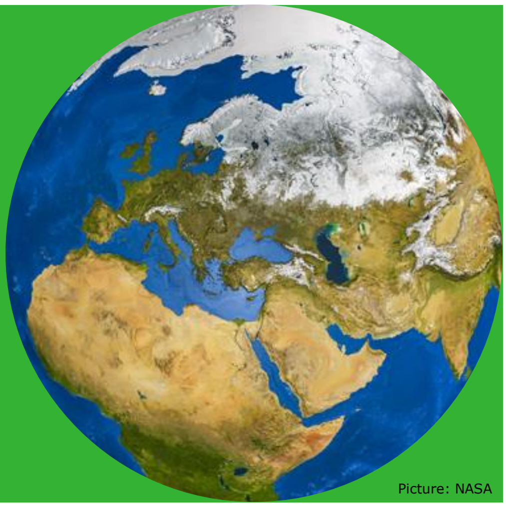
Environmental Technology

Newsletter | Spring 2017

WAGENINGEN UNIVERSITY
WAGENINGEN UR



Picture: NASA

News

UFW-KLV award for Annemerel Mol

Photo: Marjet van Veelen

Last March Annemerel Mol won the UFW-KLV thesis award for her master thesis 'Bio-electro chemical battery' in the category Environmental Sciences. This prize is awarded every year by University Fund Wageningen and by KLV Alumni Network Wageningen to outstanding students that have been graded with a 9 or higher for their M.Sc. thesis. The jury was clearly impressed by Mol's work, that they described as 'a highly accessible and entirely convincing thesis'. Not only did she provide proof of concept of a bio-electrochemical battery, but also developed a working prototype based on an original, theoretical and practical approach. According to the jury, Mol's thesis is a first step towards an environmental friendly, renewable electricity storage system that has the potential to be competitive with existing polluting battery systems.

Completely biodegradable

Current electricity-storing systems, like lithium-ion batteries, are expensive, contain rare materials and are difficult to recycle. Therefore, there is a growing need for cost-effective, environmental friendly technologies to store surplus electricity from renewable resources, like wind or solar energy. The newly developed bio-battery is definitely an excellent candidate. Mol: 'Our bio-battery is made exclusively from materials that are widely available and is completely biodegradable.

Determination

Micro-organisms play a key role in the concept of the bio-battery. The principle is based on the exchange of electrical and chemical energy.

Column **Huub Rijnaarts**

Although large amounts of fresh water are available on our blue planet, many regions still suffer from water scarcity. This limits water availability for industry, agriculture and domestic use. At ETE we develop technologies for solving this problem, for example by recycling water using state of the art cleaning methods. However, an important factor complicating wastewater cleaning is the presence of micro-pollutants, such as pharmaceutical compounds. Therefore, ETE has formed research teams, including more than 15 Ph.D.'s, to develop methods for the removal of various micro-pollutants from water.

To join forces with other knowledge institutes on water purifying topics, ETE organized, together with STOWA and spin off company LeAF, the 'Knowledge day Pharmaceuticals' in December 2016 and once again in February 2017. More than 80 delegates from all water boards in the Netherlands, drinking water companies, provinces, technology providers and knowledge institutes participated in sharing views on cleaning waste water from micro-pollutants, like pharmaceuticals. This event will be held again a year from now.

To share our knowledge and views on water-related issues, ETE also plays a key role in the 'Wageningen Water Strategy', WATER@WUR, promoting water research aiming at solutions regarding water-related issues. We do believe we can eventually solve water problems with the right technology and the right political will.

The design consists of 2 main components, a charging unit and a discharging unit, that are integrated in one system. To charge the battery, bacteria convert CO_2 and electrical energy (electrons), supplied by a sustainable resource, into acetic acid. The battery is discharged and delivers energy when different bacteria convert acetic acid (chemical energy) back into CO_2 and electrons (fig. 1). 'It was a lot of hard precision work and determination to integrate these systems', says the prize winner. 'But in the end it all worked out and we built a functioning battery!'

