# Environmental Technology

Newsletter | Fall 2015

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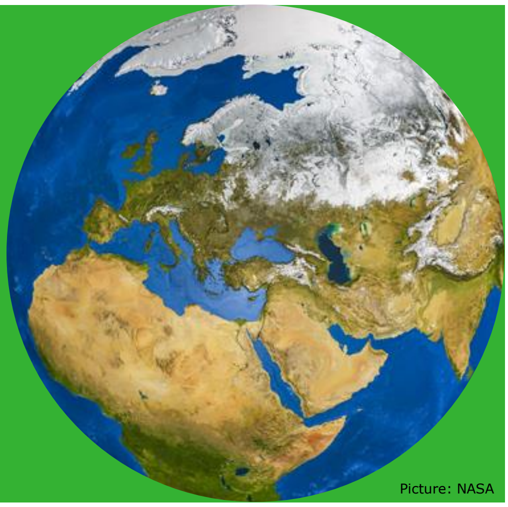
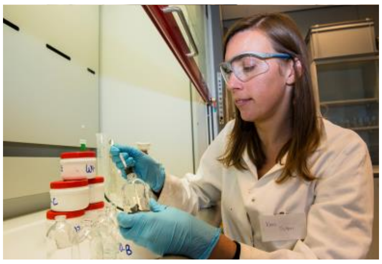


Picture: NASA

## News

### SENSE Ph.D. award for Nora Sutton



Former ETE Ph.D. student Dr. Nora Sutton received the 2015 SENSE Ph.D. award for her thesis *Microb biological and geochemical dynamics of the sub-subsurface:chemical oxidation and bioremediation of organic contaminants*' during the yearly SENSE summer symposium.
The jury particularly appreciated her fundamental scientific approach on the very practical problem of soil pollution. In addition, the Jury valued her international collaborations with both scientists and local authorities, thereby bridging gaps between engineering and practice.

### Cleaning contaminated soil

Soil polluted with organic contaminants poses a serious health and environmental risk. People may be exposed to these chemicals by inhalation or direct contact. In addition, these compounds may disperse in the environment, contaminating groundwater and water supplies, while seriously impacting the ecosystem. Therefore, many governments prioritize soil cleaning. Traditional methods to clean soil focus on excavation and disposal of the polluted soil. Recently, advances have been made in in situ techniques which clean the soil in place without excavation. During her Ph.D. research, Sutton researched chemical and biological soil treatment. She combined these methods and developed a new procedure using both chemicals and microorganisms. This resulted in a quicker, more efficient and more environmental friendly cleaning method.

### Fewer chemicals

Organic pollutants in soils can effectively be removed using chemical oxidants. The process is quick, but relatively expensive. In addition, chemical oxidants kill bacteria and may degrade soil organic matter, resulting in a clean, but poor soil. Sutton investigated the possibility to clean soil, using microorganisms following chemical oxidation. This combined approach could

## *Column* **Cees Buisman**

Last spring our department celebrated its 50th anniversary. More than 200 participants joined our congress and we concluded that our task is not yet completed. We are convinced that the Department of Environmental Technology will also be needed in the next 50 years, because many environmental problems still exist. The scandal of the diesel emissions pointed again to the severe pollution of cars and the unhealthy effects of NOx and fine particles.

The good news is that after years of crisis the mindset seems to shift to the environment again. For the climate top in Paris many state leaders will participate, and the expectations are higher than ever. This renewed interest in the environment is inspiring our researchers and students. Our department will continue to work on our mission to develop new technologies and concepts for a more sustainable world and to educate new talents. Our research is focused on developing new clean production methods, controlling pollution and reducing natural resource depletion. This way we maximize our impact.

Our vision is attractive to young people. The number of students in our department is growing every year. ETE's research is connected to 3 Wageningen University M.Sc. courses: Environmental Sciences, Urban Environmental Management and Water Technology. These result in more than 70 M.Sc. theses per year. Combined with our 60 Ph.D. students we deliver 8 new talents per month to society. We believe this is our major contribution to a more sustainable world.

improve overall soil-cleaning procedures, because fewer chemicals are needed: chemical oxidants only have to degrade part of the contaminants, while bacteria may degrade remaining pollutants. A challenging and 'out of the box' idea, since the general idea has always been that oxidizing chemicals and microorganisms do not mix. 'Some chemical treatments result in very acidic or alkaline groundwater, incompatible with bacterial growth', Sutton explains. 'Also, chemicals damage the bacterial cell walls, thereby killing them.'

