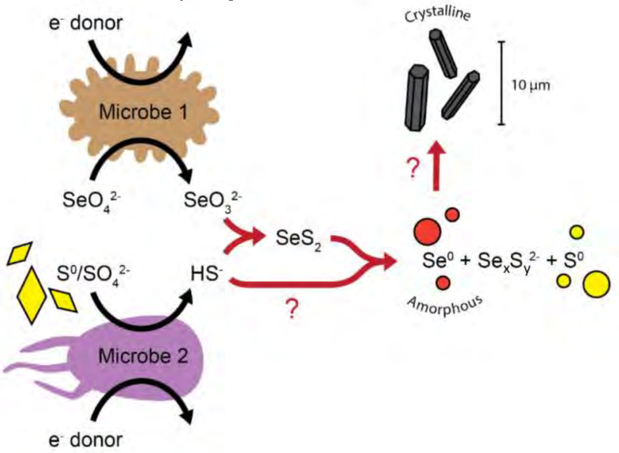
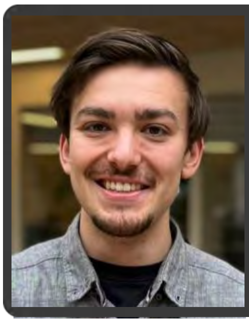


Figure 1. Schematic proposed process overview. (Illustrated by Rikke Linssen)

A better understanding of the interactions between bacteria, selenium and sulfur species and their influence on selenium crystallization can contribute to the development of a more efficient and cost-effective selenium bio-recovery process.

Research activities

-Method development for quantifying Se_xS_y species (UV-VIS/HPLC/NMR/Raman)
-Chemical and biological batch bottle experiments with relevant selenium and sulfur species
-Bioreactor design and operation
-Crystal characterization (XRD, XAS, Raman, synchrotron, SEM-EDX)



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1) scrreen.eu/crms-2023 2) www.waterkwaliteitsportaal.nl/kaartviewer 3) Staicu, L.C., Barton, L.L. (2017). Bacterial Metabolism of Selenium—For Survival or Profit. In: van Hullebusch, E. (eds) Bioremediation of Selenium Contaminated Wastewater. Springer

Unraveling phosphorus crystallization in animal manure: Defining mechanisms to innovate phosphorus recovery

Sep 2024 - 2028

Researcher	Supervisors	Promotor
Lilian Quispe-Livisi	Dr. ir. Chris Schott Dr. Renata van der Weijden	Prof. dr. ir. Cees Buisman

Motivation

Europe has the priority of deriving phosphorus (P) from secondary sources to mitigate dependency on phosphate rock. Animal manure (AM) is the largest secondary source of P and contains significant amounts of nitrogen (N) and P . A primary challenge in utilizing AM as a nutrient source is its N:P concentration ratio, where the P content often exceeds crop requirements, leading to runoff and adverse effects on aquatic ecosystems. An understanding of the mechanism that drives calcium phosphate (CaP) precipitation allows for the separation of P from other nutrients, thereby facilitating its targeted application on land and improving the sustainability of agricultural practices.

Technological challenge

At Wetsus, blackwater (BW) and AM have been investigated for CaP recovery in an Upflow Anaerobic Sludge Bed (UASB) reactor. In BW, microorganisms locally increased the pH within the granules, biologically inducing CaP precipitation in the reactor. In AM, however, P recovery as CaP was more chemically driven. High ammonia levels in pig manure inhibit microbial growth, leading to a more chemical mechanism in which CaP precipitates with calcite. In cow manure, an acidification step before the UASB reactor was required to release ions and enable CaP precipitation. The challenges of recovering CaP from AM arise from the fact that P is mainly in struvite, intense ion competition and varying precipitation kinetics among supersaturated minerals (struvite, CaP, calcite). These factors have not been thoroughly explored to understand their impact on CaP precipitation in AM.

Research goals

- Investigate the effect of calcium addition on struvite dissolution.
- Elucidate the abiotic and biotic conditions that promote or inhibit CaP precipitation.
- Identify and evaluate potential biochemical mechanisms that could induce CaP aggregation in AM.
- Optimize reactor conditions in an anaerobic reactor to maximize P recovery.

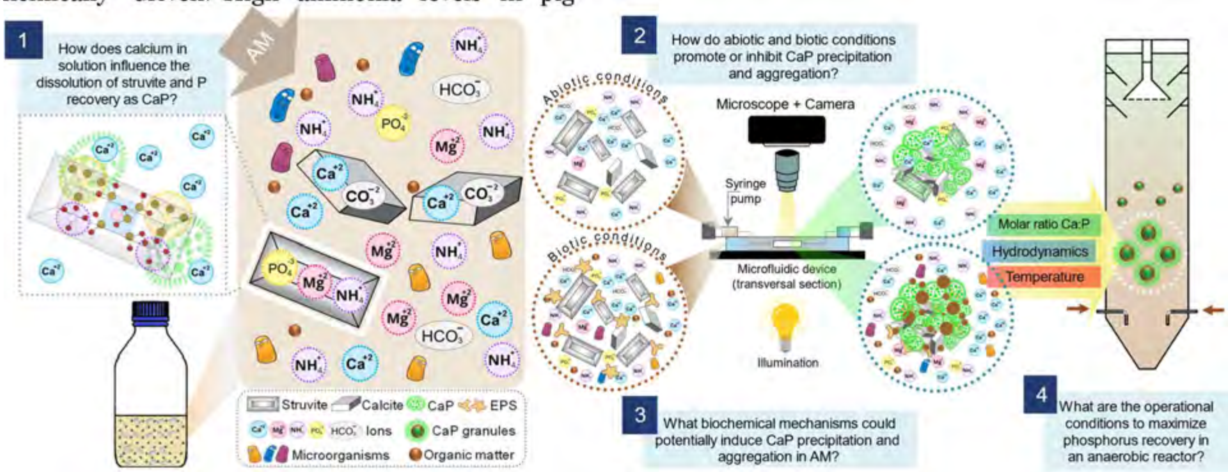

Figure 1. Project overview and schematic approach to achieve the research goals

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Synergistic recovery of nitrogen (N) and phosphorous (P) from wastewater via regenerative adsorption

Oct 2025 - 2029

Researcher	Supervisor	Promotor
Liza Romanenko	Dr. Carlo Belloni Dr. Thomas Prot	Dr. ir. Paula van den Brink Prof. dr. ir. Annemiek ter Heijne

Motivation

Conventional wastewater treatment processes focus on nutrient removal from sewage: carbon (C) is removed through oxidation by heterotrophs, nitrogen (N) via the nitrification/denitrification process and phosphorus (P) using enhanced biological (EBPR) or chemical (CPR) processes. While these technologies are well-established and reliable, they produce a significant amount of greenhouse gases (N_2O and CO_2) and do not allow for the full valorization of the COD to offset costs. At the same time N and P are both valuable resources for agriculture and are otherwise produced through energy-intensive chemical or mining technologies. Therefore, wastewater is a largely untapped resource of N and P – for example, it is estimated that up to half of the agricultural demand for P can be covered by fully recovering them from wastewater (Egle et al. 2015).

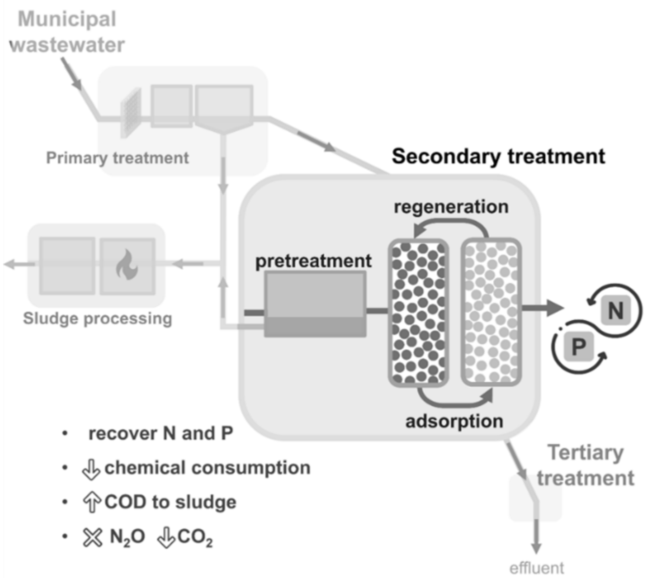
Regenerative adsorption is a promising approach to realizing the circular potential of sewage, provided a synergy can be found in the recovery of N and P, and the use of chemicals necessary for regeneration and system longevity can be minimized.

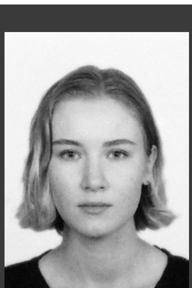
Technological challenge

Generally, the regeneration part of the process when studying adsorption is comparably under-researched, while it dictates whether the use of adsorption can be economically viable to recover N and P in real sewage treatment. There is a need to explore the possibility of recovering both nutrients using a minimal amount of chemicals, while overcoming several challenges, such as the complex wastewater matrix, the concentration disbalance between N and P as well as keeping an eye out for market-valuable compounds to be produced from the regenerant stream.

The research objectives include developing a proof-of concept process for combined desorption of N and P, transferring the design to a COD-rich realistic feedstock to test the tolerance of the system towards highly loaded wastewater, placing the system within a "WWTP of the future", and exploring ways to recover the nutrients and reuse the regenerant.

Concept for the "WWTP of the future"





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EPS-based solutions to increase soil structure and resilience to drought

Jan 2023 - 2027

Researcher	Supervisor	Promotor
Mithat Can Kuscu	Dr. ir. Annemiek ter Heijne Dr. Valentina Sechi Dr. Yujia Luo	Prof. dr. ir. Cees Buisman

Motivation

It has been estimated that almost 40% of the total agricultural land in Europe is prone to soil degradation at a moderate or higher level of severity [3]. Microorganisms and their metabolic products affect soil structure by binding loose soil particles into water-stable aggregates [2]. In particular, extracellular polymeric substances (EPS), produced by soil microorganisms, are known to have numerous, positive effects on soils, including improved water retention and aggregate stability [1]. This research project aims to develop engineering strategies to enhance EPS production and increase soil structure and resilience to drought.

Technological challenge

- The use of EPS in agriculture is still very limited
- Our knowledge of EPS composition, structures, and functions is far from complete.
- Our understanding of the mechanisms involved in the biosynthesis and degradation of EPS in soil and their role in determining soil properties is still unclear.

Research Goals

The project's ultimate goals are to develop nature-based management strategies to increase soil structure and resilience to drought via EPS stimulation (Figure 1).

The research will be targeting the following research questions:

1: What is the role of OAs and C/N ratio in soil EPS production?

2: What is the role of EPS in soil aggregation?

3: What is the relationship between EPS and drought resistance of the soil?

4: What are the effects of OA-induced EPS on different types of soils?

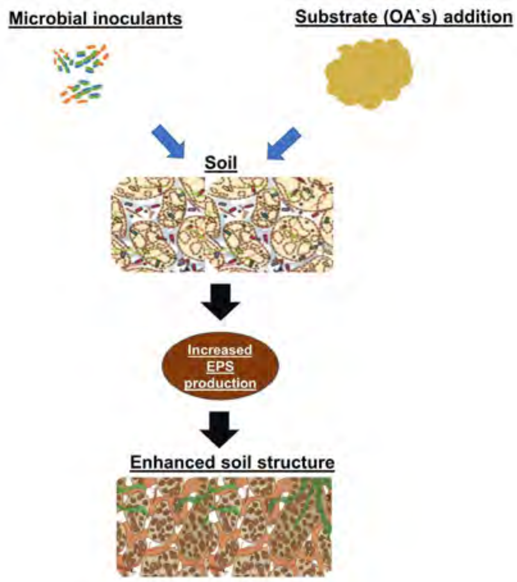

Figure 1. Modified conceptual framework of the research approach [3].

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Optimization of manure processing: Towards more sustainable manure-based fertilizers

Environmental Technology

Nov 2022-2026

Researcher	Supervisor	Promotor
Lourens van Langeveld	Dr. Ir. Miriam van Eekert, Dr. Paul Bodelier, Dr. Valentina Sechi	Prof. dr. ir. Cees Buisman

Motivation

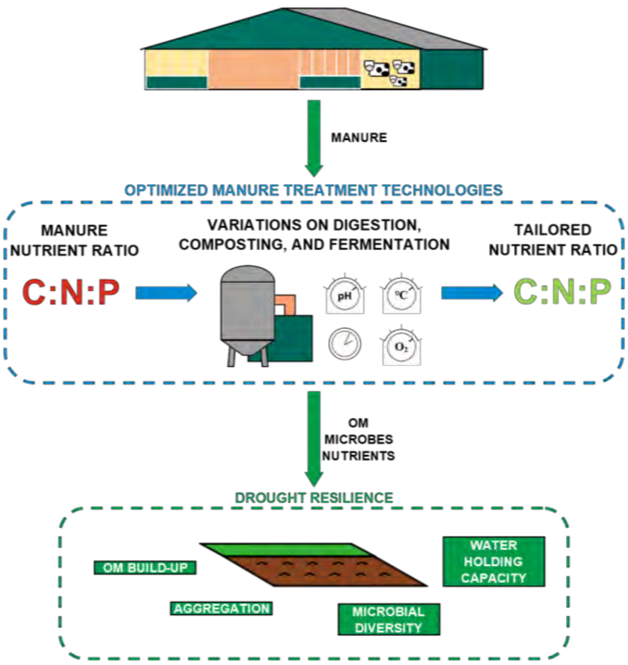
Organic matter supports many ecosystem functions vital for crop production and plays a central regulatory role in GHG-emission control and soil carbon sequestration. Globally, soil organic matter, and thus carbon stores are increasingly depleted as a result of intensive farming practices, affecting both soil functionality and productivity. As a result, many ecosystem services are negatively impacted, such as water holding capacity, GHG sequestration, and crop growth. Reintroduction of carbon into the soil system is often achieved by amendment with (treated) manure. However, current methods can lead to increased GHG-emissions and eutrophication, as treatment methods and application strategies are far from optimized. In addition, the effect of the treated manures on the microbial, physical, and chemical characteristics of the soil are poorly understood. Steps are made to move from intensive agricultural practices to more regenerative agricultural practices, with the intention to maintain crop output whilst ameliorating soil health and improving drought resilience.

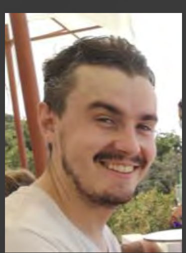
This research project aims to improve current manure treatment technologies by combining knowledge and integrating the frontier between bioprocess technology and soil science.

Technological challenge

Manure digestion, and other (post- or pre-) treatments, can improve the sustainability of agricultural practices by allowing increased reintroduction of carbon and nutrients into the food chain. However, measuring microbial traits like carbon and nitrogen use efficiency or contribution of microbial carbon to soil organic matter are still highly challenging. In order to achieve more effective use of amendments in agriculture, the impact of processed manure on soil needs to be investigated in relation to the following parameters:

- Carbon uptake
- GHG emissions
- Nutrient leaching
- Organic inputs and associated microorganisms
- Water holding capacity





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From Waste to Resource: Optimizing Phosphorus and Methane Recovery from Cattle Manure

Mar 2024 - 2028

Researcher	Supervisor	Promotor
Feride Ece Kutlar	Dr. Renata van der Weijden Dr. ir. Chris Schott	Prof. dr. ir. Cees Buisman

Motivation

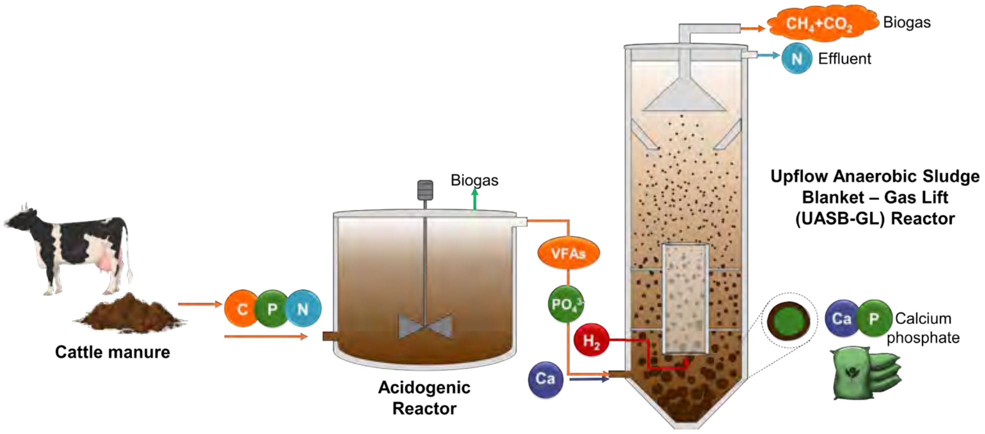
Phosphorus (P) is typically sourced from non-renewable phosphate rock, and its uncontrolled release causes environmental issues like eutrophication. Animal manure is the largest secondary source of P which can be recovered and reused. The Netherlands produces 74 million tons of animal manure annually, with cattle manure accounting for 83%. Since manure behaves unpredictably when applied directly to the soil, strict controls are needed to maintain soil stability. Processing of manure, however, can result in more reliable and safer fertilizer options.
The goal is to design a sustainable system that recovers P and methane from manure for on-farm use by applying natural principles and the microorganisms already present in cattle manure.

Technological challenge

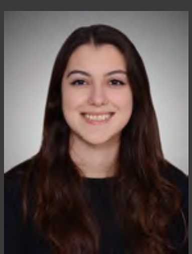
One of the primary challenges in recovering P from manure is the limited availability of reactive P, which is available for precipitation, aggregation and simple separation as CaP. Moreover, high inorganic carbon content of cattle manure limits CaP formation by binding the available Ca as CaCO3 instead.
Additionally, the high solids content in the manure complicates the mixing process within the reactor. As a result, P and C are not effectively distributed in the reactor, which can hinder the recovery of both P and methane. Furthermore, the necessity to add Ca externally for CaP precipitation introduces an additional step that adds complexity to the process. These interdependent challenges require innovative strategies that address multiple issues simultaneously.

Research goals

- Enhancing technology for efficient P and methane recovery from cattle manure
- Creating an innovative design and process that addresses multiple issues simultaneously.
- Evaluating the quality and feasibility of the recovered P product for agricultural use.
- Boosting the efficiency and sustainability of manure management contributing to nutrient recycling and waste treatment practices.



Proposed scheme for P recovery from cattle manure



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The effect of different organic fertilizers on the soil microbiome

Mar 2024 - 2028

Researcher	Supervisor	Promotor
Brenda Speek	Eline Keuning Dr. Valentina Sechi	Prof. dr. ir. Cees Buisman Prof. dr. ir. Martijn Bezemer

Motivation

Grasslands cover approximately 70% of agricultural soils worldwide and account for 53% of agricultural grounds in the Netherlands. Fertilization is an essential component of grassland management, used for increasing forage production and yield.

In the Netherlands, grasslands are often fertilized with animal manure, which serves as a vital source of nutrients crucial for plant growth and development. Manure is rich in nitrogen; excessive application contributes to emission of greenhouse gases, loss of nutrient through leaching and soil acidification. To make agricultural practice more sustainable, nitrogen emissions need to be reduced.

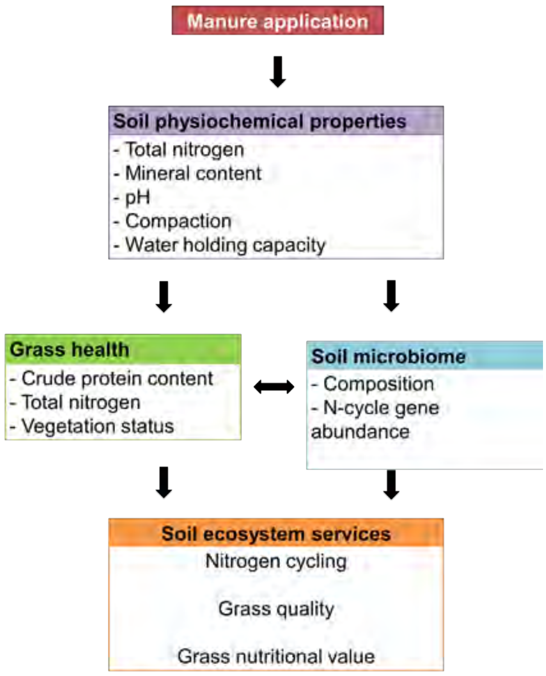
Technological challenge

Microorganisms play important roles in soil nitrogen cycling, yet the impact of organic fertilization on grassland microbiomes remains understudied. Especially in Northern-Europe, research on this topic is still lacking. Therefore, insight is needed to unravel the influence of manure application on soil microbiomes, particularly the effect on microorganisms involved in the nitrogen cycle and their influence on plant nitrogen uptake and unwanted emissions to the environment.
By elucidating the effect of manure fertilization on the soil microbiome, this study aims to contribute to the establishment of efficient fertilization strategies and reducing nitrogen emission.

Research goals

The goals of this research is to investigate the effect of different forms of manure fertilization (slurry, digestate and composted) and two different application methods (injection and above ground spreading) on the grassland soil microbiome, with a particular focus on the nitrogen cycle.
This research aims to answer the following questions:

1. What is the impact of different organic fertilizers on composition and diversity of the soil microbial community in grasslands?
2. How does fertilizer injection influence the soil microbial composition and diversity compared to above ground application?
3. Can soil and grass nitrogen content be linked to nitrogen-cycle related gene abundance?



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N_2O, NO and N_2 emissions from anaerobically stored manure

Jan 2023 – 2027

Researcher	Supervisor	Promotor
Rik Maasdam	Dr. ir. Miriam van Eekert Dr. ir. Karin Groenestein	Prof. dr. ir. Huub Rijnaarts

Motivation

In the livestock sector two major air polluting problems relating to manure management are: the release of nitrogen in the form of NH_3 and the release of greenhouse gases (GHG) such as CH_4 and N_2O. While we generally know how much and under which conditions NH_3 and CH_4 are emitted, this is not the case for the other nitrogen gasses in the nitrogen cycle: N_2O, NO and N_2. To try to minimize the emission of the environmental detrimental gasses N_2O and NO this project aims to get a better understanding on the biological conversions of nitrogen in manure.

Technological challenge

From studies on soil and wastewater treatment plants four different microbial conversion pathways are known in which N_2O, NO and N_2 might be formed and emitted: nitrification, denitrification, nitrifier denitrification and anammox.

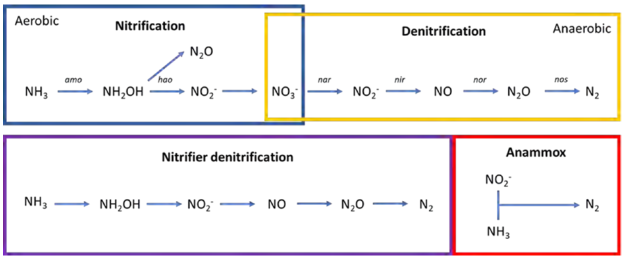


Figure 1. microbial nitrogen pathways: the coupled nitrification and denitrification, nitrifier denitrification and anammox.

While manure is stored primarily anaerobically, conventional storage tanks are partially open and therefor the surface area is under influence of the outside conditions. This can cause drying of the surface layer forming a crust, thus creating a porous aerobic environment. Hypothetically, all four of the nitrogen pathways can take place in stored manure. The technical challenge of this project will be determining and quantifying which pathway takes place under which conditions (figure 2).

This project will use multiple batch reactors with manure where the emitted gasses are continuously measured to get a better understanding on the nitrogen conversions.

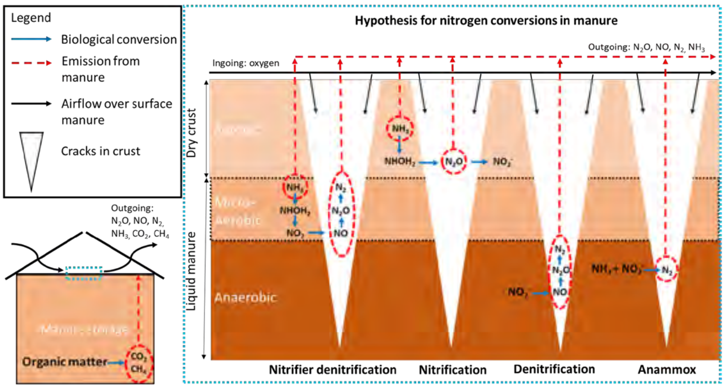
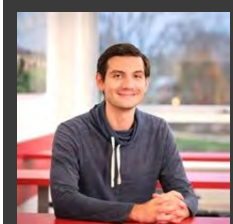


Figure 2. hypothesis for the nitrogen conversion pathways taking place in anaerobically stored manure with interaction due to crust formation.

Research objectives:

- Determine the main microbial nitrogen pathways responsible for the emission of N_2O, NO and N_2 and the effect of storage conditions and environmental parameters on these emissions.
- Propose and test mitigating strategies to minimize N_2O and NO emissions from stored manure.



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Optimization of (hyper)thermophilic blackwater treatment for recovery of biofertilizers and energy

Oct 2023 - 2027

Researcher	Supervisor	Promotor
Melissa Mwikali Mativo	Dr. ir. M.H.A. van Eekert Dr. L. Hernandez-Leal	Prof. dr. ir. Cees Buisman

Motivation

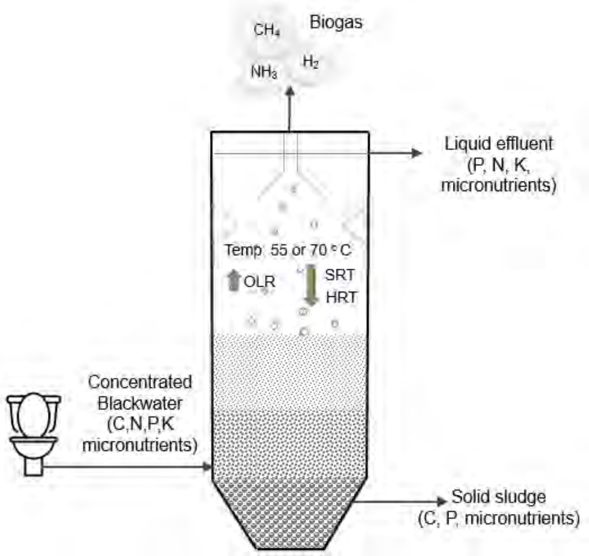
Efforts to address soil deficiencies and improve global food production have resulted in a heavy reliance on mineral fertilizers. Human feces and urine contain essential nutrients such as carbon, nitrogen, phosphorus and potassium which are crucial for plant growth. Fortunately, anaerobic treatment of concentrated source-separated blackwater under thermophilic conditions is already shows promise for effective COD removal and biogas production, along with pathogen elimination for enhanced safety of nutrients and biosolids during reuse.

Technological challenge

Thermophilic treatment of blackwater, at 55°C, is a stable process that has been previously pilot tested under the H2020 Run4Life project. Already, COD removal (~70%) and methanization conversions (~60%) comparable to those reported during mesophilic treatment have been achieved while operating at higher organic loading rates (OLRs) and shorter sludge and hydraulic retention times (SRTs and HRTs). Now, we will optimize operating conditions for (hyper)thermophilic anaerobic treatment, as enhanced hydrolysis should allow for long-term operation at even higher loading rates and shorter retention times, without compromising on effluent quality.

Hyper-thermophilic treatment of blackwater at 70°C, could result in hygienically safe products as well, but at even shorter SRTs. However, methane production was impeded by unfavorable environmental conditions, i.e., high ammonia levels and volatile fatty acid accumulation. Thus, there is need to investigate alternative products, preferably separate CNPK nutrient recovery streams as single nutrient agricultural inputs are more beneficial.

Phosphorous was largely retained in the sludge, while nitrogen and potassium was present in the effluent. Nevertheless, this study will address the fate of micronutrients in blackwater, which was not evaluated previously. Overall, even though the recovered products may not be risk-free, they need to be risk-mitigated as much as is feasible. Therefore, the removal efficiency for micropollutants in blackwater through thermophilic anaerobic treatment will be determined.



