Environmental Technology

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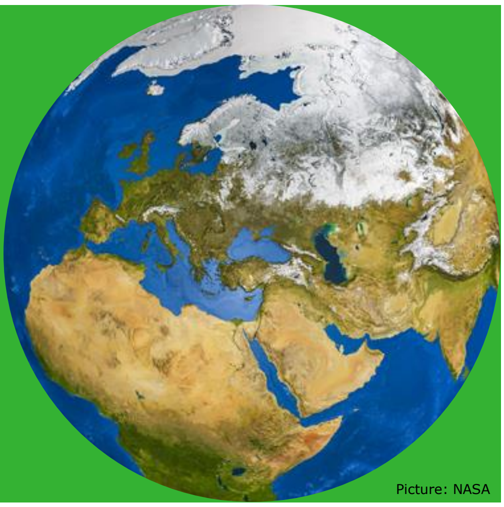


Picture: NASA

News

Dutch Innovation Award for Plant-e

On October 31st, ETE spin-off company Plant-e won the prestigious Dutch Innovation Award in the category Social Impact. The prize is an initiative of the Dutch broadcasting company AVROTROS and the Erasmus University in Rotterdam. The jury appreciated the company's innovative solution to the energy problem, its social vision and the intention to supply underdeveloped areas with truly green electricity.

Energy from plants

Founder and CEO Marjolein Helder studied environmental technology at Wageningen University and graduated in the field of energy generation from living plants. During her PhD research, she founded Plant-e. The company develops products that extract energy from natural areas without affecting nature itself.

Christmas tree

During the competition, Helder demonstrated her technology by bringing a small Christmas tree, that supplied enough electricity to let its own lights burn. Helder: 'It is crucial for your credibility to show that your idea is actually working.'

Ambition

Plant-e has an enormous ambition for the future. 'We want to generate energy from marshes and wetlands', Helder says. 'Our research has shown this is possible and we are acknowledged by a jury of format. Now we want to attract investors to expand our project.'

Column — ***Cees Buisman***

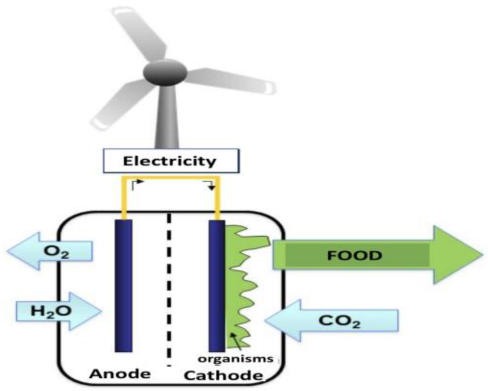
The focus on reducing the use of fossil fuels will have great influence on resource recovery. Many do not realize that carbon, including CO_2, will become a scarce resource if we stop using these fuels and transfer to renewable electricity. Many research projects, for example culturing microalgae or converting CO_2 into methane, depend on CO_2 sources from burning fossil fuels. Therefore, waste streams will become an important source of carbon instead. Consequently, environmental technologists need to develop new processes for more efficient recovery of carbon from waste. Anaerobic processes are well suited for this due to their efficiency.

The new factory of Chain Craft in Amsterdam, converting supermarket food waste into caproic acid, is such a process. Caproic acid, produced by anaerobic bacteria, can become a new source for chemicals. This process seems better suited for a carbon scarce world than the conventional anaerobic digestion, resulting in biogas.

Like carbon, also sulphur is harvested from fossil fuels. Therefore, also sulphur production will be limited when fossil fuels are not used anymore. The resulting carbon and sulphur scarcity comes on top of already limited resources like phosphorous and micro nutrients like zinc and selenium. Recovery of these resources will become crucial for future production of food and chemicals.

Lettinga Award 2017 for 'dark photosynthesis'

ETE scientists David Strik, Mathijs van der Zwart and Cees Buisman were awarded the 2017 Gatze Lettinga award. Since 2001 this prize of 10.000 euro is awarded every two to three years at the Anaerobic Digestion congress of the International Water Association. This award is to stimulate and implement anaerobic cleaning technology in society. The 2017 award was sponsored by Paques, Biothane and LeAF. The focus of this year's call was closing resource cycles using anaerobic technology. The jury concluded that the winning proposal '*Dark photosynthesis: anaerobic biosynthesis of food from wastewater and electricity*' had the most potential.



The principle of dark photosynthesis.