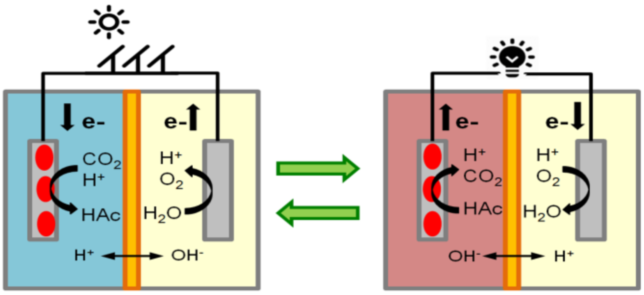


Fig. 1. Schematic overview of the Bio-electrical battery.

Open Mind Award for a revolutionary idea

Photo: David Strik

The revolutionary idea to grow plants using electricity resulted in the STW Open Mind Award 2016 for ETE scientist avid Strik and Mathijs van der Zwart, who just completed his Master Biotechnology. A challenging plan worth 50.000 euro in research money. Open Mind has been created by STW as a low-threshold subsidy for bold and challenging research ideas. The subsidy wants go encourages scientists to think out of the box, and to propose original research with social impact.

Dark photosynthesis

There is an increasing demand for agricultural products to feed the growing world population. Food production requires lots of water, nutrients and space. As a result, natural areas, like grasslands and tropical rainforests are under increasing pressure of growing agricultural activities. 'When we manage to grow plants without sunlight, I call it dark photosynthesis, we can produce food in areas unsuitable for traditional agriculture', says Strik.

Plants under power

The scientists think that the paradox of 'dark photosynthesis' is possible by using electricity to put plants under electrical power. During the first step of normal photosynthesis, plants use sunlight to oxidize water, generating electrons. These electrons are subsequently used, together with CO_2, in metabolic reactions for biomass production (growth) (Fig. 2). Strik: 'Our plan is to skip this first step and deliver electrons directly to the plant, so sunlight is not needed: effectively, we want run electricity through plants.' This principle is already functioning in bacteria: these organisms produce acetic acid using electricity and CO_2. Strik is confident that it could work for plants too, but instead of producing acetic acid, plants produce biomass.

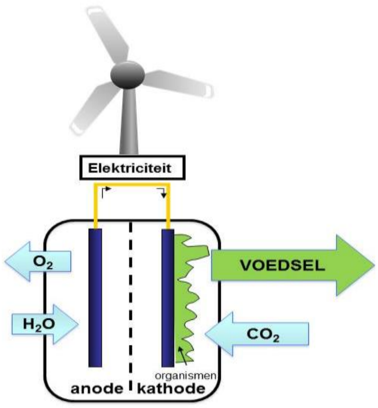


Fig. 2. Dark photosynthesis.

Breakthrough

Last February the first experiments started with microalgae, relatively simple, plant-like organisms. Algae contain a lot of useful substances, including proteins and fats, and could be used as a raw material for animal feed. The scientist wants answers to basic questions: What species are most suitable? What electrodes we need to use? How do we efficiently deliver electrons into the algae cell? The experiments will last until end of 2017, and Strik is confident the idea might work. 'We could be close to a revolutionary breakthrough.'

ETE contributes to sustainable urban development in China

ETE has started contributing to solve environmental problems related to big cities in China. In close collaboration with WIMEK and ETE, Tsinghua University will setup a new research institute in Suzhou, aimed at sustainable urban development. ETE researcher Wei-Shan Chen is facilitating this collaboration using Dutch experience and technology.

Systematic methodologies
In recent years, China is becoming more and more aware of the presence of huge environmental problems associated with air, water and soil. Increasing economic growth has urged private companies to take responsibility and start cleaning polluted areas. 'There is a tendency towards more systematic and effective methods to restore the environment', explains Chen. 'The polluting source is controlled, and soil, water and air are not only cleaned, but also restored to functionality, for example agricultural use.' Partially inspired by the Dutch clean technologies, wastewater treatments start to include nutrient recovery. Together with ETE, Tsinghua University will apply these principles to urban areas, aiming at generating sustainable metropolitan solutions.