**Best of two worlds**

During her search for a combined chemical-biological cleaning procedure, Sutton first treated contaminated soil with strong oxidizers. When the oxidative reaction had stopped, bacteria recovered remarkably quickly. 'Many bacteria proved to be surprisingly resilient towards chemical oxidation', Sutton explains. 'In some cases the oxidant degraded organic matter and released nutrients, creating favorable growth conditions for bacteria.' Her results proved that chemical and bacterial soil cleaning can effectively be combined, resulting in a relatively quick soil cleaning, using fewer chemicals. As a result, soil damage is limited and costs for chemicals are reduced. Sutton truly succeeded in combining the best of two worlds.

**Micropollutants**

Sutton is continuing her work on cleaning of pollutants with bacteria. She now works as a postdoc researching the use of bacteria to remove micropollutants such as pesticides and pharmaceuticals in different portions of the water cycle.

## Double award for ETE student Wei-San Chen

In May 2015 Ph. D. student Wei-San Chen was awarded two prestigious prizes for his research. One grant was awarded by the Ministry of Education of the Taiwanese government, the other by the Taiwanese company Delta Electronics Foundations. The awards include personal grants of € 12.000 each and are granted to outstanding environmental Ph.D. and M.Sc. students, who are studying abroad. Chen received the prizes for his innovative studies aimed at minimizing the environmental impact of organic waste treatment: reduce use of energy, the release of greenhouse gasses and pollution.

**Modified process**

Organic waste can be anaerobically digested into volatile fatty acids (VFA's, for example acetate), $CO_2$ and hydrogen. By adding ethanol, microorganisms convert these VFA's into caproic acid, a valuable component that can be used to synthesize many products, including biofuels. Chen looked into this process of caproic acid synthesis from a different angle: he analyzed the environmental impact of the method by using life cycle assessment (LCA's) for every step in the process. 'Based on these LCA's, I modified the process into a more environmental friendly procedure', Chen explains.

**More sustainable**

Chen's research indicated that replacing ethanol in the caproic acid formation procedure would result in a more environmental friendly process. 'Ethanol has a relatively high environmental impact: it is made from sugars that come from crops grown with fertilizers´ Chen explains. 'In addition, ethanol production may lead to eutrophication and acidification of the environment.´ The scientist investigated the use of methanol to replace ethanol. Methanol can be derived by lignocellulose, a compound abundantly present in agricultural and municipal waste. So, no sugar is needed for its formation. Although the current efficiency of conversion was still low, methanol could successfully replace ethanol to biologically synthesize caproic acid (fig. 1). Chen: ´In the modified method all components are now derived from organic waste, making it potentially more sustainable.´

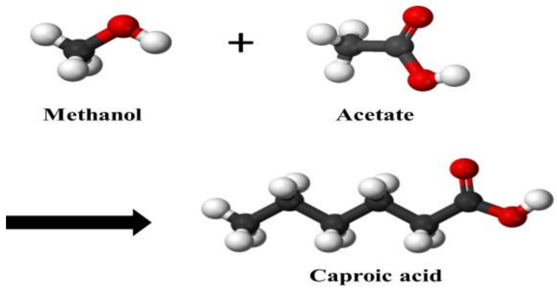
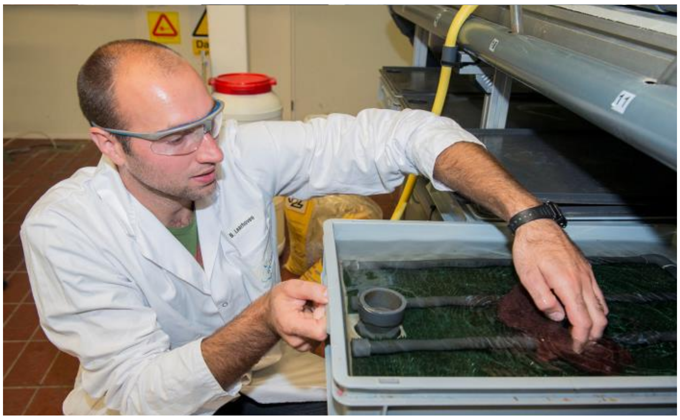



**Fig. 1 Caproic acid formation.**

**Technology of nature**

Chen is now focusing on in-creasing the efficiency of the new process. 'Current caproic acid production with organic waste and methanol is about 10 times lower than the traditional method', he says. 'However, this is only the proof-of-principle; we will perform long-term operation to find out the most comfortable working condition for these microbial workers in order to ele-vate the production and have an efficient, sustainable and economic viable process`. In addition, the scientist focuses his work on environmental friendly separation techniques to extract caproic acid. Efficien-cy is crucial here, but in this research, LCA´s are the starting point to gua-rantee an environmental friendly process. Chen: 'Applying the techno-logy of nature is the spirit of all my research.