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The road to truly circular & sustainable sewage treatment

Jul 2023 - 2027

Researcher	Supervisor	Promotor
Leon Korving	Prof. dr. ir. Cees Buisman Prof. dr. ir. Mark van Loosdrecht	Prof. dr. ir. Cees Buisman Prof. dr. ir. Mark van Loosdrecht

Motivation

The Dutch water authorities have committed themselves to be “fully circular” by 2050. Unfortunately, there is no clear definition of circularity for sewage treatment. The “Energy and Resource Factory” initiative of the Dutch water authorities has led to a lot of different pilot scale initiatives for new resource recovery options (phosphate, cellulose, Kaumera, PHA) and these developments contribute to circularity in sewage treatment but are maybe not the endpoint and integration of different resource recovery options is still lacking. The moment is getting close where big decisions have to be made on how to build or modify existing sewage treatment plants. The absence of a clear vision on what a circular sewage treatment should be, creates uncertainty and can lead to uninformed decisions.

Technological challenge

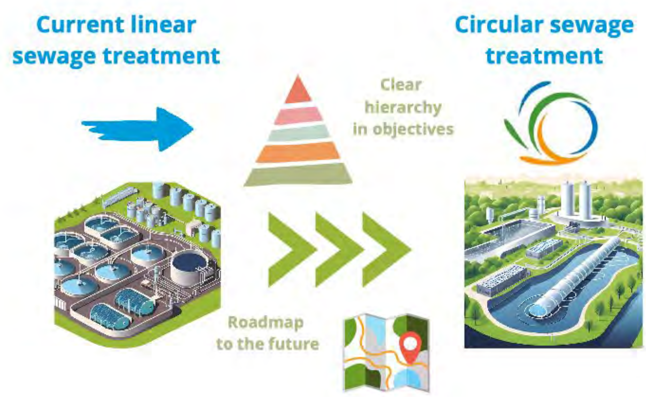
The design of current sewage treatment plants (STP’s) has been developed in the last century and their main objective has been to remove dissolved organic components and nutrients from sewage to prevent eutrophication of surface waters. They have been highly successful in reaching this objective but increasingly our society is challenged because we are reaching our planetary boundaries. STP’s have to adapt to many new challenges: they need to reduce the amount of greenhouse gases, have higher removal efficiencies for nutrients, to remove more micropollutants and to start reusing water and resources from sewage. This has led to the invention and addition of add-ons to existing sewage treatment plants. Partly these are successful but a holistic overview and approach to address all challenges together and to prioritize them is missing. Also, sewage treatment solutions may be very different, depending on the local constraints and issues.

Method

As a first step a hierarchy of priorities for sewage treatment will be developed to better understand where are the biggest societal contributions that sewage treatment provides. Using economical data, societal mass balances and results of LCA’s the relative importance of different objectives will be weighed such as: nutrient & pollutant removal, energy recovery or recovery of resources.

With the priorities clear, proposals will be made for new design schemes for truly circular treatment sewage treatment concepts to give an inspiring but realistic vision for future sewage treatment concepts.

Finally, roadmaps will be developed to show how one can transition from current treatment schemes to truly circular concepts while giving enough room for innovation.



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Sub-department of Environmental Technology

Medium chain fatty acids and alcohols production from biomass waste by granular sludge based chain elongation bioprocess

2020 - onwards

Researcher
Dr ir. Kasper de Leeuw

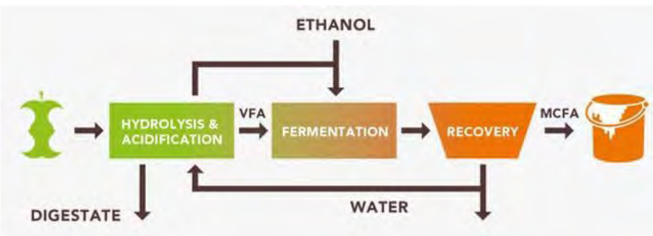
Supervisor
Dr. ir. Dr. ir. David Strik

Motivation

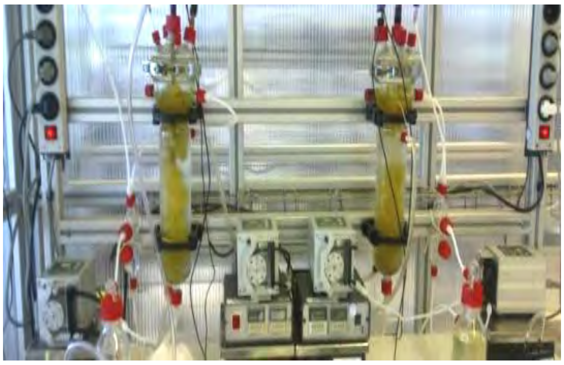
There is an increasing demand for sustainable solutions to quench our thirst for oil-derived carbon compounds. Anaerobic treatment provides the means to efficiently produce renewable chemicals from organic residues. The recent discovery of controllable microbial chain elongation processes to produce medium chain fatty acids (MCFAs) opens the possibility to develop new biorecovery technologies. MCFAs and their corresponding alcohols are platform chemicals which can be used for a wide range of products, including: flavors, fragrances, animal feed additives, emulsifiers and organic solvents.

Technological principle

Anaerobic treatment is a widespread method to produce biogas from biomass residues. With the developed chain elongation processes anaerobic digesters can be turned into biochemicals producing bioreactor. In the anaerobic microbial conversion processes the energy and carbon is largely maintained in the product, allowing for high yields and low costs during production of biochemicals. The most important factor that defines the anaerobic process is the applied selective pressure. To stimulate chain elongation ethanol or other extra electron donors are supplied.



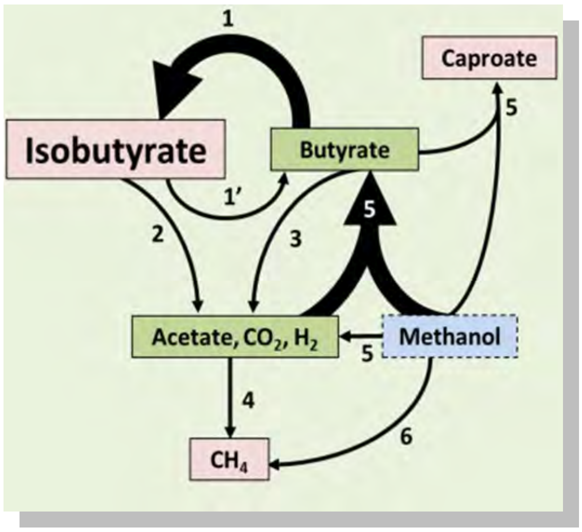
Biowaste to MCFA biorefinery



Lab-scale bioreactors

Research challenges

- ❖ Pinpoint control mechanisms of selection pressure on microbiomes which lead to effective bioreactor operation and microbial granulation
- ❖ Identify the key microbes and use their characteristics to optimize the process



Overview of potential conversion routes in mixed-culture chain elongation microbiome

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WATER & MARITIME

CHAINCRAFT

WAGENINGEN UNIVERSITY WAGENINGEN UR

Converting agricultural straw into value-added fatty acids using synthetic microbial community

Dec 2025 - 2029

Researcher	Supervisors	Promotor
Yizhuo Du	Dr. ir. David Strik Prof. Lixin Zhao	Dr. ir. David Strik Prof. Lixin Zhao

Motivation

Agricultural waste constitutes a vast and underutilized resource globally, with billions of tons of straw generated annually. Anaerobic digestion (AD) of agricultural waste has been globally commercialized as a sustainable approach for biogas production and energy substitution. Despite the ongoing efforts in energy recovery, there remains substantial potential to optimize these processes for enhanced sustainability and increased yield of value-added products. Medium-chain fatty acids (MCFA) generated by hydrolysis, acidification and chain-elongation process in AD is a promising avenue for waste valorization, showing broad applications in animal nutrition and medical fields.

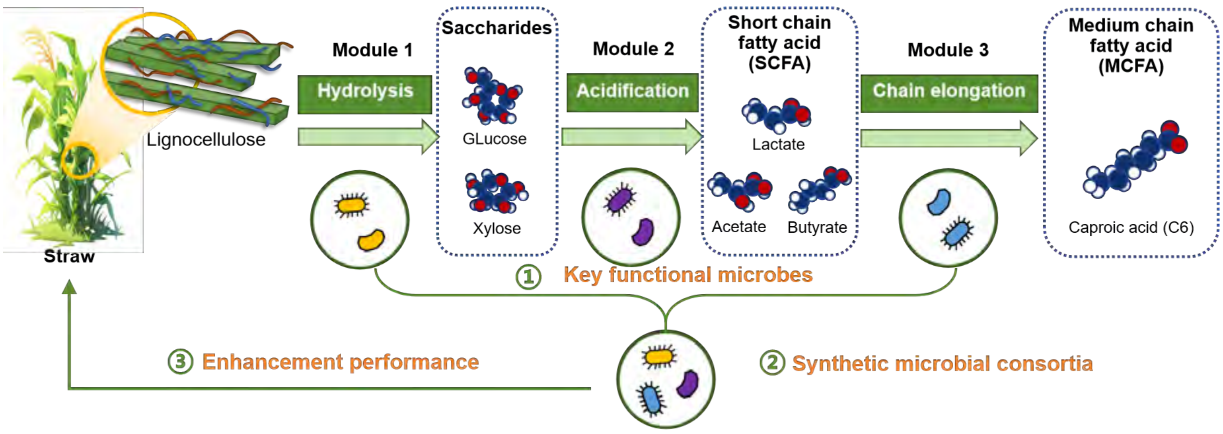
Technological challenge

This study aims to convert straw into caproate through mixed-culture fermentation. Given the recalcitrant lignocellulosic structure of straw, the conversion process requires coordinated hydrolysis, acidification, and chain elongation. To ensure high reaction efficiency within individual metabolic modules and functional synergy among microbial communities, optimization of environmental parameters and microbial cooperation is required. It is essential to minimize competitive pathway losses, prevents intermediate accumulation, and direct carbon flow toward the targeted product. Therefore, there are several challenges to be further investigated:

(1) Develop fermentation systems and processes to enhance straw degradation and MCFA production

(2) Understand the spatial distribution and synergistic interactions of key functional microorganisms involved in hydrolysis, acidogenesis, and chain elongation modules

(3) Screen functionally complementary microbial species and construct starter inocula with operational stability to optimize mixed-culture fermentation performance



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Mixed bioplastic waste fermentation into carboxylic acids to foster the circular economy

Mar 2023 - 2027

Researcher
Weishen Zeng, MSc

Supervisors
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Dr.ir. Kasper de Leeuw

Motivation

The phenomenon of plastic pollution is becoming increasingly prominent. Also implementation of recycling of plastic waste is a huge challenge faced by many countries. To reduce the present environmental impact of plastics there is a trend to create products based on biodegradable plastic polymers. These biodegradable plastic are often made from biomass which reduces the need of fossil resources. Conventional biodegradable plastic waste disposal methods have typical a down-cycle model, such as landfill and incineration.

In fact, recovering chemicals from biodegradable plastic is a potential to a promising way to foster the circular economy. Carboxylic acids like acetate, butyrate and caproate, represent key-chemicals which likely can be produced via fermentation of various types of bioplastics. These carboxylates or also groups as volatile fatty acids (VFAs) are emerging platform chemical and can for example be used for microorganism to accumulate polyhydroxyalkanoates (PHA) to re-make bioplastics (Fig.1). Recently organic waste fermentation processes to produce VFA were developed; a similar approach is proposed here.

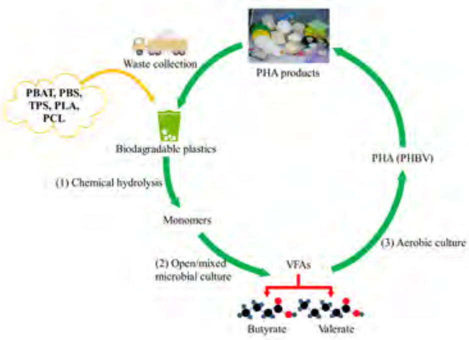

Fig.1 Biodegradable plastics closed loop recycling

Technological challenge

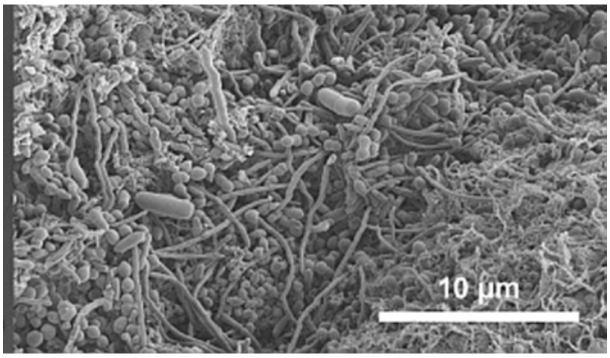

Fig. 2 Mixed microbial community producing carboxylic acids in bioreactor (Roghair et al. 2016).

The aim of study is to upgrade various biodegradable plastics wastes into VFA via a mixed culture fermentation process (Fig 2). Bioplastics can already be fermented to methane whereby the soluble monomers, including acetate and gaseous H2, are often formed as intermediate. Once one can inhibit the methanogens it is hypothesized that various volatile fatty acids will start to accumulate. Relevant hereby is to study the process of plastic depolymerization and hydrolyzation as potential rate-limiting steps of the fermentation. There are several challenges to be further investigated:

(1) Develop bioplastic fermentation processes with fast hydrolysis and methane inhibition conditions
(2) Understand the carbon fluxes during fermentation and effect of mixed plastics
(3) Elucidate the role of key-microbial players in the bioprocess to optimize the fermentation

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Recycling end-of-life PHA into renewed PHA via mixed microbial cultures

Biorecovery
Environmental Technology

2025 - 2031

Researcher	Supervisor	Promotor
Ralf Beckmans	Dr. ir. David Strik Dr. ir. Kasper de Leeuw	Dr. ir. David Strik

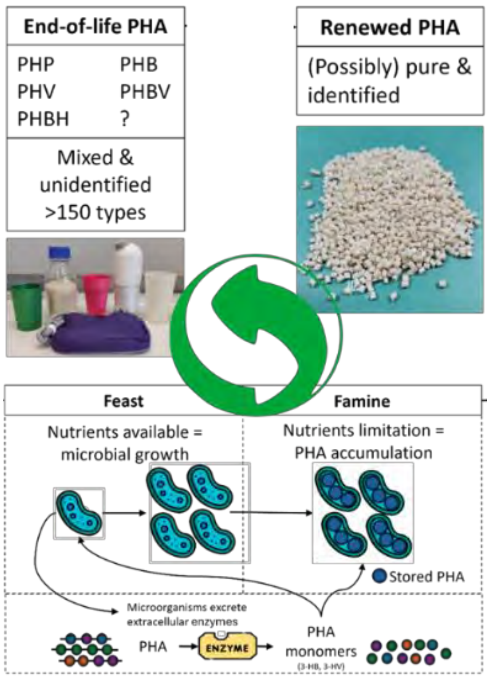
Motivation

Polyhydroxyalkanoates (PHA) are biobased biodegradable plastic materials and serve as alternative for fossil-based plastics such as PP and PE. Microorganisms produce PHA from biomass, CO_2 or even wastewater. PHAs are emerging as a key bioplastic, but their recycling opportunities are restrained. As part of circular bioplastics economy, end-of-life PHAs are potential substrates to produce PHA again. This way materials stay in societal loops and less CO_2 could be emitted compared to use of fossil plastics.

Microorganisms produce PHA under nutrient-limited conditions. By limiting a specific nutrient, most commonly N or P, a mechanism is triggered that allows microorganisms to store carbon intracellular in the form of PHA. This production process, also referred to as the feast-famine cycle, can either occur aerobic or in mixed anaerobic/aerobic conditions. Here we explore various possibilities to exploit natural occurring open-cultures and create the right selection pressure to produce new PHA and/or it's precursors like volatile fatty acids.

Technological challenges

The challenge is to develop microbial recycling processes that can handle mixed PHA based plastic materials as feedstock and produce new PHA.



Bioreactors (see photo) will be operated and with the help of research platform *Unlock* (https://m-unlock.com) microbial communities will be further unraveled. Data will be gathered with advanced online monitoring and PHA characterization techniques.

Research topics

- Development of mixed-PHA microbial fermentation processes.
- Identification of hydrolyzation products from several types of PHA, under abiotic and biotic conditions.
- Online monitoring method development.
- Key player assessment of the microbial community responsible for the recycling of PHA in a feast-famine regime.

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UNLOCK MICROBIAL POTENTIAL

WAGENINGEN UNIVERSITY & RESEARCH

TEAPOTS (agriculTurE wAste PyrOlysis and Thermocomposting for Sustainable energy)

Sep 2025 – Dec 2027

Researcher
Anran Li

Supervisor
Dr. ir. Wei-Shan Chen
Prof. dr. ir. Cees Buisman

Background

The **TEAPOTS** (agricul**T**ur**E** w**A**ste **P**yr**O**lysis and **T**hermocomposting for **S**ustainable energy) project is an EU-funded initiative that aims to develop innovative and flexible solutions for converting agricultural waste into renewable energy and valuable by-products. It focuses on the valorization of lignocellulosic and difficult-to-treat agro-industrial residues through the integration of thermochemical (e.g., pyrolysis) and biological processes, enabling the production of heat, biochar, and compost while supporting local and seasonal energy demand in the agri-food sector.

A central component of TEAPOTS is the advancement of Compost Heat Recovery Systems (CHRS). These systems harness the heat naturally generated during the aerobic biodegradation of organic biomass and transfer it to water or air for practical use, such as space heating or domestic hot water.

Compost heat recovery systems (source: Biomeiler.nl).

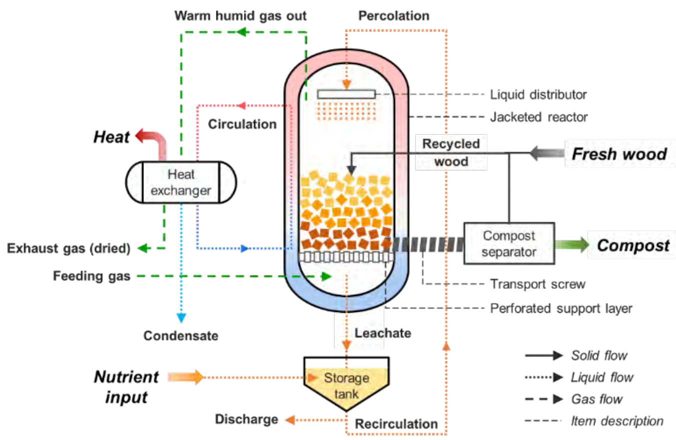
Technological Challenge

The use of woody biomass in CHRS can enable prolonged heat production. However, the low degradation rate of wood is a major limitation to achieving efficient heat generation. To address this challenge, three research focuses are identified:

(1) Effects of factors such as aeration, moisture, and additives to stimulate the reaction rate.

(2) Design of large-scale reactor that enhances mass transfer, nutrients recycling, and product removal.

(3) Understanding process dynamics for improved control and optimization of full-scale systems.



A trickle-bed reactor design for investigating integrated strategies to enhance microbial wood degradation for CHRS.

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Plant microbial fuel cell: Mechanistic characterization

March 2018-2022

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

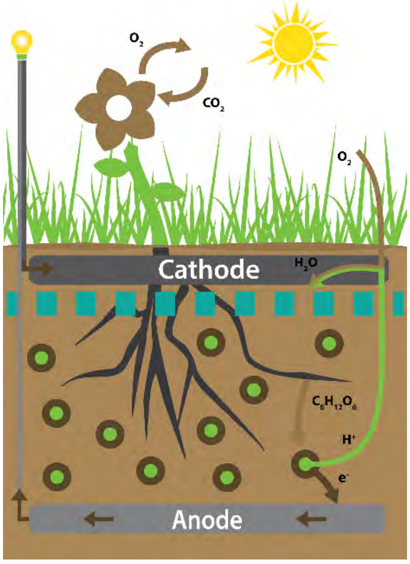
Motivation

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

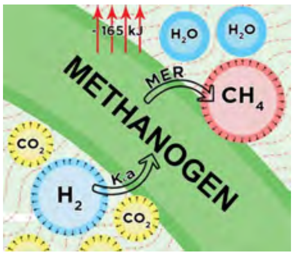
Sep 2021 - 2024

Researcher	Supervisor	Promotor
Shih-Hsuan Lin	dr. Michele Tedesco (Wetsus) dr. P (Philipp) Kuntke dr. Cristina Gagliano (Wetsus)	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,



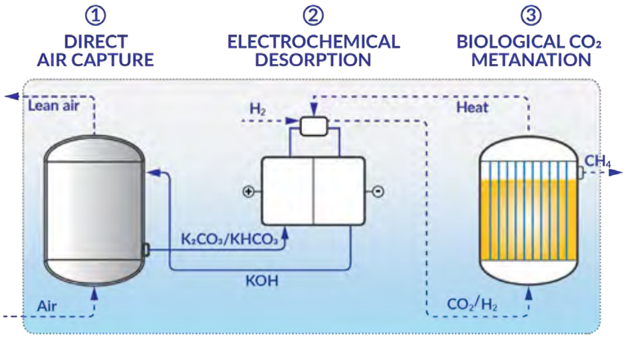
$$4H_2 + CO_2 \rightarrow CH_4 + H_2O$$
$$\Delta G^0 = -165 \text{ KJ/mol}$$

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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In operando and non-invasive characterization of electroactive biofilms with magnetic resonance techniques

Dec 2022 - 2026

Researcher	Supervisor	Promotor
Paulien Sterken	Dr. Ir. Sanne de Smit	Dr. ir. Annemiek ter Heijne

Motivation

Electroactive biofilms and technologies which make use of them are promising in wastewater treatment and electricity generation. To non-invasively measure several parameters of the biofilm (such as its morphology), this project aims to develop an *in operando* Magnetic Resonance (MR) set-up with which to measure the biofilm, where the biofilm can be measured non-invasively while it is generation energy. This set-up can then be used to improve understanding of different parameters on e.g., biofilm growth and morphology.

Technological challenge

MR techniques have long been used in the medical field to visualize the inside of human bodies (e.g., MRI) without the need for surgery. While some studies exist which measure the biofilm, few have a set-up for measuring *in operando*, and therefore a set-up will be built during this project. The main technological challenge is creating this set-up for measurement in the MR spectrometer, as the reactor will have to be miniaturized and still be able to operate as it would in a regular set-up.

Some research goals are:

- Determining the electrode material to be used in the set-up
- Determining the effect of compound necessary for MR on the electroactive biofilm

To optimally perform this project, it is performed at both Environmental Technology and BioNanoTechnology.

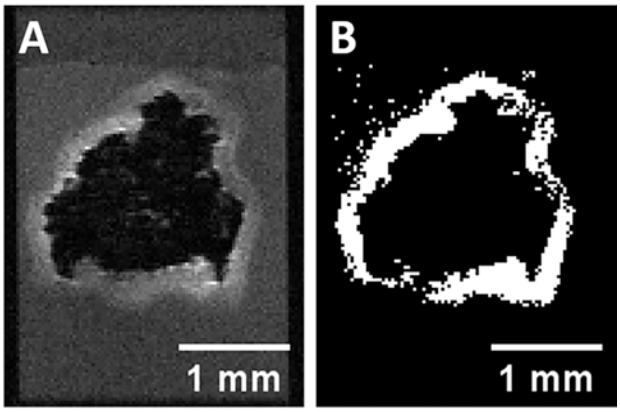


Figure 1. (Above) An example of biofilm on electrode material measured with MRI (A), and the image after threshold analysis (B). Taken from Caizán-Juanarena et al. (2019).

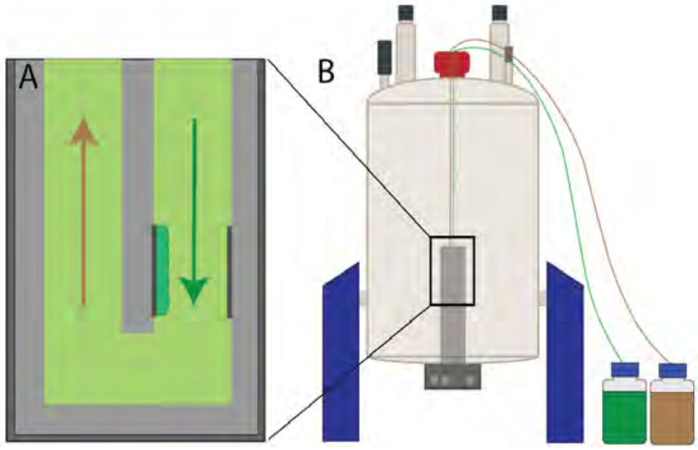
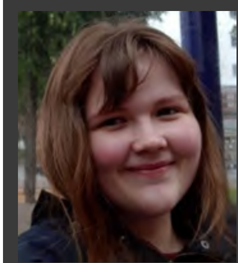


Figure 2. (Left) A schematic illustration of what the MR set-up might look like. (A) The biofilm reactor inside the MR sensor. (B) The MR scanner with the detector (gray), connected to influent (green) and effluent (brown) lines.



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Understanding the relation between local conditions and local microbial productivity in bioelectrochemical CO2 valorization systems

Oct 2024 - 2029

Researcher	Supervisor	Promotor
Jos Steller	Dr. Ir. Sanne de Smit	Prof. dr. ir. Annemiek ter Heijne

Motivation

Microbial electrosynthesis (MES) is an innovative technology that provides a sustainable and efficient method to convert carbon dioxide (CO_2) and electric energy into commodity chemicals. The integration of microbial and electrochemical conversions allows the production of a diverse range of products from renewable electricity under ambient conditions. To scale up MES, it is crucial to understand the local conditions that limit the active surface area of a bio-electrochemical system (BES). This project aims to find mass transfer limitations in an acetate producing BES by measuring local conditions (e.g. pH and H2) and the spatial distribution of microbial activity in the cathode

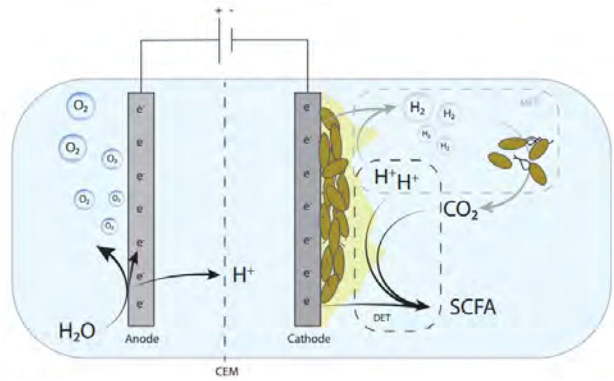

Figure 1: Schematic representation of a typical CO2 reducing dual-chambered BES.

Knowledge gap

Recently, it has been demonstrated that microsensors can measure local conditions in 3D electrodes and that these conditions differ significantly from the bulk solution. The presence of gradients in a BES promote the formation of distinct (biological) niches within the 3D electrode that support the development of diverse microbial communities. This variation likely restricts the active surface area of a CO_2-reducing BES by the formation of less productive microbial communities in niches with unfavourable local conditions. In this study, the presence of gradients in a acetate-producing BES will be revealed and linked to the microbial activity to find the main transfer limitations that decrease the active surface area. A method will be developed to measure the (local) microbial activity based on spectroscopy (e.g. raman) and metagenomic analysis.

