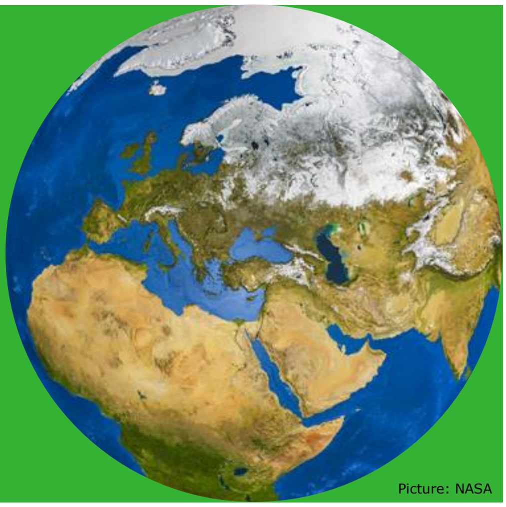
Environmental Technology

Newsletter | Fall 2014



Picture: NASA

WAGENINGEN UNIVERSITY
WAGENINGEN UR

News

VENI grant for a new microbial fuel cell design

Annemiek ter Heijne, assistant professor at ETE, was awarded the prestigious NWO VENI grant through the Technology Foundation (STW) for her project on recovering electricity from wastewater. STW realizes knowledge transfer between scientists and users and finances excellent technical research. The VENI grant offers a three-year personal budget of €250.000 for young talented scientists. Of about 100 proposals, only 12 received funding for their research idea.

Ter Heijne's project involves developing a new method to recover electricity from domestic waste water. 'There is a lot of chemical energy in organic material from waste water', the prize winner says. 'Microorganisms use the organic material as a carbon and energy source, but a substantial part of the chemical energy is released with the electrons. These can be used to generate electricity when these are captured and stored.' The principle of recovering energy from organic matter is not new. It is currently applied in a so called microbial fuel cell. In this design, electrons released by microorganisms are captured in many flat, parallel plates. This conventional design might be too costly to use at a large scale though. But by replacing these electron storage plates with small activated carbon granules, ter Heijne expects to be able to scale the process in a cost-effective way. One gram of this porous carbon may have a surface area as much as $1000 m^2$ and offers a lot of space for growth for microorganisms as well as electron storage. According to the scientist, too little is known about how and how fast the electrons are transferred to the carbon. Possibly, this charging depends on granule and pore size of the carbon used. To understand these fundamental processes, ter Heijne plans to study her new concept in a mini cell with just one carbon granule. 'We really need a breakthrough in the microbial fuel cell technology', she says. 'Hopefully this new design will be a leap in the right direction.'

Column — ***Huub Rijnaarts***

Saline water where possible, Fresh water where needed.

Water Nexus is a new research programme, led by ETE. It will run from 2014 to 2020, and will develop new solutions for water supply in freshwater-scarce regions. It is supported by 25 companies, research institutes, water boards, NWO-STW and the Ministry of Infrastructure and Environment.

With a 6 million euro budget the programme will develop innovative technologies enabling exchange of water between industry, agriculture, urban and natural systems, the use of brackish water as a resource, and the inclusion of green infrastructure for water storage and treatment. Companies and institutes will collaborate and exchange knowledge, deliver consultancy and hardware.

A total 17 Ph.D. students and 3 postdocs are part of the programme. At ETE, research topics include Saline Water Granular Sludge Technology, Electro-Membranes for Sodium and Micro-pollutant Removal, Plant-Microbial-Desalination-Cell, Wetlands Removing Micro-pollutants, Water Demand and Supply Modelling, and Integral Blueprints for Flexible Engineering and Design. Water Nexus offers a great network for interdisciplinary cooperation and functions as an in-depth science and technology platform, where partners from different universities and institutes collaborate. It completely fits with strategies of Wageningen UR and its Graduate School on Environment and Climate Research, WIMEK. The programme will be coordinated by Huub Rijnaarts and Hans van Duijne.