More pressure

Due to the growing world population, there will be an increasing demand for food. The resulting increase in agricultural activities will put even more pressure on natural areas, like grasslands and forests. 'When we manage to grow plants without sunlight, I call it dark photosynthesis, we can produce food in areas unsuitable for traditional agriculture', says ETE scientist and prize winner David Strik. Instead of culturing crops on farmland, the scientists plan to grow food in a bioreactor in an energy and water efficient way.

Plants under power

For most plants the sun is essential for growth. During photosynthesis, sunlight is used to oxidize water, generating electrons. These electrons play a key role in biomass production, i.e. growth. If electrons are directly supplied to growing plants by running electricity through them, light is not needed anymore and plants may grow in the dark. Strik: 'We want to put plants under power, so they can grow without light.' By providing nutrient-rich wastewater, for example urine, high quality food can be grown. This principle is already functioning in bacteria: these organisms produce acetic acid using electricity and CO_2.

Close cycles

With the award, the scientists intend to expand their research. Their next step will be to use urine as a nutrient source and test 'dark photosynthesis' on selected photosynthetic microorganisms. It is explorative research, but if the team gets this idea working, there will be an alternative method to produce food. 'I do hope our research will inspire other researchers to use waste water as a resource and close cycles in a clean and sustainable way', says Strik. 'A circular economy is simply a necessity.'

Science: Large scale energy storage using salt and fresh water

Based on the blue energy principle, where mixing of salt and fresh water generates energy, ETE scientist Jan Willem van Egmond was able to build a working battery unit where electricity could be stored and retrieved using salt gradients.

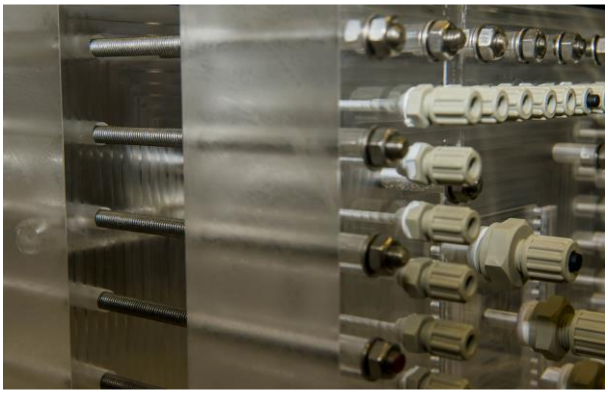
'This is our newest design of a concept to store energy', says van Egmond. He is holding a solid, silvery looking piece of plexiglas with holes and milled canals. 'We will test this prototype of our 'blue battery' during the coming months.' Van Egmond is working on a sustainable technology for large scale electricity storage. Eventually, this could make wind and solar energy a lot more attractive, since it can store surplus energy generated by these renewable energy sources.

Top priority

Sustainable large-scale energy storage is a top priority as the energy supply slowly changes from fossil fuels to more renewable energy based on biomass, wind or sun. In 2014, about 12.5% of the EU's energy consumption originated from renewable resources. The EU aims to increase this share to 20% by 2020. But energy generated from wind or sun can be rather unpredictable. Therefore, one of the issues that needs to be resolved is electrical energy storage to cover periods with low energy generation due to the absence of sun or wind. 'A widely applicable safe and sustainable technology to store energy peaks to compensate for low energy output is still lacking', van Egmond states. 'To generate substantial amounts of renewable electricity and become more independent from fossil fuels, big-scale energy storage is fundamental.'

Unsafe

Several systems to store energy are currently in use, for example the well-known lithium-ion batteries used in many consumer products. Large scale electricity storage using lithium-ion batteries is not a good alternative though: these batteries are expensive and relatively unsafe. In addition, they contain small amounts of rare materials, making recycling expensive. For this reason, about 99% of all large-scale energy storage in the world is installed in elevated water reservoirs. During peak hours, water is pumped to higher elevation using excess electricity. When energy production is insufficient, electricity is recovered by water flowing down through a turbine. However, for this system sufficient elevation is required, making its application relatively limited. 'We actually need a sustainable energy storing system that is environmentally safe, cost-effective and applicable in flat terrain', says van Egmond. 'I think our concept of 'blue battery' does the job!'



Old idea

The concept of 'blue battery' is to store energy using salinity gradients. An extensive system of high-tech membranes, permeable to differently charged ions, forms the heart of the system (fig.1).