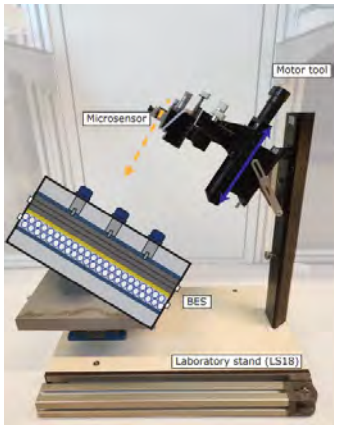

Figure 2: Set-up for making micro profiles in a BES reactor

Research Objectives

- Determine which gradients (i.e. pH, H_2 and redox) are present throughout the biocathode with microsensors.
- Develop a method to measure the spatial distribution of microbial activity in an bioelectrode.
- Find which conditions limit the active surface area of an acetate-producing BES
- Address limitations in a 17L scaled-up BES

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Optimising electrochemical phosphate recovery

Nov 2022 - 2026

Researcher	Supervisor	Promotor
Simona Pruiti	Dr. Philipp Kuntke ir. Leon Korving	Prof. dr. ir. Cees Buisman

Motivation

Phosphorous (P) is a crucial and unreplaceable nutrient for human life. Nowadays, it is mainly extracted from phosphate rocks. Unfortunately, this source is a finite and non-renewable resource. Moreover, there are no substantial P reservoirs in the European Union (EU). For these reasons, the EU declared this element a critical raw material in 2014. In addition, P is also a major polluter, and its abundance in wastewater is relatively high. A solution that would solve both aspects is the circular use of phosphorus. However, newer and cheaper solutions are needed for P removal and recovery from industrial wastewater. Electrochemically induced calcium phosphate precipitation is a suitable way to achieve that. This technology is particularly appealing for wastewater where P is close to saturation and the salinity is high (i.e., cheese wastewater).

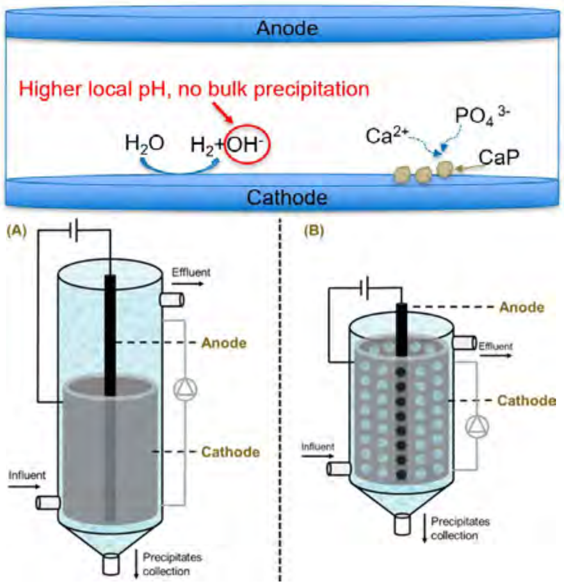
Technological challenge

This novel technology can induce calcium phosphate precipitation thanks to the higher local pH created at the cathode by the hydrogen evolution reaction without dosing any chemicals. The feasibility of electrochemical phosphate recovery has already been proven on a laboratory scale using real cheese wastewater and non-precious metal cathodes. However, the following issues need to be addressed to scale up the technology:

- Avoid chlorine evolution
- Reduce the energy consumption of the cell
- Reduce the cost of the cell
- Find a suitable way to collect the product in continuum.

To develop a pilot to treat cheese wastewater with our industrial partners and finally extend its usage to other wastewater streams, the following research questions are proposed:

- Are there ways to limit/avoid chlorine evolution and toxic product formation?
- What are the suitable electrode materials that reduce both capital and operation costs?
- What kind of cell design would allow for an effective and safe operation at the largest scale?
- Can this technology be expanded to other suitable industrial wastewater cases?



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Electrochemical nutrient recovery improvement and scaling prevention

June 2023 - 2027

Researcher	Supervisor	Promotor
Widya Iswarani	dr. Philipp Kuntke, dr. Tom Sleutels	Prof. dr. ir. Bert Hamelers

Motivation

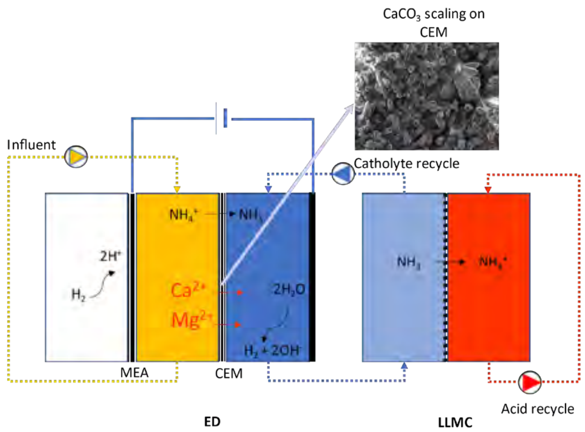
Agricultural productivity depends on the use of nitrogen (N), phosphorus (P) and potassium (K) fertilisers. However, the conventional production of these fertilisers is energy and resource-intensive and these fertilisers end up in waste streams. The production of fertiliser from (source-separated) wastewater, particularly through electrochemical systems (ES), offers significant benefits. ES can use renewable electricity and minimise the use of chemicals. Therefore, ES facilitate the recycling of nutrients to agriculture while minimising resource depletion and preventing environmental damage.

Technological challenge

The concept is proven, however inorganic scaling on the membrane still limits the application of ES on a larger scale. This project aims to mitigate unwanted inorganic scaling within the ES by investigating integrated chemical-free solutions. Improvements in cell design and operation are required to enhance circularity. Therefore, the use of fresh acids such as sulfuric acid or nitric acid in ES to separate ammonia from the concentrate stream will be limited in this project. In addition, the possibilities of ES for producing innovative sodium (Na^+) and chloride (Cl^-)-free pure fertilisers for agricultural use, such as NH_4NO_3 and K-rich streams, will be investigated.

In order to further improve electrochemical nutrient recovery to allow its integration into (source-separated) wastewater treatment, and at the same time, enhance its application in agriculture, the following research goals are proposed:

1. Apply chemical-free solutions to prevent inorganic scaling in ES.
2. Develop a model to predict scaling formation and optimise inorganic scaling prevention inside ES.
3. Reduce the chemicals (acid/base) required during ES ammonium recovery.
4. Design ES to effectively produce ammonium and potassium fertilisers (free of Na^+ and Cl^-).



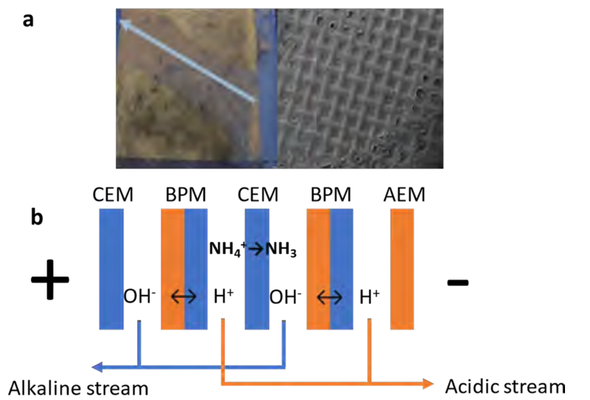


Figure 1. (left) Inorganic scaling of CEM in ES ammonia recovery. MEA: membrane electrode assembly, CEM: cation exchange membrane, ED: electrodialysis, LLMC: liquid-liquid membrane contactor. **Figure 2** (above) **a.** Inorganic scaling in CEM and spacers of ES. The arrow shows the direction of the flow. **b.** ES with possible production of acidic and alkaline streams. The possible use of these streams still needs investigation. AEM: anion exchange membrane, BPM: bipolar membrane.

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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.

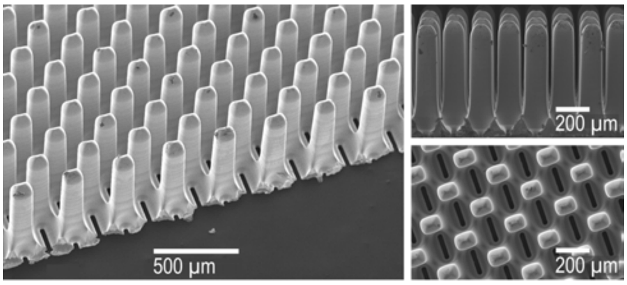


Fig 1. SEM images of the electrodes as provided by the manufacturer (Veco Precision BV).

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.

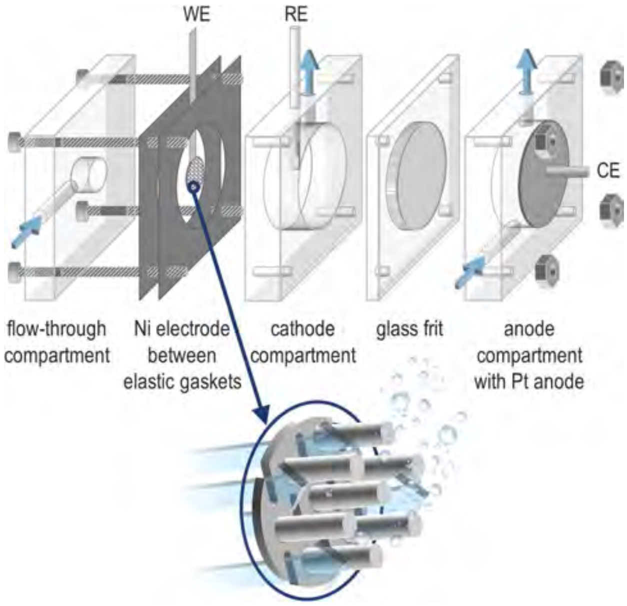
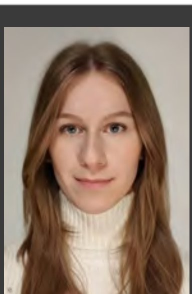


Fig 2. Experimental cell with a flow-through configuration for improved bubble detachment.



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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.

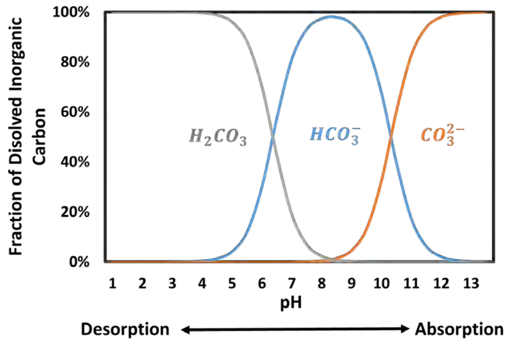

Fig. 1. Fraction of chemical species as function of the solution pH for the H_2O-CO_2 system at 25 °C.

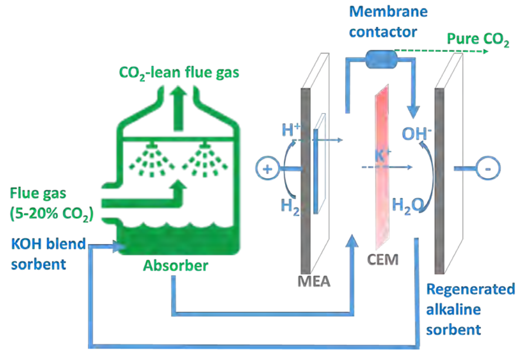

Fig. 2. Schematic illustration of the CO_2 capture process based on absorption in alkaline (KOH) blend and electrochemical regeneration.

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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Electrochemical Technologies for Resource Recovery

Nov 2022 - 2025

Researcher
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Collaborators
Dr. Annemiek ter Heijne

Motivation

With technological developments comes an increasing amount of waste streams which need to be treated before they can be safely disposed into the environment. Waste streams can range from gases that are toxic (H_2S) or attributing to global warming (CO_2) to dissolved compounds (NH_4^+) that cause eutrophication. To treat these waste streams, various technologies can be used. One of these techniques is electrochemistry, where electrical energy is used to increase reaction speed of reactions or stored as chemical energy. In electrochemistry, a catalyst can be integrated, such as a metal-based catalyst or a microbial catalyst, which can make the reaction occur even faster. The application of electrochemical techniques for the treatment of waste streams and recovery shows promise to work towards a more circular use of nutrients and materials.

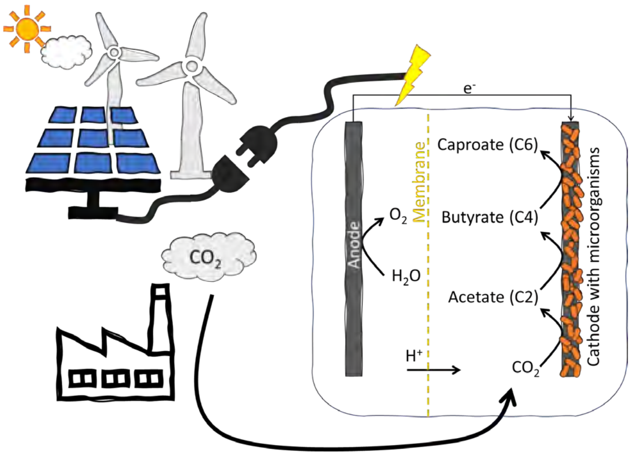

Figure 1. *Overview of bio-electrochemical system used for gaseous CO_2 recovery as volatile fatty acids, which can be used as precursor for food and chemical compounds.*

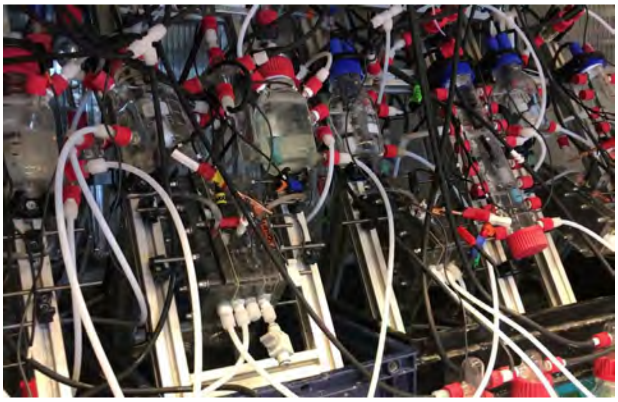

Figure 2. *Actual set-up of electrochemical systems as used in the laboratory.*

Technological challenge

Although promising, electrochemical technologies also offer several technological challenges that can be tackled. The conditions within the electrochemical cells are often unknown despite their important role in the process. Also in the field of catalysis, a great progress is yet to be made to find cheap and effective catalysts. More concrete, research aims that will be investigated are:

- Investigating local conditions inside (bio)electrochemical systems and understanding how these relate to performance
- Optimization of (bio)catalyst performance in (bio)electrochemical systems
- Investigation of biofilm structure properties and improvement thereof

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Biological Removal of Manganese as Pre-Treatment to Limit (Bio)Fouling in Oligotrophic Conditions

Environmental Technology

Sep 2023 - 2027

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Motivation

Manganese (Mn) is a common trace metal and a vital micro-nutrient for many organisms. Soluble Mn (Mn^{2+}) is naturally present in various water sources. When exposed to oxidizing agents (biotic or abiotic), Mn is oxidized to its insoluble forms (Mn^{3+} and Mn^{4+}), forming Mn oxides (MnOx). The accumulation of insoluble MnOx during water treatment can result in irreversible membrane fouling, recognizable by the black coloration of the fouling layers. Mn-oxidizing bacteria (MnOB) can remove Mn^{2+} efficiently and selectively under oligotrophic conditions (low carbon availability) by converting it into MnOx. Recent Wetsus research on a full-scale biological activated carbon (BAC) demonstrated that when MnOB grow as a biofilm on BAC granules, they continuously remove Mn^{2+} in oligotrophic conditions. This resulted in the likely protection of the reverse osmosis (RO) units placed after BAC from significant and irreversible biofouling. Therefore, this project aims to assess the effectiveness of using highly selective Mn biological removal as a common practice in various engineered systems to prevent irreversible fouling under oligotrophic conditions.

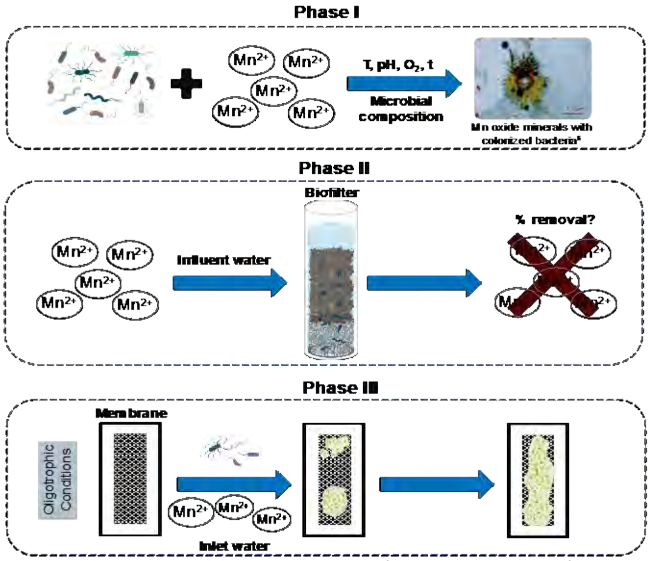


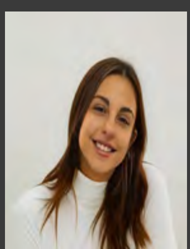
Fig. 1: Schematic representation of the three phases of the project.

Technological challenge

Implementing selective Mn biological removal as a pre-treatment before fouling-prone engineered systems (e.g., RO) presents challenges that call for a nuanced understanding of biological functions and system parameters. Optimizing Mn oxidation for efficient removal, considering the diverse water and treatment system characteristics, is crucial in preventing irreversible fouling in oligotrophic conditions. This must ensure cost-effective, long-term operability.

The project consists of three phases (Fig. 1): (I) exploring the dynamics/kinetics of biogenic Mn oxidation by mixed microbial consortia, (II) studying Mn removal in diverse lab-scale biofilters, and (III) understanding the fouling dynamics related to Mn in oligotrophic conditions.
The goals are:

- Determine the kinetics of biological Mn removal in various biofilters (in carbon-limited conditions), connecting with operational parameter influence (e.g., oxygen availability or pH).
- Design the proper biofilter for efficient water pre-treatment.
- Understanding Mn-induced fouling in several engineered systems (RO etc.) using models.



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Smell Out, Innovation In: Tackling Organosulfur with Bioelectrochemistry

Environmental Technology

June 2025 - 2029

Researcher	Supervisor	Promotor
Amin Ghaderikia	Dr. Ir. Sanne de Smit Dr. Rikke Linssen	Prof. Dr. Ir. Annemiek ter Heijne (UAB) Prof. Dr. Albert Guisasola

Motivation

Thiols (general formula R-SH) are toxic compounds with low odor thresholds and high corrosivity. They are predominantly found in fossil fuels and are also produced as byproducts in industries such as pulp and paper production and, wastewater treatment. Despite the clear need for effective thiol treatment, no strategy has yet been developed that is efficient, easy to implement, cost-effective, and environmentally sustainable.

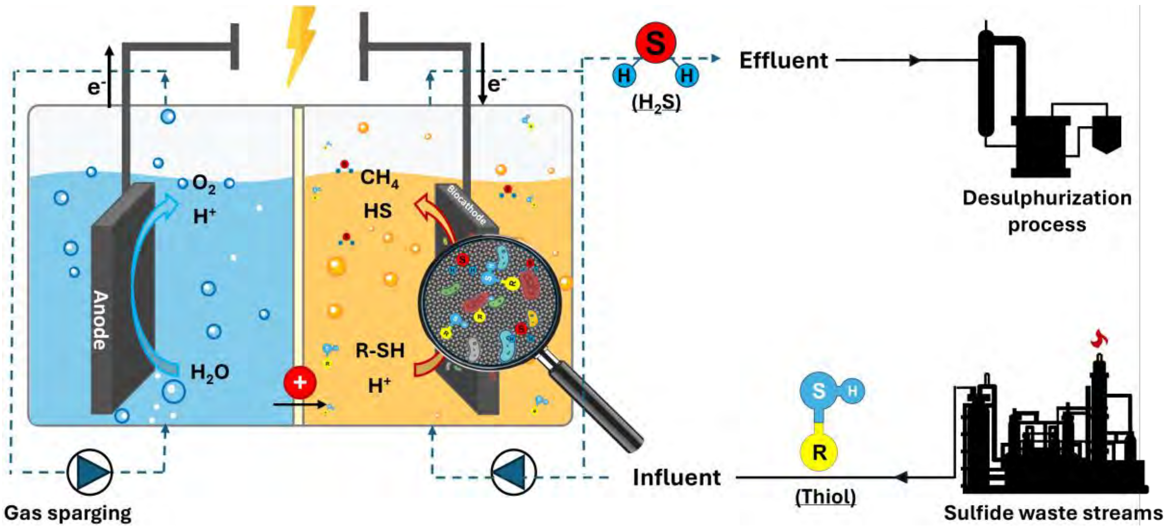
Bioelectrochemical systems (BES) have shown strong potential for the degradation of complex organic matter and the advanced treatment of organic pollutants, indicating that they may offer a novel approach for the removal of thiols.

Technological challenge

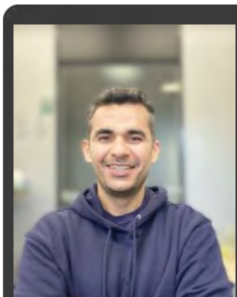
Bioelectrochemical systems (BES) are technologies in which microorganisms catalyze redox reactions at electrodes, enabling pollutant removal under sustainable conditions. Preliminary studies showed that a promising application of BES is the anaerobic degradation of organosulfur compounds at biocathodes, where thiols can be converted into hydrogen sulfide and methane However, the mechanisms governing thiol conversion at biocathodes remain poorly understood, hindering optimization and scale-up.

Research goals

- Develop a bioelectrochemical reactor and method for thiol detection
- Study bioelectrochemical and chemical thiol conversion pathways
- Assess long-term thiol degradation in BES
- Evaluate feed composition effects on thiol removal



Schematic overview of the bioelectrochemical system treating thiol



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WAGENINGEN UNIVERSITY & RESEARCH

Upgrading and valorizing vivianite recovered from sewage sludge

Oct 2025 - 2029

Researcher	Supervisor	Promotor
Yilin Yang	Dr. Ir. Thomas Prot Dr. Carlo Belloni	Prof. Dr. Ir. Annemiek ter Heijne Dr. Erik Kelder

Motivation

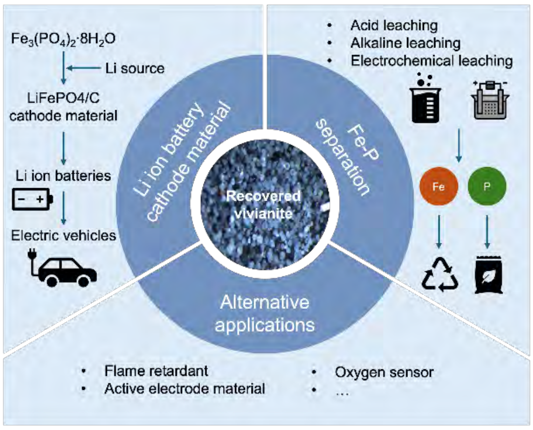
Phosphorus (P) plays a crucial role in both animals and plants; however, phosphorus rock is a finite resource and unevenly distributed globally. This creates a strong incentive to recover P from secondary sources such as sewage sludge. Over the past ten years, our research group has been at the forefront of recovering phosphorus from sludge in the form of vivianite ($Fe_3(PO_4)_2 \cdot 8H_2O$), a blue iron phosphate mineral that forms in anerobic environments such as digested sludge. Due to its paramagnetic properties, vivianite can be selectively extracted using magnetic separation.
This process, known as Vivimag™, has been patented, and the first demonstration-scale installation is currently being built with our industrial partners. For this technology to enter the market, value chains for the recovered vivianite must be developed. This project aims to develop valorization routes for vivianite, either by directly reusing it or by separately upgrading the Fe and P streams

Technological challenge

Vivianite magnetically recovered from sludge contains impurities, mainly organic matter and other divalent cations present in the vivianite crystal structure itself. Whether such impurities are favorable or unfavorable remains unknown and will depend on the chosen application. Hence, these impurities may influence the way we can valorize vivianite, which is the biggest challenge.
Two main valorization routes exist: (i) direct use of vivianite, such as precursor of lithium iron phosphate ($LiFePO_4$) cathode material, and (ii) separation of Fe and P, enabling circular reuse of Fe as a coagulant and recovery of P for fertilizer or chemical use. The role of impurities in these two routes may differ and cannot be generalized. For example, organic matter may serve as a useful carbon source in $LiFePO_4$ synthesis, whereas it could negatively affect leaching efficiency during Fe-P separation.

Research goals

The overall objective of this project is to develop valorization routes for recovered vivianite. Several options exist to reuse vivianite:
• Direct use: investigate the direct reuse of recovered vivianite as a precursor of $LiFePO_4$ cathode materials;
• Fe-P separation: develop separation routes that split vivianite into two streams, enabling reuse of Fe (e.g. coagulant) and P (e.g. fertilizer or P-products);
• Alternative applications: explore other novel applications based on its properties, for example flame retardants, oxygen sensors, or active electrode materials.



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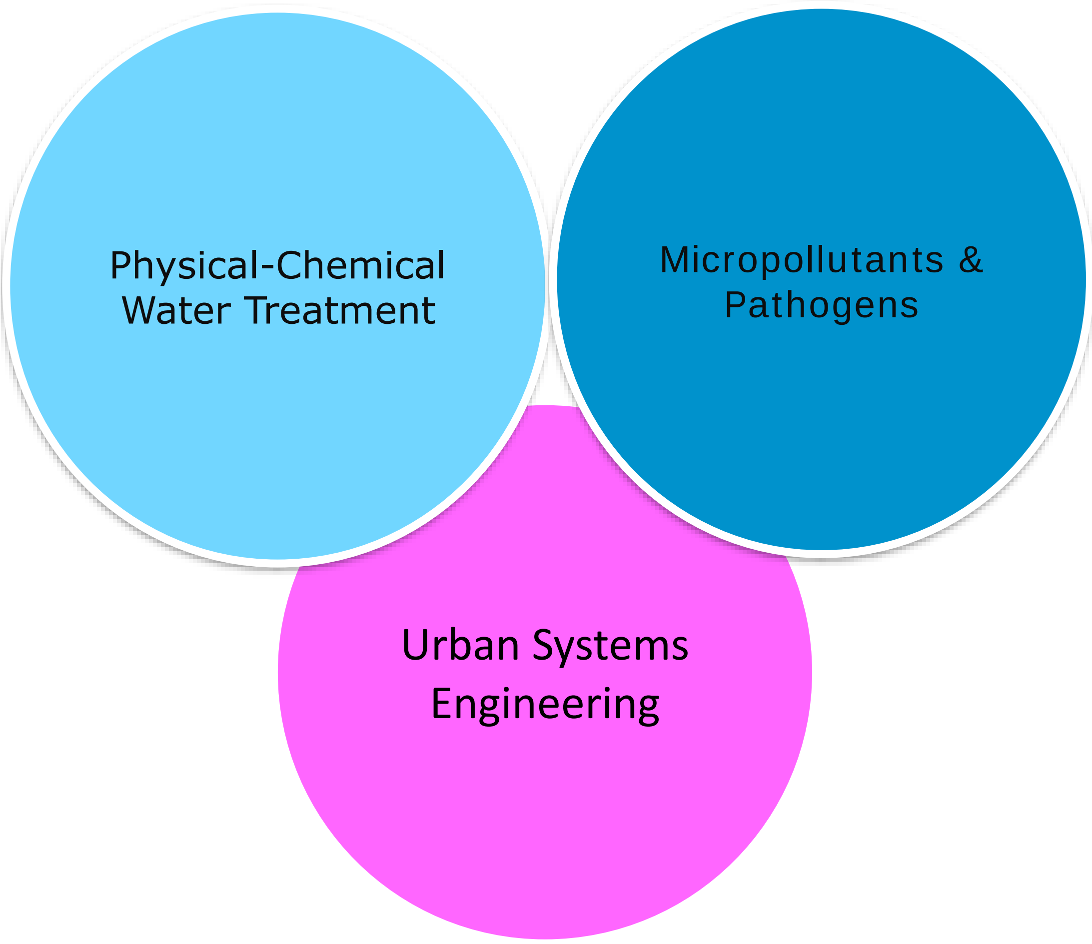
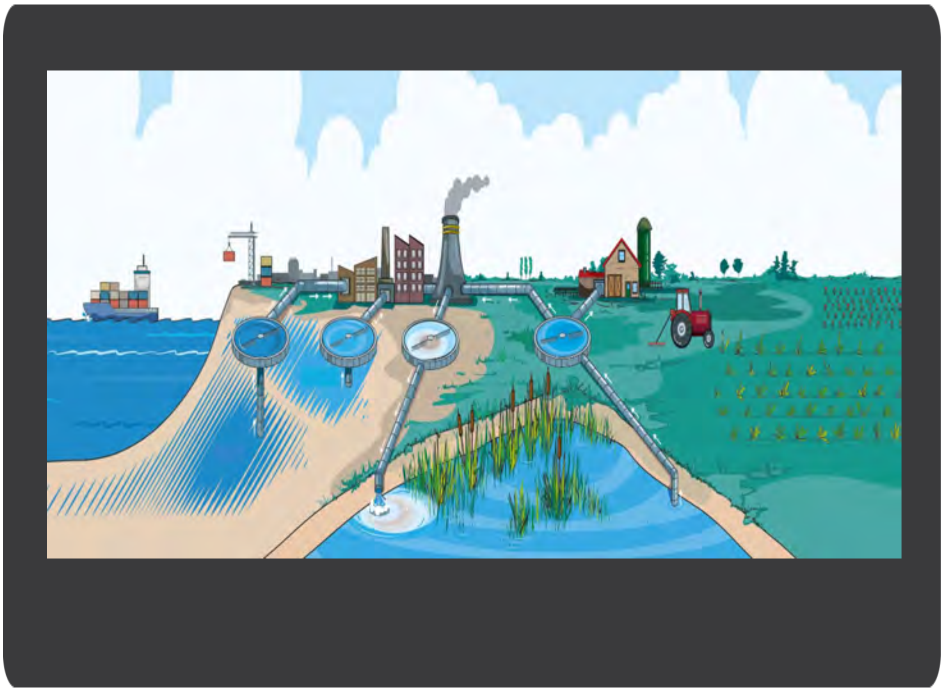
Environmental Technology

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.