Prize for former ETE student

On September 26th, former ETE student Priska Prasetya and Jelmer van Veen won the prestigious International Climate Adaptation Business Challenge. The challenge was organized by *Kennis voor Klimaat* and Climate-KIC. Their innovative idea, called AQGRI+, turns domestic waste water into compost, fish and agricultural irrigation water. Almost 80 participants from 28 countries competed for the prize. The happy winners were awarded a price of US $ 25.000 to further develop their idea.

Prasetya developed their winning business model during her M.Sc. thesis in Vietnam, where she studied the reuse of aquaculture wastewater for rice irrigation. The topic inspired her to use wastewater from Vietnamese households as a resource instead of dumping it as waste. 'Domestic wastewater contains valuable components', Prasetya says. 'With the right methods, the nutrients can be optimized for reuse to generate useful products.' The idea of AQGRI+ is straightforward and elegant. First, solids from waste water will settle in large tanks and subsequently be used as a basis for compost. The remaining water will be guided through constructed wetlands to remove pathogens. The cleaned wastewater will be used in aquaculture; it still contains nutrients that allow growth of plankton, a food source for fish. Compost and effluent from fish ponds will be sold to coffee plantation owners as nutrient-rich irrigation water as an alternative for scarcer freshwater and soil improver. The fish will be sold to local fish distributors.

Priska Presatya (second from left)

Calculations have shown that selling the three products, compost, fish and irrigation water, is profitable. Based on five stations with a minimum processing capacity of 350 m^3 per day each, the yearly profit is expected to be around EUR 45,000. These earnings will be invested in new stations over time. Together with CEWAS, a Swiss coaching organization, Prasetya and van Veen will start up and develop their business the coming year. 'CEWAS has the network to find the right partners in water and sanitation management in Vietnam', she says. 'The next step will be to find locations for pilot plants and potential AQGRI+ stations.' In five years, they are aiming to have 25 operational AQGRI+ stations in Vietnam.

High-value crystals instead of low value sludge

In July 2014, ETE started a project on magnetite bio-crystallization from iron in groundwater. This alternative iron removal method makes the water suitable for drinking, while valuable magnetite is formed instead of low-value iron sludge.

'All groundwater contains dissolved iron', says Yvonne Mos, Ph.D. student at ETE. 'This makes it unsuitable for drinking, since this metal tastes bad and precipitates in the water pipes.' To make groundwater drinkable, iron is currently removed by chemical precipitation. This results in large amounts of low-value iron sludge, that may contain small amounts of arsenic as well. If the arsenic concentration is too high, the sludge has to be dumped as chemical waste, resulting in additional costs.

Magnetite crystals

Utilizing dissolved iron to form magnetite instead of sludge, has large economic benefits since magnetite has many applications and consequently a higher value. Due to its magnetic properties, it can, among others, be used in magnetic memory devices, MRI contrast fluids and as carriers for tumor-inhibiting substances. 'We calculated a value of at least € 500,00 per ton for magnetite', say project leader Jan Weijma. 'Iron sludge is worth substantially less.'

Controlled

Magnetite crystals contain two different varieties of iron: Fe^{2+} and Fe^{3+}, while ground water mainly contains Fe^{2+}. Magnetite crystals are only formed when both forms of iron are present. 'With the help of microorganisms we aim to oxidize part of the Fe^{2+} into Fe^{3+} in a controlled way', Mos explains. 'Under the right conditions, a spontaneous formation of magnetite crystals occurs.' Eindhoven University will examine optimal crystallization conditions in solutions resembling groundwater. The effect of pH, temperature and concentrations of oxidized and un-oxidized iron on magnetite crystallization will be studied. ETE focuses on the (micro)biological aspects, like oxidation and formation of magnetite crystals using microorganisms.