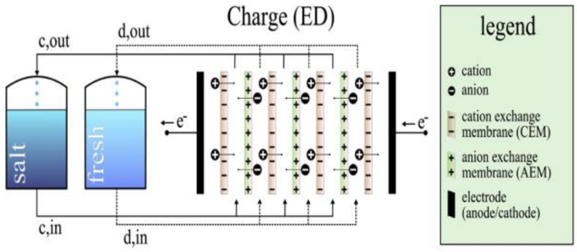


Fig. 1. Schematic overview of the Blue Battery

Fresh and salt water are separated by these membranes, creating such salinity gradients. At times when surplus energy is available, electrical energy is used to migrate salt ions against the salinity gradient from a low to high salinity (fig. 1) and the battery is charged. At times when additional electricity is required, the process is reversed by mixing fresh and salt water, generating electricity and discharging the battery. So, reservoirs of fresh and salt water potentially contain energy and may serve as environmentally friendly energy storage. 'This same principle is used since the 1960's to make fresh drinking water from sea water', explains van Egmond. 'We modified an old idea into a modern way to store large amounts of energy.'

Working concept

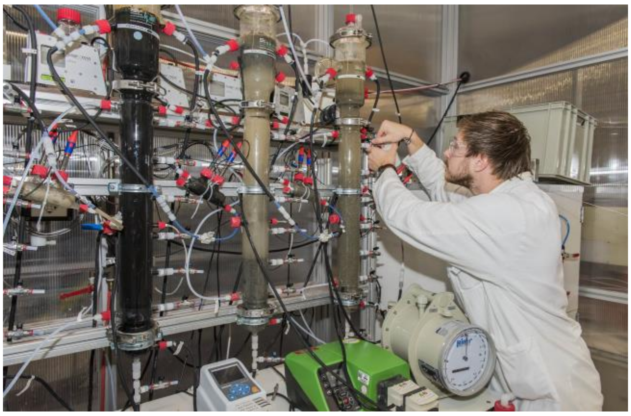
As always, the whole project started with a good idea, followed by designing and testing different battery models. After trial and error, van Egmond managed to design a working concept. Now he is strongly focused on improving the process and increasing the efficiency of the system. Better membranes, different salt solutions in different concentrations and a range of temperatures were tested. Step by step, this resulted in a more efficient battery. 'I expect big improvements in efficiency and storage capacity in the very near future', the scientist says. 'The ultimate goal would be to install blue batteries near residential areas. The size of an Olympic swimming pool is sufficient to sustain about 200 houses.' According to van Egmond the water-based blue battery will be a very competitive system for energy storage due to its low costs, safety and environmentally friendly design, based on water.

This research is part of the blue energy theme, supported by A.Hak, Alliander, AquaBattery, Fujifilm, Landustrie/Desah, REDstack, W&F Technologies.

Key publication: Van Egmond et al. 2017. The concentration gradient flow battery as electricity storage system: Technology potential and energy dissipation. The Journal of Power Sources 325: 129-139.

Science: Improved anaerobic treatment of salty wastewater

Waste water containing high concentrations of dissolved salts is unsuitable to be treated in conventional anaerobic wastewater treatment plants. The salt present harms the bacteria responsible for cleaning. By optimizing process conditions, Ph.D. scientist Dainis Sudmalis managed to have a functional system to clean wastewater containing salt. By understanding the mechanisms involved, the scientist hopes to have full-scale operative wastewater cleaning systems, able to deal with salty waste water in the future.



Many waste water streams contain substantial amounts of salt. For example, leather tanning industries, vegetable pickling factories and cheese manufacturers produce waste water with high amounts of dissolved salt. In some countries, like Hong Kong, even common households produce salty wastewater, when salt water is used to flush toilets. Worldwide, wastewater is often treated using the Up-flow Anaerobic Sludge Bed (UASB) reactor, developed by former ETE Professor Gatze Lettinga in the early 1970's. The revolutionary system replaced aerobic by anaerobic wastewater treatment and proved to be simpler, more cost-effective, while energy (biogas) and nutrients could easily be recovered. Essential for effective UASB operation are the microbial granules that are formed inside the reactor. These granules consist of densely packed microbes, that are too heavy to be washed out. However, salts present in wastewater may be toxic to microorganisms and interfere with the formation of these granules. For example, sodium may be linked to interference with binding forces keeping the microbial aggregates together. 'When sodium is present at concentrations above 8 grams per liter, these microbial granules are not formed or fall apart', says Dainis Sudmalis. 'The up-flow velocity of wastewater subsequently washes these microbes out, resulting in a dysfunctional reactor.' It is very common that wastewater contains more than 8 grams of salt per liter. To prevent reactor failure, a more robust principle, resistant to dissolved salts, had to be found.