Cradle to cradle
The main principles of sustainable urban development are based on three pillars. The first pillar is a *circular city*. That means a vital role for recycling, according to the cradle to cradle principle. The second pillar is *food safety and health*, such as local fresh food production. The last pillar is *smart, more efficient transportation*. These pillars are visualised in a demo, 'The street of the future' (fig. 3), that is led by ETE scientist Jan Vreeburg. This demo will be presented at the Dutch Floriade in 2022. Core technologies include smart ways to close cycles: innovate infrastructure, modern wastewater management systems, recycling, renewable energy, and urban farming. Chen: 'The idea is to start with this first demo followed by building more demo's using different technologies in different cities in China and the world. The whole idea is to help and learn from each other on the sustainable urban development!'

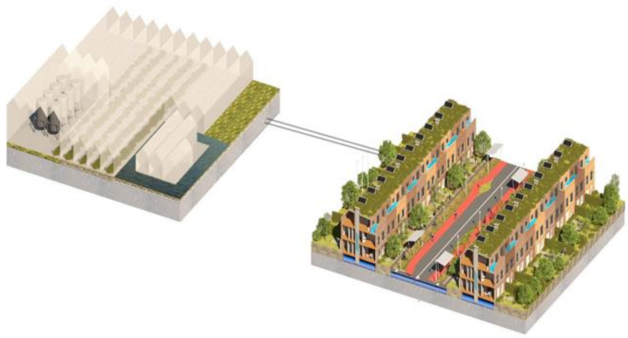


Fig 3. Visualization of 'The Street of the future'. Integrated technologies are used to close resource cycles: waste water and organic waste are transported to the building left, where wastewater treatment, urban farming and recreational possibilities are housed.

Core technologies include smart ways to close cycles: innovate infrastructure, modern wastewater management systems, recycling, renewable energy, and urban farming. Chen: 'The idea is to start with this first demo followed by building more demo's using different technologies in different countries. The whole idea is to help and learn from each other!'

ETE spin-off company Chaincraft expands its production of fatty acids

In May 2017, biotech company Chaincraft in Amsterdam started building a new demonstration factory for increased production of fatty acids from organic waste. In the current facility, several thousands of kilos of fatty acids are produced annually. The investment of 6 million euro's in a brand-new factory is aimed at a substantial increase in production: there is capacity to produce about one million kilos of fatty acids annually.

Valuable chemical building blocks
ChainCraft was founded in 2010 as a direct result of ETE's discovery of a microbiological process where organic waste is converted into valuable chemical building blocks like fatty acids (ETE newsletter spring 2016). These compounds have several applications, like anti-microbial agents in animal feed as, but also as essential components for the chemical industry producing oils, paint, glue, and coatings. Many fatty acids originate from fossil oil or palm oil. Especially palm oil production takes a heavy toll on pristine tropical rainforests, that are cleared to make room for palm plantations. Chaincraft's step to scale the production of these valuable compounds from organic waste is an important step to a growing supply of sustainable fatty acids.

Organic waste waiting to be processed (*Photo: Wild Frontiers*)

Science: Improved degradation of micro pollutants in waste water

Waste water treatment plants are relatively ineffective to remove micro-pollutants such as diclofenac and metoprolol. Ph.D. researcher Wenbo Liu improved existing technologies to degrade these components using anaerobic conditions as well as bacteria.