# Science: Reducing food waste by producing high quality worm biomass



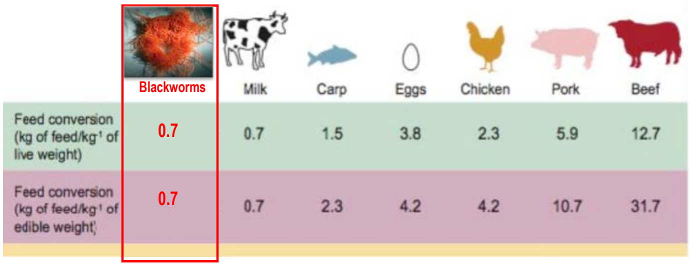
**Aquatic worms may play an important role in converting proteins from waste streams into protein-rich worm biomass that can be used in fish feed. ETE Ph.D. student Bob Laarhoven investigated the possibility to grow worms on industrial food waste and improved the performance of an existing culture system.**

The growing world population requires the production of increasing amounts of proteins, such as meat and fish. As a result, the global aquaculture industry is booming, with a yearly growth of about 8 % per year. Predatory fish, like salmon and trout, are farmed globally at a large scale. These species need high-quality, protein-rich, feed that usually originates from fish-based raw materials. To sustain these expanding fish production activities, there is an increasing need for fish oil and fish meal to produce fish feed. This puts extra pressure on already overharvested wild fish stocks. Therefore, sustainable alternatives for marine oils and proteins to support these growing aquaculture industries are desperately needed.

## Convert waste

Aquatic black worms (*Lumbricus variegatus*), may play an important role in replacing fish oil and fish meal in aquaculture feed. These invertebrates have high nutritional values, and for this reason the species is already cultured in ponds in the USA and Australia. But since they are fed with fish-based products, this is not a sustainable solution. However, these versatile creatures may feed on other protein sources as well, for example organic waste. 'Black worms are not very demanding regarding their food. They feed low in the food chain and may grow on proteins present in waste streams as well', Laarhoven explains. 'In this way, they may convert waste into valuable worm biomass.'

In addition, black worms are cold-blooded animals, resulting in a relatively high feed conversion and a low carbon footprint. About 50 % of all protein and about a third of the total organic fraction present in waste streams can be converted into worm biomass. Therefore, these worms are a sustainable alternative for fish-based aquaculture feed. In addition to being efficient, black worms are easy to cultivate: they are tough and due to their a-sexual reproduction they can easily be cultured inside a reactor.



| | Blackworms | Milk | Carp | Eggs | Chicken | Pork | Beef |
|---|---|---|---|---|---|---|---|
| Feed conversion (kg of feed/kg$^{-1}$ of live weight) | 0.7 | 0.7 | 1.5 | 3.8 | 2.3 | 5.9 | 12.7 |
| Feed conversion (kg of feed/kg$^{-1}$ of edible weight) | 0.7 | 0.7 | 2.3 | 4.2 | 4.2 | 10.7 | 31.7 |

**Fig. 1: Feed conversion of different animals. Feed is expressed as kg dry weight.**

## Unpredictable growth

Previous research has shown that black worms grow well on sludge in wastewater treatment plants, where they convert bacterial protein into worm biomass. However, worms growing in these plants accumulate some of the heavy metals present in sludge. In addition, growth is rather unpredictable due to fluctuating wastewater temperatures and nutrients present. Laarhoven focused his research on finding alternative food sources for the worms. He discovered that worms could successfully be cultured on cleaner, food-related, waste streams, for example the protein-rich sludge originating from the potato industries. In addition, he developed a completely new reactor concept to culture black worms in a controlled and predictable way. The original design of the worm-culturing reactor consisted of a cylinder made of cloth. The nutrient-rich waste stream was flowing through this cylinder, while the worms were positioned in such a way that their heads were sticking into the cylinder. 'We had to improve this concept, because the worm density, growth rates as well as the growth efficiency were too low', Laarhoven explains. 'As a result, too much sludge was not utilized by the worms.'