Diminished reactor performance

Not only negative effects of salt in wastewater towards granule formation contribute to reactor failure. When microorganisms are exposed to osmotic stress, they cope with these conditions by increasing their own osmotic pressure and take up osmo-protectants, like potassium. However, potassium interferes with the enzyme machinery of microbial cells. Therefore, eventually organic molecules, like amino acids need to be taken up or produced inside the cell. This is an energetically costly process, resulting in diminished reactor performance and less biogas production.

Bacterial granules in a UASB laboratory set-up

During a first experiment, Sudmalis examined granule formation in wastewater containing salt, while optimizing reactor conditions. 'Based on literature, we optimized many reactor variables suitable for non-saline reactor conditions', Sudmalis explains. 'We enhanced the amounts of organic substrates to be treated per day, up-flow velocity, as well as organic compound mixtures and concentrations, to create a better environment enabling many species of bacteria to grow.' With all these factors optimized, the only stressor for the microbes was high salinity. To the scientist's surprise, substantial amounts of granules were formed, despite the salt present. Possibly, the microbiota managed to take up osmo-protective compounds to cope with high salinity conditions.

Concrete answers

With this unexpected quick result, Sudmalis now aims his research at understanding how and why granules were formed under salty environmental conditions. Was it the optimized substrate mixture? Or maybe the species of bacteria seeded in the reactor was a crucial factor? To get concrete answers, the researcher will operate the reactor using different environments: 'We will de-optimize the reactor by changing the optimal factors one at the time', Sudmalis explains. 'Some wastewater substrates will allow microbial activity, but no granule formation. Therefore, we will measure reactor performance as well as granule formation under a variety of conditions.' In addition, the effect of salt fluctuations on granule formation will be investigated.

Deal with salty wastewater

Together with Paques BV Sudmalis will investigate if the findings from his lab research can be successfully applied to a full-scale reactor running at elevated salinity. Sudmalis: 'Eventually, we hope to fine-tune and control the optimal reactor conditions in such a way that we can deal with salty wastewater.'

This project is part of Water Nexus.
Key publication: Sudmalis et al. 2018. Fast anaerobic sludge granulation at elevated salinity. Water Research 128, 293-303.

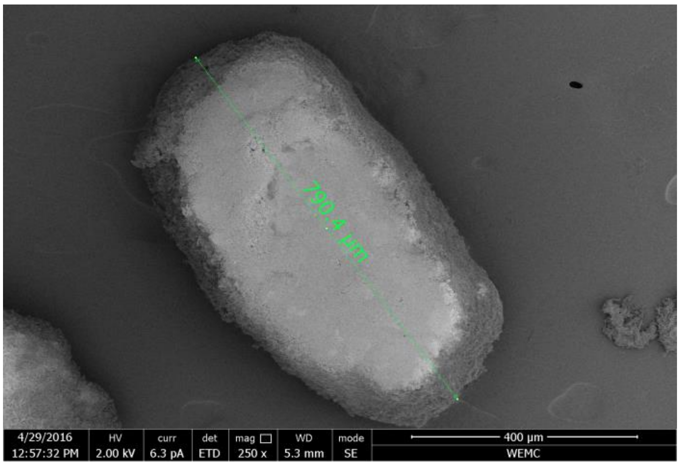
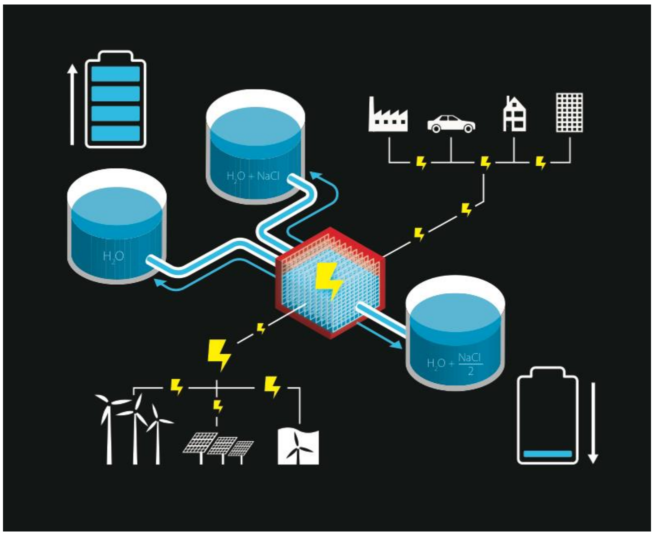


Photo: Dainis Sudmalis.
Scanning electron microscopy image of a bacterial granule formed at 20 grams of sodium per liter

Spin-off: Commercializing large scale energy storage using salt and fresh water

In 2014 former ETE Ph.D. researcher Jan Post founded AquaBattery. The spin-off company aims to commercialize energy storage using just water and salt. It is closely associated with ETE's research on Blue Energy, where energy is generated by mixing salt and fresh water. After three years, AquaBattery and partners have been successful in generating several substantial grants, and are planning to launch a commercial unit within two years.