Bacterial activity

The biggest challenge of the project will be to inhibit and control the spontaneous conversion of Fe^{2+} into Fe^{3+} in ground water by chemical oxidation, the scientists expect. At the same time, bacterial activity has to be controlled in such a way that the right amount of Fe^{2+} is oxidized into Fe^{3+}, to allow crystallization of magnetite, while as little as possible other iron precipitates will be formed.

Magnetite crystals

Mos will start her experiments in a small, closed system of just 20 ml. Oxygen supply, and thus chemical oxidation, can be controlled and consequently loss of too much Fe^{2+} can be avoided. 'With this system we aim to produce magnetite in a controlled way', says Mos. 'In a next step, magnetite crystallization conditions will be applied in continuous reactor designs, suited for upscaling.'

This project is funded by Technology Foundation (STW) and will be carried out together with Eindhoven University and six companies: Oasen, Vitens, Reststoffenunie, WML, A.Hak, and WLN.

Agenda

PhD defence (Aula, Wageningen):

3 Dec, 13:30: Lena Faust, "Bioflocculation of sewage organic matter at short retention times"

29-30 April 2015: Environmental Technology for Impact conference

1 May 2015: Alumni Day 50 years Environmental Technology

Top scores in research audit

In a recent research audit of the research school SENSE, all scientific groups were evaluated on scientific quality, productivity and social relevance. In the recently published report, ETE had top scores in all categories: 4.5 to 5 points out of a maximum of 5 points. The committee praised ETE's vision and innovative research with excellent visibility of both Prof. Buisman and Prof Rijnaarts. Also ETE scored very well with an excellent productivity of high quality peer-reviewed publications in outstanding journals. About a third of their papers are amongst the top 10 most frequently cited, and 6% of the papers are even among the 1% most frequently cited papers. Funding has also steadily increased over the years. In addition to an excellent publication record, ETE has also developed a number of patented technologies in its research field.
Social impact and relevance was also very high, the commission concluded. Contributing to a sustainable future is a core of today's international energy and environmental research. ETE's research is leading in this field and focuses on many important environmental issues related to bio-recovery, reusable water, and urban engineering. The research at ETE also initiated a number of startup companies, that, according to the commission, shows excellent societal relevance in the field.

ETEi2015 conference

50 YEARS Environmental Technology

To celebrate its 50 year Anniversary the sub-department Environmental Technology of Wageningen University will organize a 2-day conference on April 29-30 2015: *Environmental Technology for Impact. Recovery of valuable resources from waste and wastewater.*

Over 50 speakers and poster presentations about the latest findings and advances in these dynamic research fields will be presented. The conference will bring together the most eminent, international speakers on Environmental Technology. The day after the conference (1 May) all ETE alumni are kindly invited to join the 50 years ETE Alumni Day.

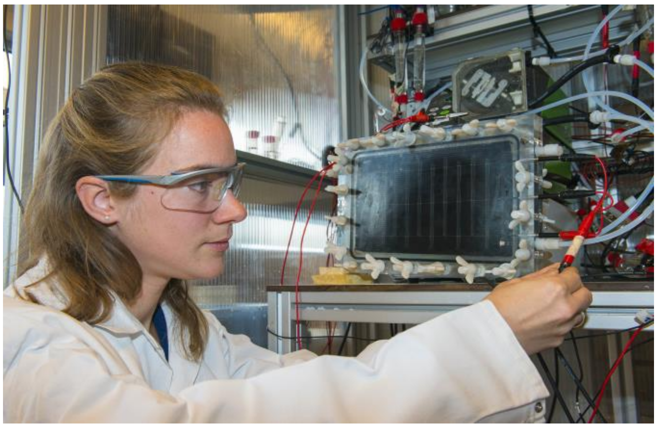
Important dates:

01 December 2014: Deadline of abstract submission and deadline for early registration

01 February 2015: Notification of abstract acceptance

For more information: **www.etei2015.org**

Science: Transportable and storable energy through microorganisms



Electrical energy may be transformed into a fuel by microorganisms. Ph.D. researcher Mieke van Eerten-Jansen developed a method where the tiny creatures use CO_2 and electricity to produce methane. In contrast to electricity, this fuel can be stored and transported easily. She graduated on September 19th.