## Sustainable replacement

To increase reactor performance, Laarhoven redesigned the original reactor concept. In the new design, the waste stream was now dosed and recirculated through a vertical column made of course sand. Worms positioned themselves in between the sand grains, while their tails were sticking outside the gravel layer, to have both access to nutrients and oxygen as they take up the oxygen by their tails (fig. 2). 'The worms are now distributed more evenly throughout the whole column', Laarhoven says. 'Higher worm densities can now be maintained, while sludge utilization is optimized.' The new patented reactor produces up to six times more worm biomass per unit of time as compared to the older version and still shows room for further improvement. 'Even if the worms are fed with plant- or bacterial- based waste, this has no large impact on the composition of worm biomass: it is consistently very similar to fish meal', Laarhoven says. 'This makes these worms an ideal and sustainable replacement for fish-based aquaculture feed.'

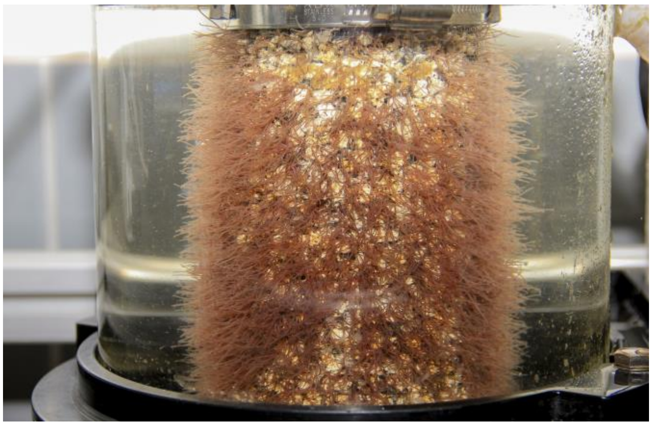


**Figure 2: Worm production system. Only the tails of the worms protrude out of the vertical gravel layer.**

## Large worm production

The controlled system now functions very well on a small scale. The reactor is stable: it continuously produces a steady amount of worms. 'We now need to scale the reactor to a much larger volume', Laarhoven says. 'It all looks very promising, but only a future pilot can really prove if this concept can be used for large scale worm production in order to start replacing fishmeal  by worm biomass.' According to the scientist, the commercial success will largely depend on the acceptance of black worms as a safe feed for farmed animals. In addition, the legalization of food waste products to use as feed in worm culturing systems is necessary.

This research was performed at Wetsus within the theme 'aquatic worms', supported by Tailtec and Duynie

# Science: Efficient selenium recovery from waste streams

**Selenium, a valuable and scarce substance used in a variety of applications, can now economically be recovered from industrial waste streams.  Simon Hageman, former ETE PH.D student, developed the method and patented the procedure. Hageman: 'I expect that the method will soon be applied to recover selenium in many waste streams.'**

Selenium is an important element used in a variety of industrial applications, such as photo-electric cells and solar cells because it can convert light into electricity. In addition, selenium is a trace element necessary to maintain good health in humans and animals. However, current resources of this valuable element are limited and possibly exhausted in less than 50 years, urging its recovery and recycling.
In contrast to its valuable health properties when consumed in small quantities, selenium is potentially toxic in larger amount and release into the environment should be avoided.  'Several waste streams from the industry contain selenium', Hageman says. 'It is among others present in the emission gasses from coal plants. When these gasses are washed before release, selenium ends up in the wastewater. Therefore, technology is needed to recover this element.' Selenium recovery from wastewater not only prevents environmental pollution. At the same time, these waste streams may function as a much needed selenium resource.

## Selective method

Removal of selenium dissolved in wastewater is no easy task. As a first step, this element needs to be converted in a solid form. This makes recovery a lot easier. Transforming dissolved selenium into solid selenium is possible using strong chemicals, but a drawback is that this method is not selective: many compounds present in wastewater precipitate resulting in a mixture of many different compounds.