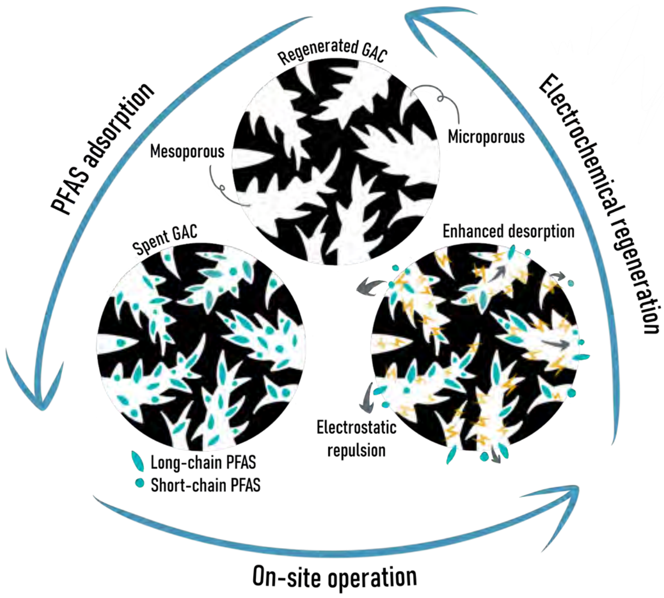
On-site electrochemical regeneration of activated carbon filters for PFAS removal

Nov 2024 - 2028

Researcher	Supervisor	Promotor
Hong Ting Au, Connie	Dr. ir. Sam Rutten Dr. ir. Jouke Dykstra	Prof. dr. ir. Albert van der Wal

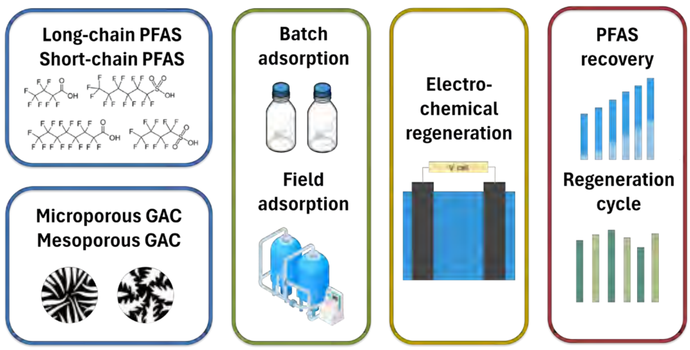
Motivation

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) are persistent and mobile pollutants that present significant challenges in water treatment. Long-chain PFAS have received considerable attention in academic research and health regulation. The increasing implementation of regulatory limits on the use of long-chain PFAS results in a worldwide shift to short-chain production. Current solutions, such as granular activated carbon (GAC) filters, demonstrate effective removal for long-chain PFAS but exhibit limited removal efficiency for short-chain PFAS. Furthermore, frequent off-site regeneration of GAC filters at elevated temperatures (>1000 °C) requires high energy and labour input. Therefore, developing alternative, sustainable, and, preferably, on-site regeneration technologies is required.



Technological challenge

This research explores a novel on-site regeneration technique for GAC filters, referred to as electro-regeneration. By applying an electrical charge to GAC filters, PFAS are desorbed through electrostatic repulsion. This approach aims to eliminate the need for thermal reactivation and significantly reduces the associated environmental impact. First, we use a dual-column system in which the carbon granules are sequentially subjected to adsorption and regeneration steps. Upon saturation of the GAC filters, an electrical current is applied, facilitating the desorption of PFAS. Afterwards, the carbon filters are considered regenerated and prepared for subsequent adsorption cycles. Improved cell configurations and process schemes will be developed. This iterative process offers a sustainable and efficient solution for PFAS removal.



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Removal of toxic amphoteric solutes in drinking water treatment by electrochemical polishing

Oct 2022 - 2026

Researcher	Supervisor	Promotor
Kaiyue Li	Dr. ir. JE (Jouke) Dykstra Dr. ir. Slawomir Porada	Prof. dr. ir. HHM (Huub) Rijnaarts Dr. ir. JE (Jouke) Dykstra

Motivation

Several weak acids, of which the valency is dependent on solution pH, such as boron, arsenic, and some micropollutants, can be toxic even at low concentrations. The presence of these solutes challenges traditional membrane-based water treatment technologies since these small solutes are, at environmentally relevant pH conditions, present in uncharged form.

In this project, a chemical-free polishing technology will be developed, which can be applied after conventional treatment steps, and consequently it remove these amphoteric species. Besides, a model will be proposed to explain the mechanisms behind the removal process with a logically consistent theory.

Technological challenge

Weak acids have a valency that is pH-dependent (see Fig. 1), which creates issues for conventional membrane-based separation technologies. Membrane separationis based on two mechanisms: charge repulsion, which leverages electrostatic force to repel particles carrying an opposite charge to the membrane, and size exclusion, which utilizes the membrane's micropores to filter particles.

For example, boron remains uncharged as B(OH)3 in surface water with a pH between 7 and 8 (see Fig. 2A), making it difficult for the membrane to block the transport based on charge repulsion. Besides, not carrying an electric charge implies a small hydration shell of the molecules, leading to poor size exclusion and low removal rates in membrane processes (see Fig. 2).

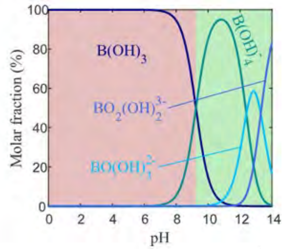

Figure 1 Speciation of boron as function of pH.

Research goals

We will study the effect of the interplay between pH dynamics, ion electrosorption, and transport phenomena in general and develop a theoretical model to explain the fundamental mechanisms for competitive electrosorption between the target components and salt ions in particular.

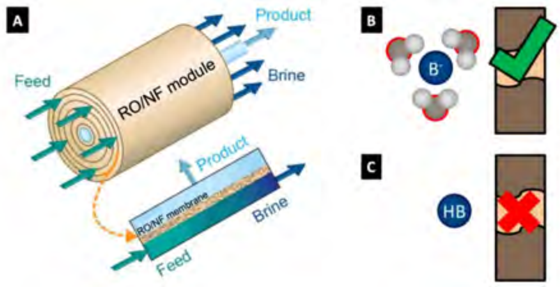

Figure 2. A) Reverse-osmosis and nanofiltration are pressure-driven separation technologies. B) Charged ions, in this case boron (B^-), are successfully rejected by the membrane, while C) uncharged solutes can pass.

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A Meteorological Exploration of Technology-Enhanced Atmospheric Moistening for more Precipitation

Mar 2023 - 2027

Researcher
Sarah Warnau

Promotors/Supervisors
Prof. dr. ir. Bert Hamelers, Dr. ir. Chiel van Heerwaarden, Imme Benedict Phd

Motivation

Freshwater scarcity is a pressing global issue, driven by several processes, including land use change, global warming and regional climate change, and the increase in demand due to population growth. Water conservation strategies play an important role in alleviating the stress on the freshwater resources. However, there is a point where these measures alone may be insufficient. In certain regions, there is a fundamental scarcity of freshwater. In these situations, an input of freshwater is needed. With the Natural Water Production theme at Wetsus, we are looking into *Technology-Enhanced Atmospheric Moistening* (TEAM) by efficiently evaporating sea water with the goal of enhancing rain regionally as a new way of increasing freshwater availability.

Technological challenge

The state of the atmosphere is driven by large scale systems (synoptic) and diurnal and seasonal changes in incoming solar radiation, affecting the regional energy and water balances, and thus the evaporation rate of the technology. This affects the growth and the composition of the Atmospheric Boundary Layer (ABL), the lowest layer in the atmosphere that is directly affected by the surface of the earth. For clouds to form and develop moist air from the surface needs to be lifted, which can be done by convection and growth of the ABL, and by lifting of the ABL, e.g. by passing over a mountain range.

Using an evaporation technology can not only affect the moisture content of the ABL, but also the temperature and stability. This interaction between the meteorological conditions and the evaporative flux of the technology make the design and implementation of TEAM for more rain a challenge. On top of that, the atmospheric response to TEAM in the form of rainfall (more rain, less rain, or no response) depends on the location, the daily conditions, and the type of technology that is used for evaporation.

This project aims to unravel the interactions between the TEAM technology and the atmosphere from the ABL to the regional scale (Figure 1) and identify regions where TEAM has a high potential for freshwater production.

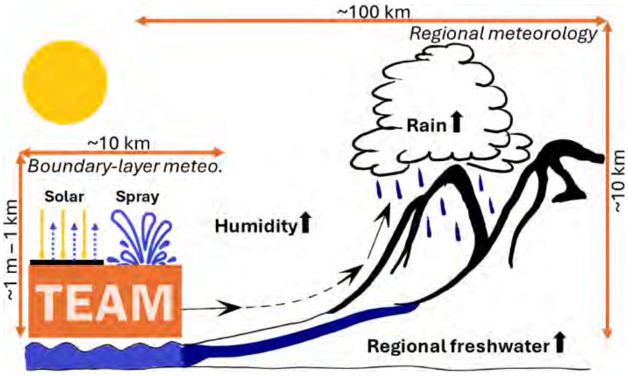
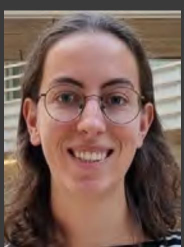


Figure 1: Graphical abstract of TEAM for more precipitation. Two main research fields are boundary-layer meteorology, concerning the local interactions of the TEAM technology and the atmosphere (left) and regional meteorology concerning the transport of the water vapor and deep convective processes (right). From Warnau et al. (2024, under review)

Ref: Warnau, Sarah, Gholammabas Sadeghi, Jolanda Theeuwen, Imme Benedict, Hubertus Hamelers, and Chiel van Heerwaarden (2024). "Technology-Enhanced Atmospheric Moistening (TEAM) for More Precipitation: A Perspective [UNDER REVIEW]".



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Efficiency and mechanism of intermittent reductive/oxidative defluorination of PFAS

Nov 2022 - 2026

Researcher	Supervisor	Promotor
Shuhao Liu	Dr. ir. Harry Bruning Dr. ir. C.H.M. Hofman	Prof. dr. ir. Huub Rijnaarts

Motivation

Nowadays per- and polyfluoroalkylated substances (PFAS) have caused broad attention due to their widely existence in the environment, persistence, bioaccumulation, and potential health risks. However, PFAS are highly resistant to conventional wastewater treatment due to their exceedingly stable C–F bonds.

As shown in Fig. 1, through traditional reductive or oxidative destructive techniques, PFAS can be degraded but not be completely defluorinated, which will cause the formation of fluorine-containing by-products with even greater toxicity. The produced fluorotelomers ($C_nF_{2n+1}-(CH_2)_m-X$) show high recalcitrance against further degradation during reductive defluorination processes, while hydroxyl radical (HO•) produced during oxidative processes can convert fluorotelomers into perfluorocarboxylates (PFCAs).

Based on these information, this PhD project aims to realize intermittent reductive and oxidative conditions through the combination of electrochemical, chemical and UV/VUV processes to develop new combinations of treatment technologies and find some strategies for the deep degradation and defluorination of PFAS.

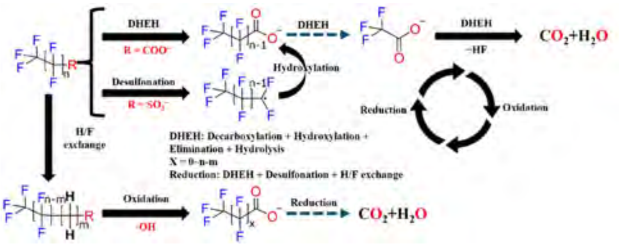

Figure 1 The degradation and defluorination of PFAS

Technological challenge

Complete defluorination is very difficult to realize just by single means of oxidation or reduction. To achieve the deep degradation and defluorination of PFAS, we propose two possible combinations of treatment technologies to realize intermittent reductive and oxidative conditions for the gradual defluorination of PFAS.

In the first scheme, we propose a circle of the UV/VUV/sulfite reductive process and the UV/VUV/H_2O_2 oxidative process, artificially controlling the structures of intermediate products and realize the further defluorination of PFAS degradation intermediates. The main challenge here is to control the mutual transformation of reduction and oxidation environment. Besides, to ensure the accuracy of the results, it is necessary to account for losses of PFAS by adsorption to reactor materials.

In the other scheme (Fig. 2), based on an electrochemical system, intermittent reductive/oxidative defluorination of PFAS is achieved by the circulation through the cathode and the anode compartments. According to literatures, the adsorption of PFAS by the electrode, especially the anode is not negligible. The main challenge here is to quantify the adsorption and desorption of PFAS during the circulation and to find some strategies to decrease the influence.

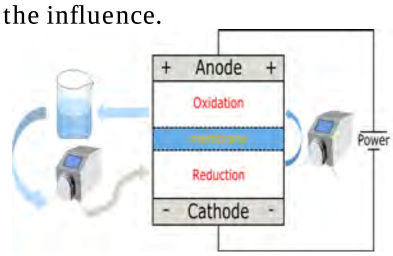

Figure 2 The process of the electrochemical system

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Modelling Dynamically Operated Biological Activated Carbon Filters

Apr 2024 - 2028

Researcher	Supervisor	Promotor
Advait Gangal	Dr. ir. Jouke Dykstra Dr. ir. Maarten Biesheuvel Dr. Amanda Larasati	Prof. dr. ir. Bert van der Wal

Motivation

Biological Activated Carbon (BAC) filters have been noted for their ability to remove organic micropollutants (OMPs), compounds that can be harmful to human and environmental health. The augmentation of biological activity to the usual adsorption process in granular activated carbon filters potentially opens up new avenues of OMP removal, which remain poorly understood within an integrated biofilter such as BAC.

This project aims to assess the validity and impact of some or all of these removal processes in BAC filters, and to construct a model that integrates these processes in a dynamic operation so that the performance of BAC filters may be optimised.

Technological challenge

There are likely several processes involved in OMP removal in BAC filters:

- Adsorption onto GAC
- Direct metabolism by microbes
- Co-metabolism with DOC by microbes
- Sorption into the biofilm
- Oxidation by captured Mn oxides in the biofilm

But it remains unclear which of these processes affect significant removal of OMPs in this integrated system, and to what extent.

Additionally, the nature of the OMP removal is unknown as well – do the converted products retain the toxicity of the original OMPs? If so, the removal is not actually effective.

For these reasons, the project seeks to understand each individual process in the context of BAC filter conditions and assess its pertinence to both ineffective and effective OMP removal. For example, a simplified representation of OMP oxidation by Mn oxides can be seen in Figure 1.

The interplay between these processes can then be considered. For instance, biodegradation may partially remediate used sites in the GAC, allowing fresh adsorption again.

The aspirational goal of this project is to integrate relevant processes into one dynamic mechanistic model that can reliably predict and optimise the performance of BAC filters.

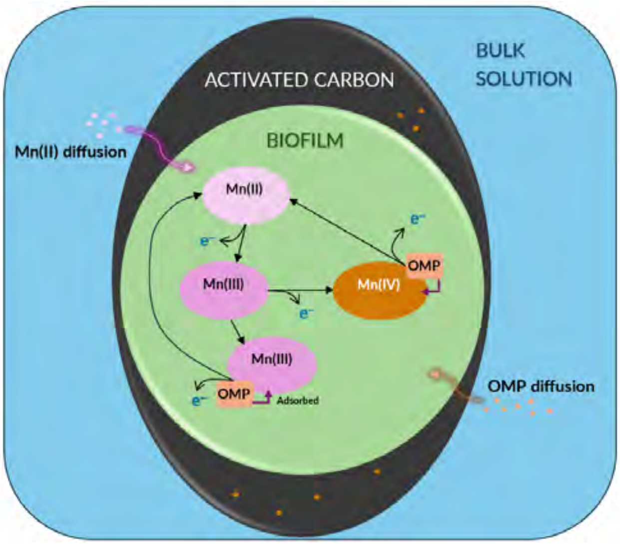

Figure 1: Schematic of OMP oxidation by Mn oxides [Mn(III) and Mn(IV)] in a BAC filter

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Biorecovery and Applications of Biopolymers from Wastewater

Reusable Water

Environmental Technology

November 2021-2025

Researcher
Berke KISAOĞLAN

Supervisor
Assist. Prof. Dainis Sudmalis
Dr. Cristina Gagliano

Promotor
Prof. Dr. ir. Huub Rijnaarts

Motivation

Synthetic flocculants are often applied in coagulation/flocculation process to trigger agglomeration of destabilized particles. A major concern associated with synthetic flocculants is their environmental impact. Promising natural alternatives are extracellular polymeric substances (EPS), due to their ability to bind cations and organics. EPS-derived bioflocculants can be produced whilst treating wastewater by open mixed microbial cultures, thereby offering an environmentally friendly and cost-effective way for synthesis.

Technological challenge

EPS are secreted by microorganisms in their natural environment for several purposes such as adhering to the surfaces, storing nutrients, and retaining water. They contain polysaccharides and proteins as main components. EPS production can be stimulated by environmental stress (**Fig 1**). It can be achieved with single or mixed carbon sources, pure or mixed microbial cultures and under sterile or non-sterile conditions. Depending on the purity, EPS can be applied in several fields such as food, health, and water treatment.

In this research, EPS production will be achieved by utilizing wastewater as a nutrient source. Mixed microbial communities will be employed for EPS production under non-sterile conditions (**Fig 2**). This is accompanied by several challenges including:

- Long-term operation of EPS producing membrane bioreactors
- Extraction and characterization of produced EPS
- Application of EPS as natural flocculant and understanding the flocculation mechanism of EPS
- Investigating the changes in the microbial community during the EPS production process

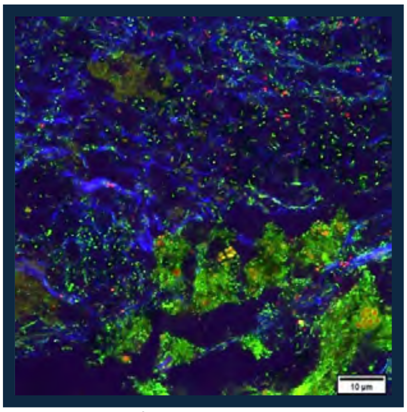

Figure 1*. CLSM image of mixed liquor sample taken from EPS-producing bioreactor run under nitrogen limitation. The sample was stained with fluorescent dyes to show individual components of EPS; Sypro Orange (green, proteins), Calcofluor white (blue, polysaccharides), Syto 63 (red, DNA).*

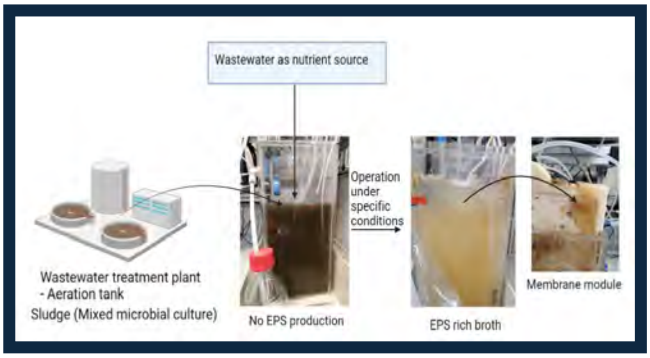

Figure 2*.Changes of membrane bioreactor inoculated with aerobic mixed microbial culture during EPS production process. EPS production starts under specific process conditions (nitrogen limitation coupled with short solid retention times). During the production mixed liquor becomes viscous as a sign of presence of EPS.*

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WAGENINGEN UNIVERSITY & RESEARCH

Making biodegradable microbial flocculants (EPS) from wastewater

May 2024 - 2028

Researcher	Supervisor	Promotor
Bohan Chen	Dr. ir. Dainis Sudmalis Dr. Carlos Contreras-Davila	Prof. dr. ir. HHM (Huub) Rijnaarts

Motivation

Synthetic flocculants such as polyacrylamide are widely used in (waste)water treatment due to their good flocculation capacity. However, these synthetic flocculants derived from fossil fuels cause environmental issues like a high carbon footprint and potential eco-toxicity. Extracellular polymeric substances (EPS), microbially-secreted polymers from activated sludge, exhibit properties like high molecular weight, non-toxicity, and biodegradability. Therefore, EPS is considered a sustainable alternative to synthetic flocculants. This project aims to investigate the underlying mechanisms of EPS production and flocculation, and apply EPS in real flocculation scenarios.

Technological challenge

The flocculation capacity of EPS is strongly affected by its properties like molecular weight and charge density. Although EPS with good flocculation capacity can be overproduced in activated sludge, what we don't know yet is how to regulate EPS properties to enhance its flocculation performance. EPS properties can be regulated by adjusting the operation condition of bioreactors. Understanding the relationship between operation conditions and EPS properties will provide us guidance in overproducing EPS with required properties.

Although EPS have shown good flocculation performance in lab-scale tests, the feasibility of EPS in real flocculation scenarios remains uncertain. The colloid properties and water chemistry in real flocculation scenarios which are more complex than that in lab-scale tests will affect the EPS flocculation performance. To enhance EPS flocculation performance in real flocculation scenarios and promote EPS outperforming synthetic flocculants, the mechanisms of EPS flocculation need to be investigated.

Research goal

As shown in Figure 1, we will regulate the yield and properties of EPS by adjusting the operation conditions of bioreactors, and explore the effects of EPS properties, colloid properties, and water chemistry on EPS flocculation performance and the mechanisms thereof. Corresponding strategies will be applied to enhance EPS flocculation performance. A case study will be carried out to evaluate the feasibility of EPS in real flocculation scenarios.

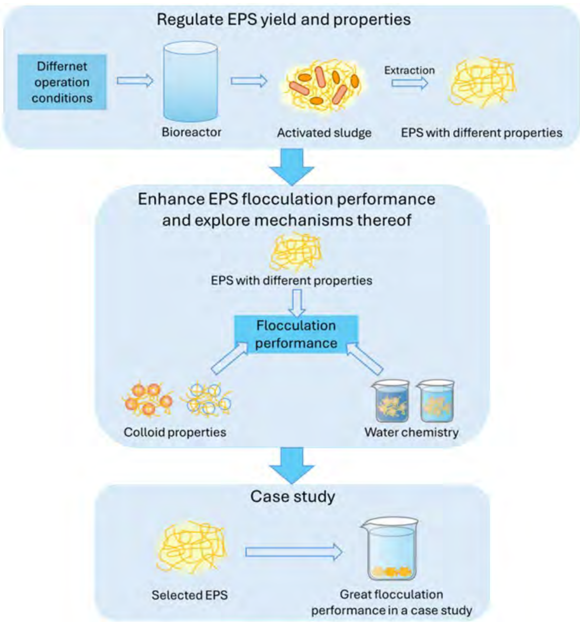
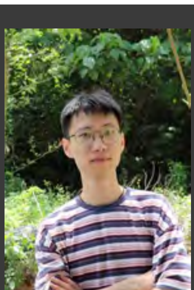


Figure 1. The schematic diagram of the process in this project.



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High-recovery & Chemical-free Desalination Using Electrodialysis Metathesis

May 2022 - 2026

Researcher	Supervisor	Promotor
Kecen Li	Dr. ir. Harry Bruning Dr. ir. Jan Post	Prof. dr. ir. HHM Rijnaarts

Motivation

Ascending water scarcity permits desalination for additional water supply. Membrane desalination is mature and cost-effective. However, its water recovery is limited due to the oversaturation of 2:2 salts (e.g., $CaSO_4$, $CaCO_3$) in the concentrate, eventually leading to scaling. Antiscalant dosing or ion-exchange processes mitigate this limitation, but these measures have negative operational and environmental impacts. Alternatively, studies have proposed Electrodialysis Metathesis (EDM; Fig 1). The EDM process avoids oversaturation of 2:2 salts; instead, it concentrates highly soluble 1:2 (e.g., $NaSO_4$) and 2:1 salts (e.g., $CaCl_2$) separately. However, the process requires the addition of NaCl. For a chemical-free goal, we develop our a high-recovery desalination scheme, including EDM, but with electricity and source water as sole inputs.

Technological challenge

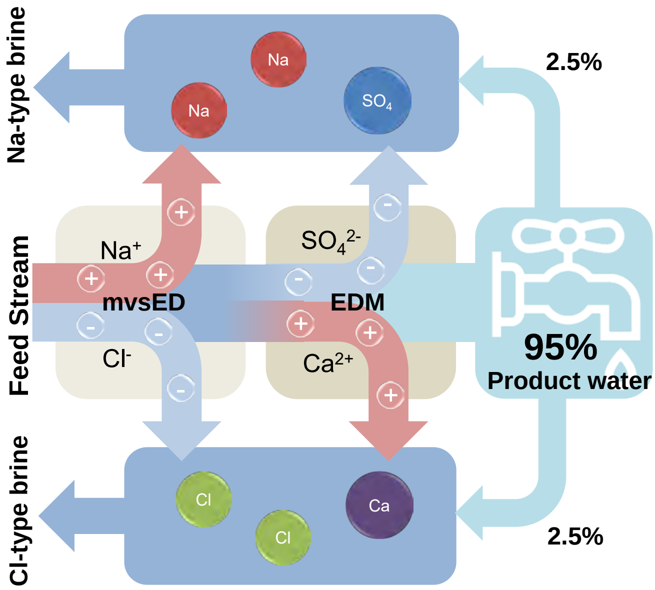
The process we propose consists of 2 steps. In step 1 monovalent ions migrate from the feed stream to form a 1:1 brine in a monovalent selective ED (mvsED) process. In step 2 divalent ions migrate from the feed to recombine with monovalent counter-ions from the 1:1 brine from step 1, forming a 1:2 brine (Na-type) and a 2:1 brine (Cl-type).

Regarding development and real-life applications, the main challenges are as follows:

➢ Without chemical additions, the source water's ionic composition fully defines the ability to rearrange ions into different brines, hence also the water recovery it can obtain.

➢ The scheme involves at least four types of ion-selective membranes which interact within the process. Essential are the properties of each of these membranes: e.g., counter-ion over co-ion selectivity, monovalent over divalent selectivity, water permeability.