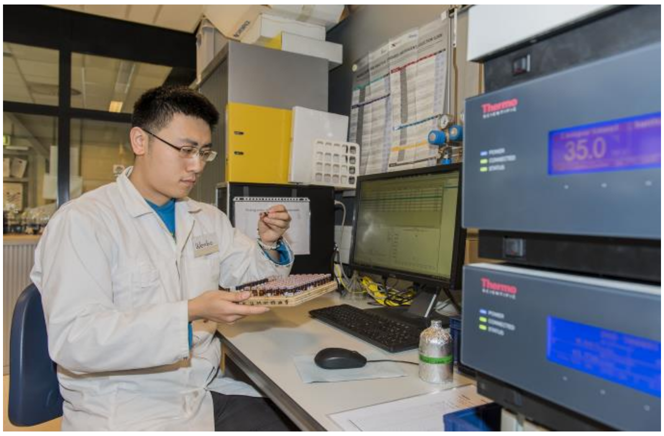


Photo: Wild Frontiers

During the last decades, waste water treatment technologies have improved dramatically. Removing organic substances and nutrients, like phosphorous and nitrogen, are highly effective. However, increasing amounts of pharmaceutical residues end up in waste water and are not sufficiently removed with conventional technologies. As a result, these substances end up in natural water systems. Despite their low concentrations, their toxicity pose an increasing threat to the ecosystem as well as the drinking water supply. For example, in The Netherlands diclofenac, a non-steroid anti-inflammatory drug (NSAID) (fig. 4a) and beta-blocker metoprolol (fig. 4b) is used by more than one million people annually.

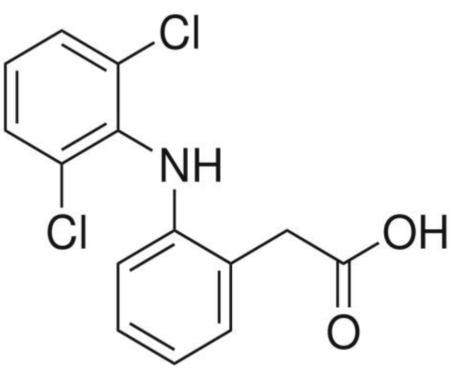


Fig. 4a. Diclophenac: 2 persistent phenyl rings

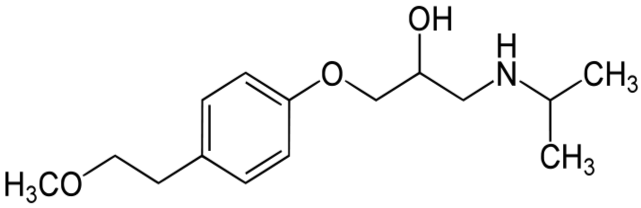


Fig. 4b. Metoprolol: 1 persistent phenyl ring

Often, as much as half of these compounds are not taken up by the body, but excreted in urine. In addition, breakdown products are excreted as well and may pose additional risks to the environment and affect our ecosystem and drinking water safety. With ageing populations, amounts of pharmaceuticals discharged into aquatic ecosystems will only increase. ‘Diclofenac is among the most persistent and toxic pharmaceuticals’, says ETE scientist Wenbo Liu. ‘It shows toxic effects already at low concentrations.’ Therefore, EU placed this pharmaceutical on the watch list of persistent compounds, requiring environmental monitoring. Nevertheless, release of pharmaceuticals into the environment is not yet regulated.

More efficient methods

‘Current methods to remove micro-pollutants from waste water include advanced oxidation, adsorption to activated carbon’, Liu explains. ‘These methods are often not very efficient. Therefore, we were looking for improved, more efficient methods to degrade recalcitrant pharmaceuticals, like diclofenac and metoprolol.’ By experimenting with different reaction conditions and the absence or presence of microorganisms to help degradation, Liu managed to improve the well-established manganese-oxide (MnO_2) oxidation method. In the absence of oxygen (anoxic conditions), degradation of diclofenac was largely improved, he found out. After 24 hours of reaction, removal efficiencies were about 60% with oxygen, but increased to over 90% under conditions without oxygen, an improvement of 50% (fig.5).

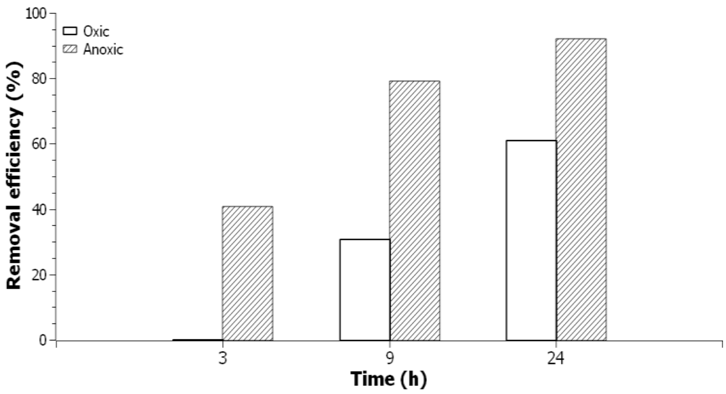


Fig. 5. Removal efficiency of diclophenac using MnO_2 in the presence with and without oxygen.