Electricity is the most common form of energy produced from sustainable resources like sun, wind and biomass (Table 1).

Resource / Energy type	Heat	Electricity	Fuel
Sun	+	+	-
Wind	-	+	-
Biomass	+	+	+

Table 1. Energy type recovered from different sustainable resources.

However, generating electricity from these sources has some limitations. It results in a fluctuating supply, while energy demand varies over time as well. Since electricity is difficult to store or to transport, a mismatch in supply and demand may occur. Therefore, research is conducted to transform electrical energy into a transportable and storable form. For example, electricity is used to produce hydrogen gas from water. Hydrogen is an energy carrier that can be used in special engines. However, the gas has several drawbacks. Storage and transport require very large and heavy tanks. High pressure tanks containing hydrogen at a staggering 700 bar need four to five times as much space as a gas tank with similar mileage. Consequently, transport is expensive and inefficient.

CO_2 neutral

Converting electricity into fuel, like methane, solves the drawbacks of inconsistent generation of electricity by wind or sun. Methane is easy to transport and store, and in The Netherlands an extensive gas infrastructure is already in place. Therefore, converting electricity into fuel solves the problem of the mismatch between supply and demand. Microorganisms may play a key role as catalysts in the conversion of electricity into methane. Van Eerten-Jansen successfully developed a fuel cell where microorganisms use electricity to produce methane. 'A cocktail of microorganisms grow on a thin piece of graphite felt in a salt-water filled fuel cell', she explains her method. 'The felt is where the magic happens and methane is formed.' In the fuel cell electrons flow from the anode to the cathode giving the felt (cathode) a negative charge. CO_2 is dissolved in salt water that fills the cathode compartment. At the anode hydrogen ions are formed through hydrolysis and migrate to the cathode. Stimulated by electrons, microorganisms catalyze the conversion of CO_2 with hydrogen ions into methane (fig. 1). 'Our reactor converts electrical energy into chemical energy', she says. 'The reaction is CO_2-neutral and the methane can be produced independently of biomass.'

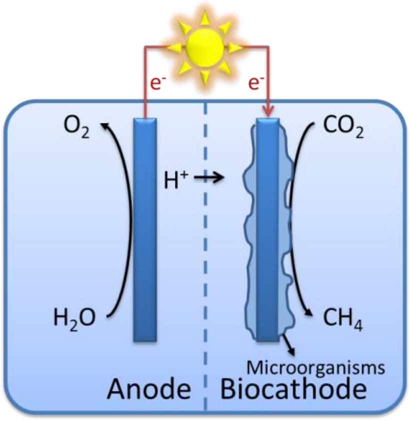


Fig. 1. Schematic of the bioelectrochemical system in which CO_2 is reduced to methane at the biocathode.

More efficient

Although the reactor functions well and produces a maximum 200 ml methane per liter reactor per day, gas production is still a factor 25 lower than in commercial biomass fermentors. And electricity costs are still relatively high. Van Eerten-Jansen: 'One m^3 of methane contains 10 kWh of energy, while we need 18 kWh to produce it. An efficiency of just 55 percent'. But the scientist has many ideas how to boost the reactor's efficiency and make it more competitive. Perfecting reactor design by innovative electrode design and by increasing the felt surface area relative to the reactor volume is a possibility. Also the cocktail of microorganisms can be improved by removing those species that do not produce methane or create conditions inhibiting methane production. Besides efficiency, also the source of CO_2 is important to make the method really sustainable. Ideally, CO_2 from air should be used, but that is still not cost-effective. 'We have many ideas to make this method competitive', says van Eerten-Jansen. 'Now we have to prove that we can make it more efficient.'