➢ The process design is complicated since it includes multiple streams (feed, product, recycle, brines).



Research goals

Experimentally validating the performance of our concepts and investigating the optimum design and operational conditions for the various industrial applications (e.g., drinking water, oil, and membrane companies).

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Nanostructured electrode materials for selective ion recovery

Jan 2025 - 2028

Researcher	Supervisor	Promotor
Kaiyuan Zhou	Prof. dr. ir. Louis de Smet Dr. ir. Jouke Dykstra	Prof. dr. ir. Louis de Smet

Motivation

Selective ion separation and recovery are essential in water treatment and resources extraction: valuable elements (Li, Co, Ni) for electronic industry, nutrient elements (N, P) from agriculture and municipal wastewater, and heavy metals (Pb, Cd, Cr) in the industrial wastewater. Electrochemical ion separation technology like capacitive deionization (CDI) offers advantages in energy efficiency and environmental compatibility. But the solution mixing during regeneration and low capacity of the electrode limits CDI ion separation performance.

By applying circuit-switching and pulse voltage on a special ion shuttling electrode (orange electrode in Fig 1), electrochemical ion pumping (EIP) technology can achieve continuous ion separation, reduce energy consumption and dependence on high-capacity electrode materials. This project aims to develop novel ion-selective electrodes utilizing advanced materials based on EIP platform.

Technological challenge

Currently, research on EIP remains in early stage. Only a few studies based on EIP-like principles have been published, and mostly focused on feasibility and performance of specific cell configurations and material combinations. Ion selectivity has rarely been addressed, and the underlying mechanisms remain largely unexplored.

We expect that the library of electrode materials for EIP is potentially extensive. However, EIP electrodes exhibit dual functionalities—both electrode and membrane, which increases the complexity of EIP electrode fabrication and application.

The effectiveness of the EIP process is primarily determined by its electrode, which is structurally composed of electroactive, conductive, and supportive layer (Fig 2). Some advanced materials such as Prussian blue analogue (PBA) and MXene have been confirmed with tunable ion-selectivity, but whether these materials can be effectively adapted for EIP remains uncertain.

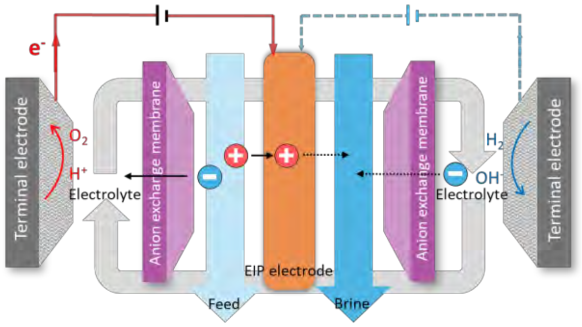

Figure 1. Working principle of simplest EIP system.

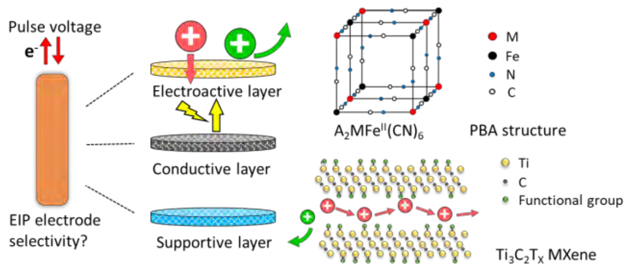

Figure 2. Composition of EIP electrode (left), PBA structure (right top), MXene structure (right bottom).

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Three phase flow behaviour of granular upflow anaerobic sludge blanket reactors

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.

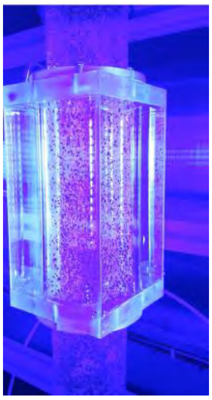


Figure 1 Experimental set-up for fluid flow visualization

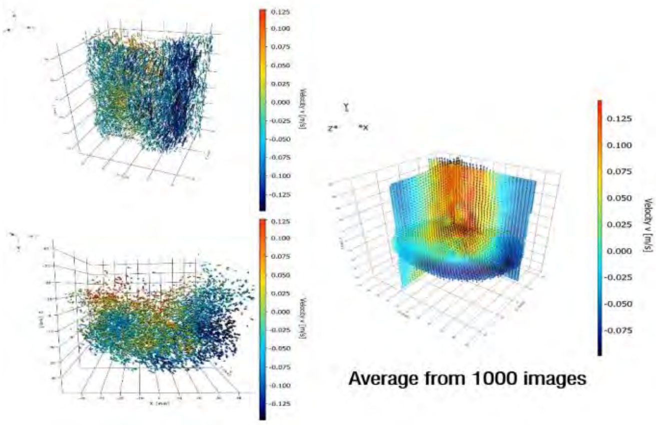
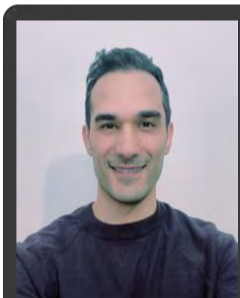


Figure 2 Time-resolved (left) an time-averaged (right) velocity distribution of liquid in the reactor

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.



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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.

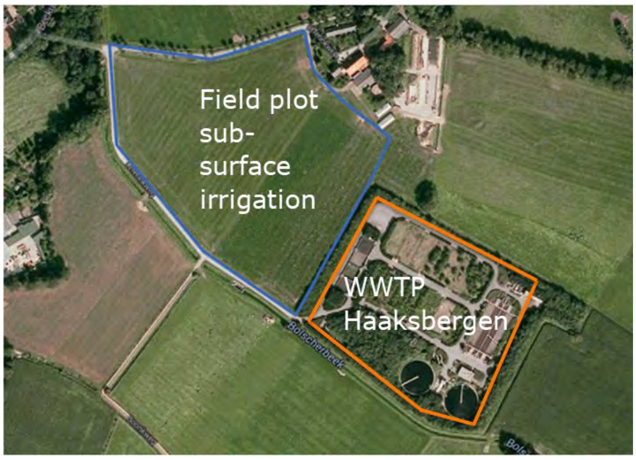

Figure 2 Field-scale pilots (lysimeter Qatar)

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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The influence of DOC quality on micropollutant biodegradation in drinking water aquifers

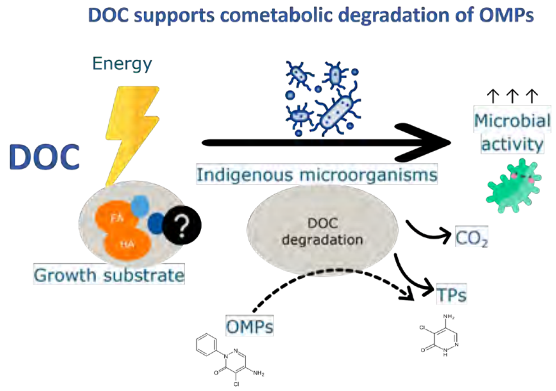
Oct 2022 - 2026

Researcher
Silvana Quiton Tapia

Supervisor
Dr. Nora B. Sutton

Motivation

In groundwater, Dissolved Organic Carbon (DOC) is used as main source of energy for microbial activity. As water infiltrates through the aquifer, some constituents of DOC are preferentially degraded by indigenous microorganisms. This results in a change of DOC quantity and quality that affects the overall microbial activity. However, in oligotrophic conditions, microbes also develop strategies in order to survive, like being able to consume different substrates at high substrate affinities (i.e. different DOC qualities and even organic micropollutants OMPs as carbon source). This metabolic flexibility allows the expression of a larger pool of catabolic enzymes that can boost *in-situ* biodegradation of OMPs.



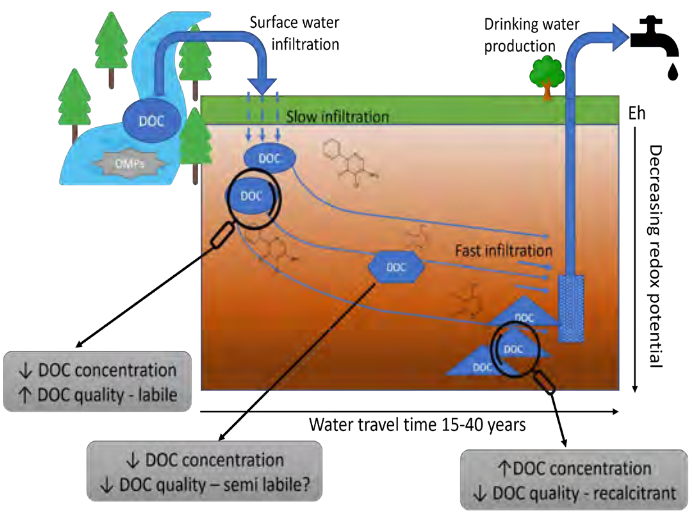
Technological challenge

We hypothesize that DOC quality is driving OMP removal. Therefore, we will characterize DOC quality by combining fluorescence spectroscopy and parallel factor analysis (PARAFAC). Understanding the relationship between microbial kinetics, DOC quality and OMP biodegradation will be paramount to provide an in-situ biodegradation strategy for drinking water aquifers.

Research goals

In this project, a series of microcosm studies aim to provide fundamental knowledge will be performed using field groundwater and microorganisms to address the following goals:

- Identifying changes in the DOC structure during its biodegradation
- Determining substrate affinity of different DOC (from labile to recalcitrant) for groundwater microbiome
- Identifying minimal threshold of DOC to induce OMP biodegradation
- Evaluation of in-situ oxygen dosing as an strategy to synergistically enhance OMP biodegradation with iron precipitation.



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Micropollutant biodegradation in municipal wastewater in synergy with covalent organic framework membranes

Oct. 2024 - 2028

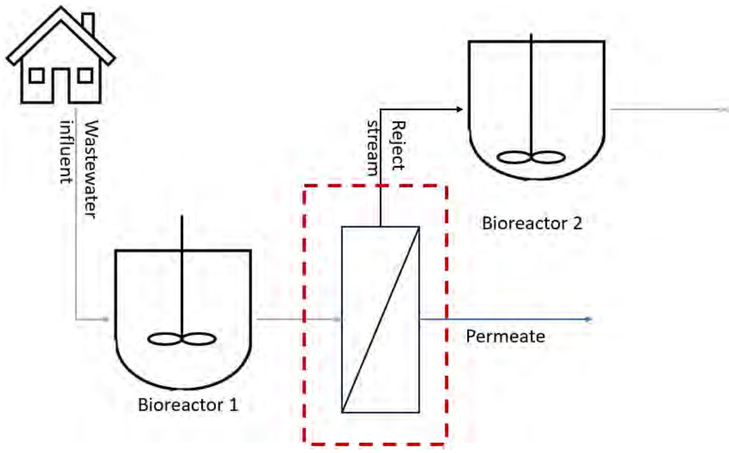
Researcher	Supervisors	Promotors
Nena Zwart	Dr. ir. A Asadi Tashvigh Dr. Dainis Sudmalis	Dr. Nora B. Sutton Prof.dr. JH Bitter

Motivation

Increasing amounts of organic micropollutants (OMPs) for instance, medicines, pesticides, PFAS, etc., end up in our wastewater. The OMPs pose a risk to public health and the environment when they are not removed. Current OMP removal methods are often energy-intensive, chemically intensive, or both. Another removal option would be the biodegradation of OMPs since this would lower the energy and chemical demand.

However, to improve the biodegradation the OMPs need to be concentrated with nanofiltration (NF) membranes. Developing Covalent Organic Framework (COF)-NF membranes could be a suitable option since the crystalline nature of such membranes gives high control over the characteristics, such as pore size and active groups.

The challenge is to make them suitable for membrane use without losing their highly crystalline nature. In this project, new NF membranes using COFs will be developed and integrated into a bench-scale wastewater treatment to look into the potential of COF-NF membranes and their effect on biodegradation, such as the effects of the OMP concentration and salinity on biodegradation. The figure below shows an overview of the envisioned system, where the municipal wastewater is treated in the first bioreactor, followed by an NF membrane to concentrate the OMPs, which are in turn treated in the second bioreactor.



Technological challenge

- Optimizing the synthesis of covalent organic frameworks.
- Develop NF membranes with the COFs and test the rejection of OMPs, salts, and dissolved organic carbon (DOC).
- Identifying the effect of reject streams on biodegradation

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Engineering of biological activated carbon (BAC) filters for micropollutant removal from wastewater effluent

Oct 2024 - 2028

Researcher	Supervisor	Promotor
Chenxiao Xu	Dr. Gabriel Sigmund Dr. Amanda Larasati Dr. M. Cristina Gagliano	Dr. Nora B. Sutton

Motivation

Micropollutants (MPs), including pharmaceuticals, pesticides, and industrial chemicals, are detected in surface waters globally at concentrations from pg/L to µg/L. Wastewater treatment plants (WWTPs) are a primary source of MPs, as inadequate MP removal during conventional treatment processes leads to their release into surface water through WWTP effluents. Recognizing these environmental risks, the European Union has updated the Urban Wastewater Treatment Directive for stricter MP removal from WWTPs. This highlights the need for sustainable and efficient quaternary treatment technologies. Biological activated carbon (BAC) filters are a promising technology to remove MPs from WWTP effluent before discharge. Across BAC granules, the MP removal results from a synergy between sorption and biodegradation (Fig. 1). MPs can be temporarily retained through sorption by activated carbon and biofilms, prolonging their biodegradation availability (Fig. 2). The subsequent biodegradation can regenerate partial sorption capacity, extending filters' longevity. However, the interdependent effects of sorption and biodegradation to MP removal remain largely unclear.

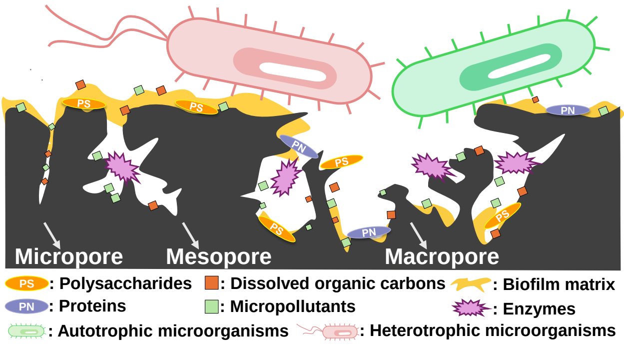


***Figure 1**. Illustration of the BAC granules surface.*

Technological challenge

For MP removal, BAC filters combine sorption, desorption, chemical oxidation, and biodegradation. Understanding the individual contribution of these mechanisms remains challenging. To maintain functional BAC filters and advance their applications, further investigations and fundamental insights into the contributions of these individual processes are needed. For instance, a critical challenge is decoupling the real MP retention time needed for biodegradation from the empty bed contact time (EBCT), as it directly affects MP removal. Elucidating the biodegradation pathways is also complicated due to the involvement of diverse extracellular enzymes. Moreover, varying operational parameters, such as oxygen dosing, can shape different microbial communities and biofilm characteristics, thereby influencing the long-term performance of BAC filters.

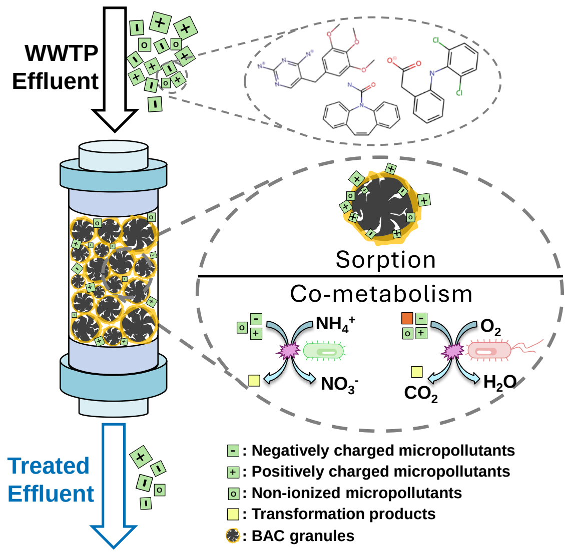
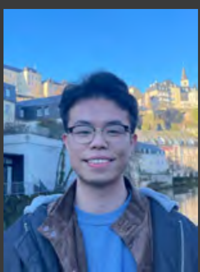


***Figure 2**. Main MP removal pathways in BAC filters*



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Biological treatment of organic micropollutants present in nanofiltration membrane concentrate

Jul 2022 - 2026

Researcher	Supervisor	Promotor
Claudia Rodriguez	Dr. ir. Dainis Sudmalis Dr. ir. Gabriel Sigmund	Prof. dr. ir. Huub Rijnaarts

Motivation

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

Wastewater treatment plants (WWTP) are considered as hotspots for the OMP release into the environment as they were not designed to include the removal of OMP. We are studying a new process that might significantly increase OMP removal by WWTP, without having to increase its footprint.

Recycling of the OMP to the WWTP's bioreactor increases the contact time and availability between the microorganisms and OMP, further increasing the chances of OMP biodegradation.
This study focusses on biodegradation of the OMP and the effect of recirculation of the OMP on the biological functions of the MWTP, i.e. oxidation of bulk organic pollutants, nitrogen removal and digestion of the waste sludge. Partners in our project are studying the (multi-layered) nanofiltration membranes that can selectively remove OMP. The treatment of the concentrate of these nanofiltration membranes is the topic of our study.

Technological challenge

- Perform several lab-scale experiments in reactors to identify removal mechanisms of OMPs in activated sludge reactors such as biodegradation, sorption or adsorption.
- Use different COD concentrations in the reactors or batch experiments to identify the effect on the degradation of OMP on the microbial activity.
- Identify the effect of recirculation of the concentrate in the reactors on microbial activity.
- Compare removal efficiency with others technological approaches such as membrane bioreactor.

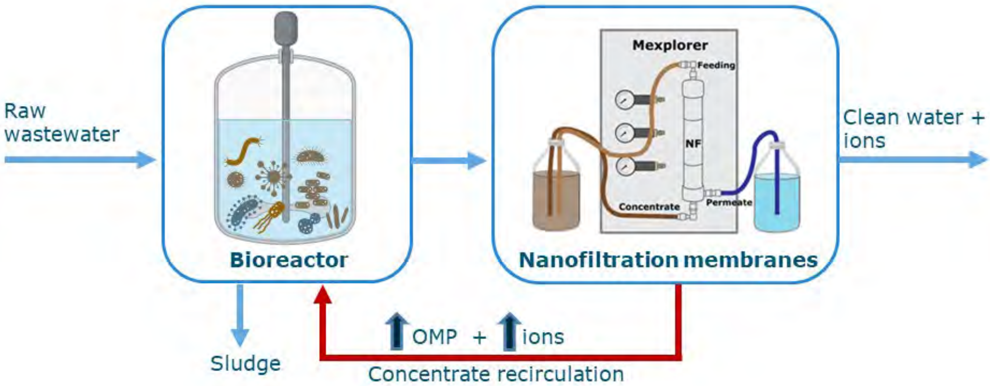

Figure 1 The proposed process, a combination of nanofiltration and biological treatment.

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No plastic to waste: Use microplastics to remove micropollutants

Apr 2020 - 2022

Researcher
Dr. Nora B. Sutton

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.

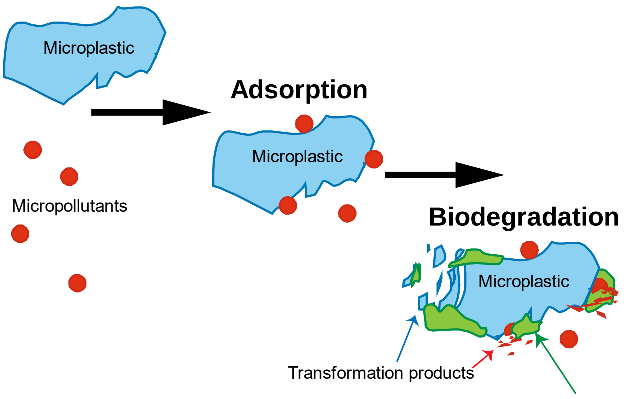

Fig. 1: Experimental approach to investigate the adsorption of organic micropollutants to microplastics and their biodegradation by microbial communities

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Engineering bioremediation of organic micropollutants in drinking water aquifers

Environmental Technology

Oct 2023 - 2027

Researcher	Supervisor	Promotor
Merel Nederend	Dr. Silvana Quiton Tapia Dr. Nora B. Sutton	Dr. Nora B. Sutton

Motivation

The majority of Dutch drinking water is produced from groundwater resources. The quality of drinking water aquifers is threatened by the presence of organic micropollutants (OMPs). To protect water security, it is essential for drinking water companies to find cost-effective ways to treat OMPs.

Technological challenge

Local flow rate is determined by distance from the extraction well (blue arrows, Fig. 1). This leads to variations in contact time between the indigenous microbial community attached as biofilms and the passing electron acceptors, dissolved organic carbon (DOC) and organic micropollutants.

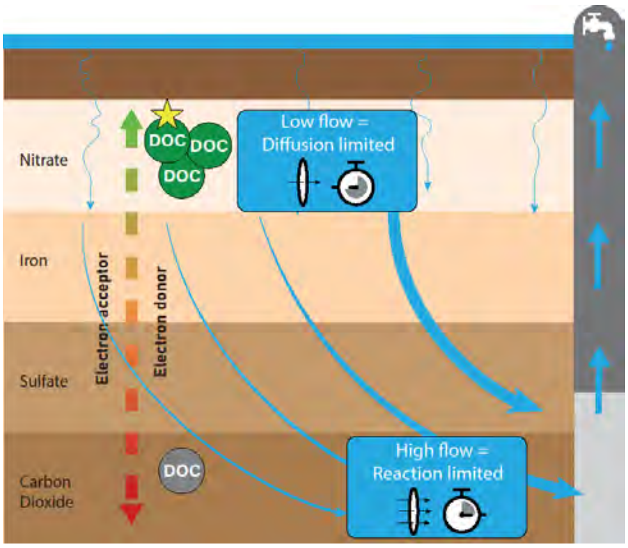

Figure 1 – Aquifer conditions become less favorable for OMP biodegradation with depth. Most labile DOC is consumed in the upper layer, as well as more favourable electron acceptors (oxygen, nitrate). Blue lines indicate heterogeneity in flow rates, with flow speeds increasing closer to the extraction well. At the well, the mixture of different flows is extracted as the raw resource for drinking water production.

Laboratory experiments (Fig. 2) and field work are combined to investigate the ways in which redox conditions, DOC and microbial diversity can be utilized to promote OMP biodegradation. Laboratory results are linked to reactive transport models to interpret the effect of flow and flux on OMP biodegradation.

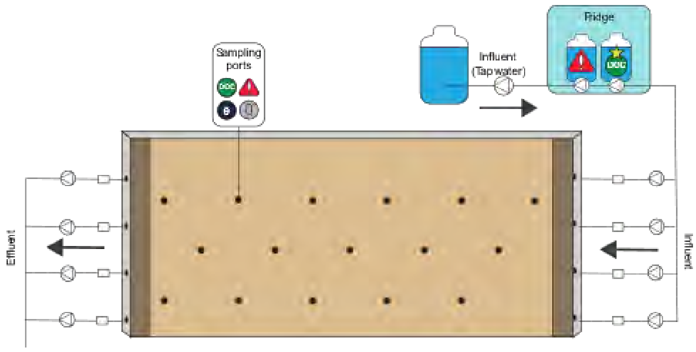

Figure 2 – Laboratory experiment set-up of the 2D flow reactor (130x80x15 cm) filled with sand and water (total liquid volume: ± 56 L). Electron acceptors, DOC, OMP and microbial community composition are measured at sampling ports. Flow is horizontal and influent is spiked tap water. Reactor is inoculated with groundwater. Both sides have an infiltration layer with gravel to redistribute in- and outflow. Retention time is ±3 days, with a flow of ±0.85 L/hour.

Research goals:

- Survey the biodegradation capacity of Dutch drinking water aquifers.
- Explore factors predicting the occurrence of OMPs at extraction wells.
- Operate a 2D-flow reactor to optimize OMP biodegradation under different conditions.
- Investigate the effect of DOC addition on extracted water quality.

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WAGENINGEN UNIVERSITY & RESEARCH

Using organic amendments to prevent pesticide leaching in soils

Reusable Water

Environmental Technology

Oct 2022 - 2026

Researcher	Supervisor	Promotor
Marija Gadžimuradova	Dr. Valentina Sechi Dr. Peter van der Maas	Assoc.prof.dr. Nora B. Sutton

Motivation

More than 2.4 million active pesticide ingredients are applied worldwide annually to control the occurrence of weeds, insects, and other unwanted organisms. European Union Directive 2020/2184 sets a limit of 0.1 µg/L for pesticides in the water intended for human consumption. Despite the regulations, one or more pesticides in concentrations above 0.1 µg/L are detected in 30 % of all EU water monitoring sites, posing hazard to humans and ecosystems. Alternative methods for pesticide removal from drinking water are imperative to protect human health.

Organic amendment (OA) application is an agricultural practice that increases soil nutrient and organic matter content. Additionally, organic residue application modifies the sorption behavior of pesticides. This effect has potential to enhance future pesticide transformation and reduce their transport through the soil profile. Thus, OA application for direct pesticide remediation in the soil is a promising approach to preventing water pollution.

This research aims to develop a fundamental understanding of factors responsible for the fate of pesticides in soil, as well as interactions between pesticides and organic amendments. Obtained knowledge will be used to propose soil management and organic amendment application guidelines for pesticide leaching prevention.

The main benefits would be:

- Obtaining nature-based solution for pesticide removal in soil.
- Preventing surface and groundwater pollution.

Technological challenge

- Accounting for the complexity and abundance of the physical, chemical, and biological interactions in the soil-water matrix.
- Accounting for the variable nature of the organic amendments, and pesticide intrinsic properties.
- Establishing the influence of soil management practices on pesticide environmental fate.
- Combining the obtained knowledge to propose soil management and OA application guidelines. OAs should first adsorb and then desorb the pesticide at the optimal rate for its degradation in soil.

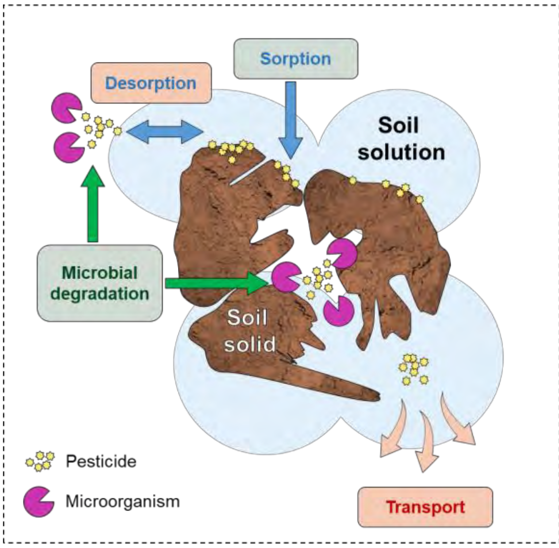

Figure 1. Schematic of processes governing pesticide fate in soil solution.

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WAGENINGEN UNIVERSITY & RESEARCH

Environmental Technology

Transformation and sorption of organic chemicals in the environment

Mar 2024 - 2028

Researcher	Supervisor	Promotor
Reiner Amir Yah	Dr. Nora B. Sutton	Dr. Gabriel Sigmund Dr. Steven Droge

Motivation

In the early stages of R&D for new pesticides, a mechanistic understanding of transformation and sorption processes is crucial for predicting their behavior in the environment.

This consists in understanding if pesticides are transformed to determine biodegradability and persistence as well as sorption to evaluate how they move through soil and water. Transformation and mobility parameters are key for assessing environmental fate and risks of pesticides.

The current methods used are time demanding, costly and form a bottleneck for the rapid evaluation of new compounds which delays the selection of promising safer candidate pesticides.

Therefore, this project aims to develop high throughput methods for transformation and sorption for pre-screening.