Hard to degrade

To enhance diclofenac degradation even more, Liu combined anaerobic MnO_2 oxidation with additional breakdown by microorganisms. This didn't result in a better removal efficiency though. 'Based on other research, we expected to see a better degradation of diclofenac, because certain bacteria are able to break down persistent compounds', says Liu. 'But possibly diclofenac is too difficult to degrade for bacteria due to the presence of two stable phenyl rings in the molecule.'

Metoprolol, on the other hand, showed significant improved degradation when combining anaerobic MnO_2 oxidation and microorganisms. After 50 days, using MnO_2 oxidation only, metoprolol concentrations dropped from 11 mg/l to 7 mg/l, a decreased of about 36%. Including microorganisms spectacularly decreased concentrations to less than 1 mg/l.

the scientist concludes. 'The deployment of bacteria to enhance micro-pollutant degradation should be tested and whenever effective implemented in waste water treatment systems.'

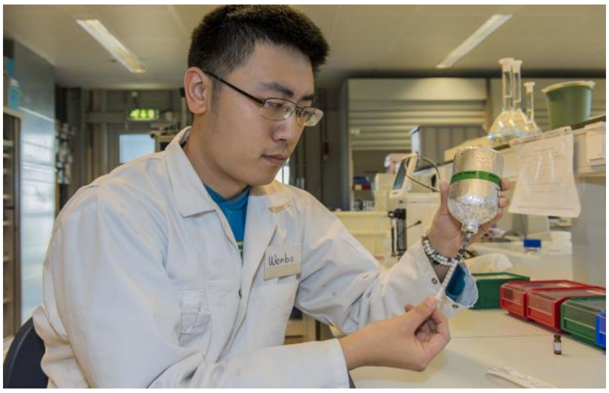


Photo: Wild Frontiers

Spin-off: Electricity from living plants

R&D company Plant-e uses plants to generate electricity. ETE played a key role in designing and improving the efficiency of this so-called Plant Microbial Fuel Cell. Now Plant-e is further developing the technology to boost yield and reduce costs.

Led lights powered by plants at Atlas building, Wageningen UR campus. (*Photo: Wild Frontiers*)

A red and a black electrical wire stick from the soil of a small plant pot. Pim de Jager, researcher at Plant-e, connects the two and a small LED lights up. Electricity from plants, a green dream that has become reality! 'Bacteria and plants live in symbiosys', de Jager explains the principle. 'The plant uses solar energy to synthesize organic compounds for growth. Part of these substances are released by the root system into the soil, and utilized as fuel by bacteria.

'Metoprolol has just one stable phenyl ring, that can obviously be degraded by micro-organisms present',

In this process electrons are formed, that can be harvested by an electrode to generate electricity.'

Electrical current

The principle of micro-organisms generating electricity was first discovered in wastewater treatment systems. An important part of this water cleaning process includes the bacterial removal of organic compounds. Scientists found out that these microorganisms converted organic contaminants into biomass, while producing CO_2, hydrogen ions and electrons. By placing a positive (cathode) and negative (anode) electrode into wastewater, electrons were formed at the anode and could be harvested. Closing the circuit resulted in an electrical current. This principle was subsequently applied in the microbial fuel cell (MFC). Soon, scientists discovered that plants and their symbiotic soil bacteria could replace waste water (fig. 6). As soon as the proof of principle was demonstra-ted, in 2009, spin-off company Plant-e was founded.