Key publication: Van Eerten-Jansen MCAA, Jansen NC, Plugge CM, De Wilde V, Buisman CJN, Ter Heijne A. (2014). Analysis of the mechanisms of bioelectrochemical methane production by mixed cultures, Journal of Chemical Technology & Biotechnology, DOI: 10.1002/jctb.4413.

This research is being continued by PhD researcher Dandan Liu and supported by Dirkse Milieutechnologie (DMT) and Alliander.

Science: Drug residue removal from wastewater

Microalgae can be used to remove drug residues from wastewater. Arnoud de Wilt, Ph.D. student at ETE, tested the drug removal capacity of photo-bioreactors containing microalgae. His results showed that this system is efficient in removing certain drug residues from wastewater; algae may substantially contribute to this elimination.

Pharmaceutical residues resulting from human medicine use are an increasing environmental problem. The body excretes painkillers, antibiotics, anti-epileptics, heart medications, birth control agents and many other drugs, as well as their breakdown products in urine and feces. These residues subsequently end up in the sewer system and are transported to wastewater treatment facilities. As conventional wastewater treatment facilities are not designed to treat pharmaceutical residues, most of these compounds are not removed in the treatment facilities. Consequently the residues are discharged to surface waters, enter the ecosystem and even infiltrate in ground water. About one third of all Dutch drinking water originates from surface water and two thirds from ground water, the presence of this chemical cocktail therefore threatens all portions of the drinking water supply chain.

Combined effects

More than 3000 different drugs are sold in the European Union, while more than 200 different compounds are regularly found in Dutch wastewater. In The Netherlands alone, about 1250 tons of medication was used in 2007; that is roughly 160 pills per person per year. In the future, medicine use will only grow, with an expected increase of more than a third by 2050. This will inevitably result in increased exposure to the environment and eventually also our drinking water. ´Toxicity tests have shown that concentrations of individual compounds are well under the human toxicological threshold´, de Wilt says. ´But the combined effects of a cocktail consisting of more than 200 biologically active compounds is unknown.´

Estrogen active

A lot of evidence exists on effects of pharmaceutical residues on aquatic animals. Exposure to these chemicals resulted in abnormal swimming behavior in Daphnia, feminization in fish, due to hormone residues and other estrogen-active substances, and cell deformities in liver and kidney of rainbow trout. 'It is obviously important to remove these pharmaceutical residues in an early stage, before they can enter the ecosystem and subsequently the drinking water', says de Wilt. 'Most logical is removal in wastewater treatment facilities; water released from the facility should be harmless to the environment and not jeopardize our drinking water.'

Microalgae cultures

Chemical or physical removal of pharmaceuticals in wastewater is expensive and consumes high amounts of chemicals and energy. Therefore, de Wilt investigates possibilities to use microorganisms in wastewater drug removal. In a study, together with Andrii Butkovskyi and Kanjana Tuantet, he specifically looked into the possibilities of using microalgae to remove pharmaceutical residues. He studied two new sanitation systems that make use of microalgae in so called photo-bioreactors. In the first sanitation system (Fig. 1a), vacuum toilet waste 'black water' is collected and anaerobically digested before it is fed to photo-bioreactors.

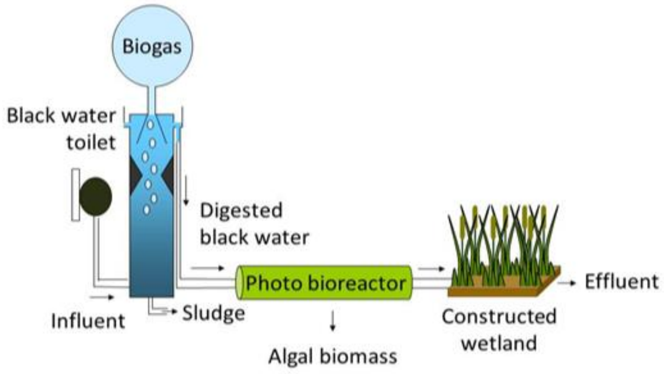


Fig. 1a. Schematic overview of the black water sanitation system.