Technological challenge

- Use an *in silico* approach to identify key molecular properties that influence transformation and sorption to aid pesticide selection for experimental method development.
- Fungi are common in nature and essential for the natural degradation of pesticides. These produce stable exoenzymes with broad substrate specificity that can be extracted for degradability tests. We study how these exoenzymes can be used to develop suitable biotransformation assays to screen pesticides for biodegradability and persistence.
- Soil or organic matter packed HPLC columns can be used as an efficient method to determine sorption of pesticides. This method consists of injecting pesticides on a HPLC with inline detection can be used to quantify sorption and thereby environmental mobility of pesticides.

Research topics

This project is divided in an *in silico* study and an experimental phase (see Figure 1); focusing on the following:

- Assess which molecular properties influence transformation and sorption via an *in silico* approach and select compounds of interest.
- Evaluate the use of fungal derived exoenzymes to screen pesticides for biodegradability .
- Investigate the use of soil packed HPLC column to determine mobility of pesticides.

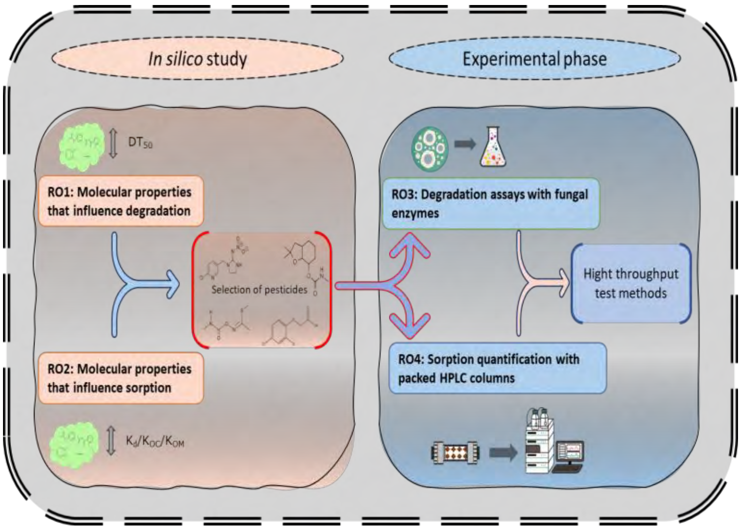

Figure 1. Scheme of the proposed research approach

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Environmental Risk Assessment Group - WenR

WAGENINGEN UNIVERSITY & RESEARCH

Enhanced soil passage stimulating organic micropollutant sorption and biodegradation

May 2024 - 2028

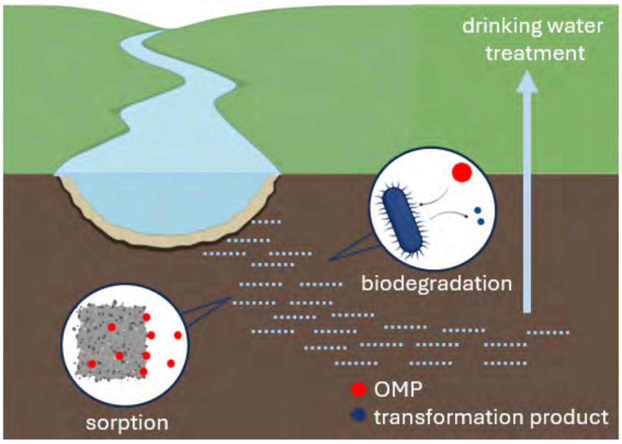
Researcher	Supervisor	Promotor
Anne van Dalen	Dr. Gabriel Sigmund Dr. Thomas Wagner	Dr. Nora Sutton

Motivation

Organic micropollutants (OMPs), like pharmaceuticals, pesticides, and industrial chemicals, are a threat to drinking water quality. Worldwide, a major part of drinking water is produced from surface waters. Surface water is especially vulnerable to OMP contamination by the release of wastewater treatment plant effluent and run-offs from agricultural land directly into surface waters. Current drinking water technologies cannot remove OMPs from surface water in a cost and energy effective way, so novel strategies are needed to optimize OMP removal in existing drinking water technologies.

Technological challenge

Existing technologies for micropollutant removal from surface water include soil passage, like riverbank filtration and managed aquifer recharge. Here, surface water is passed through soil and collected in a nearby drinking water well, after which the water is used for drinking water production. During soil passage, OMPs are removed by naturally occurring biodegradation and sorption. However, the majority of OMPs is not effectively removed, and non-degradable, harmful transformation products are expected to occur.



Research objective

The objective of this project is to enhance removal of OMPs and their transformation products during soil passage by stimulation and balancing of biodegradation and sorption. To do so, laboratory sorption and biodegradation experiments on small scale (batch bottle), medium scale (continuous flow column) and outdoor pilot scale will be performed and OMPs and their transformation products will be analyzed by LC-MS.

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The impact of salinization on the fate of antibiotic resistance in agricultural soil and nature-based irrigation water treatment

Nov 2023 - 2027

Researcher	Supervisor	Promotor
Yukun Xue	Dr. Thomas Wagner	Dr. Nora B. Sutton

Motivation

Human and veterinary overuse of antibiotics leads to increased risks to human health as a result of the spread of antibiotic resistance by antibiotic resistant bacteria that carry antibiotic resistance genes (ARGs). The use of manure and irrigation water containing ARGs potentially increases this spread of ARGs in farmland and surface water. In addition to this, stress caused by climate change may also affect the abundance, distribution, and risk of ARGs. Climate change results in salinization of agricultural soils and irrigation water, but the effect of this salinization on the spread of ARGs is not well understood. Therefore, it is necessary to better understand the spread of ARGs under saline water irrigation and to explore sustainable methods (microbial agents and constructed wetlands (CWs)) to mitigate ARGs enrichment in the (salinized) agricultural soil.

Technological challenge

To better understand the impact of salinization on the distribution and abundance of ARGs in the agricultural soil and the efficiency of the mitigation methods, I will perform four experiments.

- The influence of two microbial agents, *Bacillus subtilis* (a bacterium) and *Trichoderma harzianum* (a fungus) on the spread and abundance of ARGs will be evaluated in a microcosm experiment in which these are added to agricultural soil (Fig. 1a).
- The effect of varying salinities on the spread and abundance of ARGs will be evaluated in similar microcosm experiments. The microbial agent that demonstrates superior performance in Experiment 1 will be further tested to evaluate its efficacy in managing ARGs under salinity stress.
- Sixty-centimeter-deep soil columns will be used to determine the vertical distribution of ARGs in agricultural soils exposed to different saline irrigation levels (Fig. 1c). This experiment builds on the findings of Experiment 2 to provide deeper insights into how saline irrigation affects the vertical distribution of ARGs under influence of processes, such as leaching.
- The efficiency of CWs in removing ARGs and antibiotics from surface water under varying salinity levels will be evaluated (Fig. 1d). Different salinity levels in irrigation water will be tested, along with soil amendments in the CW substrates, to assess their impact on ARG and antibiotics removal.

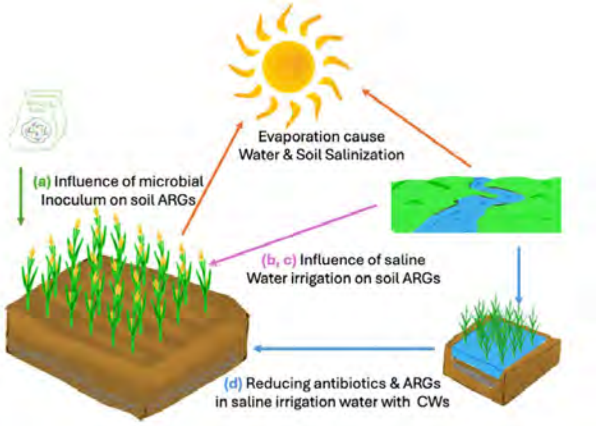

Fig 1. The focused parts in this project.

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Engineered nature-based systems to protect drinking water aquifers against organic micropollutants

Oct 2024 - 2028

Researcher	Supervisor	(Co)-Promotor
Han Liu	Dr. Roel J.W. Meulepas Dr. Ahmed M. Mahmoud	Dr. Nora B. Sutton Dr. Thomas V. Wagner

Motivation

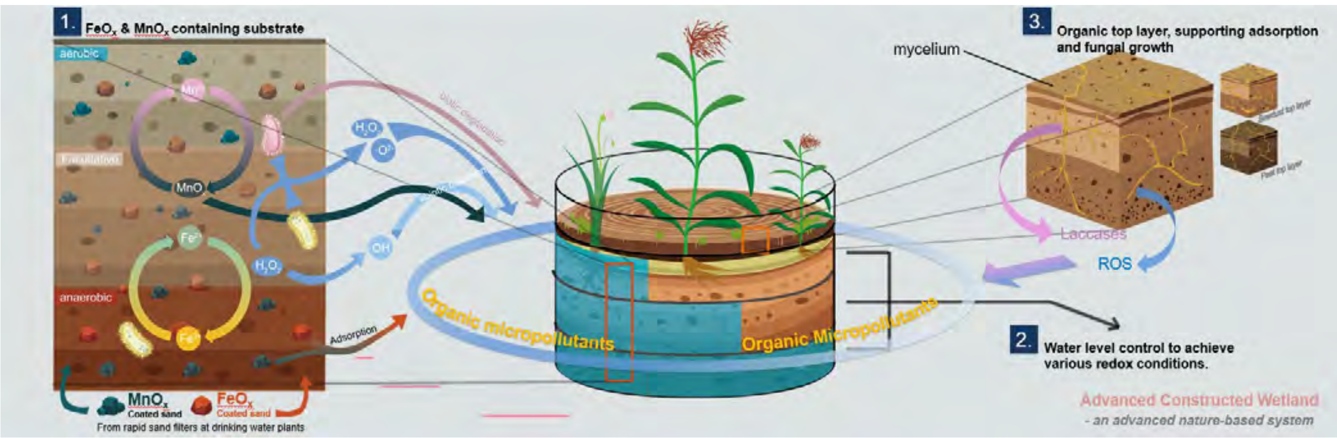
Approximately 60% of the drinking water in The Netherlands is produced from groundwater. However, to be able to extract enough groundwater in the future, there is a need to recharge groundwater aquifers with surface water. However, surface water contains OMPs and their introduction in groundwater should be prevented. For this purpose, natural surface water pre-treatment systems in the form of constructed wetland can be used to remove OMPs prior to surface water infiltration.

Technological challenge

The technological challenge of this study is to design a constructed wetland system with increased OMP removal efficiency based on the integration of biological FeO_x/MnO_x and an organic layer in/on the sandy substrate. The integration of FeO_x/MnO_x requires insights in the biological/physical and chemical processes that result in sorption, leaching, regeneration and biodegradation. This knowledge is needed to determine the most operational parameters for the FeO_x/MnO_x constructed wetland for optimal OMP removal.

Research objectives

- ***To quantify*** *the contribution of biodegradation, adsorption and chemical oxidation to OMP removal from surface water by biological FeO_x/MnO_x in constructed wetlands.*
- ***To identify*** *the impact of operational parameters, such as alternating aerobic/anaerobic conditions, on the adsorption and biodegradation of OMPs by biological FeO_x/MnO_x.*
- ***To determine*** *the impact of additional organic top layers and plants on biological FeO_x/MnO_x-mediated OMP removal in constructed wetlands.*



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Micropollutant uptake and transformation in constructed wetland plants

March 2025-2029

Researcher	Supervisor	Promotor
Selina Ilchmann	Thomas Wagner, Rumyana Karlova, Stefan v. Leeuwen	Nora Sutton

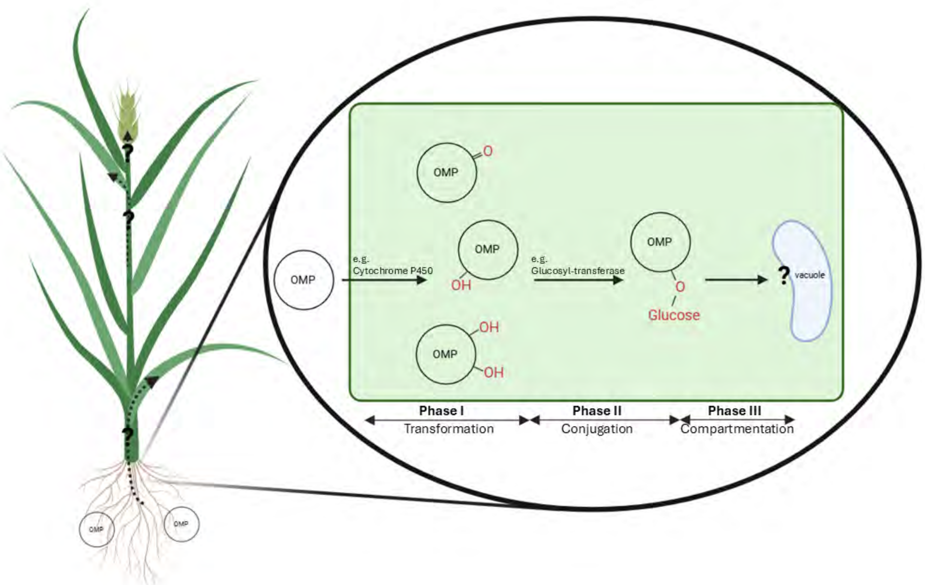
Motivation

Organic micropollutants (OMPs) are human-made chemicals that persist in the environment in very low concentrations (ng-µg/L) and pose risks to ecosystems and human health. Constructed wetlands (CWs) are increasingly studied as post-treatment systems for wastewater treatment plants effluent. They combine plant uptake, microbial biodegradation, and sorption to remove up to 80% of OMPs, while being energy-efficient. Once the OMPs enter plants, they act as xenobiotics that can cause abiotic stress by disrupting hormone balance, photosynthesis activity, and gene expression. However, plants may detoxify them through a three-step system involving transformation, conjugation, and sequestration.

Technological challenge

The objective of this research is to study the uptake and transformation in CW plants. Thus, only a few OMPs have been investigated and their transformation products (TPs) identified. Often, plants were divided in above and blow ground material, whereby little attention was paid to different plant tissues. Hence a more specific localization is missing. Although, some enzymes relevant for in-planta transformation have been shown, the holistic plant transcriptomic response and the plant's key drivers to this form of abiotic stress have not been illuminated yet. This research will contribute to pinpointing parent compounds and TPs final localization in the plant, elucidating their mode of transformation and transportation.

At the current phase of the project, we are optimizing protocols for high resolution mass spectrometry to detect OMPs and TPs from plant material in a targeted and untargeted approach. Additionally, plant development and phenotype are studied to identify ideal treatment parameters for RNA sequencing. The research is conducted with the model species *Brachypodium distachyon* and the CW plant *Phragmites australis*.



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Identifying transformation products after radical oxidation of triazole micropollutants

Environmental Technology

Nov 2025 - 2026

Researcher
Nikoline Marxen

Supervisor
Dr. Gabriel Sigmund

Motivation

Organic micropollutants (OMPs) are found in the environment at trace concentration (ng – ug/L), yet cause toxic effects on ecosystems and human health. Conventional wastewater treatment is not equipped to sufficiently remove OMPs, and even with advanced treatment processes many OMPs are not mineralized but instead form transformation products (TPs). These TPs can exhibit higher persistence, mobility, and toxicity.

Triazole compounds are a group of OMPs used as fungicides, pharmaceuticals, and in certain industrial chemicals. In the environment, triazole compounds exhibit direct toxicity towards aquatic organisms and are linked to the development and spread of antimicrobial resistance.

Technological challenge

Triazole compounds contain a 1,2,4-triazole ring (a 5-membered aromatic ring with three nitrogen and two carbon atoms), which is considered a persistent moiety. During degradation of triazole fungicides, TPs typically retain the triazole ring and form 1,2,4-triazole as a standalone compound. As a result, even when parent compounds are no longer detected, the toxic and persistent structure remains intact and can accumulate in the environment.

Oxidation processes using hydroxyl (OH•) or sulfate (SO_4^{-}•) radicals are increasingly used for OMP removal in advanced wastewater treatment. While several studies indicate that these oxidation processes can partially degrade triazole compounds, most of the identified TPs still contain at least one fully intact triazole ring. Additionally, the complexity of wastewater matrices introduces challenges such as radical scavenging and interference decreasing the efficiency of treatment.

Using suspect screening and target analysis with high resolution mass spectrometry (HRMS) and PatRoon (an R-based tool), TPs and degradation pathways can be identified. Additionally, studying the oxidation of 1,2,4-triazole as a standalone compound, may aid in understanding how ring opening and mineralisation can be promoted with oxidation processes.

Research Goals

- Compare degradation pathways and formation of TPs for triazole OMPs using OH• and SO_4^{-}•.
- Evaluate the ability of oxidation processes to mineralise the persistent 1,2,4-triazole ring.

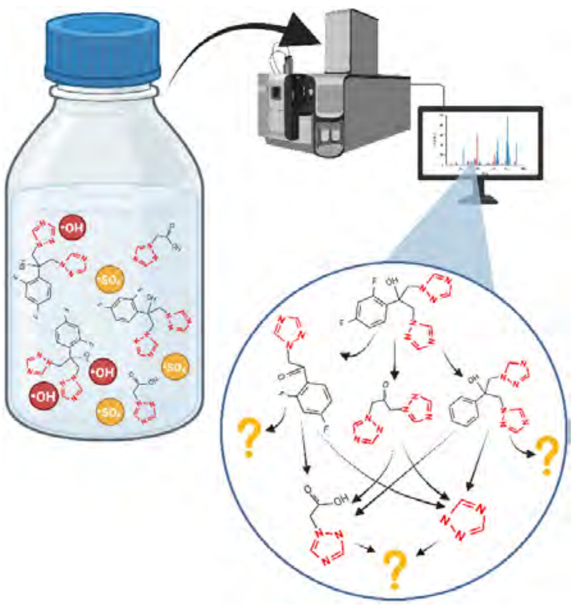

Figure 1 - Overview of the experiment with batch bottle oxidation treatments, HRMS measurements, and TP identification using R-based PatRoon

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Non-target screening for monitoring organic micropollutants and their transformation products in wastewater treatment

Dec 2025 - 2028

Researcher
Alessia Ore

Supervisor
Dr. Gabriel Sigmund,
Dr. Nora B. Sutton

Motivation

Organic micropollutants (OMPs) are not fully removed in conventional wastewater treatment plants (WWTPs). During treatment, OMPs can be fully degraded or transformed into transformation products (TPs) through biological and abiotic processes. While some OMPs are persistent, others degrade but may form TPs that are equally or even more persistent. As a result, the quality of WWTP effluents depends on both the influent composition and the treatment technologies applied. This is of interest not only because WWTPs are important point sources for OMP emissions into surface waters, but also because the reuse of treated wastewater is increasingly considered to address freshwater scarcity, particularly for applications such as irrigation.

Technological challenge

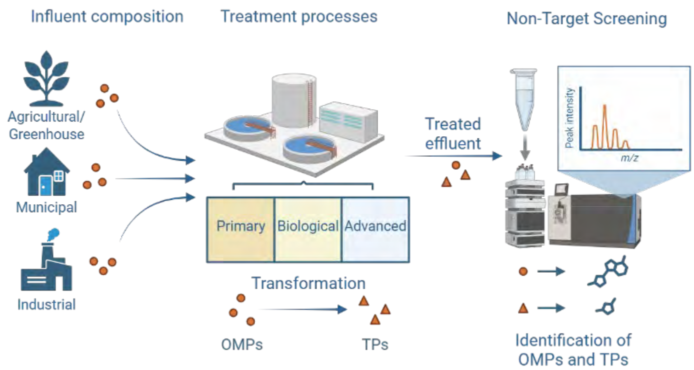
This project investigates how influent type and composition (municipal, industrial, agricultural, or mixed) and WWTP configurations influence the occurrence and formation of OMPs and TPs in effluents. Particular attention is given to persistent TPs formed during treatment and how their patterns vary across different treatment setups.

To achieve this, advanced analytical approaches based on non-target screening (NTS) using high-resolution mass spectrometry are applied and further developed. These approaches enable the detection of a wide range of known and previously unidentified compounds, providing a more comprehensive picture of OMPs and TPs in wastewater.

A key objective is to establish harmonized, WWTP-tailored workflows for sampling, sample preparation, and data analysis to ensure consistent and comparable results across sites.

The project involves six Dutch waterboards and multiple WWTPs across the Netherlands, allowing for a systematic comparison of different influent compositions and treatment technologies. These include conventional activated sludge processes as well as advanced treatment options such as ozonation and activated carbon, which are increasingly implemented to meet stricter regulatory requirements for OMP removal. Standardized sampling of influent, effluent, and intermediate treatment stages enables the assessment of OMP dynamics along the treatment train.

This research will provide new insights into the formation, removal, and persistence of TPs in wastewater treatment, supporting the design and optimization of advanced treatment processes and informing emerging policies aimed at reducing the release of harmful contaminants from WWTPs.



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Micropollutant removal in constructed wetlands: plant uptake, translocation, and biotransformation

Oct 2025 - 2027

Researcher	Supervisor	
Dr. Zhaolu Feng	Dr. Thomas Wagner	

Motivation

Micropollutants (OMPs), such as pharmaceuticals and per- and polyfluoroalkyl substances (PFAS), are frequently detected in treated effluents from municipal wastewater treatment plants (WWTPs), due to their poor removal efficiency in conventional treatment processes. To mitigate the potential risks of OMPs to aquatic ecosystems and human health, additional post-treatment strategies are required to further removal OMPs.

Constructed wetlands, as nature-based treatment technologies, represent a sustainable and cost-effective polishing step for WWTP effluents. This technology has shown the potential of OMP removal through physicochemical or biological processes. To date, these processes have been investigated mainly in relation to wetland substrates (filler materials), including OMP sorption onto different substrates and biotransformation by microorganisms colonizing the substrates. However, constructed wetlands are complex plant–microbe–substrate systems, and the role of wetland plants to OMP removal remains insufficiently understood.

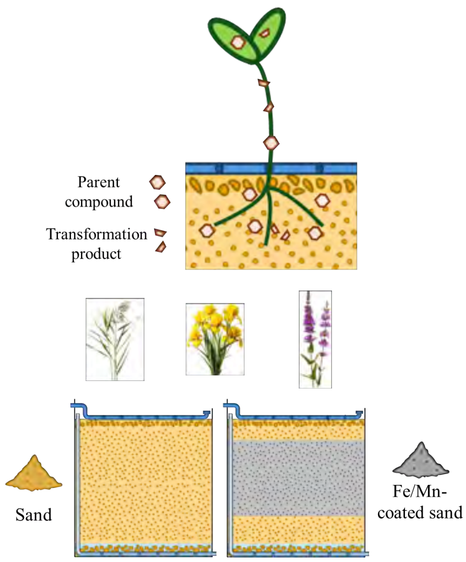
Technological challenge

Plants growing in constructed wetlands play a crucial role in providing microorganisms with oxygen and easily assimilable organic compounds, as well as maintaining overall wetland stability. In addition, plants can take up OMPs simultaneously with nutrients via their root system and may subsequently metabolize these compounds within plant tissues, leading to the formation of transformation products. Thus, plant-related processes, including uptake, translocation, and biotransformation, are critical for understanding the fate of OMPs in constructed wetlands and for further optimizing OMP removal from a plant-centered perspective.

The aims of this project are to:

- Investigate the removal of OMPs in pilot-scale constructed wetlands planted with different species (Phragmites australis, Iris pseudacorus, and Lythrum salicaria).
- Assess the effects of two substrate types (normal sand and Fe/Mn-coated sand) on plant growth and OMP removal.
- Evaluate OMP biotransformation within constructed wetlands by identifying parent compounds and their transformation products.

Uptake, translocation, biotransformation



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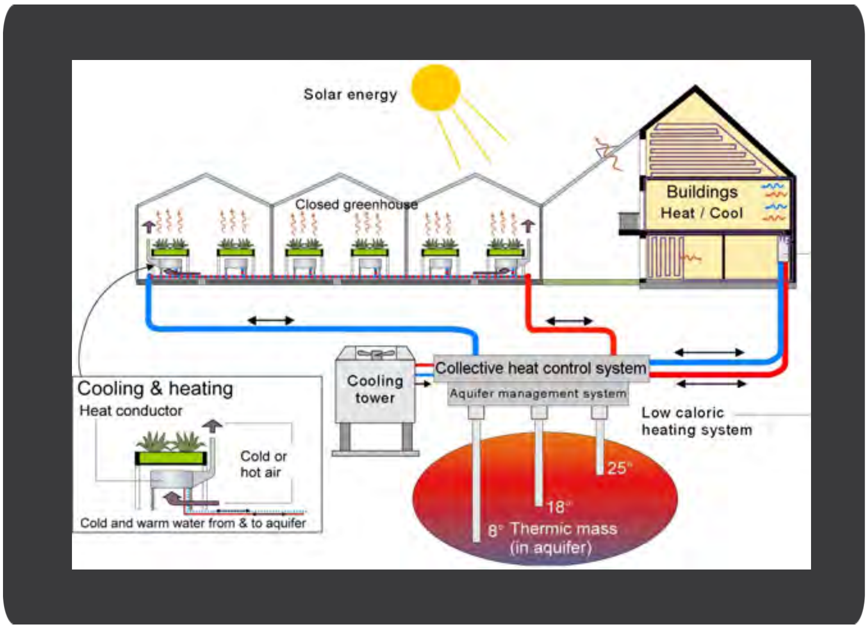
Urban Systems Engineering

Urban Systems Engineering and Biorecovery

Urban Systems Engineering and Reusable Water

Urban Systems Engineering



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.

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

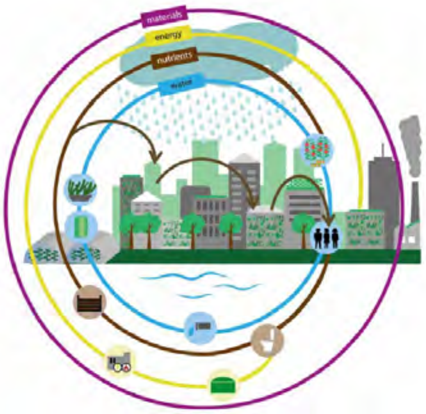
Urban circular cities – Optimisation of recovery of organic matter and nutrients

Sep 2025 - 2029

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

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 for growing more crops. 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 elements exists a lack of knowledge on the flows and speciation of these elements from plants via food/feed and organic residues back to agriculture.

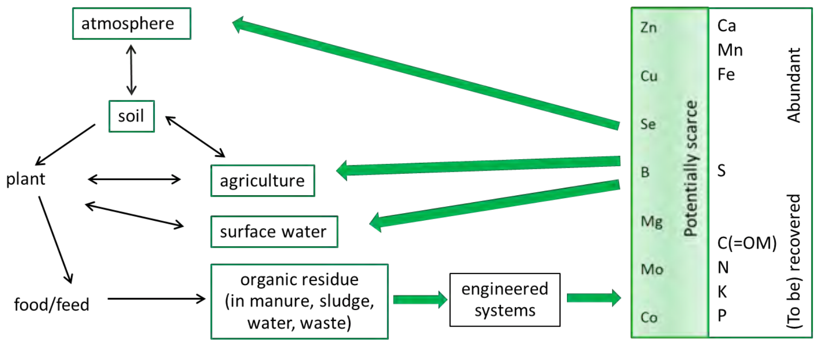


Adapted from doi: 10.2166/bgs.2020.930

Research challenge

There is already a variety of (nature based) technologies in place for the recovery and reuse of nutrients (C, N, P, K) from biomass and waste streams in the urban environment. Methods for micronutrients, that are expected to become scarce on human timescales, often still need to be developed. The variety of waste streams used as input, recovery technologies and nutrient products (CNPK, others) lead to a very complex comparative assessment for the optimal recycling strategy in the urban environment.

However, getting a clear overview is essential to design new circular recovery strategies. To enable structural analysis of nutrient recycling strategies we will develop overviews of recycling schemes and identify and quantify products for each nutrient source. This approach can be used to get a better quantitative understanding of nutrient cycles on an urban scale.