Photo: Wild Frontiers

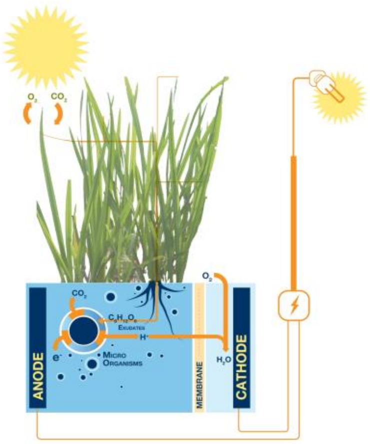


Fig. 6. Principle of the Plant Microbial Fuel Cell

Hard Cash

For CEO and founder Marjolein Helder, the establishment of Plant-e was a gradual process. During her Ph.D. she built the company step by step. Grants and personal loans generated hard cash. ‘There is now about one million euros in Plant-e, including 250,000 euros in personal loans and many hours of unpaid work’, Helder says. I don’t consider this a risk, because I strongly believe in the product. I cannot imagine it won’t work in the end!’ Plant-e built the first working system where plant power was generated in 2011, on top of the roof of the Netherlands Institute of Ecology (NIOO-KNAW) in Wageningen. The system was used to perform experiments and to collect data.

Great Appearance

According to Helder, it is too early to use the system as an alternative to generate electricity. Helder: ‘Our invention is more like an integrated product with plants, that delivers electricity and has a great appearance! It is meant for customers who want to lead the way and appreciate a beautiful green gadget.’ An area of 100 square meters costs about 60,000 euros and provides enough electricity to recharge a mobile phone or to illuminate several LED lights. Local and central governments appreciate the technology and its potential and purchase the system, supporting research and development. For example, in the building of Interpolis in Tilburg, plants supply energy to a mobile phone charging unit, while a plant-powered wifi-hotspot was built on a schoolyard in Zeist.

Challenges

Over the years, revenues for Plant-e have increased gradually, reaching about 700.000 euro in 2016, the first year that the company reached break even. But there is still a long way to go before the system is efficient enough to compete with other energy sources. Despite obvious challenges, Plant-e expects that further research and development will result in a dramatic increase in efficiency.

Roof-top experimental units at NIOO-KNAW. (P*hoto: Wild Frontiers*)

Mobile phone charging point at Interpolis in Tilburg. (*Photo: Wild Frontiers)*

Many improvements were made and even though some obstacles still need to be taken, Plant-e decided to commercialize the product at an early stage. By the end of 2014, the first commercial systems were launched. ‘We have developed the basic technology into a system that can be applied in real life’, says Helder. ‘Our current commercial system consists of several modules, series of plant trays of about 50x50 centimetres, generating 5 Volts of electrical voltage.’ According to the World Economic Forum, Plant-e has developed into one of the most innovative firms in the world.

But to increase efficiency, a better understanding of how the system works is needed. ‘Our research now focuses on the basics of the system’, say Pim de Jager. ‘For example, we need to know more about species of bacteria that contribute and what compounds, the fuel, they prefer to generate electricity. Increasing these substrate concentrations, for example by supplying the right fertilizers to the plant, might result in a better efficiency.’

Clean energy supplier

Not only bacteria, but also the plant species effects the amount of electricity formed, since the amount and type substrates excreted by the roots differs between species. Grasses do particularly well, as long as they grow in a water-saturated soil, with little oxygen. For this reason, Plant-e is currently developing a tubular system that can be submerged in moist nature areas like wetlands, flood plains or rice paddies. The system works in the lab and is now being tested at two locations in the Province of Brabant and Zuid-Holland. If these tests succeed, nature as a clean energy supplier is within reach.

Test site for the newly developed submerged tubular system to generate plant electricity in Brabant. (*Photo: Wild Frontiers)*

Agenda

PhD defences (Aula, Wageningen):

June 21, 2017, 16:00: Wei-Shan Chen. ´Fuel the future: Medium chain length fatty acids, sustainable building block from organic waste ´

Oct 10, 2017, 11:00: Justine van Eenennaam. ´Rational application of chemicals in response to oil spills to reduce ecotoxicological damage´

Oct 10, 2017, 16:00: Yujie He. ´Remediation of wastewater contaminated with medicine residues ´

Contact

Annemiek ter Heijne (Environmental Technology)
E: Annemiek.terHeijne@wur.nl
www.wageningenur.nl/ete

Hans Wolkers (Wild Frontiers B.V.)
E: Hans.Wolkers@gmail.com
www.wildfrontiers.nl, www.science-explained.nl