Schematic overview of the principle of Aqua Battery.

When Post finished his Ph.D. on Blue Energy in 2009, funding to start a pilot plant was lacking. Therefore, he applied his knowledge to desalination research. 'Desalination is the reverse process of Blue Energy', Post explains. 'Removing salt from one solution and placing it in another one costs energy. Mixing these solutions again generates energy; this process is studied in the Blue Energy project. So, you can store energy by desalination. That is the principle of AquaBattery.' But back in 2010 research was focused on energy generation, not on storage, so the idea of AquaBattery was not further developed.

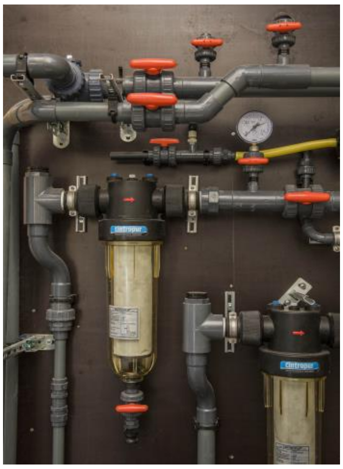
Energy storage

But with increasing generation of sustainable energy, the attention slowly shifted towards energy storage. When Post founded Aqua Battery in 2014, he had no funding whatsoever. To involve people with the right knowledge in his project he paid them in AquaBattery shares. 'This way, I have given away more than half of the company', Post says. 'But I got a lot of knowledge in return!' A year ago the young company won the Herman Wijffels innovation prize from the Rabobank in the category Circular Economy, based on their innovative set-up in a garage box. The 20.000 euro gave Post the opportunity to hire the first employee. But things had to become more seriously. Post: 'We asked ourselves: are we going to continue winning prizes or do we aim for a working product? Hiring personnel was risky, but it was a necessary step: no guts no glory!'

Minimal viable product

The dedication of the team was rewarded in 2016 by a substantial EU grant. AquaBattery and their partners, Wetsus and Fuji Membranes, got four million euro for a four-year project to further develop their technology. Two weeks later a second grant, a 580.000 euro project budget, followed for AquaBattery and Blue Energy firm REDstack. Post: 'This is the start of something great!' With these two grants, Post and partners aim to develop what they call 'a minimal viable product': a table-top aqua battery that works, is well designed and attractive, and can be sold for individual households. At the same time, the team is working on a large-scale pilot plant in The Green Village in Delft, a living laboratory located at the campus of Delft University. Here, innovations on sustainability are developed and tested. Post: 'Energy from solar panels is stored in our batteries and enables residents to enjoy renewable energy 24 hours a day!

Image: Green Village.
Artistic impression of Green Village in Delft. The red circle indicates the container with the pilot plant of AquaBattery.



Pumping and filtering unit of the Aqua Battery pilot plant

Safety and sustainability

The future for AquaBattery lies in the development of much bigger battery units that are placed underground and store energy for residential areas of about 100 to 200 households. Post has calculated that such an underground battery measures just a mere 10x10x3 meter. 'Using bigger units has the advantage that peak use due to energy-demanding equipment, like a vacuum cleaner, is divided over the whole battery', says Post. 'A smaller single household unit is less able to generate such a peak power.' The advantage of this system is its safety and sustainability: unlike in lithium batteries, there's no fire or explosion risk, all materials are natural, while the battery has no power loss. 'AquaBattery will revolutionize the way we store energy and will promote the growth of renewable energy technologies around the globe', Post concludes.

Agenda

PhD defences (Aula, Wageningen):

Bob Laarhoven December 15, 2017 11.00h. "Valorisation of waste streams, "From by-product to worm biomass"

Liu Wenbo January 26, 2018 13.30h. "Anaerobic manganese- or iron-mediated pharmaceutical degradation in water"

Arnoud de Wilt February 2 2018 16.00h. "Pharmaceutical Removal: Synergy between Biological and Chemical Processes for Wastewater Treatment"

Dandan Liu April 13, 2017 16.00h. "Bioelectrochemical production of methane from electricity and CO_2"

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