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Circular nutrients and water in Zeeland

Mar 2025 - 2029

Researcher	Supervisor	Promotor
Daan Metz	Dr. Renata van der Weijden Dr. ir. Paula van den Brink Dr. ir. Hans Cappon	Prof dr. ir. Annemiek Ter Heijne

Urban Systems Engineering
Environmental Technology

The Delta Climate Center

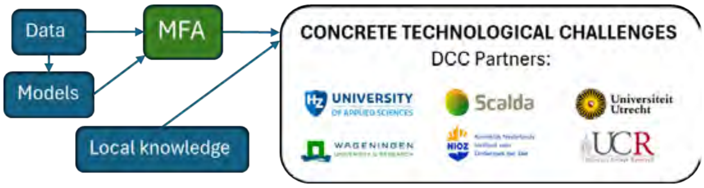
Zeeland, located around the Scheldt delta, faces challenges around climate, biodiversity, freshwater availability and rising sea levels. The Delta Climate Center (DCC), aims to make the Zeeland a more sustainable, resilient and flourishing delta, utilizing the province as 'living lab' and working together with businesses, and knowledge institutes from trade schools to universities. Zeeland's arable land, water bodies, and industrial infrastructure provide opportunities for the transition to a circular economy, which the provincial government aims to achieve fully by 2050, along with the rest of the Netherlands.

ProceZ is the DCC's project that focuses on this transition towards circularity: of nutrients, like many agri-food systems in the Netherlands aim to achieve, but also of freshwater, due to Zeeland's location-specific challenges.

Approach: Material Flow Analysis (MFA)

MFA involves the bookkeeping and mapping of substance flows, and is an important step in the move towards a circular economy because it allows for identification of opportunities for resource recovery and closing loops. A recent MFA carried out for the Flemish agri-food system emphasized the importance of approaching MFA's from the bottom up, disaggregating flows into as much detail as possible. Distinguishing between point- and non-point sources allows for identifying flows available for recovery/reuse, and can open the door for specific technologies and business cases, instead of a general assessment of whether circularity goals are achieved.

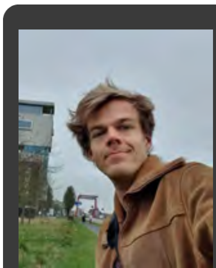
Approaching Zeeland's problems with a highly detailed MFA for water and nutrients will allow for the creation of an inventory of technological challenges. Those challenges can in turn be coupled to technological solutions or new projects across a range of education levels, enabled by the DCC's partnerships with WUR, Utrecht University, UCR, NIOZ, Scalda, and Hogeschool Zeeland.



Possible BSc/MSc theses within this project could include:

- Assessment of wastewater treatment technologies that can be feasible for increasing Zeeland's freshwater availability.
- A material flow analysis of Zeeland's aquaculture.

Input is appreciated since this project has just taken off. If you're up for the challenge of carrying out a thesis at this brand new institute, and want to do it in the Netherland's province with the most beaches and sunshine? Feel free to contact me.



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Delta Climate Center
WAGENINGEN UNIVERSITY & RESEARCH

BioTherm- Use of emerging biotechnologies for upgrading products from thermochemical conversion of municipal solid waste

Jan 2021 - 2024

Researcher	Supervisor	Promotor
Jinyang Lu	Dr.ir. DPBTB (David) Dr.ir. Wei-Shan Chen Strik Dr.ir. Ming Zhao	Prof.dr.ir. HHM (Huub) Rijnaarts

Motivation

The current major treatment methods (incineration and landfill) for the organic fraction of municipal solid waste (OFMSW) cause greenhouse gas emissions like CO_2 and CH_4 and have low-value products. OFMSW treatment needs to pursue higher carbon recovery and product value, on the premise of rapid processing and volume & weight reduction. Valuable chemicals and alternative fuels can be produced by integrating thermochemical processes (gasification and pyrolysis) and biological processes using OFMSW as feedstock. Combining thermochemical and biological methods to treat OFMSW allows higher carbon recovery rates and product values to be pursued, on the premise of quick treatment and reduced volume/weight of OFMSW.

Technological challenge

In the combined technical route of thermochemistry and biological methods, the thermochemical method is at the front end to complete the decomposition of OFMSW in a short time. Biological methods are at the back end. Microorganisms use small molecule products produced by thermochemistry to ferment to produce high-value products such as ethanol, protein, medium-chain fatty acids, etc. Although there are many types of thermochemical methods and there are many mature technical routes, they all have their limitations because the thermochemical technical routes were not originally designed to connect with biological methods. Thermochemical methods need to adjust their reaction conditions to produce product components suitable for subsequent biological methods. Even if the thermochemical process is theoretically designed, as the size of thermochemical reactors continues to increase, reaching theoretical values requires the support of continuous optimization of simulations and pilot-scale experiment data.
The OFMSW is a heterogeneous feedstock, the thermochemical method produces not only chemicals that can be used for microbial fermentation but also potentially bio-toxic chemicals that need to be removed. The impact of these additional products on microorganisms will determine the yield of the final product and even disrupt the coupling of thermochemical and biological methods. Although some bio-toxic substances also have pollution properties, their removal technologies have been discussed in depth. However, purification technologies for potentially bio-toxic substances produced by thermochemistry have not yet been systematically studied and integrated.
The technical challenge is to design and optimize thermochemical methods to produce the feedstock needed for biological methods while inhibiting and removing bio-toxic chemicals.

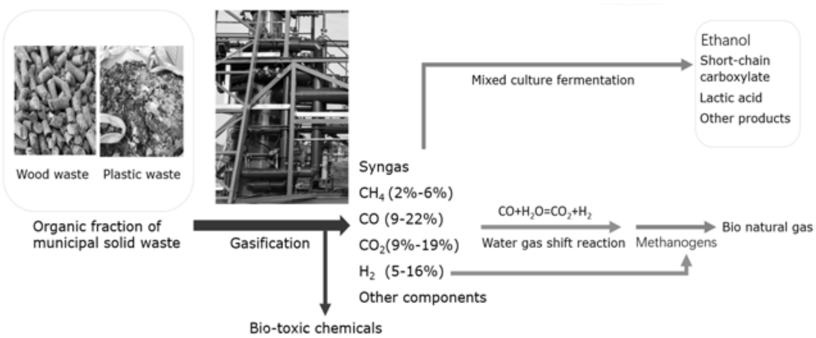

Figure 1: One type of technical route of combining thermochemistry and biological methods using gasification

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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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Inorganic solid waste & modeling. Nanoparticles.

Dr. Renata D. van der Weijden

Prof. dr. ir. Cees Buisman
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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.

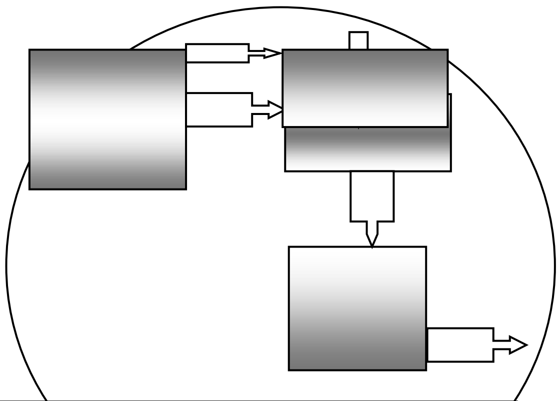

Figure: Open Resource Cycle

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Renewable and sustainable plastic transition pathways - developing roadmaps with a co-creation design tool

Sep 2022 - 2026

Researcher
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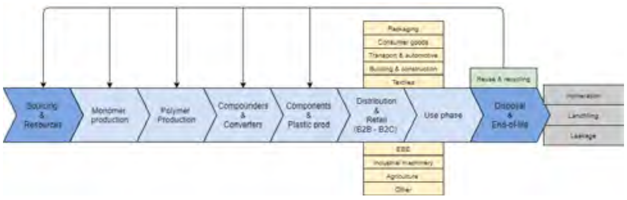
Marieke Brouwer MSc. (FBR)
Dr. Ulphard T.v.Velzen (FBR)

Motivation

Plastics have a large impact on global society. There are 7 major and many more plastics/polymers which are embedded in thousands of different (complex) commodities and products in our daily life. A transition in the world of plastics is of priority and urgency, given the fact that plastic production accounts for ~10% of all fossil resources. Estimate is that 32% of all plastics are leaking into the environment, posing serious threats to nature and health. Many plastic transition developments are ongoing, like new recycling techniques and the development of biobased as well as or biodegradable plastic products.



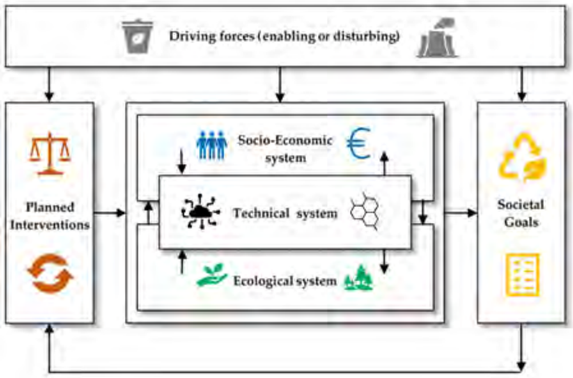
However, current initiatives often fail to facilitate the plastic transition due to the lack of understanding of the current plastic system and its value chain. In addition, there are uncertainties regarding the incorporation of various social-economic transition enablers and barriers. The transition is influenced by various policies, directives, societal behaviors and stakeholders. It is therefore essential to understand how this system works and to forecast how the transition and future society will potentially look like.

Objective

The research project aims to showcase plastic transitions will look and identify critical steps that will have to be made to realize set goals. For this, a novel design tool will be made which tackles crucial interventions and barriers to deliver plausible transition pathways for our society. The conceivable best answers for this will be found by bringing relevant stakeholders together and connecting them to co-create the 'optimal' transition pathway scenario based on real-world cases and the latest scientific and technological insights.

Research approach

To provide the plastic transition pathways and provide quantitative answers, relevant stakeholders have to be included to address the topic in an integrated way. The *'Butterfly Framework'*, developed by Bos, De Haas and Jongschaap (2022), will be used as the basis to stud the transition toward a circular and sustainable economy. Furthermore, a novel transdisciplinary and co-creative methodology will be developed, which should be able to design quantitatively different transition pathways.



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Improving Circularity in Plastic Packaging Waste

Oct 2023 - 2027

Researcher
Dalia Carbonel

Supervisor
Dr. ir. Wei-Shan Chen
Dr. ir. Kamonashish Haldar

Promotor
Dr. Hans-Peter Weikard

Motivation

Plastic waste accounts for 12% of the global municipal solid waste (MSW) composition, amounting to 288 million tons of plastic waste per year. Plastic packaging (PP) is a significant category of plastic due to its high production and disposal rates, environmental impacts, public health hazards, and economic consequences. According to The Ellen MacArthur Foundation only 14% of PP is collected for recycling worldwide, while 14% is destined for energy recovery, 40% is landfilled, and 32% leaks into the environment. This poses both a pollution and a resource recovery challenge.

Effective segregation and recycling at the individual level, increase of formal recycling and effective local policies, could enhance the overall system's performance. However, the potential impact and interaction of these interventions is often underestimated or not well understood. A better knowledge and recognition of individual and local contributions could inform and improve policy formulation. The consequences of this problem are significant. Citizens do not segregate their waste. Formal and informal recyclers are often undervalued. Governmental officials implement ineffective policies. This, in turn, leads to the loss of plastic resources and pollution from MSWPP that are being final disposed of and leaked into the environment.

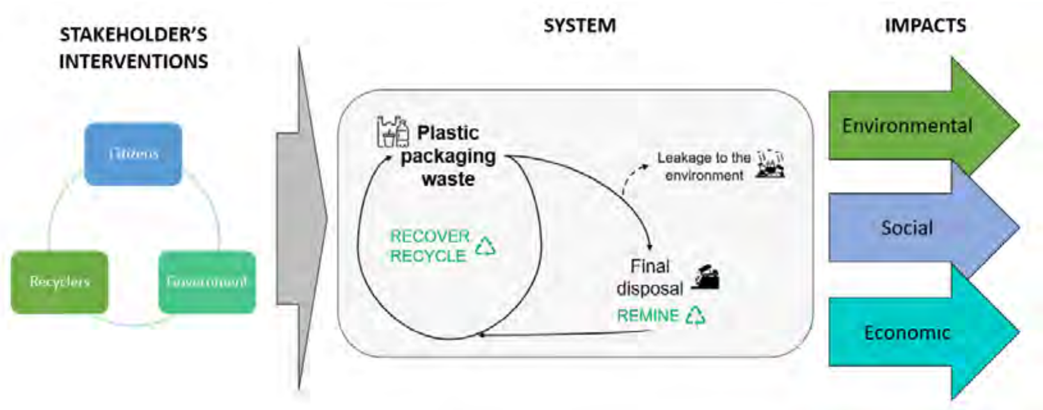
Practical challenge

The study aims to simulate the impact of agent interventions to identify efficient and sustainable strategies for improving segregation, recycling, and recovery of MSWPP.

The specific research questions are:

- What are the existing components, processes, and dynamics of the MSWPP system in Lima?
- What is the impact of citizen behavior and local interventions on household separation and disposal and district-level collection outcomes?
- What is the impact of household behavior on PPW commercialization and recycling?
- What are the impacts of selected recovery technologies and policy interventions?

The modelling approaches used to address the research questions include: Mass Flow Analysis (MFA), Agent-Based Modelling (ABM) and, System Dynamics (SD).



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Develop a sustainability transition design tool for Single-Use Plastic fresh beverage Cup in China

Oct 2025- 2028

Researcher	Supervisor	Promotor
Xiaojue Wang	Dr. ir. Wei shan Chen,Xin Yao	Adriaan Mels

Motivation

China's freshly made beverage sector is expanding rapidly, generating a large and growing flow of single-use plastic fresh beverage cups (SUPBCs). Although most SUPBCs are made of technically recyclable plastics such as PP and PET, their actual recycling rate remains very low.

This is not only a waste issue, but also a design and governance issue. Compared with PET bottles or PP takeout containers, beverage cups are far more diverse in materials, labels, colours, coatings, lids, and formats, which lowers their sorting and recycling value.

At the same time, packaging choices are strongly shaped by brand owners, who use packaging for product presentation and differentiation. This makes beverage cups a particularly important case for targeted intervention.

Challenge

Current research and policy mainly treat beverage cups as part of the broader packaging category. Existing measures focus on general plastic reduction, reuse, recycling, or EPR, but do not adequately address the specific design complexity of SUPBCs.

In practice, cup flows and impacts are poorly tracked, sustainability criteria remain inconsistent, and there is no clear way to compare different cup designs and business models.

Most importantly, there is still no practical bridge between design differences and differentiated responsibility. As a result, differences in recyclability and downstream cost are rarely translated into clear accountability or operational policy tools.

Possible research topics:

- Data architecture and minimum datasets for cup flows, design features, and life-cycle impacts
- Design standards and operational criteria for more sustainable cup solutions
- A transparent grading framework for comparing cup designs and business models
- Links between circular economy policy and climate change
- Policy lessons from Waste Electrical and Electronic Equipment （WEEE） recycling and recover
- Plastic pollution governance and international treaty negotiations

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Coherent seasonal heat storage management to avoid electrical grid overload

Oct 2022 - 2026

Researcher	Supervisor	Promotor
Ir. Aad de Klerk	Dr. ir. Wei-shan Chen Prof. dr. ir. Cees Buisman	Prof. dr. ir. Cees Buisman

Motivation

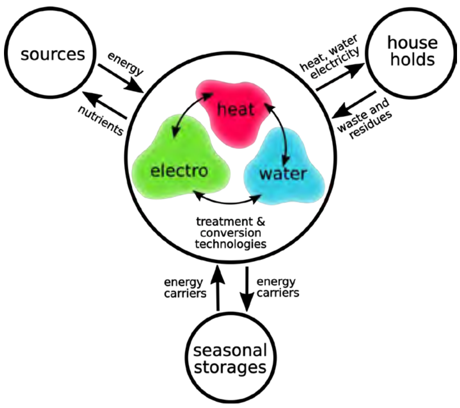
Current domestic heating demands are dominantly fulfilled by burning natural gas or other fossil fuels which are neither renewable nor sustainable. The strongly encouraged use of heat pumps as a replacement of natural gas heating boilers can overload the current electricity grid infrastructure and its renewability and sustainability is questionable and heavily dependent on national electricity sources. This research will develop knowledge and tools to assist the adoption and implementation of alternative heat sources, their seasonal storage and use in residential areas and mitigate foreseeable overload of the centralized electrical grid.

Technological challenge

The energy required for home heating forms the bulk of households' up till 83,5% of the total energy requirements. Given the large quantity of energy consumption for heating and their current non-renewable supplies, achieving sustainable home heating is crucial and plays a significant role in energy transition. The large seasonal variation in heat demand is typical for homes; it has high demand in winter and low or no demand in summer. This variation in demand should be matched with energy supply of sustainable sources by means of different kinds of seasonal energy storage system : thermal, biomass and bio-methane.

Alternative heat supply sources and means that are potentially more renewable and sustainable have emerged in recent years, but how residential areas can optimally adopt and implement these innovations to achieve energy transition is not yet clear.

Another challenge is interconnecting renewable water, electricity and heat sources and seasonal energy storages in an intelligent manner which could result in a decentralized, renewable, sustainable, circular, non-toxic and nutrients producing system. An autonomous local energy and sanitation organisation for a group of household could come into existence without or minimal use of large interregional, national of supra-national energy and water networks.



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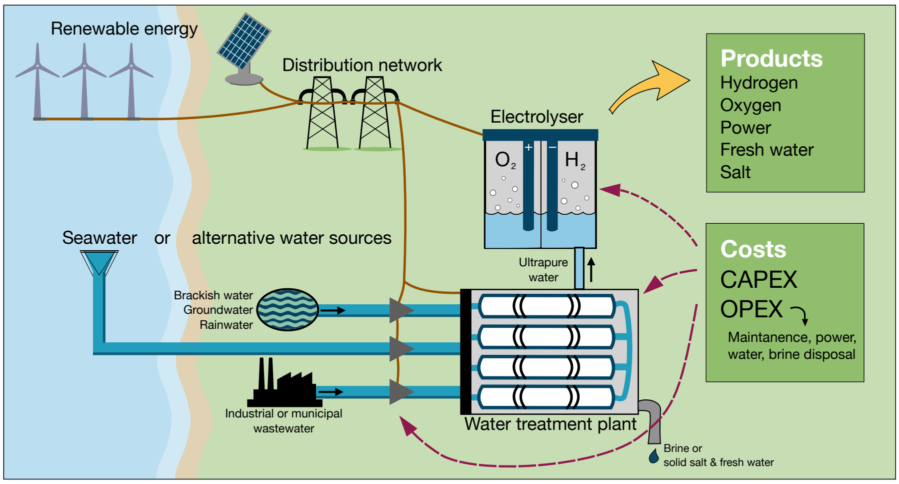
Alternative water resources for green hydrogen production:
from Zeeland to delta regions worldwide

Urban Systems Engineering
Environmental Technology

Nov 2022—2026

Researcher	Supervisor	Promotor
Elizabeth Carlisle	Dr. Hans Cappon	Prof. Dr. Huub Rijnaarts



Motivation

In recent decades, hydrogen has gained attention as a potential solution for a low-carbon energy future. Renewable hydrogen, also known as green hydrogen, is produced through the electrolysis of water and is considered carbon neutral. However, its production requires large amounts of water and electricity, increasing the production cost and raising concerns about water scarcity. This project, focusing on a case study in the province of Zeeland, seeks to describe the alternative water sources available for hydrogen production and explore the costs and impacts of their usage compared with freshwater or seawater.

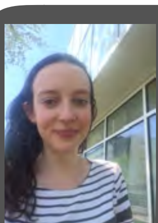
Ultimately, this project aims to answer the following questions:

1. Which water source(s) is/are least expensive considering all infrastructure and treatment costs?
2. Which solutions are most sustainable and robust?
3. Should the hydrogen production schedule be based on seasonal availability of water & energy?

Technological challenge

The goal of this project is to set up an optimization framework to decide an optimal hydrogen production schedule, hydrogen plant location, and any required infrastructure investments to provide the hydrogen plant with energy and water, including the water network to connect water sources and water treatment plants. We also plan to model various water treatment technologies. Several different options for water treatment can be used, based on the quality of the source water: reverse osmosis, forward osmosis, membrane distillation, or electrodialysis, for example. In addition, the future energy and water availability are uncertain, necessitating the use of stochastic programming or similar methods.

The technological challenge comes from the formulation and implementation of mathematical optimization methods to solve this problem. Accurate models to represent water treatment technologies must be used, but a complicated model could make the optimization problem infeasible to solve. Thus, it may be necessary to use techniques such as convex relaxation, decomposition, or machine learning.



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WAGENINGEN UNIVERSITY & RESEARCH

Investment and operation planning under uncertainty for future urban energy systems

Urban Systems Engineering
Environmental Technology

Mar 2023 - 2028

Researcher	Supervisor	Promotor
ir. Tim Zonjee	dr.ir. Shahab Torbaghan	prof.dr.ir Huub Rijnaarts

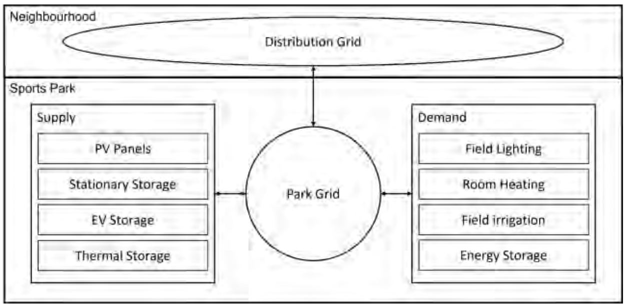
Motivation

As part of the challenge to reduce human-induced climate change, energy systems need to transition to a more sustainable operation. This energy transition has caused a quick and significant increase in electrical energy demand and the deployment of the renewable electricity supply technologies associated with it. To match supply and demand at all times, local distribution networks need to be carefully operated and expanded where required. In this study, we aim to find novel strategies that optimize the operation of and investment in electricity related networks and technologies on a local level, while considering the uncertainties of the future.

Technological challenge

The transition towards more sustainable energy systems implies a need for increased electrification. As a consequence, local electricity supply and demand have been increasing. On the supply side, the conventional renewable energy technologies are often non-dispatchable and reliant on energy sources with variable output (solar, wind). This, together with increasing supply capacity overall, causes increased supply peaks. On the demand side, the general increase in electricity demand, also causes increased demand peaks. To accommodate for both developments, the capacity and flexibility of distribution networks should be expanded. The problem is that this very development is lagging behind. As a consequence, local prosumers cannot expand the capacity of their distribution network connection, and therefore need to find smart ways to exploit the flexibility on their side (e.g. increase on-site supply, load shifting, energy storage) to match the growing demand and supply.

In this project we consider such a real-life case where sports parks of the municipality of Amsterdam act as prosumers. The challenge lies in finding a way to fulfil the parks' short-term energy needs while ensuring their long-term sustainability transition. Therefore, we develop a decision-support toolbox that optimizes for the parks' operation and suggests optimal investment plans on technology and park network infrastructure expansion. This optimization factors in municipal policies as potential objectives (e.g. minimizing costs, CO2 emissions) and uncertainties of the future (e.g. demand growth, variability in supply profiles). Finally, the model will be expanded to not only describe the parks' electricity systems, but also related energy systems (e.g. heat, water), objectives of other parties on the parks, and energy needs of the neighbourhood (function as an energy hub). As MSc student you would work on a project that might look something like this: Design an optimization code in Python in which you model part of the sports parks' energy system and minimize the investment cost and CO2 emissions (often conflicting objectives) simultaneously.



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Wageningen University & Research
python Programming
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Optimal operation of hydrogen distribution grid under uncertainty

Sept 2025 - 2029

Researcher	Co-promotor and Supervisor	Promotor
Ryvo Octaviano	Dr. ir. Shahab Torbaghan Dr. ir. Pejman S. Omrani	Prof. dr. ir. Adriaan Mels

Motivation

Hydrogen, as a renewable energy carrier, is expected to play a crucial role in the clean energy transition. However, transporting hydrogen safely and reliably through pipelines presents significant challenges. Variability in demand, fluctuating production from renewable sources, limited storage capacity, and insufficient monitoring infrastructure are common operational hurdles faced by network operators. To address these issues, intelligent decision-support tools are needed to help operators develop planning and operational strategies that are fast, accurate, cost-efficient, reliable, and safe.

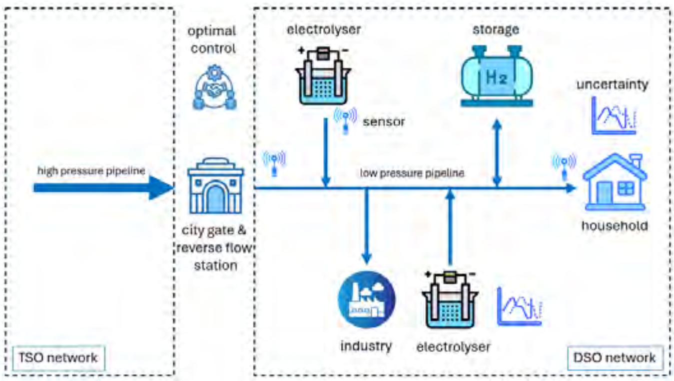
Technological challenge

Gas networks are typically divided into high-pressure transmission systems and low-pressure distribution systems. In current natural gas networks, Transmission System Operators (TSOs) are responsible for balancing supply and demand, while Distribution System Operators (DSOs) generally have limited or no experience with such tasks. This research focuses on supporting DSOs in operating future hydrogen distribution networks.

Future hydrogen distribution networks face multiple operational challenges. These include maintaining network integrity by keeping pressure within acceptable limits, balancing supply and demand flows, managing limited linepack and storage capacity (due to smaller pipelines and shorter network lengths), dealing with complex meshed network topologies with multiple loops, and overcoming the lack of sufficient monitoring points to measure pressure and flow throughout the system. In addition to operational challenges, several uncertainties complicate decision-making, these include:

- *Production uncertainty* – coming from the variability of renewable electricity from weather-dependent sources such as solar and wind.
- *Demand uncertainty* – caused by diverse and unpredictable consumption patterns of industrial and residential users.
- *Market uncertainty* – where fluctuations in electricity prices influence both hydrogen production and consumption.
- *Modeling uncertainty* – arising from the limited number of measurement points and the dependence of simulation tools on sparse input data.

Addressing these challenges requires developing mathematical optimization methods and modeling frameworks that accurately capture network behavior and support effective control and decision-making. These tools are essential for creating operational strategies that ensure safety, reliability, and efficiency even under changing and uncertain conditions



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Advancing Sanitation Systems Towards Circularity and Resilience in Tourism and Built Environments of Marine Protected Area

2023 - 2027

Researcher
Erbi Setiawan

Supervisor and Co-promotor
Dr. Katarzyna Kujawa-Roeleveld

Promotor
Prof. Dr. Ir. Adriaan Mels

Motivation

Nowadays, urban areas host over 50% of the world's population, and it is predicted that by 2045, the world's population will increase by up to 6 billion, or 2/3 of the world's population (United Nations, 2015; World Bank, 2023). One of the unique/fascinating forms of urban typology is coastal areas, where the tourism sector contributes significantly to socio-economic activities and is considered one of the largest and fastest-growing tourism sectors in certain regions of the world (Garcés-Ordóñez et al., 2020; Jarratt & Davies, 2020; Leposa, 2020). However, tourism intensifies anthropogenic activities in urban coastal areas, driving unprecedented resource demand and placing environmental pressures. Interventions must therefore be taken to prevent stress on urban coastal environments and increase their resilience. One possible intervention is to reduce pollution caused by tourism wastewater. Wastewater is a land-based stressor on the coastal ecosystem because it contains nutrients N and P. At the same time, these nutrients offer opportunities for reuse and recycling, especially in fertigation, making wastewater an essential alternative for coping with intensive resource demand in (peri-)urban coastal areas and hinterlands.