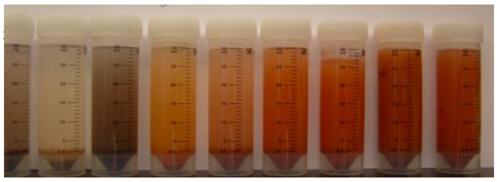


**Fig. 1. Different selenium solutions. The colour of the liquid indicates the selenium particle morphology. The brownish liquid corresponds with needle like structures.The more orange colors correspond with amorphous spherical particles.**

A more subtle and selective method is by using microorganisms. ‘Wastewater contains dissolved selenium in two main oxidized forms: selenate and selenite’, Hageman explains. ‘Microorganisms can convert the first form, selenate, directly into selenium. This consequently precipitates in amorphous, nano-scale sized particles.’ Due to their size, these particles are quite difficult to recover.

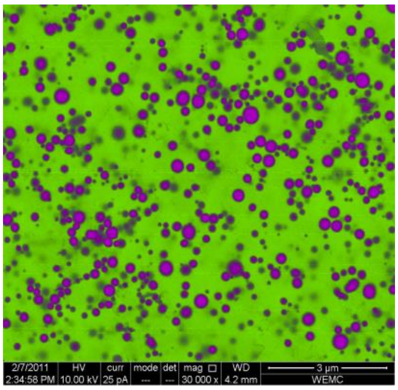


**Fig. 2. SEM image of small selenium particles (purple) formed at a temperature of 30 °C.**

Hageman discovered that by manipulating reaction conditions like temperature and pH, the size of precipitated selenium particles could be influenced. By increasing the temperature to 50 °C and keeping high pH, around 8 or 9, relatively large selenium crystals were formed, Hageman found out. Hageman: ‘Selenium particle formation can clearly be controlled. These larger, crystalline selenium particles can be recovered more easily and makes the separation economically feasible.’

## Large selenium particles

During the experiments, Hageman found an even better process for selenium recovery. Selenate is very stable and not easy to transform. The other form however, selenite, is highly reactive and may more easily be converted into selenium. The scientists managed to find out the specific reactor conditions where almost all selenate was transformed into selenite: that occurred at a temperature of 30 °C and neutral pH.

Sulphide, formed by microorganisms in waste streams, can react with selenite to form seleniumsulphide that precipitates. Microorganisms present in sludge subsequently convert seleniumsulphide back into sulphide and solid selenium. The selenium thus recovered had a crystalline structure, while particles were visible and relatively large, in the order of micrometers.

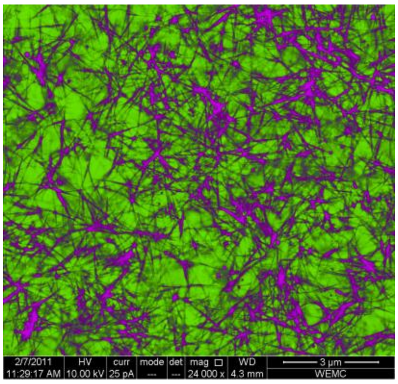


**Fig. 3. SEM image of small selenium crystals (purple) formed at a temperature of 50 °C.**

## Proof of principle

According to Hageman, this indirect route, via selenite, to recover selenium, is more promising than the direct microbiological conversion from selenate into selenium. The required temperature is lower, saving energy, while sulphide is continuously recycled during the reaction process. In addition, the method is practical and easily applied, while the recovered selenium particles are larger, enabling a more efficient recovery. ‘The proof of principle is there, the final step will be to test the method in a practical industrial setting’, says Hageman.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## *Agenda*

**PhD defences (Aula, Wageningen):**

8-12-2015, 13:30: Ni Zhuobiao. ´Bioremediation of Chlorinated Ethenes in Aquifer Thermal Energy Storage´

20-01-2016, 13.30: Rosa Elena Yaya Beas. ´Development of integrated, compact treatment systems for the safe use of reclaimed domestic wastewaters in irrigated agriculture in Lima, Peru´

18-02-2016, 11.00: Rungnapha Khiewwijit. ´New wastewater treatment concepts: Towards energy saving and resource recovery´

15-04-2016, 11.00: Sjoerd Kerstens. ´Sanitation planning in developing countries: Added values of resource recovery´

19-04-2016, Adam Wexler (in Leeuwarden): ´Electrically excited water – The prerequisite condition for life´

22-04-2016, 16.00: Koen Wetser. ´Electricity from wetlands by the plant microbial fuel cell´

**Workshop:**
10-12-2015, 9.00-17.00. Liftup of Lowlands.
Workshop Subsidence in peatland area: Sediment use as part of the solution?!