In the second sanitation system (Fig. 1b) urine, collected via waterless urinals, is directly fed to photo-bioreactors.

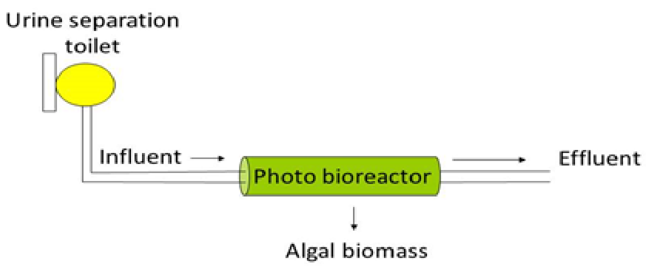


Fig. 1b. Schematic overview of the urine sanitation system.

Microalgae remove nitrogen and phosphorous from the nutrient rich streams, generating new biomass. Surplus algal biomass can be harvested and used in further applications. Within the photo-bioreactor, drug residues may be degraded by algae, bacteria and light. 'We were mostly interested if these reactors could effectively remove drug residues', say de Wilt. 'But we also carried out lab-scale experiments to separately test the individual contribution to drug removal of algae, bacteria, and light.'

Added value

The system proved to be effective in removing some pharmaceutical residues from wastewater, while others drugs were more resilient towards degradation (Fig. 2). For example, tests with painkillers ibuprofen and diclofenac showed high removal (more than 60 %) with and without algae and bacteria. ´These compounds are degraded just by light, photolysis´, concludes de Wilt. 'There was no added value of the bacteria and microalgae cultures.' But other compounds showed removal just by microorganisms. For example, the beta blocker metoprolol, didn´t show any photolysis. With just natural background bacteria, present in black water, removal was about 55%, while bacteria and algae together resulted in a 99% removal. If urine was used instead of black water bacterial drug removal was only 20% due to a different bacteria population. This improved to 50% if also algae were present. Algae growth was not inhibited by the presence of drug residues despite 100 times higher medicine concentrations in the test water compared to environmental levels.

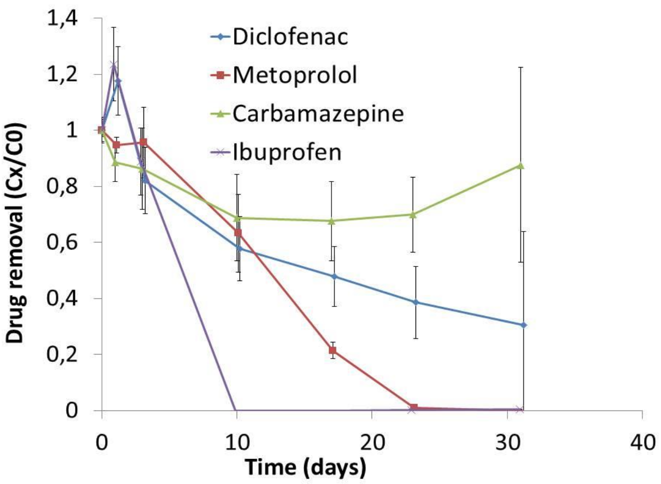


Fig. 2. Removal of different pharmaceuticals from digested black water in a photo-bioreactor.

After these promising results, several aspects still need further investigation. 'We need to scale-up the process and see if it works at larger scale too', says de Wilt. 'It is also essential to check the effluent of the system for potential toxicity. The original compound has been degraded, but resulting breakdown products may have even larger toxic effects.' Drug uptake by algae was low, less than 5%. Due to these low concentrations, algal biomass might have application as, for example, fertilizer, but the quality still needs to be researched.

Key publication: De Wilt HA, Butkovskyi A, Tuantet K, Fernandes TV, Hernández Leal L, Zeeman G, Langenhoff AAM (2014). Micropollutants removal by algae grown on source separated wastewater. In preparation.

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