Research Design and Technical Challenge

This research focuses on improving sanitation systems, including technological interventions to address wastewater from intensive tourism activities in urban coastal areas, aiming to reduce nutrient loads before discharge while facilitating resource recovery. A baseline assessment of the existing sanitation practices and management is conducted at the beginning of this research, followed by the development of technological interventions and resource recovery strategies to improve sustainability in the area. This research is a part of the INREEF project located in Bali, Indonesia.

Research Objective and Questions

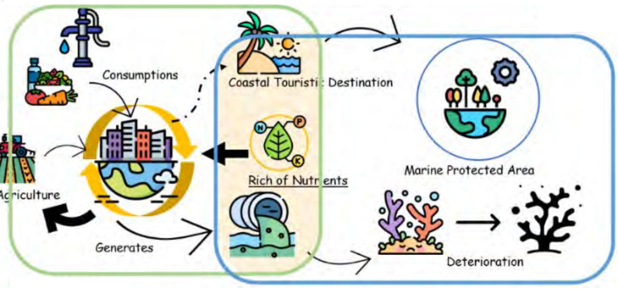
This research aims to contribute to coastal environmental resilience in small islands by reducing nitrogen (N) and phosphorus (P) from wastewater effluent at tourism locations, while simultaneously exploring the co-benefit of resource recovery potential to promote circularity. To achieve the aim of this research, the questions to be answered are:

Main research question:

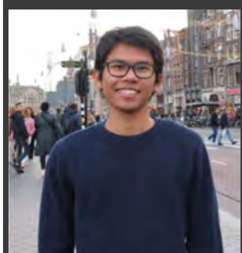
How can nutrient emissions in wastewater effluent from tourism in (small-island) coastal built environments be lowered while facilitating resource recovery?

Research Questions:

1. How can the water system profile be defined and explored in selected (small) islands with the typology of tourism environments?
2. What sanitation systems, including technological interventions, are contextually suitable for improving sanitation practices and management in coastal tourism destinations?
3. How do the treated wastewater and resource recovery strategy contribute to the circularity in the selected small island configurations?
4. How can improving sanitation and resource recovery be optimised by implementing a framework for sustainable sanitation practices in (small island) coastal tourism destinations?



Research Overview



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Develop Model-based Planning of Nature-Based Solutions to design adaptive and Resilient water supply in African countries

Environmental Technology

Researcher	Supervisor	Promotor
Lidya Lulseged Assefa	Dr. Ir.Wei -Shan Chen	Dr. Ir.Adriaan Mels Prof. dr. ir. HHM (Huub) Rijnaarts

Motivation

Nearly half of the world's population experiences water scarcity every year, and that number is expected to increase, particularly in cities. Developing nations are especially vulnerable to the effects of water scarcity caused by human activities such as population growth, increased urbanization, and climate change. Nature-based solutions can be effective in mitigating climate change and meanwhile improving water security in fast expanding metropolitan regions.

The scientific advancement to date in tackling those urban water challenges lacks an integrated approach or framework in creating dynamic models for supporting the planning of NbS to maximize their multi-functionality and long-term resilience under climate change. Integrated techniques are uncommon, particularly in global south metropolitan regions. As a result, it is critical to advance research in this area to provide efficient, cost- effective, and multifunctional NbS for decision makers in handling urban water concerns.

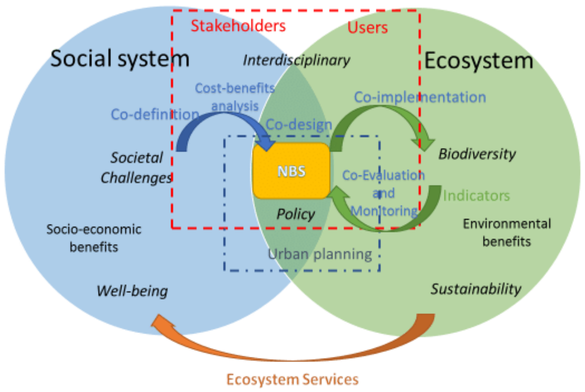

Figure 1: Integrated approach in planning nature-based solution.(Source: https://rb.gy/0eplo)

Objective

This research aims to develop integrated modelling frameworks to support the planning of Nature-based Solutions (NbS) in catchment systems, with the main goal of ensuring water supply that is adaptive to long-term climate change and resilient to short-term shocks and stresses.

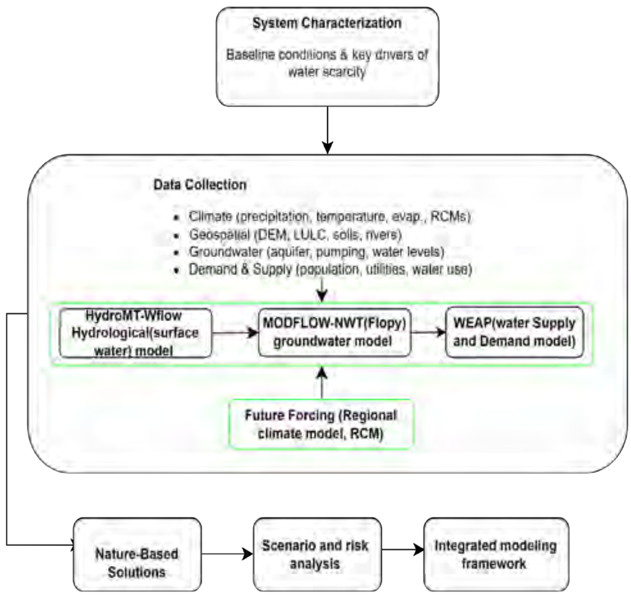

Figure 2: Methodology flow chart

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VEi Dutch Water Operators

WAGENINGEN UNIVERSITY & RESEARCH

Physics-Informed Neural Networks for Optimal Water Flow Modeling

Urban Systems Engineering
Environmental Technology

Mar 2023

Researcher	Supervisor	Promotor
TBD	dr.ir. Shahab Torbaghan	prof.dr.ir Huub Rijnaarts

Motivation

Countless instances of optimal water flow (OWF) need to be solved when it comes to evaluating uncertain scenarios, finding optimal control setpoints, and determining the optimal investment strategy in critical water infrastructure. However, the exact formulation of the OWF equations in the OWF problem is non-linear and nonconvex, which could result in significant difficulties for long computational times. A large body of literature exists on deriving approximations of the OWF problem, with the most popular ones being the linearized OWF, other linear or convex approximations, and convex relaxations, that will ensure fast computation speed and convergence guarantees.

Technological challenge

There is a revived interest in machine learning methods to accurately estimate the OWF solution which have demonstrated a computation speedup of 100–1000 times compared with the conventional methods. This means that in the time it would take to assess one scenario by solving one OWF instance, we can now assess up to 1'000 scenarios simultaneously. However, these machine learning algorithms experience two significant challenges. First, **the availability and quality of training datasets**: to train a neural network with considerable accuracy, we need OWF results for a huge set of operating points that will cover both normal and abnormal situations. Such datasets often do not exist, or it is often challenging to generate. Convex relaxation techniques were proposed to efficiently generating such large datasets, concentrating closer to the security boundary. Along the lines of improving the performance of such Machine Learning algorithms, a method was proposed in to identify and include adversarial examples in the training data set during training. The second major issue limiting the Neural Network (NN) widespread adaptation is that, so far, **none of the proposed machine learning algorithms have supplied any worst-case performance guarantee**. With OWF often used for safety–critical applications, the neural network estimates must not violate any OWF constraints, e.g., pressure, or pump capacity. To mitigate these limitations, the NN predictions can be post-processed to satisfy operational constraints as proposed in for OWF. However, this could negatively impact the optimality of the solution.

This research attempts to address these challenges by using a physics-informed neural network for OWF applications. It aims to introduce the physical equations in the form of the OWF Karush–Kuhn–Tucker (KKT) conditions inside the neural network training. By doing that, the neural network can reduce its dependency on the size and quality of the training dataset, and instead, it can determine its optimal parameters based on the actual equations that it aims to emulate. Efforts will be made to determine that extract worst-case guarantees for generation and line flow constraint violations of the neural network OWF predictions. In summary the aim is to (i) determine the worst violations that can result from any neural network output across the whole input domain, and (ii) propose methods to reduce them.

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WAGENINGEN UNIVERSITY & RESEARCH

python Programming

Decision-Making for the Operation, Design, and Expansion of Water Distribution Networks in Zeeland

Environmental Technology

Oct 2024 - 2028

Researcher	Supervisor	Promotor
Corné Opgenoort	Dr. ir. Shahab Torbaghan	Prof. dr. ir. Huub Rijnaarts

Motivation

Water is essential for life and a critical resource for industrial, urban, and agricultural systems. **Water distribution networks** (WDNs) play a vital role in transporting and supplying water reliably. Climate change is putting pressure on water availability, particularly in vulnerable deltas like the province of Zeeland, where salinization and droughts are becoming more frequent. To mitigate the societal, economic, and ecological risks of water scarcity, a robust water system is needed. A novel technology to achieve such a system is a **water bank**—a seasonal water storage that stores excess water in underground aquifers during wet periods for use in dry seasons. In this study, we aim to develop novel methods for operating, designing, and expanding WDNs at a regional scale, using Zeeland as a case study. Our focus is on integrating water banks while accounting for **future uncertainties**.

Technological challenge

The **main technological challenge** lies in the **decision making process** behind operating, designing and expanding the WDN and making decisions such as determining the optimal locations for pumps, storages and pipes, as well as timing of investments. These decisions are made under uncertainties such as fluctuating water availability, climate change, and the evolving needs of industrial, urban, and rural users. While navigating these uncertainties, ensuring the long-term reliability and resilience of the system, particularly when integrating solutions like water banks, is crucial. This results in a **complex problem** that is difficult to address through human decision-making alone.

To address this complexity, **decision-making tools** are needed to make optimal decisions, in which one requires the use of **machine learning** and **mathematical optimization tools** that guide the operation, design and expansion of WDNs. However, before we can reach high-level optimization, it is essential to build a solid basis through **technology modelling**. This step helps us understand the underlying system and capture its complexity in a way that supports informed decision-making. Hence, as an **MSc student**, possible project topics may include:

- Modelling of specific water treatment technologies, such as Electrodialysis, Ion exchange, Sedimentation etc.
- Designing a decision-making framework in Python

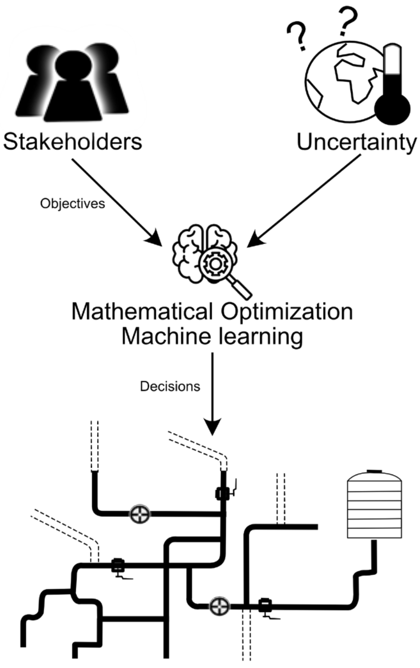

Figure 1. Simplified diagram of decision-making for Water Distribution System expansion

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python Programming

WAGENINGEN UNIVERSITY & RESEARCH

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

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

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.

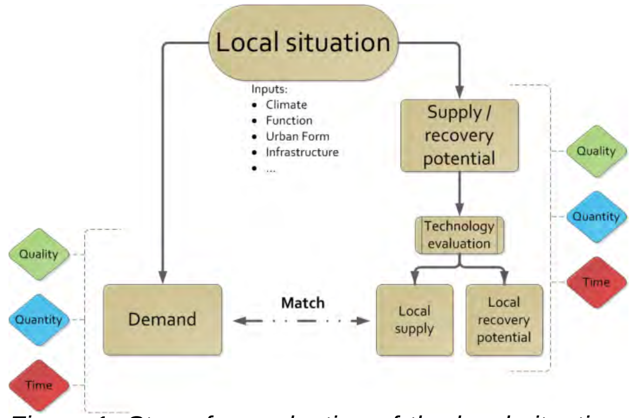

Figure 1: Steps for evaluation of the local situation and technology selection

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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Decision support system for designing transition pathways towards circular hospitals

Sep 2024 – 2028

Researcher	Supervisor	Promotor
Yifan Yang	Dr. ir. Wei-Shan Chen Dr. ir. Shahab Torbaghan	Prof. dr. ir. Huub Rijnaarts

Motivation

Modern healthcare consumes substantial single-use medical plastic products, due to the high patient throughput in medical facilities and high hygiene standards asked by safety concerns. The reduction of carbon footprint and adoption of circularity along medical plastics management in healthcare are therefore urgently pursued by all relevant stakeholders. The Dutch Research Council supported the ESCH-R (Evidence-based Strategies to create Circular Hospitals: Applying the 10-Rs framework to healthcare) consortium to contribute to a more sustainable healthcare sector (esch-r.org). This PhD project from ESCH-R aims to understand potential circular interventions for current plastic management, and proceed with the optimal planning of interventions.

Figure 1 Daily medical waste in ICU per person in Erasmus MC. Photo by Marcel van den Bergh.

Technological challenge

Medical plastic products (MPPs) are a complex mixture of chemical compositions and functions. In the context of circular transition of Dutch healthcare, a comprehensive identification of hotspots of medical plastic products (HMPPs) in based on multiple criteria is lacking, causing difficulties in matching, planning and implementing circular interventions.

Various R-interventions based on the 10-R strategy (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover) have been practiced in various hospital settings, yet the improvement of circularity came with trade-offs in multiple aspects, leaving room for optimization. To do so, it is essential to model and understand beforehand the current MPPs management at different scales and potential R-interventions applied thereto.

Potential thesis topics

- Identification of HMPPs from procurement data and circular transition barriers in post-treatments.
- Multi-scale dynamic material flow analysis (MFA) of MPPs in hospital.
- Machine learning aided MFA building for operating room (OR).
- Investigation and optimization of R-interventions.

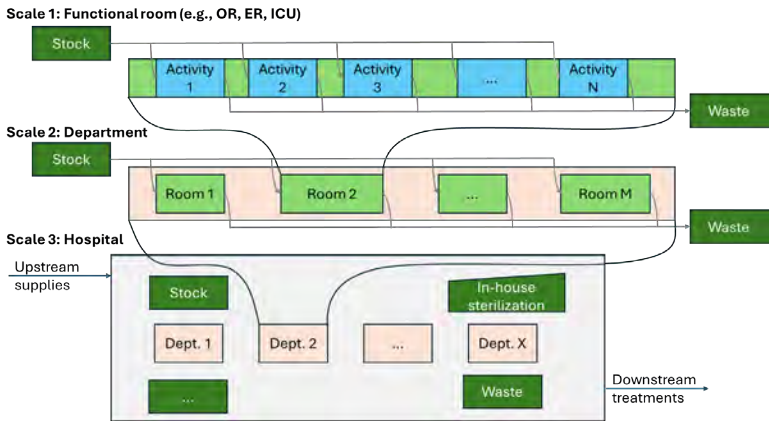

Figure 2 Multi-scale MFA of MPPs in hospital.

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Transition of urban infrastructure towards circular & resilient cities

Urban Systems Engineering
Environmental Technology

Dec 2018 – Present

Researcher
Kimberley Wang

Supervisor
Dr.ir. Wei-Shan Chen

Motivation & Technological Challenge

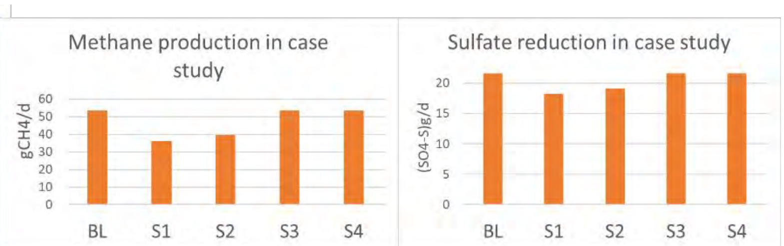
In 2050, there will be likely 10 billion people on the Earth and more than 70% of them will live in urbanised area. At least doubled urban infrastructures are needed to provide the basic services in the coming decades for both new and existing cities, especially for safe ty and sanitary purpose. Existing 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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Assessment and Localization of Sewer Infiltration and Inflow

Mar 2022 - 2024

Researcher	Supervisor	Promotor
Hao Zhang	Dr. ir. Wei-shan Chen Dr. ir. Alida Alves Beloqui Prof. dr. ir. Haifeng Jia (Tsinghua University)	Prof. dr. ir. Huub Rijnaarts

Motivation

Especially in older cities high infiltration and inflow (I/I) input into the sewer network can arise from area drains, manhole covers, defective pipes, leaky connections. The global average share of I/I has been assessed to be about 30-50 percent. The situation is often further aggravated by extreme rainfall, i.e. due to climate change. Take Suzhou (China) as example, for a situation of 36mm precipitation in 24 hours, the I/I would account for 73%. The regular and extreme event related extraneous water causes tremendous negative effects on the sewage system, such as larger energy consumption of pumping stations, larger use of chemicals at wastewater treatment plant (WWTP), sewage overflow, flooding, etc. This research aims to develop an I/I assessment and localization method. This can help urban stakeholders to quantify the I/I situation in their regional sewer network and to localize places for most effective measures for I/I reduction, such as renewing sewer pipes and/or creating local storage facilities for excessive pluvial water.

Technological challenge

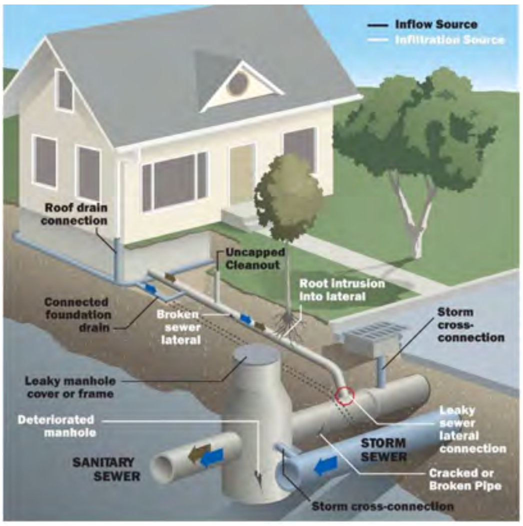
I/I is an inevitable problem due to continuous aging of sewer and WWTP components. What we can do is try to alleviate this problem and its corresponding negative effects. This research starts with qualitative I/I assessment and followed with I/I hotspot localization. The I/I process is influenced by numerous factors, such as pipe attributes (length, diameter, age, etc.), surrounding soil characteristics, groundwater level, maintenance, etc. However, there is a lack of an assessment method, which could well take into account all the factors of influence, due to insufficient basic network data or monitoring data.

The assessment process developed here aims to provide information on the regional I/I situation, which could qualitatively assess the I/I contribution for a certain subarea.

Nevertheless, this regional assessment result, is unable to tell in what specific part of the network I/I actually occurs. For this a more accurate I/I localization method is required, which could directly point out where I/I happens. Based on the assessment result and principles of pollutant transport, this part aims to combine sewer model and algorithms such as genetic algorithm and swarm particle algorithm to localize I/I.

Three research topics are listed below.

1) Using pharmaceuticals as tracers in quantifying regional I/I amount
2) Assessment of I/I, based on influencing factors
3) Localization of I/I, based on assessment result, sewer model and genetic algorithm



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Water and Sanitation Systems Transition for Improving the Quality of Life

Researcher		Timeline
Dr. Kamonashish Haldar		2026 - 2029

Motivation

Lack of access to affordable and safe water and sanitation infrastructure poses a significant concern in the rapidly growing cities of Asia and Africa. Additionally, climate change-induced water scarcity and complex governance arrangements aggravate water and food insecurity. Research shows that the current practice of inadequate treatment and subsequent discharge of wastewater and faecal sludge into natural streams would put Asian and African cities as a pollution hotspot in the coming decades. Although proven technologies exist for ensuring universal access to safe water and sanitation, the direct and indirect socio-political drivers influence the good governance of wastewater and faecal sludge management. Thus, a socio-technological transition is necessary to ensure access to adequate water and sanitation infrastructure that meets local demand, which in turn would improve overall quality of life.

Research Design

First, the dynamics of designing appropriate water and sanitation infrastructures to improve the quality of life in vulnerable and rapidly changing environments would be investigated. Then, an investigation is needed to understand the role/influence of appropriate water and sanitation infrastructure in improving the quality of life, especially for people living in low-income settlements. Next, research is needed into the impact of resource recovery on improving environmental quality. Finally, the extent of resource recovery from water and sanitation infrastructure in generating revenue to finance the operation and maintenance of the infrastructure should be assessed. The research should be carried out using a mixed-methods approach, incorporating both qualitative and quantitative assessments.

The following research questions are anticipated under this topic:

- *How does the availability of existing water and sanitation infrastructure affect the health and well-being of peri-urban communities under varying climatic conditions?*
- *What are the socio-economic impacts of poor water and sanitation infrastructure at the household level?*
- *What is the potential financial viability of a community-based business model for resource recovery, considering the local costs and market demand for recovered products?*
- *Which infrastructural/technological improvements are necessary to optimize the effective management (collection, transfer, treatment) of water and sanitation resources?*
- *Which economic mechanisms and community engagements are crucial to increase the use of recovered resources from water and sanitation infrastructure by local communities?*

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Air-Space-Ground Integrated modelling for Metropolitan Challenges

August 2023 - Present

Researcher	Supervisor	
Dr. Lixia Chu	Prof.dr.ir. AR (Adriaan) Mels	

Motivation

Climate change is driving urban heat, drought, flooding, and air pollution, threatening both people and ecosystems. Strengthening resilience requires understanding how climate, green–blue infrastructure, and human adaptation interact. This demands transdisciplinary approaches that integrate macro- and micro-scale models using multi-source data from satellites to ground sensors.

Technological challenges

Differences in data formats, methods, and disciplinary approaches separate macro- and micro-level models, creating gaps in integrated applications. For instance, while soil water content models work well at the micro scale, scaling them up remains difficult, with few frameworks bridging both levels. A similar gap exists in urban heat studies, where micro- and macro-climate models differ but remain poorly connected.

Research lines

This research vision advances three interconnected research lines:

- Urban Drought:

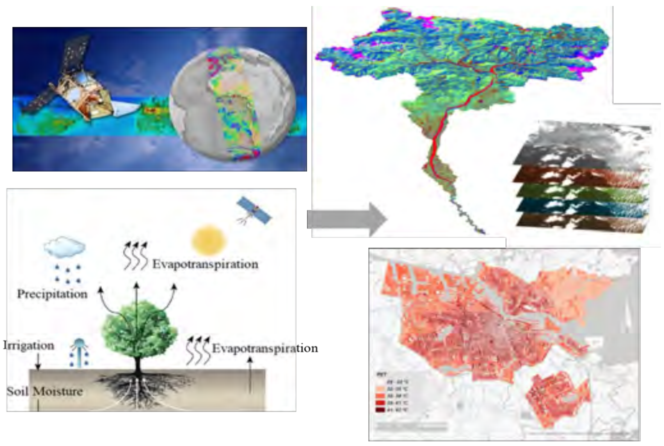
Urban drought will focus on developing an air–space–ground framework for soil drought modelling across scales. By combining satellite observations, ground measurements, and process-based models, it will quantify the water demand of urban green spaces in a local, regional and national scales. The goal is to optimize irrigation, support vegetation survival, and enhance ecosystem performance, ultimately helping to mitigate urban heat stress.

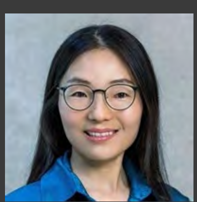
- Urban heat:

This study will focus on the integration of micro-climate model and macro-climate model. At the micro-climate level, the risk assessment, vulnerability of residence would be studied combining the socio-economic features and weather-station based features. At the macro-level, an integrated model and database will be the focus.

- Platform establishment

A metropolitan challenges platform will be established, integrating urban drought, urban heat, and air pollution themes. It will provide a public, interactive dashboard for visualization, storytelling, and data exploration, serving researchers, city planners, and policymakers.





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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.

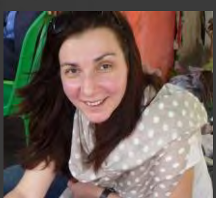
Technological challenge

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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Appendix a.

Overview Courses

Course Number	Course Name
ETE10806	Introduction Environmental Technology
ETE21306	Water Treatment
ETE22806	Principles of Urban Environmental Management
ETE24804	Fundamentals of Environmental Technology
ETE 25306	Basic Technologies for Urban Environmental Management
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
ETE33806	Planning and Design of Urban Space
ETE34306	Urban Energy, Water and Nutrient Cycles
ETE34806	Resource Quality in the Circular Economy
ETE35306	Environmental Electrochemical Engineering
ETE35806	Data driven Environmental Modelling and Optimization for resource management
ETE50401/ ETE50406	Capita Selecta Environmental Technology
ETE50803/ ETE50806	Capita Selecta Urban Systems Engineering
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	ETE80909 BSc Thesis Environmental Technology Part 2
ETE70224 and 70424 Internship Environmental Technology	ETE70724 and 70824 Internship Urban Systems Engineering
ETE78324 and 79324 MSc Research Practice Environmental Technology	ETE78424 and 79424 MSc Research Practice Urban Systems Engineering
ETE80424 and ETE80436 Thesis Environmental Technology	ETE81824 and ETE81836 Thesis Urban Systems Engineering

PhD courses (WIMEK-SENSE)
Micropollutants in the water cycle

We participate in the following MOOCs

MOOC
Sustainable Urban Development: Discover Advanced Metropolitan Solutions
Circular Economy: An interdisciplinary Approach

Appendix b.

PhD Theses Environmental Technology 2025

Name	Promotor(s) *and ETE co-promotor(s)*	Title
Sebastian Castaño Osorio	Van der Wal *Dykstra*	*Nanofiltration for micropollutant removal: Integrating mechanistic understanding with theory development*
Chang Gao	Rijnaarts *Sudmalis*	*Anaerobic granulation: Interplay between substrates, microbial communities, and viscoelastic properties of their exopolymers*
Sha Gao	Rijnaarts *Sutton*	*Pathogens in urban surface water: Monitoring and mitigation with Amsterdam as case study*
Yong (John) Jin	Strik *De Leeuw*	*Anaerobic fermentation of biodegradable plastics into carboxylates*
Kestral Johnston	Buisman/Keesman *Mol*	*Optimization of polysulfide in the biological desulfurization process*
Rikke Linssen	Ter Heijne *De Smit*	*Intermittent energy storage mechanisms for sulphide oxidising bacteria*
Pejman Shoeibi Omrani	Rijnaarts *Shariat Torbaghan*	*Operational optimization of geothermal plants under uncertainty*
Xiaofang Yan	Ter Heijne *Buisman/Liu*	*Exploring ammonium conversion at bioanodes of microbial electrolysis cells*

EngD Thesis Environmental Technology 2025

Name	Supervisors	Title
Jorn de Vos	Rijnaarts/Chen/Chu/ Van den Broek	*RainOasis: a dynamic model to match seasonal water demand and supply to sustain Urban Green during future droughts*

Appendix c.

Publication List Environmental Technology 2025

Article

- Audenaert, W., Bellandi, G., Vlasschaert, P., Rehman, U., Gkoutzamani, I., & van den Brink, P. F. H. (2025). Lachgasemissies omlaag en zuiveringsprestaties omhoog dankzij monitoring en modellering. *Water Matters : Kenniskatern voor Waterprofessionals - Dutch edition*, (juni), 8-11. https://edepot.wur.nl/695942
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- Dykstra, J. E., Li, K., Geranikolahlooei, H., Rutten, S. B., Nordstrand, J., & Porada, S. (2025). Pushing the boundaries of electrochemical ion separation for near-identical ions. *Chemical Engineering Journal*, *525*, Article 169668. https://doi.org/10.1016/j.cej.2025.169668
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